Documentation for aerosol dataset collected in the WINTRE-MIX flight campaign, 2022

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Ver. 1.0

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Description:

A suite of aerosol instruments were integrated on the NRC Convair-580 aircraft and operated in the WINTRE-MIX flight campaign, between February and March, 2022. The list includes a Condensation Particle Counter (CPC), Ultra-High Sensitivity Aerosol Spectrometer (UHSAS), Single Particle Soot Photometer (SP2), and a Cloud Condensation Nuclei counter (CCNc), which were installed in the aircraft cabin to sample via an isokinetic inlet installed on top of the fuselage. In addition, NRC wing tip mounted UHSAS was installed and sampled throughout the whole campaign.

Due to the nature of Intensive Operational Periods (IOP)s, most of the flight time in the domain was spent in-cloud or in precipitation with the associated risk of flooding the cabin aerosol instruments, which led to the suspension of aerosol sampling. To address this issue, towards the latter portion of the campaign, starting from IOP7, a Counter-flow Virtual Impactor (CVI) inlet system was integrated on the fuselage starboard side window, for the first time. The CVI inlet allowed in-cloud sampling of the residual aerosol (remaining core after evaporation of the hydrometeors above a selected cut-off diameter). A cabin inlet-switching mechanism was designed for the campaign, allowing to switch between the sampling lines of an isokinetic inlet and a CVI inlet. The collected data includes information for in-cloud and clear-air aerosol particle size distributions, CCN activation properties, activated fraction, vertical profiles, and limited information about composition (Black Carbon vs. light scattering aerosol).

The CVI was never tested on this aircraft before WINTREMIX. Therefore, the quality of data requires further review and validation.

Contents

Instruments

The aerosol instruments used for sampling in this campaign are listed in Table 1 and described in detail below. The measurable quantities are summarized in Table 2.

Table 1. List of aerosol instruments.

Instrument	Model, S/N	Manufacturer	Owner	Reference
UHSAS-A	1710-011	DMT	NRC	UHSAS-A manual [1]
UHSAS-C	1210-039, AAA-0053	DMT	ECCC	UHSAS manual [2]
CCNc-100 with CPI	CCN 1110-0098, CPI 0910-039	DMT	ECCC	CCNc Manual [3], CPI manual [4]
CPC	3775, 70902299	TSI	ECCC	CPC manual [5]
SP2	1010-035	DMT	ECCC	SP2 manual [6]
CVI inlet system	Model 1204, S/N 008	BMI	ECCC	CVI manual [7]
Isokinetic heated inlet	# AAA-0093	DMT	NRC	

Table 2. List of measurable quantities.

Instrument	Measurable quantities	operational range
CPC	• Total concentration	(~4 to ~3000 nm)
2 x UHSAS	• Total concentration “of CCN-like” • Particle size distribution	(60 to 1000 nm)
SP2	• Concentration • Particle mass distribution • Particle size distribution • Type (composition) • Morphology (structure)	**Scattering:** (~200 – 430 nm) **BC**: (70 – 500 nm)
CCNc	• CCN concentration at set %SS • Activated fraction (+UHSAS) at SS% • Hygroscopicity (for mono-modal aerosol size)	**Activated droplets**: 0.75 – 10 µm
CVI inlet	• Allows advanced analysis of residual aerosol from the sampled hydrometeors	**hydrometeors** >8 µm

Wing UHSAS-A

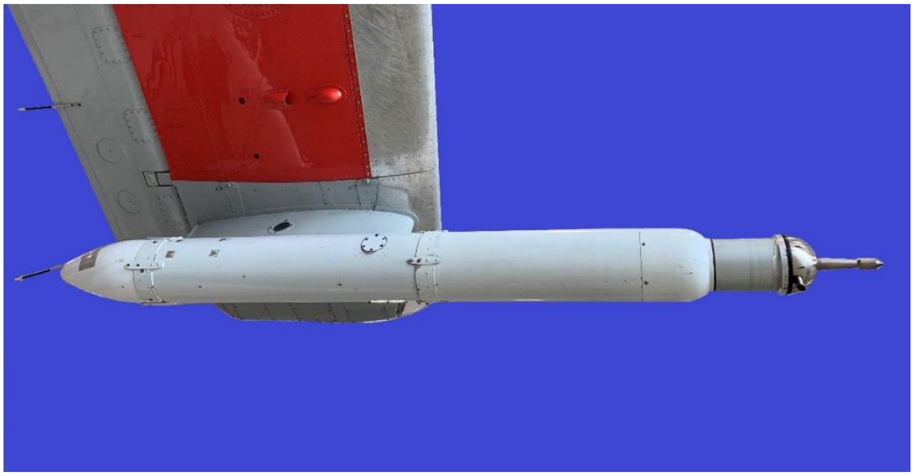

Figure 1. UHSAS-A (Port wing tip mounted UHSAS).

The airborne version of UHSAS is a modified PMS canister design that was fitted on the NRC Convair-580 research aircraft (Figure 1). This instrument was operated continuously between takeoff and landing. Inside the UHSAS-A, a laser beam illuminates particles, which scatter light that is collected by two pairs of Mangin optics. An amplification of the signal allows the system to detect particles as small as 65 nm.

The specifications for the instrument limit its operation to > - 40 °C and < 12 km altitude, however there have been some operational issues at lower altitude and warmer temperature, notably noise in the first channels or anomalously low measurements of concentration. These have been improved, but not eliminated, through modifications to the instrument. Small-diameter noise count in particular continues to be a problem. The probe covers the full size-range through the use of two different detectors, each having two gain circuits [1]. The instrument is designed to operate primarily in clear air, out of cloud, environment. A thorough review of the uncertainties of the instrument that need to be considered can be found in [9].

UHSAS-C cabin

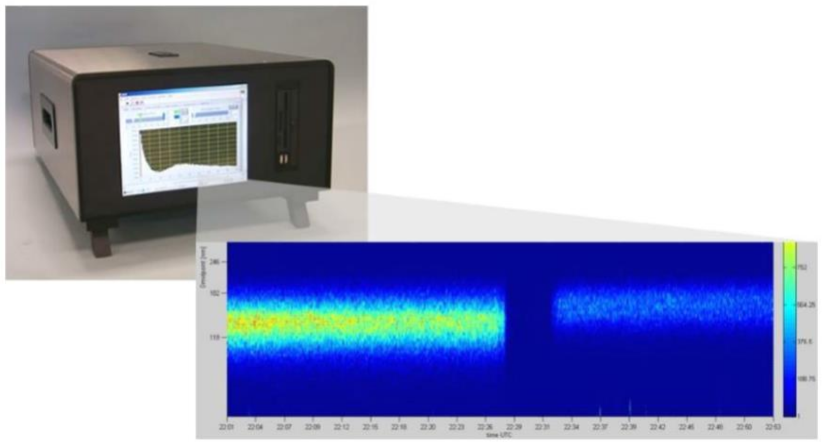

Figure 2. Cabin UHSAS with data visualization.

This commercial cabin instrument (Figure 2) has similar specifications:

- Optically measures aerosols in the size range 60 nm < Dp< 1 µm
- Size resolution at 1 – 2 % of particle size
- Eliminates sizing uncertainty associated with scattering spectrometers that measure at sizes larger than the excitation wavelength.
- Particles size distributions collected in up to 100 size bins
- Can output size distributions at rates up to 10 Hz
- Able to count up to 3,000 # s^{-1}
- Uses two detection systems: a primary, highly sensitive Avalanche Photo-detector (APD)-based system to size smaller particles, and a secondary PIN photodiode system to size larger particles
- Compensates for small drifts in laser power via an automatic gain control.

The instrument was calibrated at NRC. For more details about the instrument see UHSAS-C manual [2].

CCNc-100 with a CPI

Figure 3. Cloud Condensation Nuclei Counter with Constant Pressure Inlet for airborne operation [3,4].

The Cloud Condensation Nuclei (CCN) counter (Figure 3) contains a vertical column with the sampled aerosol entering at its top. The wall temperature along the column gradually increases to create a well-controlled and quasi-uniform centerline supersaturation. The aerosol sample thus becomes progressively supersaturated with water vapor as it traverses down the column. At any given point in time, the CCN unit operates at a single supersaturation. This is because the temperature and water vapor gradient along the wetted walls are approximately constant along the wall. Software controls allow the user to change from one supersaturation to another, and the supersaturation can be varied between 0.07% and 2%. Approximately 30 seconds wait (realistically up to 2 min) is required for a supersaturation shift. Activated droplet counting is done with an Optical Particle Counter (OPC) at the bottom. The sizing range for activated particles is 0.75 to 10 μm [3]. The Cloud Condensation Nuclei counter with one column was complemented with a Constant Pressure Inlet (CPI) [4]. The CPI was connected to the CCNc to maintain a constant altitude pressure as described in [4]. During the flights, a constant pressure of 600 hPa was set on the CPI. A pressure correction factor needs to be calculated and applied for real ambient concentration calculation. Therefore, using the CPI system requires also an external recording of the ambient static pressure and post processing correction of the CCN concentration. The true concentration needs to be corrected by a factor:

$$f_{corr} = Pressure\_outside / Pressure\_CPI \quad \text{(Eq.1)}$$

The true CCN concentration is therefore:

$$CCN_{conc\_true} = CCN_{conc} \times f_{corr} \; [particles/cc] \quad \text{(Eq.2)}$$

CPC 3775

Figure 4. CPC 3775. Image by the manufacturer (TSI).

Condensation Particle Counter (CPC) model 3775 is a general-purpose counter that detects airborne particles down to ~4 nm (Figure 4). It provides highly accurate measurements over a wide concentration range from 0 to 10^7 particles cm^{-3}. The instrument condenses butanol on the aerosol and allow droplets growth followed by optical detector where they are counted. At low concentrations, the optical detector counts individual pulses produced as each particle (butanol droplet) passes through the sensing zone. For very high particle concentrations, the CPC model 3775 transitions from the single count mode to a photometric mode where the total light scattered from the particles is used to determine concentration based on calibration [5].

SP2 , 8 channels

The SP2 (Single Particle Soot Photometer) uses the high optical power available intra-cavity from an Nd:YAG laser. Light-absorbing particles containing mainly black or elemental carbon absorb energy and are heated to the point of incandescence (Figure 5). The incandescent emission is measured and correlated to the particle's black carbon mass with the help of black carbon calibration proxies like fullerene soot.

The SP2 also includes a scattering detector, which detects single-particle light-scattering at 1064 nm. The scattering signal can be used to infer particle size and the black carbon mixing state at the single-particle level. The scattering detector can also be used to detect non-BC-containing aerosol number and mass concentrations.

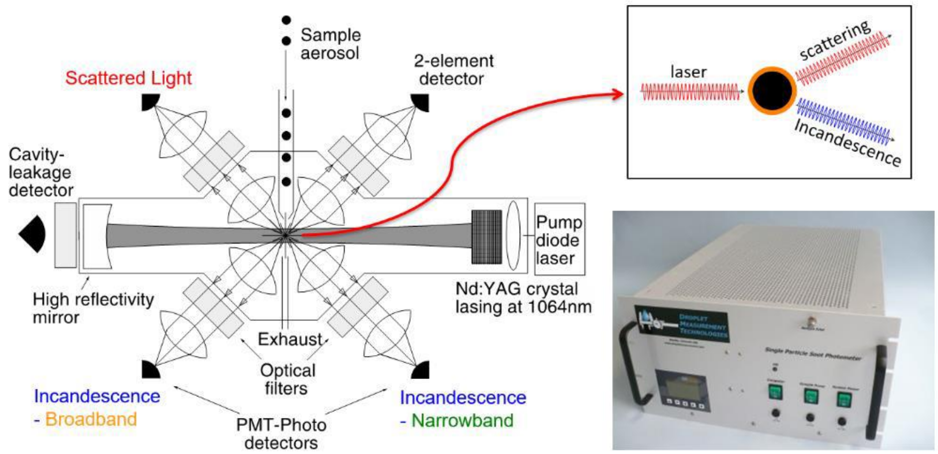

Figure 5. SP2 schematic reproduced from [6]

CVI model 1204

The Model 1204 Counter flow Virtual Impactor (CVI) Inlet System [7,8] is designed for aircraft applications. It delivers variable counter flow rates between 1 and 10 lpm at a constant 15 LPM of sample flow to instruments for air speeds between about 50 and 150 m/s. The droplet diameter cut size of the CVI is user-adjustable between roughly 8 and 10 microns during operation. The panel maintains the desired counter flow rate in response to changes in air speed, temperature, and pressure.

The CVI was integrated on starboard side window of the fuselage, at the front, close to the cockpit (Figure 6). The CVI assembly was installed on the aircraft using an adaptor plates with a specified tilt in the angle of attack (~2 deg), similar to the angle of adapter plates of underwing pylons, designed to account for aircraft pitch during sampling. The CVI housekeeping data was recorded at 1 Hz resolution and aligned on to the core DAS time grid.

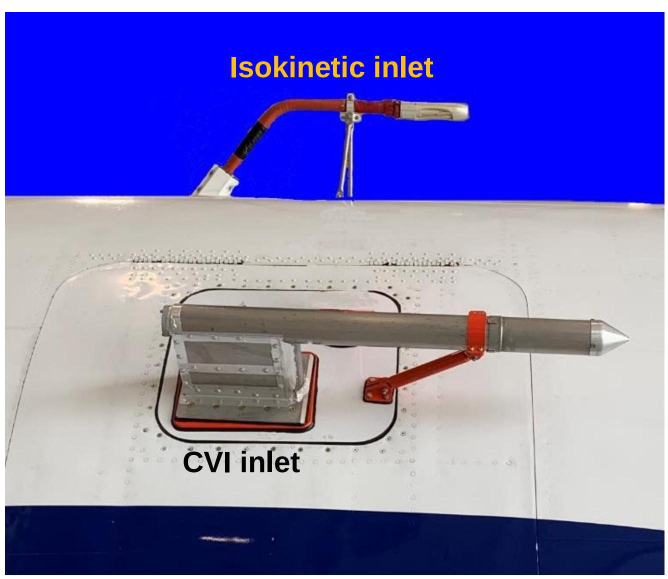

Figure 6. Aerosol Isokinetic inlet for clear-air sampling (interstitial aerosol) on top and a CVI inlet on the fuselage starboard window for in-cloud (residual aerosol) sampling.

Sample droplets have a minimum Stokes number or inertia to pass through the counter flow and into the sample air flow. The droplet Stokes number is generally controlled by the velocity of the droplets and their diameter. The diameter corresponding to the minimum Stokes number for sampled droplets is referred to as the 'cut size' diameter of the inlet. It is defined as the size at which 50% of the ambient droplets penetrate the counter flow and enter the sample flow. Droplets smaller than the cut size are rejected (blown away from the tip) by the counter flow, while droplets larger than the cut size penetrate the counter flow and enter the sample flow (Figure 7). For a given counter flow, droplet velocity, temperature, and pressure, the cut size of droplet that penetrates into the inlet is fixed [7].

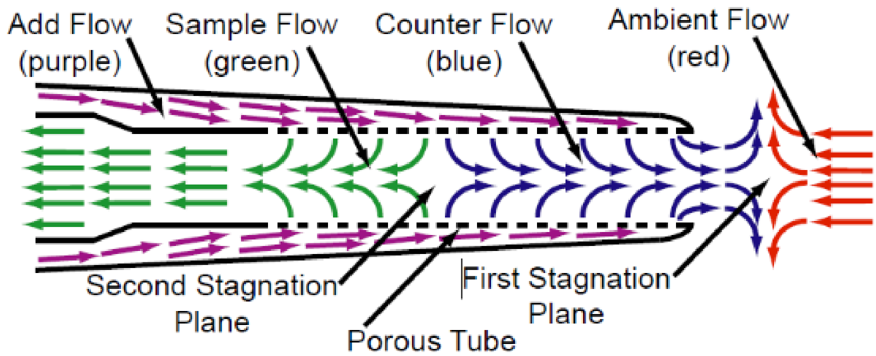

Figure 7. CVI inlet tip and the different flows illustration reproduced from the CVI manual [7].

Particles with sufficient momentum (Stokes number) can travel through the counter flow and into the sample flow. Water droplets large enough to penetrate into the inlet system are decelerated and exposed to warm temperatures in order to evaporate their water and reduce their size. The size reduction is important to ensure efficient sampling of the droplets, which are too large to be drawn effectively into the sampling system. The dry, heated (to counter flow temperature) sample flow denudes (evaporates the water from) these particles. These dried residual particles sampled are typically considered to be cloud condensation nuclei (CCN), as they originally likely participated in the activation of cloud droplets within cloud. However, it is possible that the size, composition, and morphology of the dried residual particles have been altered by the coalescence process of cloud droplets with non-activated particles or by other processes like compaction during the denuding step. The smaller, residue particles are drawn into the inlet sampling manifold where the aforementioned instruments can be used to measure aerosol size, concentration, chemical composition and other properties. The calculated transmission efficiencies through the external probe body for residue particles between 0.01 and 6 microns in diameter are greater than 95% [7]. The CVI inlet enhances the concentration of the residuals, and the enhancement factor is estimated to be 5.4 [10].

Isokinetic inlet

In clear air, a few measurements of the total dry aerosol particle population was done behind a heated isokinetic inlet installed on top of the fuselage (Figures 6, 8). Two thermocouples on the inlet itself were used to control the 4 inlet heaters. Three additional thermocouples measured the inlet tubing extension inside the cabin, cabin temperature downstream (near ceiling), and temperature near the aerosol rack. All thermocouples were connected to an ADAM (8-channel thermocouple input module). Using a high-volume blower, the main flow through the inlet was kept isokinetic and laminar, near the true air speed of the aircraft (~100 m s^{-1}) while excess flow was ejected through the starboard window exhaust hole. When the sampling was switched to the CVI inlet, a back-flush pump would turn on to blow backflow of filtered air through the isokinetic inlet to prevent water accumulation or snow clogging in the isokinetic inlet during CVI sampling.

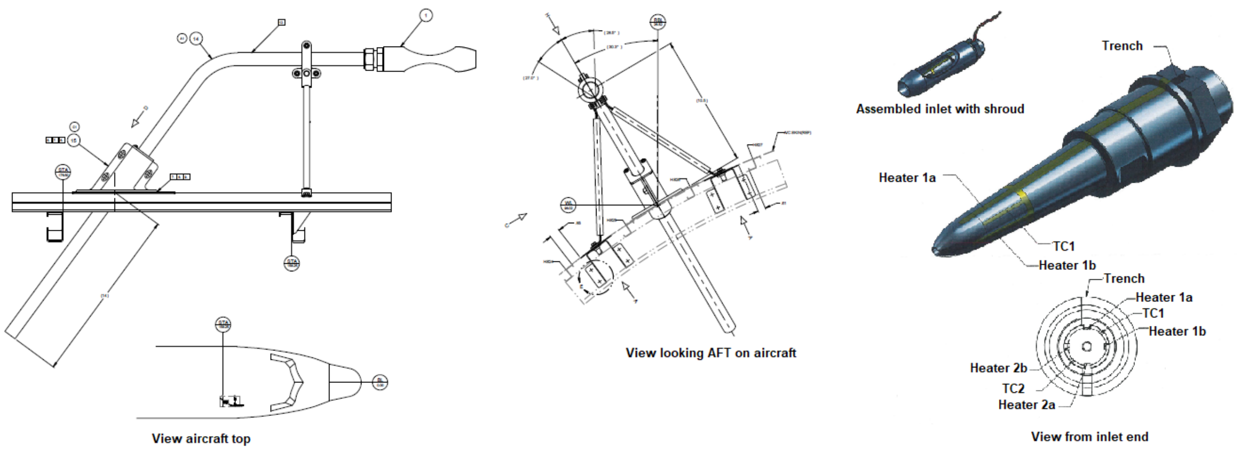

Figure 8. Left: Drawings of the heated isokinetic inlet assembly. Right: Drawings with indication of heaters location, reproduced from DMT manual.

Operation in flight

There was limited flexibility to accommodate aerosol sampling strategies in WINTREMIX, a precipitation oriented campaign with predefined flight tracks. However, a couple of flight segments were allotted with aerosol sampling time e.g., in flights F05, F07, F08.

The CPC is capable of operating at altitude up to 2 km or inlet pressures of up to 750 hPa, while during the campaign, the aircraft occasionally climbed up to 7 km (410 hPa). The reduced pressure has a direct impact on the flow through the internal critical orifice and reduce the 1-butanol saturation ratio in the internal condenser. Therefore, altitude dependent bias in counting efficiency is inevitable [11]. Moreover, the Instrument operates with a liquid Butanol reservoir, tilting angle of the reservoir may impact the operation of the instrument by variation of the available vapors for condensation. In clouds, liquid water accidentally ingested through the isokinetic inlet may flood and remain in the instrument until it is opened and the water is actively evaporated.

The CCN was operated at a constant supersaturation setting (0.3 % with respect to water), which is more suitable for such rapidly changing flight environment.

Sampling

The sampling periods and data availability are summarized in Table 3. The isokinetic inlet sampling was suspended due to operational risks in a predominantely wet environment in clouds and precipitation systems, which significantly increased the risk of flooding the cabin instruments. Subsequently, sampling was resumed from IOP7 onwards after the CVI was installed and a switching mechanism was designed to shift between the isokinetic inlet and the CVI inlet when needed (Figure 9). The isokinetic sampling of non-activated, out-of-cloud, interstitial particles was used only for short periods in flights F05 to F09, while wing UHSAS-A sampled throughout the whole campaign with an inherent bias during in-cloud sampling.

Table 3. Aerosol sampling details during WINTREMIX (instrument operation times do not necessarily fully overlap with flight time).

IOP #	NRC flight #	Date time UTC (start – end)		UHSAS-A (wing)	CVI with cabin instruments	Short segments of isokinetic inlet sampling
IOP1	F01	03-Feb-2022 01:34:53	03-Feb-2022 06:30:12	✓	×	×
IOP3	F02	12-Feb-2022 00:01:00	12-Feb-2022 05:07:33	✓	×	×
IOP4	F03	18-Feb-2022 03:07:26	18-Feb-2022 07:07:01	✓	×	×
IOP5	F04	22-Feb-2022 23:48:22	23-Feb-2022 03:46:09	✓	×	×
IOP7	F05	01-Mar-2022 20:32:17	02-Mar-2022 01:09:17	✓	✓	✓
IOP8	F06	06-Mar-2022 12:59:50	06-Mar-2022 17:13:36	✓	✓	✓
IOP9 (2 flights)	F07	07-Mar-2022 15:59:45	07-Mar-2022 20:04:34	✓	✓	✓
	F08	07-Mar-2022 21:23:03	08-Mar-2022 01:40:34	✓	✓	✓
IOP10	F09	12-Mar-2022 03:34:34	12-Mar-2022 07:51:25	✓	✓	✓

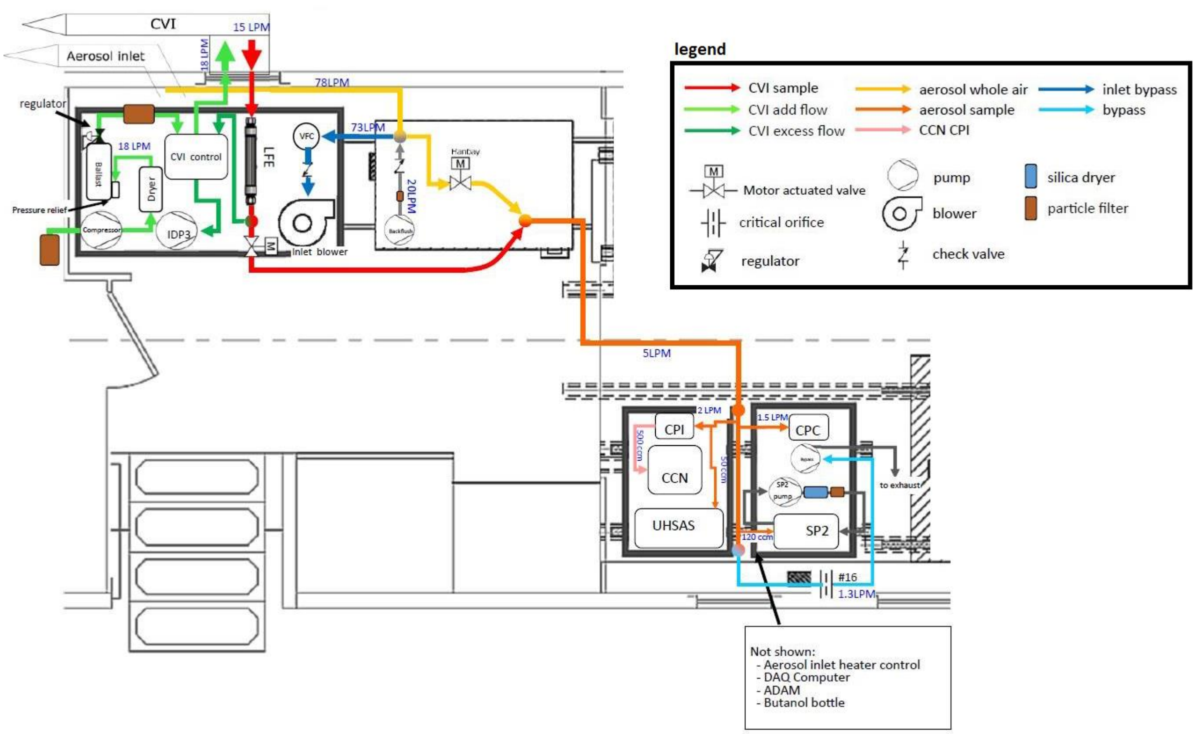

Figure 9 Illustration of aerosol sampling design in clear air and in-cloud during WINTREMIX (designed in collaboration with ECCC).

Aerosol data is often corrected for sampling biases (Table 4) like inlet sampling efficiency, CVI concentration enhancement factor, inlet icing impact on flow, wind direction and inlet shadowing, SP2 postprocessing. In these datasets, we have only applied time synchronization correction and will apply pressure correction in the next version, using Equation 2.

Table 4. Corrections and flagging for nanoparticle sampling in WINTREMIX archive.

	Applied	Planned to be applied
Time synch correction	✓	
CCN concentration pressure correction	×	✓
CVI enhancement factor correction	×	✓
Inlet sampling efficiency correction	×	×
Inlet icing impact on flow correction	×	×
Wind direction and inlet shadowing correction	×	×
SP2 data post processing	×	×

Dataset structure

Here we summarize the aerosol dataset variables uploaded to the archive. For thorough analysis these aerosol datasets should be used in conjunction with atmospheric state (e.g., Temperatures, Pressure, RH, horizontal wind direction), aircraft state (Altitude, position), and cloud microphysics (cloud/clear-air classification) data in the EOL archive.

UHSAS-A

Variable name	Description	Units	Notes
bin_lower_uhsas_w	UHSAS-A bin lower edges	µm	
bin_upper_uhsas_w	UHSAS-A bin upper edges	µm	
Nuhsas_w	UHSAS-A Number Particle Size Distribution	#	
scatter_uhsas_w	UHSAS-A housekeeping parameter: background DC molecular scatter level from the APD	volts	housekeeping
current_uhsas_w	UHSAS-A housekeeping parameter: current being supplied to the instrument'	volts	housekeeping
sampleflow_uhsas_w	UHSAS-A housekeeping parameter: flow of the sample air	sccm	Use for concentration calculations
sheathflow_uhsas_w	UHSAS-A housekeeping parameter: flow of the sheath air	sccm	housekeeping
ref_uhsas_w	UHSAS-A housekeeping parameter: laser reference voltage	volts	housekeeping
temp_uhsas_w	UHSAS-A housekeeping parameter: voltage from the temperature sensor	volts	housekeeping
pres_uhsas_w	UHSAS-A housekeeping parameter: ambient pressure	kPa	housekeeping
time	seconds since 1970-01-01T00:00:00+0000	s	

UHSAS-C

Variable name	Description	Units	Notes
bin_lower_uhsas_c	UHSAS-C bin lower edges	µm	
bin_upper_uhsas_c	UHSAS-C bin upper edges	µm	
Nuhsas_c	UHSAS-C Number Particle Size Distribution	#	
scatter_uhsas_c	UHSAS-C housekeeping parameter: background DC molecular scatter level from the APD	volts	housekeeping
current_uhsas_c	UHSAS-C housekeeping parameter: current being supplied to the instrument'	volts	housekeeping
sampleflow_uhsas_c	UHSAS-C housekeeping parameter: flow of the sample air	sccm	Use for concentration calculations
sheathflow_uhsas_c	UHSAS-C housekeeping parameter: flow of the sheath air	sccm	housekeeping
ref_uhsas_c	UHSAS-C housekeeping parameter: laser reference voltage	volts	housekeeping
temp_uhsas_c	UHSAS-C housekeeping parameter: voltage from the temperature sensor	volts	housekeeping
pres_uhsas_c	UHSAS-C housekeeping parameter: ambient pressure	kPa	housekeeping
time	seconds since 1970-01-01T00:00:00+0000	s	

CCNc with CPI:

Variable name	Description	Units	Notes
SS_setting	CCNc Set Supersaturation % over water	%	
ccn_num_conc	particle number concentration	$\#/cm^3$	
time	seconds since 1970-01-01T00:00:00+0000	s	

CPC:

Variable name	Description	Units	Notes
cpctconc	CPC total number concentration	$\#/cm^3$	
time	seconds since 1970-01-01T00:00:00+0000	s	

SP2:

Variable name	Description	Units	Notes
scatorg	Organic light scattering aerosol - real time concentration (uncorrected)	#/cm^3	
BC	Black Carbon real time concentration (uncorrected)	#/cm^3	
time	seconds since 1970-01-01T00:00:00+0000	s	

Flow (CVI+CPI, Isokinetic inlet):

Variable name	Description	Units	Notes
Samp_inlet	Boolean indicator for the selected sampling inlet: 1 for CVI, 0 for Aerosol isokinetic inlet		
time	seconds since 1970-01-01T00:00:00+0000	s	

Quicklooks

In this section we present some quicklooks generated using the datasets in the archive (Figures 10-15).

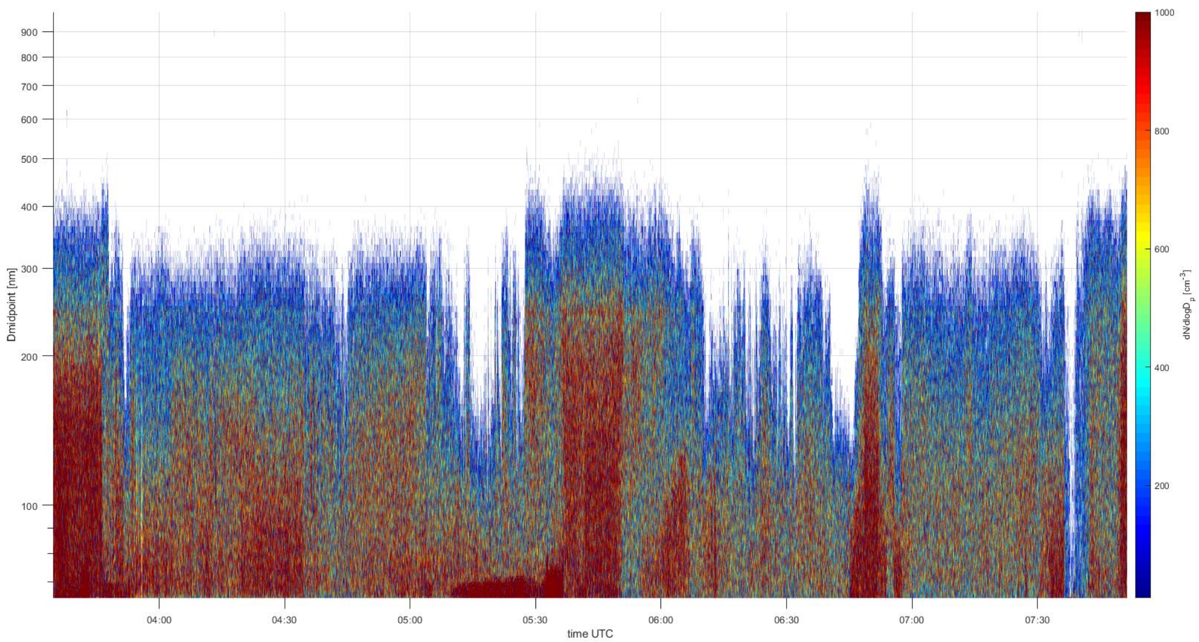

Figure 10. UHSAS-A wing particle size distribution (PSD) time series for F09 (IOP10).

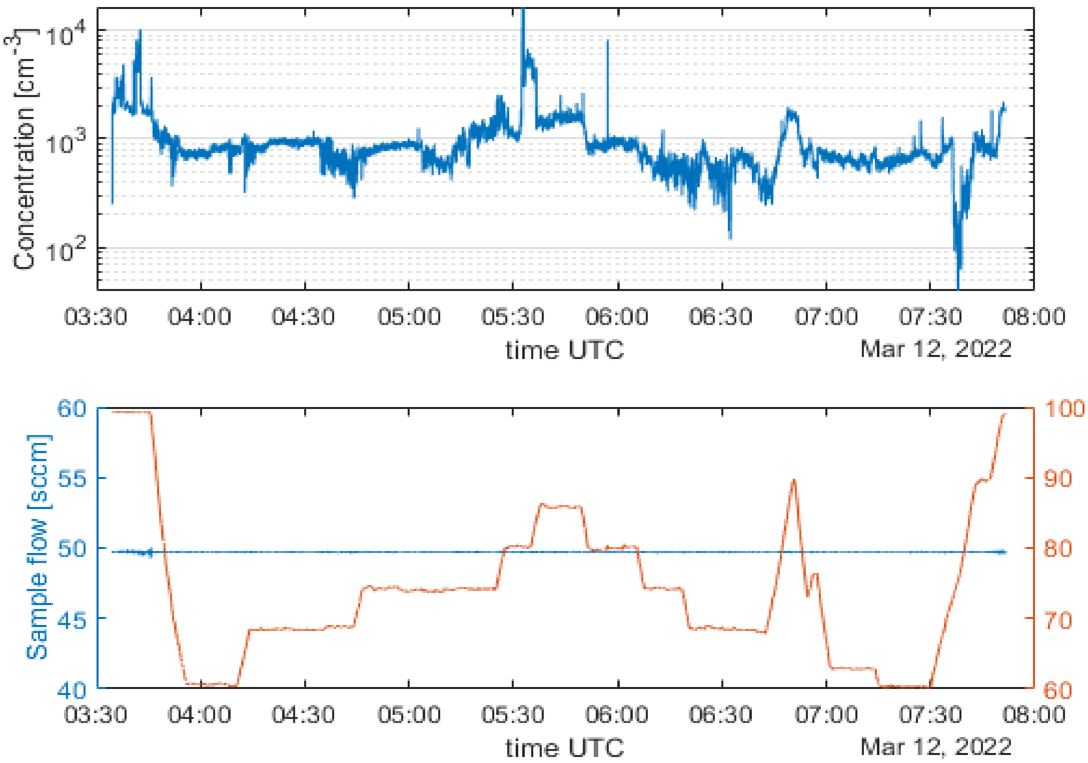

Figure 11. (Top) UHSAS-A wing total concentration (bottom) sample flow and pressure for F09 (IOP10).

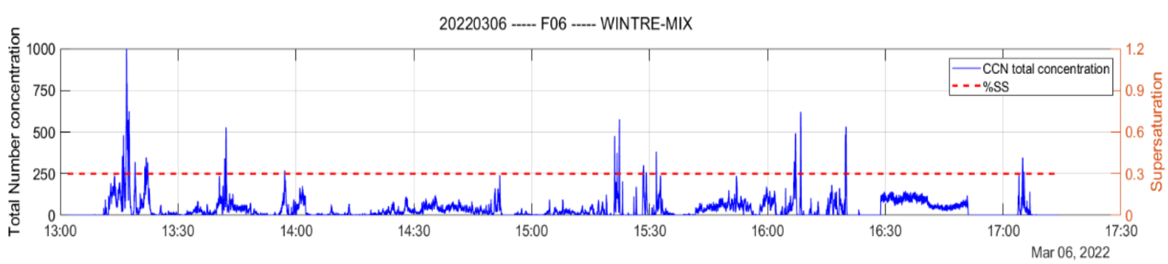

Figure 12. F06 CCN total concentration (uncorrected) and the set supersaturation % over water (in red).

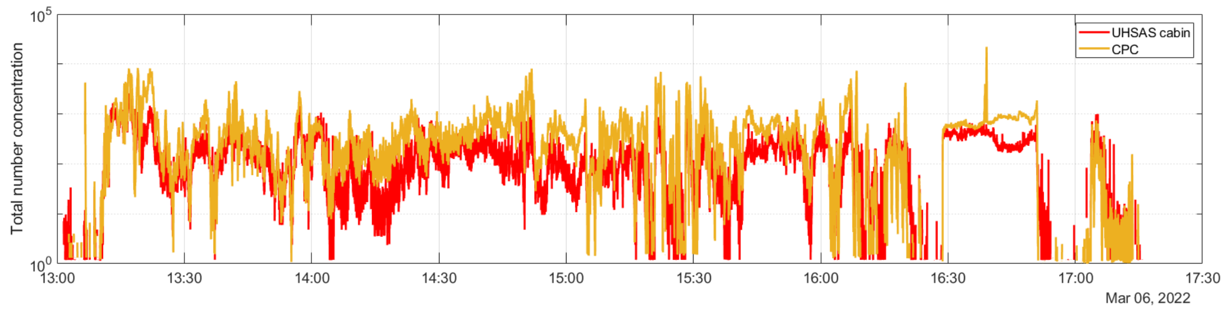

Figure 13. F06 CPC total concentration overlapped with UHSAS-C total concentration.

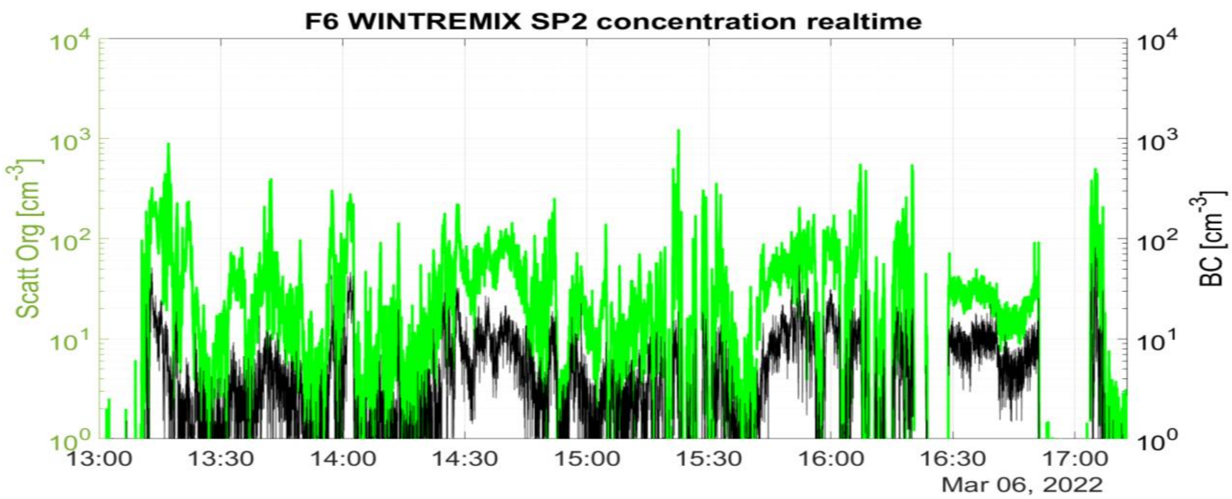

Figure 14. F06 SP2 realtime concentration of scattering aerosol and black carbon.

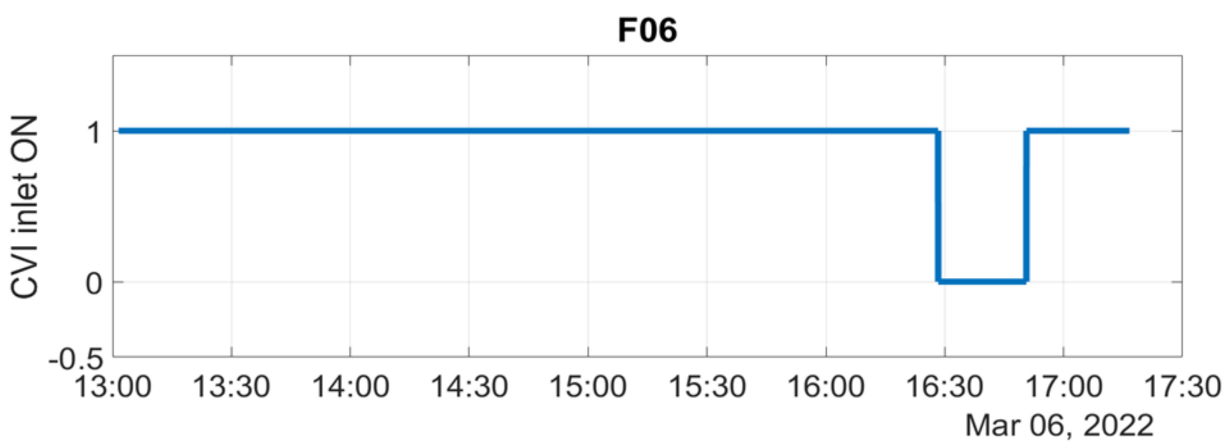

Figure 15. F06 CVI operation period. Around 16:30 UTC the flow was switched to the isokinetic inlet sampling.

References

1. Ultra High Sensitivity Aerosol Spectrometer Airborne (UHSAS-A), Operator manual, DOC-0211, Rev D-3, Software Version 4.1.0, Droplet Measurement Technologies, 2013.
2. Ultra High Sensitivity Aerosol Spectrometer (UHSAS), Operator manual, DOC-0210, Rev E-4, Software Version 4.1.0, Droplet Measurement Technologies, 2013.
3. Operator Manual for Single-Column CCNc, DOC-0086 Revision I-2, Droplet Measurement Technologies, 2012.
4. CPI manual: Constant Pressure Inlet (CCN) Operator Manual, DOC-0125, Revision J, Droplet Measurements Technologies, 2011.
5. CPC manual: TSI Condensation Particle Counter Model 3775, Operation and Service Manual, Revision K. April 2014.
6. Single Particle Soot Photometer (SP2) Operator Manual, DOC-0171, Droplet Measurement Technologies, 2013.
7. CVI Manual: Counter flow Virtual Impactor Inlet System Model 1204, Brechtel Manufacturing Incorporated, Manual Version 2.0, 2014.
8. Shingler, T., Dey, S., Sorooshian, A., Brechtel, F. J., Wang, Z., Metcalf, A., Coggon, M., Mülmenstädt, J., Russell, L. M., Jonsson, H. H., and Seinfeld, J. H.: Characterisation and airborne deployment of a new counterflow virtual impactor inlet, Atmos. Meas. Tech., 5, 1259–1269, https://doi.org/10.5194/amt-5-1259-2012, 2012.
9. Kupc, A., Williamson, C., Wagner, N. L., Richardson, M., and Brock, C. A.: Modification, calibration, and performance of the Ultra-High Sensitivity Aerosol Spectrometer for particle size distribution and volatility measurements during the Atmospheric Tomography Mission (ATom) airborne campaign, Atmos. Meas. Tech., 11, 369–383, https://doi.org/10.5194/amt-11-369-2018, 2018.
10. Shingler, T., Dey, S., Sorooshian, A., Brechtel, F. J., Wang, Z., Metcalf, A., Coggon, M., Mülmenstädt, J., Russell, L. M., Jonsson, H. H., and Seinfeld, J. H.: Characterisation and airborne deployment of a new counterflow virtual impactor inlet, Atmos. Meas. Tech., 5, 1259–1269, https://doi.org/10.5194/amt-5-1259-2012, 2012.
11. Nobuyuki Takegawa & Hiromu Sakurai (2011) Laboratory Evaluation of a TSI Condensation Particle Counter (Model 3771) Under Airborne Measurement Conditions, Aerosol Science and Technology, 45:2, 272-283, DOI: 10.1080/02786826.2010.532839.