A Miniature Optical Particle Counter for In Situ Aircraft Aerosol Research*

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ABSTRACT

Modification of a commercial Met One 237A optical sensor to accept custom electronics consisting of a single logarithmic amplifier providing 256 size bins over the 0.3–14-μm diameter range is described. Configuration of the optical particle spectrometer for airborne aerosol measurements is found to be effective for both miniature remote control aircraft and large research aircraft (NASA P-3B). The instrument is rugged, of low cost, uses low power, and is easily integrated into various platforms. The high size resolution and the 1.6 l min^{-1} sample rate provide excellent count statistics and high sensitivity for ambient out-of-cloud aircraft measurements and for other diverse applications. It can be readily configured for isokinetic or subisokinetic aircraft sampling. Initial comparison with other optical particle counters over the Sea of Japan reveals it to be an effective instrument for in situ aircraft measurements.

1. Introduction

Direct measurements of the size distribution of atmospheric aerosol are an important component of many airborne research activities. These activities include studies of atmospheric pollution, atmospheric chemistry, aerosol radiative effects on climate, visibility, electro-optic propagation, interpretation of satellite radiances, gas-particle interactions, emission studies, flux studies and so on. A variety of techniques are currently employed, using numerous instruments. However, airborne and other applications demand increasingly compact, rapid, robust, and low-power capabilities without sacrificing size resolution. One such application is aboard light or unmanned airborne vehicles (UAV) for which payload limitations constrain the choice of tools available and sampling at ambient conditions is desirable.

A number of small optical particle counters recently have become available for clean-room, personal, or ambient sampling. However, these often have coarse sizing capabilities and are frequently designed for routine use, with unnecessary or undesirable functions and controls. One such instrument is the Met One Model 237A (Pacific Scientific Instruments company, Grants Pass, Oregon) with six particle-diameter size bins between 0.5 and 10 μm. Although suited well for many applications, this device has limited size resolution, poor calibration options, proprietary or nonexistent computer interface options, and it lacks other measurement features often required for aircraft use and/or related research objectives. In our work, we find six size channels to be inadequate to resolve subtle changes in aerosol size that are of interest or to describe aerosol optical effects properly. As a consequence, we sought to utilize the benefits of the small optical detector available in this instrument while changing the electronics, configuration, interfacing, software, and inlet design to make it suitable both for regular aircraft research and for use on our remote-controlled UAV.

When aerosol samples are brought into an aircraft they can be significantly perturbed because of particle losses in inlets, transmission losses in sampling lines, size changes associated with humidity changes, and so on. Hence, in situ measurements in minimally disturbed air are desirable for many applications, and external

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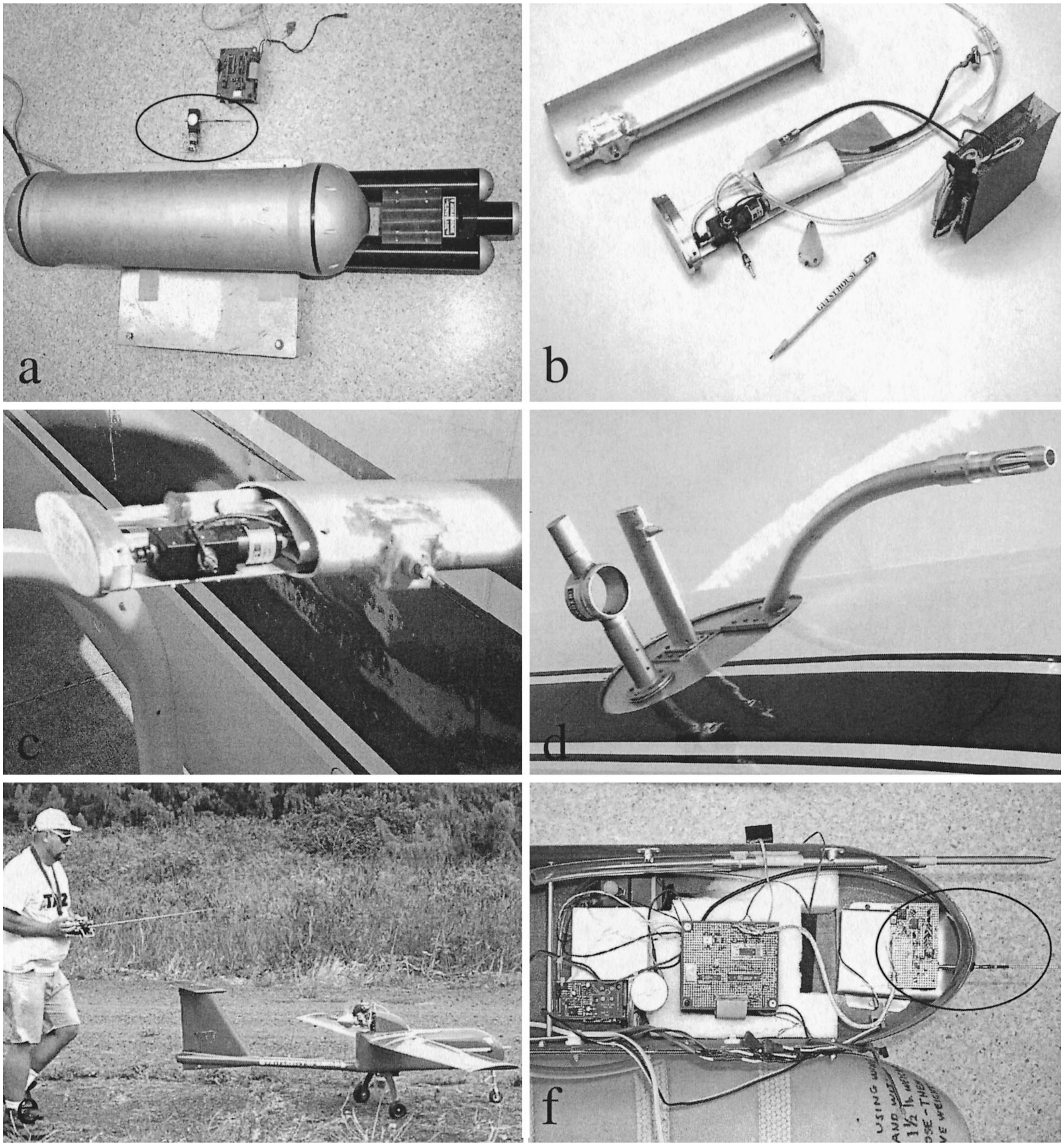

FIG. 1. (a) Side-by-side comparison of the mini OPC (circled) and standard FSSP-300 compared here. (b) Exploded view of P-3B wing strut with mini OPC, electronics, inlet cone, and RH sensor. (c) Mini OPC with inlet removed and partially extracted for mirror change. (d) Mini OPC strut (middle) as mounted with other inlets on P-3B during TRACE-P. (e) The University of Hawaii UAV. (f) Mini OPC mounted in nose of UAV (circled) and connected to onboard computer (middle) and other instruments.

optical probes mounted on the aircraft fuselage or wings are frequently employed. Such ''wing probes'' are often in pods that weigh 20 kg or more, such as the commonly used Forward Scattering Spectrometer Probe (FSSP-300; Fig. 1) manufactured by Particle Measuring Systems, Inc., with a size resolution of about 40 bins over the range 0.3–20 μm (Fig. 1). The FSSP-300 range includes both large aerosol sizes and small cloud droplet sizes. Our miniature optical particle counter (mini OPC; Fig. 1) described here has 256 size bins and a similar range as the FSSP-300 but is designed only for aerosol sampling and not for cloud droplet measurements. The sizes of ambient atmospheric aerosol often depend upon ambient RH, and interpretation of size data requires knowledge of measurement RH. Because particle light scattering at any size depends upon particle refractive index (a function of RH), appropriate calibrations must be employed for the mini OPC as for all similar instruments that are based upon particle light scattering (e.g., Garvey and Pinnick 1983).

2. Instrument

The mini OPC uses the laser and optical cavity (Fig. 1) taken from a Met One 237A particle counter. The 780-nm-wavelength laser diode (15 mW) is collimated into a parallel 2.5 mm by 3.5 mm beam. The light enters the scattering chamber through a cylindrical 20-mm focal-length lens that brings the 3.5-mm-''thick'' beam to a thin sheet crossing the aerosol flow that enters directly in one side of the optical block and out of the other. The beamwidth is orthogonal to the aerosol flow, and the beam continues into a light trap opposite to the laser. The beam is nominally 0.1 mm thick (maximum) at the laser-end edge of the inlet and is assumed to be diffraction limited, say 1000–1500 nm, at the thinnest point. This point is somewhat offset from the center of the inlet by about 1 mm toward the light trap. This offset creates a tapered wedge for the effective scattering volume and potentially gives a nominal transit time (''pulse width'') at 10 m s^{-1} of 10 μs for a maximum beam thickness (0.1 mm) down to possibly 100 ns. Measured typical pulse widths were typically 1–2 μs.

A 15-mm-diameter gold surface spherical mirror with a radius of 12.2 mm is mounted opposite the detector about 10 mm from the scattering volume and reflects a 100° solid angle fraction of the scattered light to the detector, centered on 90°. The detector is a 3.8 mm $\times$ 3.8 mm silicon ''PIN'' diode mounted about 15 mm from the scattering volume. The detector also receives an insignificant direct 15° solid angle fraction of the scattered light. We feed the detector output directly into a custom logarithmic pulse-height analyzer (N. Ahlquist, Ms. Electron, Inc., 2002, personal communication). The signal processor consists of a transresistance amplifer followed by a second-order Bessel response low-pass filter. The power density of the laser beam varies over the wedge-shaped scattering volume created by the cylindrical lens, but the total energy scattered for a given size and velocity particle is constant. For short-duration input pulses, the low-pass filter integrates them to a constant-width pulse with amplitude proportional to their area. The cutoff frequency is selected to minimize the variation in peak height for monodisperse particles without greatly reducing the height of the longest pulses. This gives the best compromise of coincidence loss, flow-rate sensitivity, size resolution, and minimum detectable size.

The pulses feed a chain of 11 saturating amplifiers with a gain of about 2 each. The sum of the outputs from all stages forms a piecewise linear approximation of logarithmic response over about three decades, down to the ''thermal'' random white noise from the detector load resistor. The transfer function can be described by a true logarithm of the signal plus a small positive offset. The operating point of the idle amplifier chain is controlled by a gated baseline corrector that keeps the output between particle pulses at this offset level.

The logarithmic signal is digitized at 5 MHz by a 12-bit analog-to-digital converter and is mapped into 256 voltage channels. Though stored as 256 discrete channels of data, these are typically averaged over about 10 channels. A fast microcomputer extracts the peak heights and discards overly long pulses from stray particles that escaped from the aerosol stream. The next pulse is not accepted until the signal is back down to the thermal noise baseline. The minimum time to resolve two particles is about 2 μs. The average busy time is measured and is used to correct for coincidence losses of up to about 10%. Particle concentrations of 1500–2000 cm^{-3} can be counted before coincidence effects become significant. Other performance characteristics for a similar circuit adapted to lidar applications can also be found in a paper by Lienert et al. (2002).

Additional modifications include reducing the original diameter of the Met One 237A inlet from 2.4 to 1.6 mm and bringing the inlet closer to the laser beam (about 1 mm) to define the particle pulses better. This is done using a smaller-diameter brass tube that also serves to extend the inlet for sampling in a straight axis parallel to the airflow for airborne applications. A target sample flow rate of 1.6 L min^{-1} results in speeds of about 13 m s^{-1} into the cavity and pulses of about 2-μs half-width. Because sheath-airflow is not employed in our current system, some particles do leave the aerosol stream as it is drawn through the OPC cavity. These particles can drift around the cavity and through the laser beam to result in occasional detection of long stray pulses that can also raise the signal baseline. These particles can also deposit on the collecting mirror and reduce its reflectivity. We reduce these effects by feeding a filtered low flow ($\sim$0.4 L min^{-1} to purge the cavity) through a 0.3-cm-diameter fitting that replaces the manufacturer's optical light trap that is normally present in the block opposite the laser. Hence, the lifetime of large particles drifting in the cavity is reduced, and their trajectories are less likely to recirculate through the laser beam. This flow apparently does not influence particle passage through the laser beam. We have operated with about 2.0 L min^{-1} total flow, with about 0.4 L min^{-1} of that as purge flow. At higher purge flow, some impact on concentration and resolution has been observed.

3. Airborne application

The small size and weight ($\sim$300 g) of the mini OPC makes it suitable for mounting in diverse applications, including miniature airborne research platforms such as our remote-controlled UAV (Figs. 1e,f). This application will be discussed in a later paper. However, its

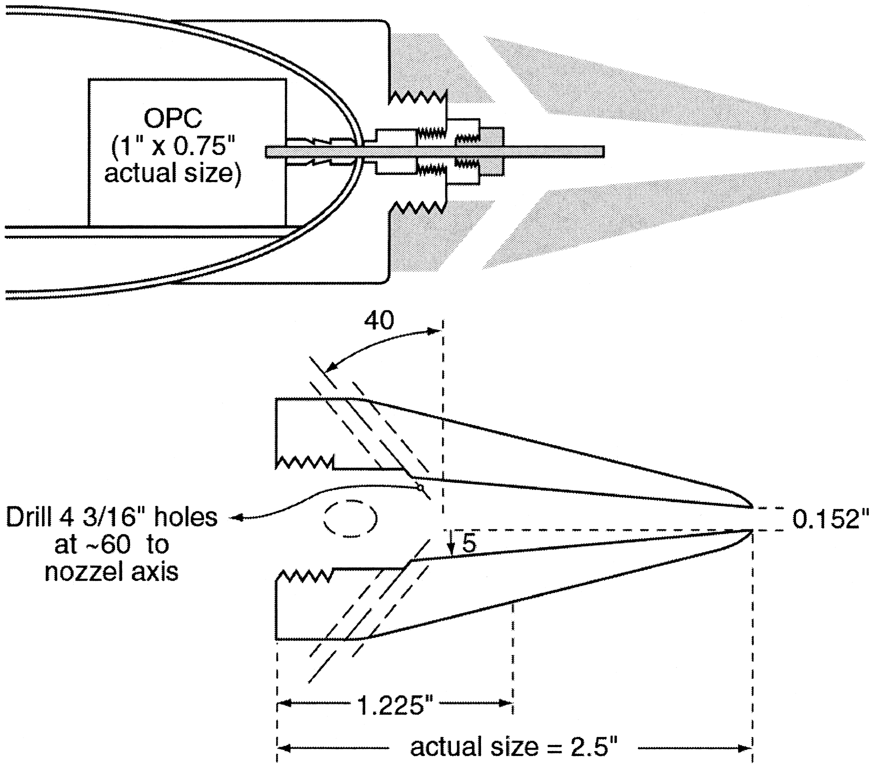

FIG. 2. Cross section through wing strut, mini OPC, and diffuser nozzle inlet showing principal design elements as used aboard the NASA P-3B during TRACE-P.

convenience and capabilities are of interest for larger aircraft also. Because it can be easily mounted in a lightweight strut attached to a standard research aircraft window mounting plate (Fig. 1d), the mini OPC can be installed on most aircraft with little engineering or impact on payload. For pressurized aircraft, such as the National Aeronautics and Space Administration (NASA) P-3B discussed here, the electrical and airflow connections pass through bulkhead fittings at the base of the wing strut (Figs. 1b,d) such that the strut is maintained at ambient temperature and pressure. A similar but smaller strut is employed on our six-passenger Seneca aircraft.

For aircraft use, it is also important to deliver the flow to the inlet in a prescribed manner so that particle sampling and sizing characteristics can be controlled. Often it is desirable to keep the sample inlet flow close to aircraft speed so as to maintain isokinetic conditions and thereby to obtain accurate measured particle concentrations for all sizes. At other times, there are advantages to operating at nonisokinetic speeds. Ambient supermicrometer or ''coarse'' particle number concentrations are generally orders of magnitude lower than submicrometer or ''fine'' particle aerosol. Hence an inlet operated at lower inlet velocity than the air passing it acts as a ''virtual impactor,'' thereby enhancing the concentrations of larger aerosol in a way that increases particle count statistics (Porter et al. 1992). This increase in coarse-particle concentration and count statistics can be beneficial if done in a predictable manner.

The NASA Transport and Chemical Evolution over the Pacific (TRACE-P) experiment provided us with a valuable opportunity to test and compare our prototype instrument with other instruments but was in an unknown and uncontrolled environment. We expected to encounter both clean and heavily polluted environments with variable amounts of dust. Hence, we designed an inlet that allowed us to operate under subisokinetic conditions (coarse-particle enhancement) so that better statistics could be obtained at larger sizes. Because no time for testing was available, this choice was based upon our experience with other diffuser inlets (Porter et al. 1992) and the physical constraints involved in incorporating it into our mini OPC wing strut mount (Figs. 1b,c,d). Performance evaluations were not made until after the TRACE-P mission (see below).

The nominal inlet velocity into the mini OPC sample tube (Fig. 2) is about 13 m s^{-1}, which is similar to moderate surface wind speeds but is well below aircraft speeds. Our UAV airspeed is about 30 m s^{-1}, our Seneca 1 airspeed is about 60 m s^{-1}, and the NASA P-3 airspeed is about 120 m s^{-1}. To accommodate high aircraft speeds, we fabricated a diverging nozzle to slow down the airflow before it reaches the mini OPC inlet. The nozzle used on the NASA P-3 and Seneca, as indicated in Fig. 2, has a shallow (5°) half angle to reduce turbulence development at the inlet walls near the tip and has a nozzle opening of about 4 mm, 2 times the diameter of the mini OPC inlet tube. Four holes near the base of the nozzle act to exhaust the flow entering the nozzle. Flow velocity is steadily reduced as the air moves to larger cross sections of the nozzle. The inlet tube length (shaded gray in Fig. 2) can be sized to position the inlet tube at a nozzle cross section where the decelerated airflow in the nozzle is appropriate for the desired performance. In this case we tried to achieve a modest subisokinetic mini OPC inlet for the NASA P-3B measurements discussed here, as described below. The UAV has a similar but smaller inlet arrangement to keep weight down.

Other features were added for the P-3B installation. Because ambient aerosol size is a function of relative humidity, we included a Humicap 50 (Vaisala, Inc.) RH and temperature sensor at the exhaust of the mini OPC to monitor it and to compare RH with ambient values (Fig. 1b). Although this sensor is not likely to register the same conditions as that of the mini OPC sample cavity, it can be used with ambient measurements to estimate OPC conditions. Future versions will include a temperature sensor embedded in the cavity to define better the sample RH as measured. The mini OPC collection mirror can also be contaminated by very high aerosol concentrations that can change its reflectivity and the calibration. Hence, the mirror has been made easy to replace by sliding the assembly partially out of the strut (Fig. 1c) and removing the mirror through a hole in the support base. As a precaution against cloud droplets or raindrops entering the inlet, we have also added solenoid valves (inside the aircraft, not shown) that reverse the flow and force purge air back through the unit and out the inlet. This arrangement did not prevent the largest cloud drops and raindrops from penetrating the instrument but dramatically reduced their presence and the contamination of the mirror. The solenoids can be both manually activated or activated by computer control if RH values exceed some selectable threshold (e.g., near clouds).

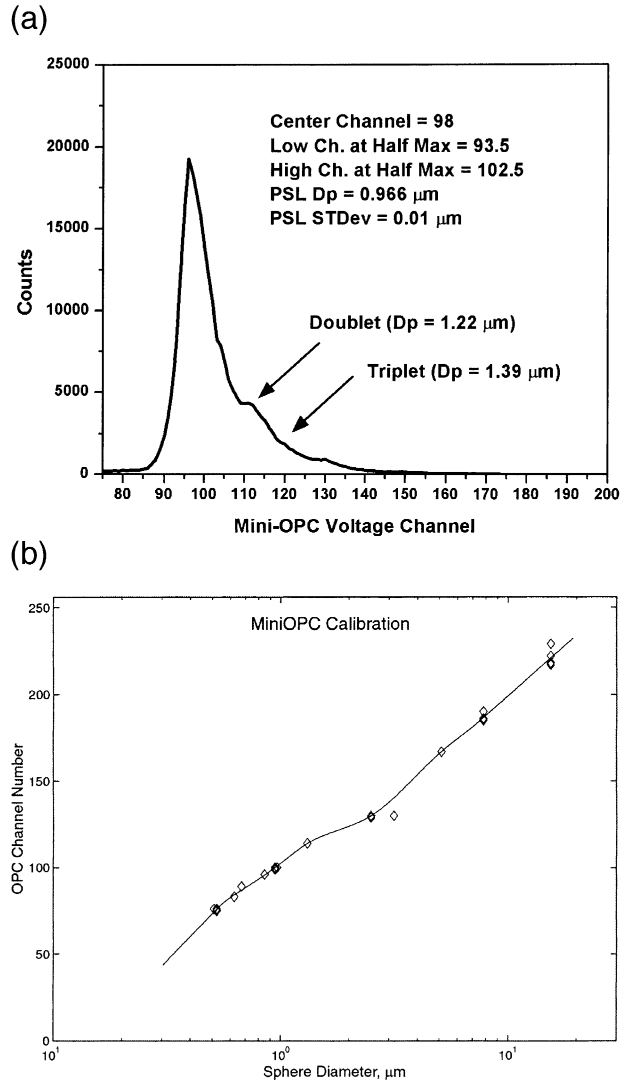

FIG. 3. (a) Mini OPC voltage response to indicated PSL calibration aerosol. Upper-channel tail includes doublets and triplets of primary size (see text). (b) PSL and glass bead calibration curve that establishes mini OPC output voltage vs size.

4. Calibration and inlet tests

Calibration was performed using polystyrene latex (PSL) calibration spheres and glass calibration spheres over the range of 0.3–12 μm. An example of a calibration using 0.966-μm-diameter PSL (std dev = 0.01 μm) is shown in Fig. 3a. The peak is resolved well by the 256-channel sizing and reveals a half-width of about 10 voltage channels. At 0.966 μm, the 10-channel voltage half-width corresponds to a range of about 0.88–1.03 μm as compared with about 0.955–0.975 (3 voltage channels) expected for the PSL particles. The larger observed half-width range shown here is due in part to the laser and optics configuration (ongoing refinements have already reduced this by almost a factor of 2). Nevertheless, this performance is far superior to the six size bins used over the original full range of the Met One instrument and provides very good resolution for most applications.

Our resulting calibration curve linking measured output voltage to calibration sphere diameter is shown in Fig. 3b along with a "best-fit" line that describes the calibration relationship. The nonlinear behavior in the calibration curve is primarily a result of the optical response to transitions from Rayleigh to Mie to geometric scattering (Bohren and Huffman 1983). Some smaller fluctuations result from deviations from nonlinearity in the logarithmic amplifier. Future versions of the electronics will reduce this effect. Actual sizing based upon this calibration suggests that sizes out to about 14 μm can be measured before saturation of the detector. The efficiency of particle detection at the nominal small-particle limit near 0.30 μm is influenced by noise in this prototype version. New versions under development using a more sensitive detector and greater attention to internal scattering surfaces have improved sensitivity down to particle sizes of 0.23 μm.

The TRACE-P experiment (http://www-gte.larc.nasa.gov/gte_fld.htm#TRACE) in March of 2001 allowed us to evaluate the mini OPC on the P-3B aircraft under research conditions. Because we had no time to characterize our new inlet configuration prior to the TRACE-P experiment, postexperiment flow evaluations were necessary. These evaluations were carried out in our wind tunnel, which provides air velocities of up to about 35 m s^{-1} over about a 160-cm^2 cross-sectional area. During these tests, the inlet and mount were located in the center flow out of the tunnel where velocities were about 32 m s^{-1}. Airspeeds were determined in front of and around the inlet using a velocity transducer (TSI, Inc., Model 8455) and the associated pressure fields near and in the inlet were determined using a pitot tube. This wind-tunnel velocity is only about 30% of aircraft velocities employed during TRACE-P, but for the purposes of this assessment the results are assumed to scale accordingly. This assumption is consistent with the less-than-3% difference between incompressible and adiabatic determinations of ''ram'' air pressures at TRACE-P aircraft speeds (Zham 1927).

The deceleration of air as it enters the diverging nozzle produces a ram air pressure that is related to changes in the square of the air velocity relative to the OPC inlet. The apparent ram pressure was measured along the center axis of our inlet using a Pitot tube calibrated against measured velocities in the tunnel. This pressure was also corrected for the small pressure perturbation induced by the inlet in the tunnel flow. Our test configuration allowed direct measurements past the mini OPC inlet tube position as used on TRACE-P (vertical arrow). The indicated airspeed at the mini OPC sample tip (Fig. 4) is proportional to the square root of the pressure (Zham 1927) and corresponds to about 19 m s^{-1} at the TRACE-P position for the wind tunnel speed of 32 m s^{-1}. This speed scales to about 63 m s^{-1} at this location under nominal TRACE-P P-3B flight speeds (120 m s^{-1}). Hence, the 13.8 m s^{-1} mini OPC sample tube flow used during most of TRACE-P meant the mini OPC sample tube was typically subisokinetic by a factor of about 4.5.

This subisokinetic sampling is a result of two factors. First, our mini OPC sample inlet opening was 32 mm back from the tip, whereas it should have been 45 mm behind the tip if flow at the tip scaled only with nozzle cross section. This offset is calculated to have contributed a factor of 2.6 to the subisokinetic ratio. A similar factor of about 1.7 was found to be due to velocities in the nozzle being significantly enhanced along the axis as compared with near the walls. This latter behavior is also suggested by the lack of a pressure change (no velocity change) in the first 6 mm behind the inlet tip

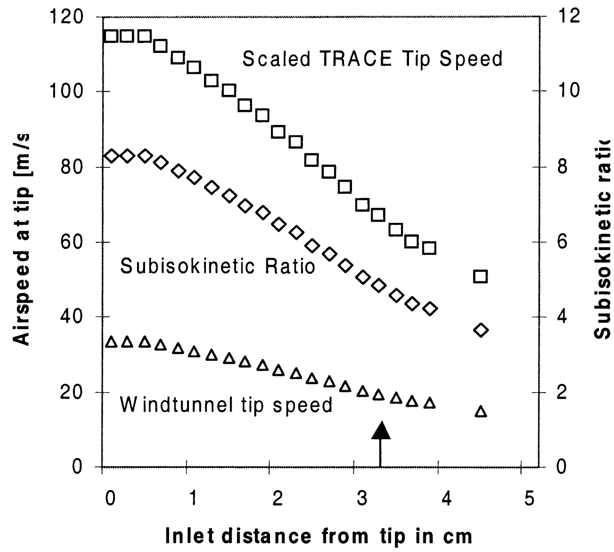

FIG. 4. Airspeed at tip along center of diffusing nozzle in wind tunnel operating at 35 m s^{-1} and tip speed scaled up to expected TRACE-P conditions. Subisokinetic ratio is calculated based upon the scaled TRACE tip speed. The vertical arrow indicates position of mini OPC sample tube inlet in nozzle during TRACE-P associated with 4.5 subisokinetic ratio.

(Fig. 4) despite the increasing cross-sectional area of the nozzle (Fig. 2). Hence, the size distributions measured by the mini OPC on TRACE-P have been corrected for this subisokinetic sampling. As determined above, these yield enhancements of the largest sizes by about a factor of 4.5 for 10-μm particles but have little effect on particles with diameters below about 1 μm (e.g., Porter et al. 1992). The data shown below indicate the effect of this size-dependent correction.

5. Instrument performance

TRACE-P took place over the Pacific Ocean between Hong Kong and Japan and included deliberate efforts to study both pollution and dust aerosol such that particles of all sizes detectable by the mini OPC were represented. The TRACE-P experiment aboard the P-3 aircraft included exposure to natural, pollution, and dust aerosol conditions. Installation on the P-3B aircraft also made our custom LAS-X OPC (Clarke et al. 1996) and wing probe (FSSP-300) (both Particle Measuring Systems, Inc.) available for extended comparison under a wide range of aerosol environments. The mini OPC support wing and nozzle (Fig. 1) had to be fabricated for immediate installation on TRACE-P, and no wind tunnel or performance tests were possible. Hence, engineering considerations were recognized but not optimized. The mini OPC was mounted on the right side of the aircraft (as was the FSSP-300) on the first window plate behind the cockpit area (Fig. 1d) and about 6 m behind the nose of the aircraft. The inlet was about 30 cm away from the fuselage, which had a surface boundary layer

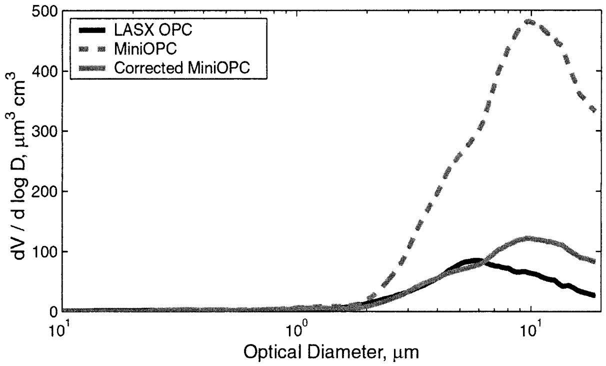

FIG. 5. Comparison of mini OPC volume distributions, before and after subisokinetic correction (see text), with onboard LAS-X OPC distribution.

estimated at about 10 cm at this location (determined from prior aircraft tests). The window plate also included the shrouded inlet to the laser optical particle counter (LAS-X), and both inlets were angled upward about 1.5° to match the nominal angle of attack of the aircraft. Deviations of $\pm 1°$ can be expected depending upon fuel load and altitude, and so on. This shrouded inlet has been evaluated during inlet tests as part of the Preliminary Evaluation of the Low Turbulence Inlet (PELTI) experiment in 2000 in which it was found to have good transmission performance for dry particles (e.g., within 15% of actual for 4 μm) and somewhat worse for wet particles (e.g., within 30% of actual for 4 μm), presumably due to ''wet'' particles colliding with and sticking to the wall (Huebert et al. 2000).

Figure 5 shows an example of the size distributions measured by the mini OPC and the onboard LAS-X for a period of elevated dust concentrations during TRACE-P that allow us to characterize the coarse-particle sizing characteristics. Both instruments employ integral side-scattering optics. The LAS-X includes a helium–neon (HeNe) laser (632 nm), custom electronics, and a dryer dilution flow that has been employed for our aerosol measurements for a number of years (Clarke et al. 1996) and allows for sizing between 0.1 and 12 μm. All sizes are based upon calibration of dry latex spheres with refractive index of about 1.5. Because concentrations of larger aerosol (say, 3 μm) are about 3 orders of magnitude lower than 0.3-μm particles, ambient data are averaged over about 50 min so that statistically significant counts (e.g., greater than 50 particles per size bin) are present for both fine- and coarse-particle dust aerosol in both instruments. This data period was selected because it was measured aloft under relatively dry (30% RH) conditions such that correction for possible differences in particle size due to different instrument RH (as mentioned earlier) is minimal. We note that the LAS-X data represent distributions averaged over 1 min and taken every 3 min (18 1-min averages) because this system was cycled to look at other thermally heated aerosol for 2 min out of each 3-min period. Also, the higher sample flow rate (1.6 vs 0.3 l min^{-1}) and subisokinetic sampling (up to a factor of 4.5 enhancement) increase relative mini OPC sampling statistics relative to the LAS-X OPC by a factor of 5–24 depending upon particle size.

The mini OPC data are shown (Fig. 5) both before and after correction for the size-dependent effect of subisokinetic sampling. The $dV/d(\log Dp)$ versus logDp volume distribution (area under curve is proportional to aerosol volume), where V is volume and Dp is particle diameter, best reveals sizing performance at larger sizes because of the cubic dependence of volume on particle diameter. Little subisokinetic correction is evident below 1 μm, but before reaching 8 μm the correction approaches an asymptote near a factor of 4.5. Note that, below about 5 μm, the mini OPC data, after correction for subisokinetic flow, are within about 15% of the LAS-X OPC data and are within the combined flow uncertainties expected here. At larger sizes, the corrected mini OPC shows significantly higher ambient concentrations. This result is because both the sample inlet and tubing to the LAS-X OPC have particle losses that have not been accounted for and because the LAS-X inlet itself is known to have particle losses for sizes above about 7 μm. Hence, we contend that the mini OPC has equivalent performance to the LAS-X particle counter between 0.4 and 5 μm and probably superior performance above that size.

The high flow rate of the mini OPC (1.6 L min^{-1}) relative to the LAS-X (0.3 L min^{-1}) and FSSP-300 (0.25 L min^{-1}) means the mini OPC also has intrinsic factor-of-5 or better count statistics than the other instruments. This quality is particularly valuable, over its size range, for measurement of the coarse particles (e.g., dust) generally present at low number concentrations and makes it effective at measuring representative size distributions in rapidly changing environments such as those encountered during vertical descents. This is demonstrated over a range of conditions (Fig. 6) for a descent profile over the Sea of Japan during TRACE-P during which highly structured pollution and dust plumes were encountered.

The detailed vertical structure in aerosol optical properties for these continental aerosol plumes is illustrated here in the concurrently measured profiles of aerosol light scattering (nephelometer Model 3563 from TSI, Inc.) and light absorption coefficients (particle soot absorption photometer from Radiance Research, Inc.) during the descent (Fig. 6a). These data (15-s average) provide a context for the size distribution measurements. The integrated aerosol volume from the LAS-X, mini OPC and FSSP-300 are included in Fig. 6b. Small altitude offsets evident here are due to 1-min-average values being recorded for the mini OPC and LAS-X while 15-s data were stored for the FSSP-300. These integral volume measurements are clearly correlated. Differences are consistent with the recognition that coarse particles dominate the volume so that the FSSP-300 with

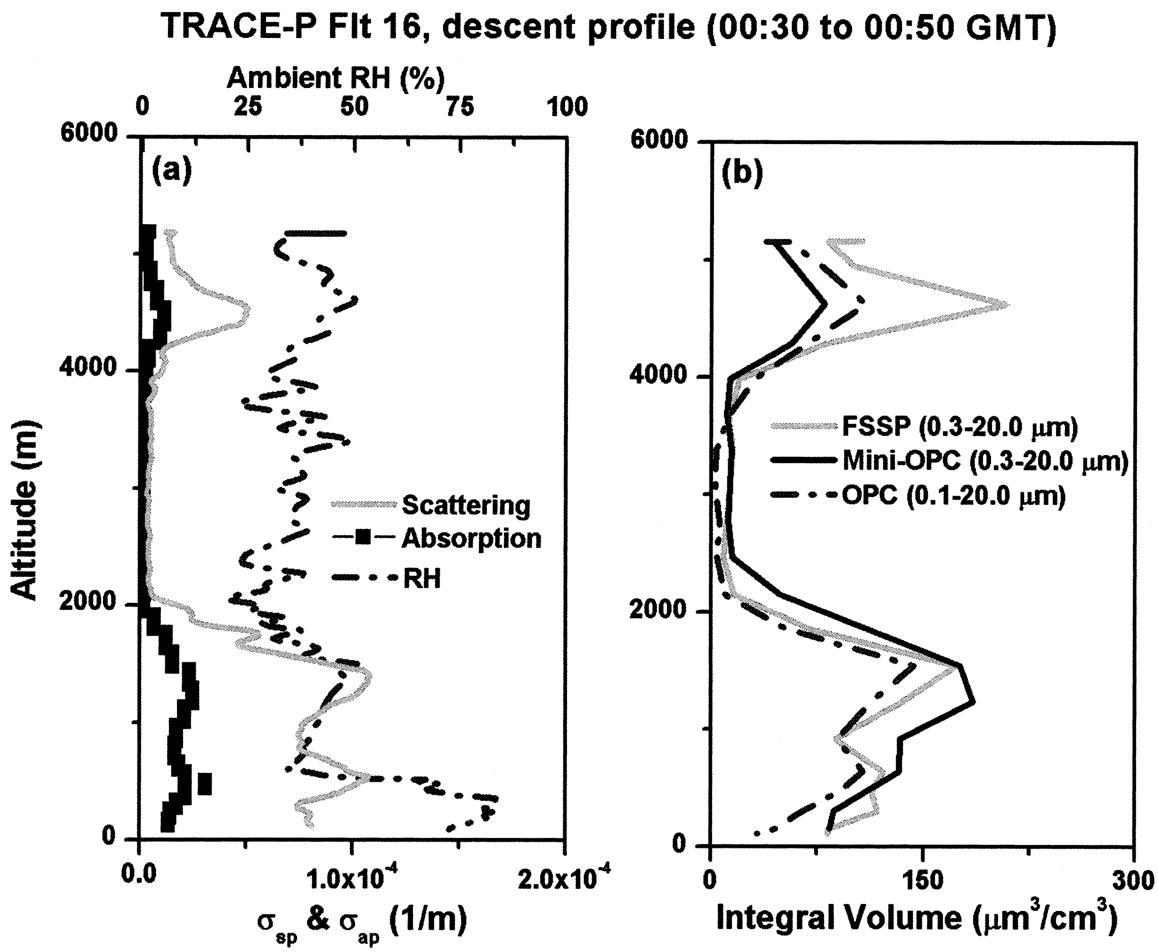

FIG. 6. (a) Vertical profiles of aerosol light scattering, light absorption, and ambient humidity that reveal aerosol column optical structure. (b) Corresponding profile of integral volume concentration from the mini OPC LAS-X and FSSP-300 size distributions. Relative concentrations are consistent with size ranges of instruments and operating humidity (see text).

greatest sensitivity to largest aerosol is highest, followed by the mini OPC, and then the LAS-X, which has the smallest upper size range and shows the lowest volume. Note that for these 1-min-averaged data the FSSP volume is relatively higher than the OPC and mini-OPC volume near 4.5 km than elsewhere in the profile. This is apparently due to a few large aerosol near 10-μm diameter (Fig. 7) that were not detected in the other two instruments. Since the FSSP has the poorest count statistics this difference may also be a sampling artifact. Otherwise the three instruments show remarkably good agreement over the profile. Note that, under more polluted settings in which the smaller accumulation-mode aerosol dominates the mass, the LAS-X (with its superior sensitivity below 0.3 μm) will best resolve the actual aerosol volume.

To examine smaller particle characterization with the mini OPC, we have plotted the same data for the profile in Fig. 7 as a continuous surface-area size distribution (shaded by concentration contours). Because surface area depends on the square of the diameter instead of the cube (volume), submicrometer and supermicrometer particles contributions are both better revealed. A typical representative size distribution from 1.5 km is also included below each contour plot for clarity. The mini OPC and FSSP-300 data are also truncated at 0.3 μm where their signal-to-noise limits are reached; the LAS-X provides well-resolved sizes down to about 0.1 μm. The more variable contours in the distributions for the FSSP-300 data reflect a combination of coarse size bins and limited sample volume as compared with the LAS-X and mini OPC. This prototype mini OPC clearly exhibits excellent qualitative and quantitative characterization of aerosol size. The high flow rate clearly provides improved count statistics over those of the LAS-X and FSSP-300 (Baumgardner and Spowart 1990).

6. Conclusions

We have developed, tested, and deployed a prototype custom mini OPC and inlet system for in situ aircraft studies of noncloud aerosol. The unit employs a solid-

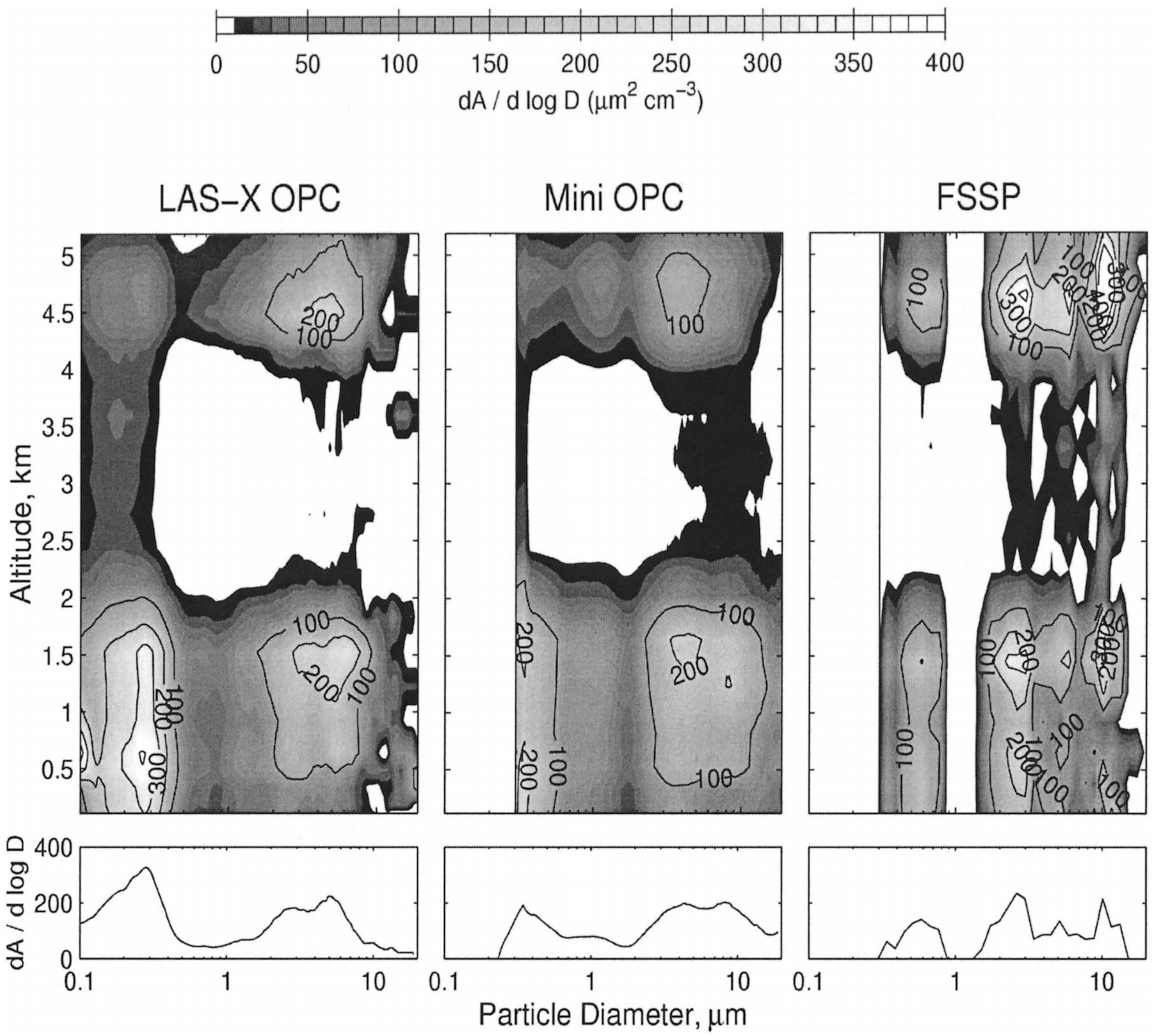

FIG. 7. Concentration contours of surface area as measured by the LAS-X, the mini OPC, and FSSP-300 for a vertical profile near Japan on TRACE-P. The lower sensitivity limits of 0.3 μm have been masked off on the latter two instruments. An example of a distribution from each instrument as measured at 1.2 km is also included below each panel for clarity.

state laser and optical block from a Met One 237A optical particle counter coupled to a custom-designed logarithmic amplifier, electronics, and sample inlet configuration. The device has been found to work successfully for applications on small remote-controlled aircraft as well as on full-size research aircraft.

Comparison with size distributions obtained concurrently using a LAS-X (inside aircraft) and FSSP-300 (mounted on wing) optical particle counter were undertaken as part of the TRACE-P experiment, which sampled both pollution and dust aerosol near Japan. Though not optimized for this application, the prototype mini OPC was found to work dependably and with good quantitative performance under a range of conditions and to provide reliable partially dried size distributions from about 0.3 to 14 μm. Future incorporation of temperature sensors inside the optical cavity are planned to quantify uncertainties in operational RH and associated effects better. Low particle losses for larger aerosol resulted in improved characterization of large aerosol relative to that possible with the LAS-X. The simpler optical system and high flow rate provided superior performance when compared with the FSSP-300 up to about 14-μm particle sizes. The small size, low power, low cost, versatility, wide size range, and high resolution of the device make it ideal for a large number of airborne and surface applications.

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