

Cloud Condensation Nucleus Instrument for Airborne Measurement

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LONG-TERM GOALS

The long-term goal of our research is to develop techniques for measurement of atmospheric aerosols and cloud condensation nuclei to develop deep understanding of the processes that control cloud formation and of the role of aerosols and clouds in radiative forcing.

OBJECTIVES

Our objectives are to design, construct, implement, and apply state-of-the-art instrumentation for airborne measurement of aerosols and cloud condensation nuclei.

APPROACH

Our approach is three-pronged: laboratory studies, aircraft-based measurements, and theoretical analysis of data. In the aircraft-based measurements, we have participated in several large-scale field programs. The CIRPAS facility at the Naval Postgraduate School plays a key role in our work.

WORK COMPLETED

Cloud Condensation Nucleus Instrument

A new instrument for measuring cloud condensation nuclei (CCN) onboard small aircraft has been developed. Small aircraft are attractive mainly because they are less costly, but require instruments that are designed for minimum weight, volume, and power consumption, that are robust, and that are capable of autonomous operation and making measurements at a frequency appropriate for aircraft speeds. The instrument design combines the streamwise gradient technique and the alternating gradient condensation nuclei counter. Field and lab measurements, and modeling studies show that this combination exhibits poor sensitivity for the measurement of CCN spectra; for the climatically important range of critical supersaturations, 0.03 to 1%, the measured variable, droplet diameter, varies by 30%. Studies of this instrument in a fixed supersaturation mode show that it can measure CCN at a single supersaturation in the range of 0.1 to 2%. The instrument is capable of making accurate, high frequency (> 0.1 Hz) measurements of CCN at a fixed supersaturation, while satisfying the constraints for small aircraft.

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Measurements of Cloud Condensation Nuclei in ACE-2

Measurements of cloud condensation nuclei (CCN) concentration at 0.1% supersaturation were made onboard the CIRPAS *Pelican* over the northeast Atlantic during June and July, 1997, in the vicinity of Tenerife, Spain, as part of the second Aerosol Characterization Experiment (ACE-2). The average CCN concentration (N_{ccn}) in the marine boundary layer for clean air masses was 27 ± 8 and $42 \pm 14 \text{ cm}^{-3}$ for cloudy and clear conditions, respectively, consistent with measurements made near the British Isles and close to Tasmania, Australia, during ACE-1 for similar conditions. A local CCN closure experiment was conducted. Measured N_{ccn} is compared with predictions based on aerosol number size distributions and size-resolved chemical composition profiles determined from measurements and the literature. A sublinear relationship between measured and predicted N_{ccn} , $N_{ccn} \sim N_{ccn,predicted}^{0.51}$, was found. This result is consistent with some previous studies, but others have obtained results much closer to the expected 1:1 relationship between measured and predicted N_{ccn} . A large variability between measured and predicted N_{ccn} was also observed, leading to the conclusion that, for 95% of the data, the predictions agree with measurements to within a factor of 11. Relationships between below-cloud N_{ccn} and aerosol accumulation mode concentration, and in-cloud cloud droplet number concentration, measured onboard the *Pelican* and the Meteo-France *Merlin IV*, respectively, were calculated for periods while the two aircraft were in close proximity at approximately the same time. Measured relationships were reproduced by an adiabatic parcel model, and are also consistent with some previous studies. However, the shape of the CCN spectrum, or the aerosol size distribution, and the updraft velocity are predicted by the model to affect these relationships to a significant extent. Therefore, parameterizations of cloud microphysical properties need to include these variables to accurately predict cloud droplet number concentration.

In Situ Aerosol Size Distributions and Clear Column Radiative Closure During ACE-2

As part of the second Aerosol Characterization Experiment (ACE-2) during June and July of 1997, aerosol size distributions were measured on board the CIRPAS *Pelican* aircraft through the use of a DMA and two OPCs. During the campaign, the boundary layer aerosol typically possessed characteristics representative of a background marine aerosol or a continentally influenced aerosol, while the free tropospheric aerosol was characterized by the presence or absence of a Saharan dust layer. A range of radiative closure comparisons were made using the data obtained during vertical profiles flown on four missions. Of particular interest here are the comparisons made between the optical properties as determined through the use of measured aerosol size distributions and those measured directly by an airborne 14-wavelength sunphotometer and three nephelometers. Variations in the relative humidity associated with each of the direct measurements required consideration of the hygroscopic properties of the aerosol for size distribution based calculations. Simultaneous comparison with such a wide range of directly measured optical parameters not only offers evidence of the validity of the physicochemical description of the aerosol when closure is achieved, but also provides insight into potential sources of error when some or all of the comparisons result in disagreement. Agreement between the derived and directly measured optical properties varied for different measurements and for different cases. Averaged over the four case studies, the derived extinction coefficient at 525 nm exceeded that measured by the sunphotometer by 2.5% in the clean boundary layer, but underestimated measurements by 13% during pollution events. For measurements within the free troposphere, the mean derived extinction coefficient was 3.3% and 17% less than that measured by the sunphotometer during dusty and non-dusty conditions, respectively. Likewise,

averaged discrepancies between the derived and measured scattering coefficient were -9.6%, + 4.7%, +17%, and -41% for measurements within the clean boundary layer, polluted boundary layer, free troposphere with a dust layer, and free troposphere without a dust layer, respectively. Each of these quantities, as well as the majority of the > 100 individual comparisons from which they were averaged, were within estimated uncertainties.

RESULTS

The Scanning Flow DMA

A new method of differential mobility analyzer (DMA) operation has been implemented in which the flow rates are continuously changed in conjunction with the applied voltage. By optimizing the flow and voltage ramps, improvements can be made in the DMA's measurable size range, counting statistics, resolution, or a partial combination of each of these. The experimental system enabled accurate control of flows that were varied by an order of magnitude in as little as 30 s. Excellent agreement was obtained between mobility distributions recovered from a voltage ramp, a flow ramp, and a combined voltage and flow ramp. Slight deviations were apparent in the recovered data as the flow scan time was reduced from 60 to 30 s.

Improved Inversion of Scanning DMA Data

Recovery of aerosol size distributions from either stepping or scanning mode differential mobility analyzer (DMA) measurements requires an accurate description both of the characteristics of the DMA itself, as well as certain properties of the aerosol. Inversion of scanning DMA data is further complicated by the non-unique relationship between the time a particle exits the DMA and the time it is ultimately detected. Without an accurate description of this relationship, as well as an appropriate method of accounting for it, inverted distributions will be broadened and skewed relative to the true distribution. A simplified approach to this has been developed in which adjustment of the raw data to account for the delay time distribution associated with the instrument is accomplished prior to final inversion. The accuracy of this procedure has been demonstrated through analysis of actual as well as test-case data.

Mixing Type Condensation Nucleus Counter

A new mixing-type condensation nucleus counter with small mixing volume has been developed. With this detector, scanning DMA measurements have been made in as fast as 1 second. This new CNC offers great promise for fast airborne measurements of aerosols.

Drizzled Entrainment Cloud Study 1999

One of the outstanding questions facing the Caltech CCN instrument, as well as many other airborne instruments, is how instrument performance in the field compares with results obtained under controlled laboratory conditions. To address this question, an *in situ* calibration was performed on the CCN instrument over the course of several flights during the Drizzle and Entrainment Cloud Study (DECS), based in Monterey, CA during the summer of 1999.

The calibration was made possible by reconfiguring the ACADS instrument, which also flew during the DECS mission. During flight legs where a very high portion of the aerosol population was expected to be hygroscopic, the RDMA in the ACADS instrument was switched from its normal voltage-scanning mode to manual voltage control. After exiting the DMA, the monodisperse flow is split between the CCN instrument and the condensation nucleus counter in the ACADS instrument, thereby providing simultaneous CCN and total particle concentrations. By adjusting the voltage in the DMA, these relative concentrations can be obtained for several particle sizes, producing an *in situ* calibration curve for the CCN instrument.

The experiment described above was conducted four times over a two-week period during DECS. For the first two, conducted during the 03 July and 06 July flights, the CCN instrument was set to a nominal supersaturation of 0.2%. The second two experiments, conducted on 14 July and 17 July, had the instrument set to a nominal supersaturation of 0.4%. The first, second, and fourth experiments went very smoothly, and the data indicates a supersaturation very close to the expected value ($D_{50\%}$ was predicted to be approximately 90nm at 0.2% supersaturation, and 60nm at 0.4%). The concentration ratios for the third experiment were much lower than the other runs, but other instruments on the aircraft indicated that the air mass was not as clean as had been expected, and may have also changed significantly during the flight leg, rendering the experiment meaningless for calibration purposes.

IMPACT/APPLICATIONS

Our work is expected to have a major impact on the airborne sampling of aerosols and cloud condensation nuclei.

TRANSITIONS

Our DMA design is now in use by several other research groups utilizing aircraft sampling.

RELATED PROJECTS

None.

PUBLICATIONS

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