Reviewer 1 (Dr. Twohy)

We thank Dr. Twohy for helpful comments that have greatly assisted us in producing an improved version of the manuscript. Detailed responses to each comment are provided below.

General Comments:

The paper presents results from wind-tunnel and aircraft testing of a new CVI inlet. The authors use previously established wind-tunnel test procedure to characterize the CVI performance for conditions consistent with Twin Otter operation. The sampling performance determined from laboratory experiments is validated from analysis of aircraft-based measurements of cloud size distributions and total concentration downstream of the CVI. The paper is reasonably well written and the experiments and analysis are quite thorough. I have a few minor comments that are listed below, which I hope the authors can address.

Specific Comments:

p. 1517, line 23-24: The dilution flow argument is unclear. In my experience, a lower sample flow rate (<10 l min-1) is used to keep the same stream laminar, and this is usually sufficient without dilution for a wide variety of instruments. What is the Reynolds number in the sample stream using 15 l min-1? Also, the rapidly expanding diffuser just behind the tip is likely to induce turbulence.

Response: The sample tube inner diameter is 27.5 mm, resulting in a Reynolds number of approximately 765 for a sample flow of 15 l min^{-1}. The need for higher flow rates is important for instruments such as the PILS that demand up to 15 L min^{-1}, and we already address this point in the text. The subset image in Fig. 1 is not drawn to scale; the expansion angle of the diffuser between the extension tube behind the tip and the sample tube is 10.1°. Additional text has been added to address this:

"The sample tube has an inner diameter of 27.5 mm, resulting in an average velocity of 42 cm s^{-1} and Reynolds number of 765, when operated with a sample flow rate of 15 L min^{-1} at STP."

Also, in the Figure 1 caption we add: "(Note that the expansion angle of the diffuser between the extension tube behind the tip and the sample tube is 10.1°.)"

p. 1518, line 3: Insert "some" before "older CVI designs". There are some CVI inlets that have operated for 20 years without having ever used siloxane.

Response: This change has been made.

p. 1518, line 20: What is the temperature of the add-flow and of the tip, and how is it controlled?

Response: The temperature of the add-flow is measured at the upstream MFC and again at the tip. The add-flow temperature at the tip is controlled using a heating element near the tip. The set point at the tip was set to 35°C during the E-PEACE campaign. Additional text as has been added to address this comment:

"Air is heated within this annular space and controlled with the airflow temperature measured immediately upstream of the porous section (segment B in Fig. 1)."

p. 1519, line 20: Based on subsequent information given, I assume the 15 l min-1 is volumetric, but it should be defined here especially since a MFC is specified as the control mechanism.

Response: We have modified this sentence to clarify that the flow controllers are operating in a volumetric mode.

p. 1520, line 2: Define BMI here or on p. 1518 when Brechtel is mentioned.

Response: We have defined the acronym BMI on p. 1518.

p. 1520: Is there any measurement or estimate of the turbulence intensity inside the wind tunnel and how that compares to the typical flight conditions? This could affect the calibration results.

Response: The turbulence intensity inside the wind tunnel was measured using a hot-film probe at 100 m s^{-1}. The following text has been introduced to reference this:

"Turbulence intensity in the BMI wind tunnel was measured using a hot-film probe (Dantec Dynamics, Model 55R01)at the 100 m s^{-1} condition and ranges from 4% ($1\sigma = 3.5$) at the perimeter to 2% ($1\sigma = 1.5$) at the centerline."

p. 1520, line 21: Is 1 l min-1 the lowest counterflow rate that could be used without getting particle contamination? If so, it might indicate high turbulence levels or poor alignment with the mean airflow (unlikely for the tunnel tests but possible for the aircraft work.)

Response: The minimum counterflow rate was not extensively investigated. Brief changes during the field campaign were made to the counterflow rate and 1 l min^{-1} was chosen for normal operations.

p. 1521, line 4: Change "grew" to "increased".

Response: We have made this change.

p. 1521: I believe there was some flow modeling done for this inlet; it should probably be at least briefly discussed here for comparison, unless published elsewhere.

Response: No internal inlet flow modeling was performed for this instrument model.

p. 1522, line 6: This describes an optimization procedure for C1 which should produce a calculated cut size that is as close to the predicted cut size as possible; thus I would expect the mean error to be close to zero. I think the authors mean that 12.6% is the maximum error for the six conditions tested. Perhaps this could be rewritten to give the actual residual % differences for all six conditions, most of which actually seem to be less than 12.6% and vary in sign.

Response: We agree with this comment and have revised the text to clarify this:

"Over this range, the C_1 value has a mean error of 1.7% for the conditions tested. Individual percentage differences between the predicted and measured values, for each of the six conditions tested, are reported in Table 1."

p. 1522, lines 25-27: It's surprising that the transmission efficiency is so low for particles slightly larger than the cut size, particularly when using glass beads that might be expected to stick less readily than water droplets. On the other hand, water droplets slightly larger than the cut size will be expected to partially evaporate as they stop, which would increase their transmission efficiency. Also, the flow through the porous tube (which apparently was not used in the transmission efficiency experiments) is expected to collimate the flow and trajectories of some particles (e.g., Laucks and Twohy, 1998), increasing transmission efficiency. These factors may change the laboratory-derived transmission efficiency from expected in-flight results, although they may be compensating. At any rate, it would be useful to know how sensitive the flight results shown in Fig. 6 are to the applied transmission efficiency curve. I.e., without it, would the slopes decrease to 1.5? 2.0?

Response: We conducted the suggested analysis and added text to report the results:
"To assess the sensitivity of the Fig. 6 results to the transmission efficiency results, an analogous analysis was done while ignoring the correction to the cloud probe N_d values to account for the transmission efficiency (Fig. 5). The increase in the Fig. 6 slopes ranges between factors of 2.49-3.86."

Also, dimensions for the CVI parts (as requested below in the figure comments) would help understand the potential losses. Perhaps lower sample flow rates would help reduce this problem.

Response: The requested dimensions of the internal tubing are: porous tube ID, 4.57 mm; porous tube length, 10.2 mm; extension tube ID, 5.84 mm; extension tube length, 159 mm; sample tube ID, 27.53 mm; sample tube length, 487 mm. As mentioned, the long extension tube directly behind the porous section of tube could be removed or shortened to greatly increase the transmission efficiency of particles larger than the cut size.

p. 1523, line 18: How was the 4.2 l min^{-1} for the instruments controlled, and was it monitored by the CVI electronics or just assumed to be constant? With that many instruments, small errors could add up.

Response: We agree with this reviewer comment and have added text to address this:
"When sampling was conducted through the CVI in cloud, the total flow required by the instruments was typically near 4.2 L min^{-1} with the CVI sample-flow MFC controlling the

remaining 10.8 L min^{-1}. Minor variations existed in the total sample flow rate based on fluctuations in flow requirements among the various instruments downstream of the CVI. "

p. 1524-1525: I don't believe potential wake capture of small particles by large droplets can be tested in clear air, since the droplets are not present.

Response: We agree with the reviewer's comment. This sentenced has been removed for clarity.

p. 1525, line 7: The alignment with the mean flow is laudable, but how far from the fuselage was the inlet tip located? This can also affect the sampled size distribution (e.g., King, JTECH, 1984.)

Response: The tip to fuselage distance was measured at 178 mm. This distance places the inlet tip outside the maximum shadow zone for the E-PEACE twin otter aircraft of 160 mm. This was calculated for the maximum aircraft fuselage diameter of 1.605 m. The following text has been added to include this information:

"The inlet tip-to-fuselage distance of 178 mm places the sampling stream outside the maximum shadow zone of 160 mm for the CIRPAS Twin Otter aircraft. The maximum shadow zone is calculated as 20% of the aircraft's fuselage radius (King, 1984)."

p. 1525: Also, was there an instrument onboard to detect drizzle drops, and were drizzling clouds excluded due to potential artifacts of breakup? (e.g., Weber et al., 1998.) Large drops can breakup even upstream of the trap, due to inertial forces and wall impaction.

Response: A Cloud Imaging Probe (CIP; D_p ~ 25-1600 μm) was including in the instrument package on the Twin Otter to detect drizzle drop size distributions during E-PEACE. Two flights experienced more drizzle than others and the periods with extensive drizzle were removed from the analysis to avoid such artifacts due to breakup. We address this issue in the text:

"Periods with extensive drizzle, as identified with a Cloud Imaging Probe (CIP; D_p ~ 25 - 1600 mm) were omitted for this analysis owing to potential artifacts associated with the breakup of large drops (Weber et al., 1998)."

p. 1525, line 23 (Fig. 6): It looks like the difference between the CDP and CAS may be as large as the difference between these instruments and the CVI. The uncertainties in these instruments (in concentration and sizing near the cut size) should be discussed. Also, some idea of the droplet size distribution and the percentage of all droplets actually sampled by the CVI would be useful.

Response: This is a good point by the reviewer and we agree that more discussion of this issue is needed. We add text to clarify that the comparisons of these two independent probes with the CVI around the cut size is imperfect but that the goal of this comparison is to capture the changes in the slopes in Figure 6 with varying minimum bin sizes for the two probes. The uncertainties in sizing and counting have been documented elsewhere for these probes (e.g. Baumgardner et al., 2001; Conant et al., 2004; Lance et al., 2010) and these are thought to be dependent on a number of factors such as drop size and LWC. We add text to address the issue of these probes:

"These probes were calibrated during the E-PEACE campaign using monodisperse polystyrene and glass beads. Uncertainties in counting and sizing associated with these instruments have been documented elsewhere (e.g. Baumgardner et al., 2001; Conant et al., 2004; Lance et al., 2010). As noted below, neither of the probes have size bin limits that directly match the CVI cut size of 11 μm, therefore, a purpose of the following analysis is to examine relative changes in the ratio of N_a to N_d when integrating drop distributions over different drop size ranges."

We emphasize that the drop distribution in Figure 8 is representative of the conditions experienced during the E-PEACE campaign, including both background marine conditions and conditions associated with fresh ship plumes perturbing clouds. We report the fraction of droplets larger than the CDP bin size of 10.37 μm, which is the largest size of the two cloud probes that is still less than the expected cut size of 11 μm. We added the following text:

"Based on CDP drop distributions integrated above 10.37 μm, the fraction of drops larger than the CVI cut size for the entire duration of Figure 8, which is representative of conditions experienced during E-PEACE, was 78.2 $\pm$ 18.9%, where the lowest fractions are associated with being immediately above cloud base (UTC 17:54 - 18:00: 58.2 $\pm$ 19.2%) as compared to being near the middle and below the top of the cloud deck (UTC 18:00-18:15: 86.2 $\pm$ 11.2%). Ship plume influenced regions of clouds are associated with reductions in the sampled drop fraction owing to the reduction in droplet size as shown in Figure 8."

p. 1527-1528: The single larger residual mode could also be a result of the CVI missing smaller droplets, which are more likely to nucleate on smaller particles. This could particularly be true in a modified cloud with more, smaller droplets. Again, some details of the droplet distribution would be useful. Also, the actual data points should be included in Fig. 8 in order to assess the appropriateness of the fits.

Response: We added the raw data to Figure 9 and include more discussion of the results in the text. There are signs of some smaller sub-100 nm particles activating into droplets in the smoke-influenced cloud regions, but in the background cloud areas, there is less signal behind the DMA for these sub-100 nm particles. We discuss issues with noisy DMA data at low diameters and that caution must be exercised when viewing the sub-50 nm data. We expect that there likely are smaller particles that the CVI misses as those droplets are smaller than the 11 μm cut size, and we make that clear in the text. To address the reviewer comment about showing details of the drop distributions, we emphasize that the drop distribution in Figure 8 is representative of conditions during the entire E-PEACE campaign. We also mention our additional text to address this in the previous comment above. We added the following text:

"Figure 9 shows raw and fitted size distribution data from a scanning differential mobility analyzer during the same sampling periods used to generate the AMS pie charts. The background aerosol below cloud, sampled from the sub-isokinetic inlet, was fit to a two-term lognormal function. The size distributions obtained behind the CVI were considerably noisier, owing to a dramatic reduction in raw particle counts in the instrument. These size distributions were fit to a single lognormal function using the size distribution data greater than 50 nm diameter only, because the existence of a particle mode at these sizes can be confirmed by the scattering channels on the SP2 (data not shown). Therefore, caution should be used when viewing data at sub-50 nm as these data are subject to larger correction factors in the DMA data inversion owing to diffusional losses in the instrument. The *Point Sur* smoke crossings below cloud were sufficiently narrow such that an entire DMA scan (~110 s) did not properly capture the size distribution of this source, and thus only one average distribution is presented. The background sub-cloud size distribution exhibits a bimodal character with a sub-100 nm mode and a larger mode, indicative of cloud-processed aerosol. The single mode fits to the droplet residual size distributions peak at approximately 200 nm diameter, indicating that the larger of the two modes below cloud was most effective at activating into droplets (at least for droplets larger than the cut size of 11 µm). It is likely that smaller particles may have activated into drops that could not be sampled owing to being smaller than the inlet cut size. The raw data show that the number concentrations of droplet residual particles in the mode larger than 100 nm are expectedly higher in the plume-influenced regions of clouds. More detailed results of the physicochemical properties of droplet residual particles from the E-PEACE study will be forthcoming."

Miscellaneous: One of the new features is an inlet that can be easily cleaned to avoid build up of material within the inlet; was this done and is there any evidence that it was helpful?

Response: During the E-PEACE campaign, the tip was removed, inspected for material deposition, and cleaned. The process was extremely quick and effortless. Different tip configurations can be easily interchanged to alter cut size limits.

Fig. 1 & 2: Dimensions, both lengths and internal diameters, would be useful in assessing performance and suitability for other aircraft. A photograph of the CVI location on the Otter would also be helpful. In the Fig. 1 inset, it looks like the short porous tube extends through almost the entire tip upstream of the expansion, but in Fig 2., the tip looks very long. Which is not to scale?

Response: The requested dimensions of the internal tubing are: porous tube ID, 4.57 mm; porous tube length, 10.2 mm; extension tube ID, 5.84 mm; extension tube length, 137 mm; sample tube ID, 27.53 mm; sample tube length, 463 mm. The Fig. 1 inset is intended to be a visual representation of the different flow paths and is only as a loose representation of the inlet structure and is not to dimensional scale. The figure caption has been revised to clarify the issue of the diagram scale:

"Figure 1. Schematic depiction of the BMI CVI inlet and the flows innate to its operation (inset, not to scale)."

Fig. 3 & 4: To avoid confusion, it should be made clear in the captions that Fig. 3 is based on tests in CVI counterflow mode, while Fig. 4 is for tests without the counterflow (and tip, apparently.)

Response: We have addressed this comment in the two captions.

“Figure 3. Transmission efficiency of hollow glass beads at different add-flow rates based on counter-flow mode experiments conducted with the BMI wind tunnel at different air velocity conditions (50 and 100 m s^{-1}). The dashed horizontal lines correspond to 50% transmission efficiency, which defines the inlet cut size ($D_{p,50}$).”

“Figure 4. Transmission efficiency for hollow glass beads in various parts of the CVI inlet based on wind tunnel experiments with the inlet not operating in counter-flow mode. "Tubing prior to expansion" refers to segment (B) in Fig. 1 and "Expansion" refers to segment (C) in Fig.1.”

Note that the last line of the Figure 4 caption indicates in Fig. 1 that the tip assembly is not considered.

Fig. 8: This figure should be enlarged for legibility.

Response: We agree with this comment and this issue is an artifact of how the previous draft was published on AMTD. We will make a point that the figure be enlarged in the final production of the manuscript.