Reducing and quantifying uncertainties in climatically relevant cloud microphysical parameters derived from optical array probes

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1. Motivation

- **In situ measurements of ice crystal number distribution *N(D),* ice water content *IWC*, median diameter D_m, effective raidus r_e, and extinction β from 2D Cloud Probes (2DCs) potentially affected by shattered artifacts**

- **Data from National Research Council of Canada Convair-580 collected during Indirect and Semi-Direct Aerosol Campaign (ISDAC) and from National Science Foundation (NSF)/NCAR C-130 during Instrumentation Development in Airborne Science 4 (IDEAS-4) campaign used to assess impact of shattered artifacts on *N(D)*, β, D_m, r_e and *IWC* in varying cloud conditions**

2. Shattering removal techniques

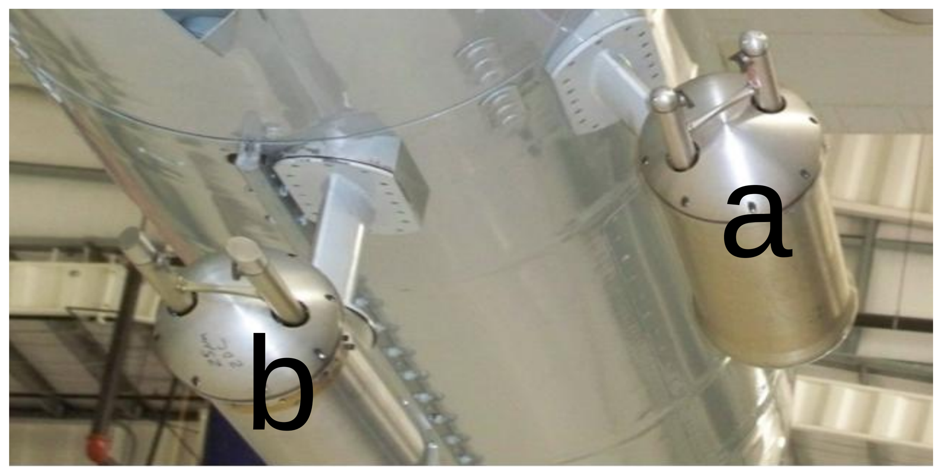

*Figure 1. 2DCs with **(a)** standard tips and **(b)** tips modified to sweep shattered particles away from sample volume mounted on C-130 during IDEAS-4. Similar probes used on Convair during ISDAC.*

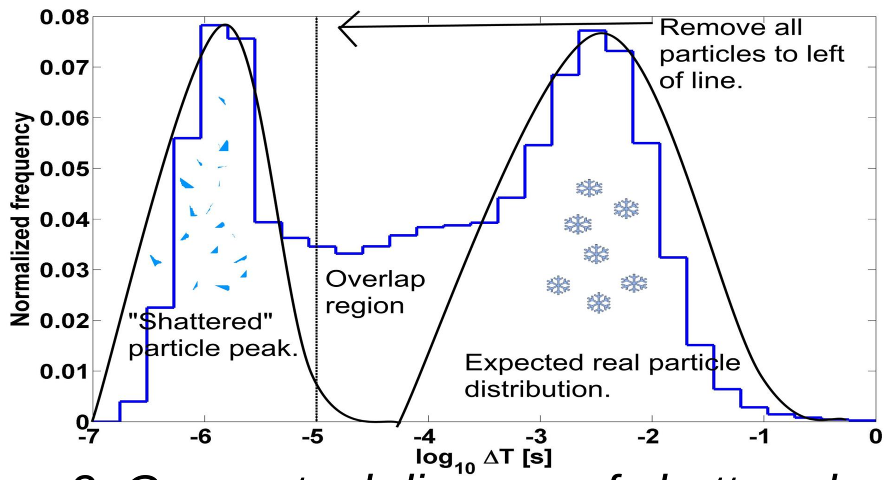

Figure 2. Conceptual diagram of shattered artifact removal algorithm (cf. Field et al. [2006]). Blue line = normalized frequency of particle interarrival time ΔT for IDEAS-4. Black line = threshold used to classify particles as shattered artifacts.

Conclusions from past studies differ on efficacy of techniques used to remove shattered particles and may depend on probe/cloud conditions:

- **[*Korolev et al.* 2011] noted redesigned tips more effective than processing algorithms for removing artifacts from 2DC**
- **[*Lawson* 2011] noted algorithms more effective than redesigned tips for 2D Stereo Probe**

3. Field projects

Parameters derived from ISDAC (30 Apr. 2008) and IDEAS-4 data (25 Oct. and 1 Nov. 2011):

- **N_{st}(.025 < D < 1.6 mm), IWC_{st}, β_{st}, $r_{e\text{-}st}$, and $D_{m\text{-}st}$ from *standard* tips 2DC**
- **N_{mo}(.025 < D < 1.6 mm), IWC_{mo}, β_{mo}, $r_{e\text{-}mo}$, and $D_{m\text{-}mo}$ from *modified* tips 2DC**
- **High-resolution particle images from a (3V) Cloud Particle Imager.**

Method: Compare *N(D), IWC,* D_m, r_e, and β for 2DCs processed with/without shattering removal algorithms.

4. Analysis of *N(D)*

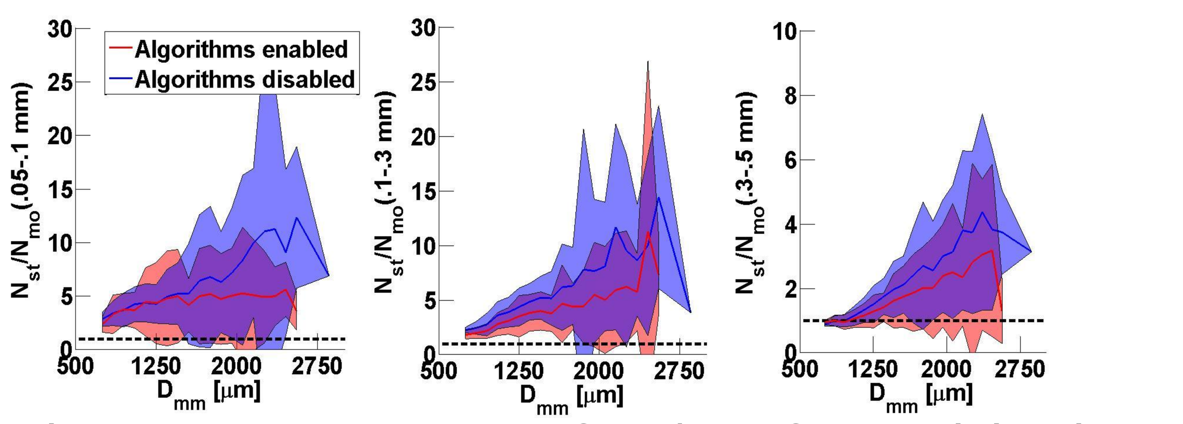

Figure 3. Mean ± 1 σ of N_{st}/N_{mo} for particles in indicated size range for IDEAS flights as function of median mass diameter D_{mm} using (red) and not using (blue) shatter correction algorithms. Dashed line is 1. N_{st}/N_{mo} increases with D_{mm} → D_{mm} predictor of shattering. N_{st}/N_{mo} > 2 even when using algorithms.

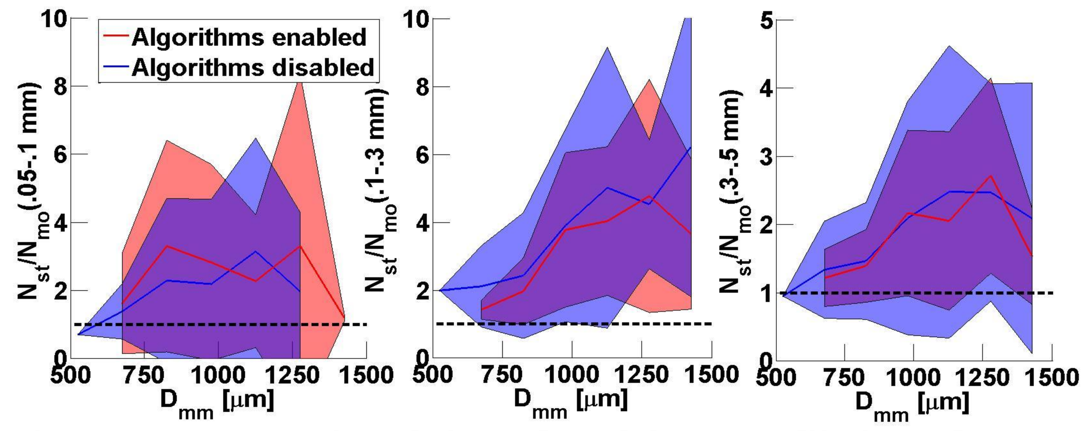

Figure 4. As Fig. 3 but for 30 Apr. flight of ISDAC. Similar results to Fig. 3 are noted.

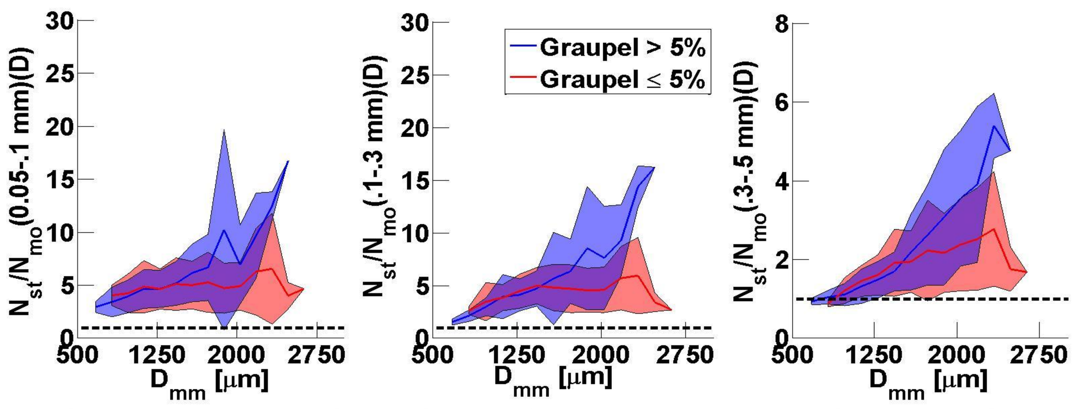

Figure 5. As in Fig.3 for IDEAS-4, but red represents cases with < 5% of particles with D > 1 mm identified as graupel; blue ≥ 5% graupel. Large increase in ratios for D_{mm} > 2 mm when graupel (rimed particles) present.

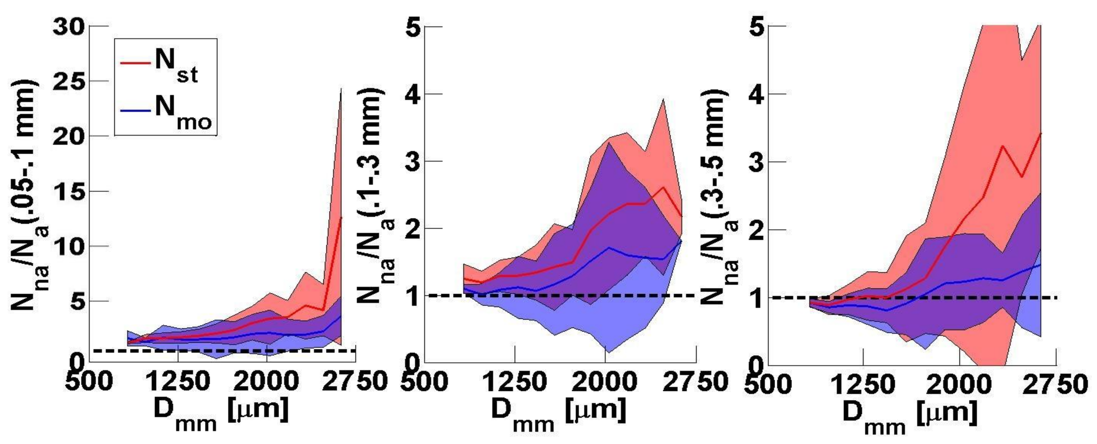

Figure 6. N_{na}(no algorithms used)/N_a (algorithms used) for IDEAS-4 for standard (red) & modified (blue) probes. Shattered artifacts present with modified tips → need algorithms. N_{na}/N_a < N_{st}/N_{mo} [Fig. 3]→ tips more effective than algorithms at removing shattered particles.

5. Bulk properties

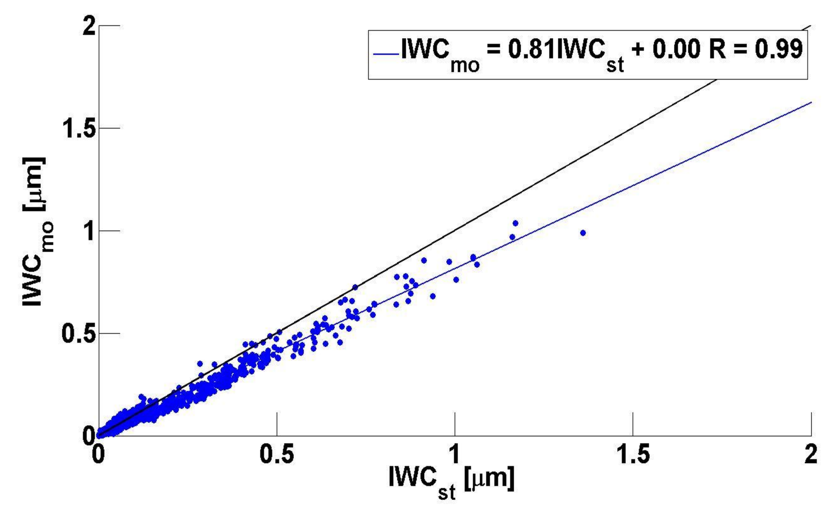

Figure 7. IWC_{mo} vs. IWC_{st} for IDEAS+ISDAC showing ~20% difference. No algorithms used.

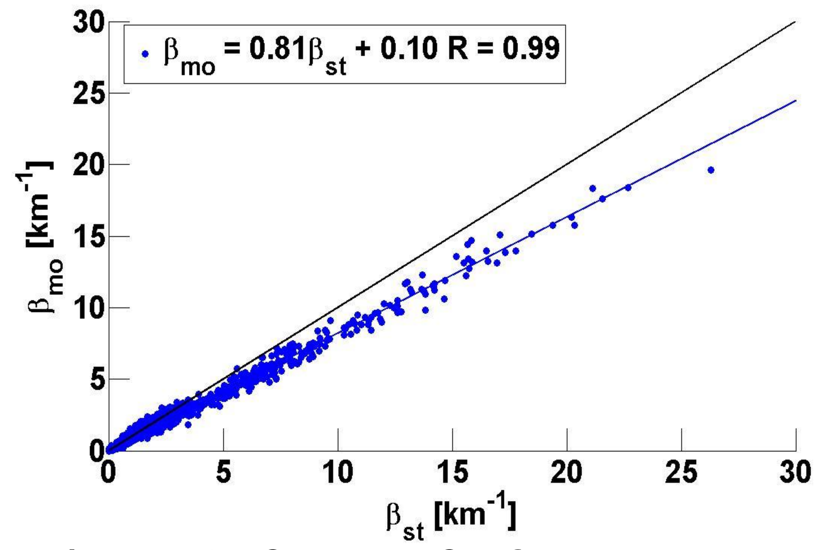

Figure 8. β_{mo} vs. β_{st} for IDEAS+ISDAC showing ~20% difference. No algorithms used.

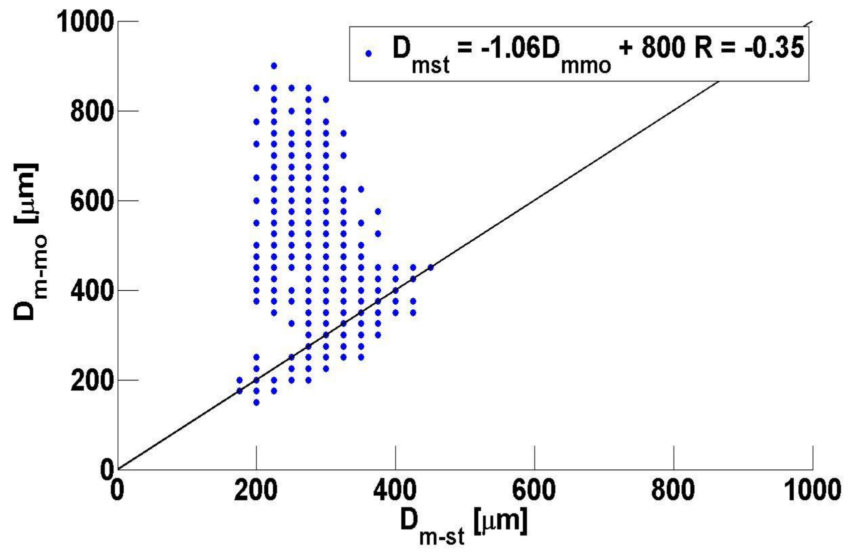

Figure 9. $D_{m\text{-}mo}$ vs. $D_{m\text{-}st}$ for IDEAS+ISDAC showing differences up to a factor of 4, and by 67% on average. No algorithms used.

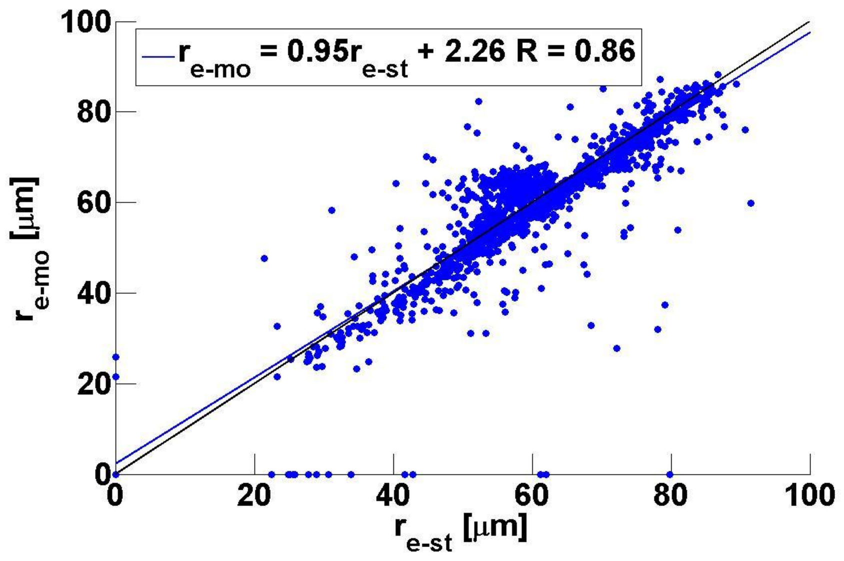

Figure 10. $r_{e\text{-}mo}$ vs. $r_{e\text{-}st}$ for IDEAS+ISDAC showing no systematic bias. No algorithms used.

6. Conclusions

- **Using shatter reducing tips reduces *N(D < .5 mm)* by factor of > 2 for D_{mm} > 1 mm**
- **Larger D_{mm} and presence of graupel are predictors of amount of shattering**
- **Using modified tips & artifact removal algorithms removes more shattered particles than artifact removal algorithms alone for 2DC**
- **Shattered artifacts still impact *N(D)* derived from probes with modified tips**
- **Use of modified tips reduces β, *IWC* from 2DCs by ~20% no systematic bias in r_e .**
- **Bias in D_m up to a factor of 4, with 67% difference on average.**

7. References

Field, P.R., et al. (2006), Shattering and particle interarrival times measured by optical array probes in ice clouds, *J. Atmos. Oceanic. Technol.*, *23*, 1357-1370.

Korolev, A.V., et al., (2011), Small ice particles in tropospheric clouds: fact or artifact?, *Bull. Amer. Meteor. Soc.*, *92*, 967–973.

Lawson, R.P. (2011), Effects of ice particles shattering on the 2D-S probe, *Atmos. Meas. Tech.*, *4*, 1361-1381.

8. Acknowledgements

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