Single-Scattering Properties of Aggregates of Plates from TWP-ICE

Junshik Um and Greg M. McFarquhar
University of Illinois, Urbana IL
junum@atmos.uiuc.edu

1. Introduction

During the 2006 Tropical Warm Pool International Cloud Experiment (TWP-ICE), aggregates of bullet rosettes (Um and McFarquhar 2007) and chain aggregates of plates were observed using a Cloud Particle Imager (CPI). Aggregates of plates were also observed during previous field campaigns (i.e., TEFLUN-B, CRYSTAL-FACE, and EMERALD-II). Many aggregates consisted of clusters of 2 or more plates attached together.

Here the single-scattering properties (i.e., asymmetry parameter g and scattering phase function P_{11}) for idealized models describing these aggregates are calculated using a ray-tracing code at solar wavelength (λ=0.55μm). The relation between the single-scattering properties and ice crystal morphology is investigated.

2. Lab studies and Observations

Laboratory experiments have shown that chain aggregates of plates can be formed due to the electric fields (Figure 1) that fall in the range of those measured in anvils. During TWP-ICE, aggregates of plates were measured in anvils (Figure 2).

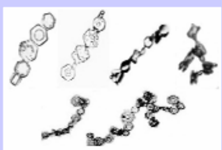

Figure 1. Examples of linear and chain aggregates generated in the laboratory from the influence of electric fields. Top: field – E=0.5x10^5 Vm^{-1}, temperature T=11ºC, from Wahab (1974); bottom: -E=1.0x10^5 Vm^{-1}, T=-12ºC, (Saunders and Wahab 1975). Individual plate sizes vary from 30 to 50 μm. (figure from Connolly *et al.* 2005)

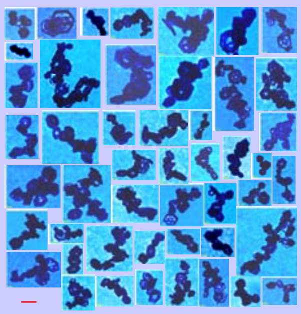

Figure 2. CPI images of Aggregates of plates obtained during TWP-ICE. The 200 μm red bar is embedded.

3. Geometry of Ice Crystals

In this study, seven types of plates (Table 1), whose sizes lay in the range of those measured during TWP-ICE, are selected to calculate single-scattering properties of aggregates of plates.

Plate Type	R (μm)	L (μm)	Aspect Ratio (L/2R)
A	40	14.30	0.179
B	50	15.89	0.159
C	60	17.33	0.144
D	70	18.64	0.133
E	80	19.86	0.124
F	90	21.00	0.117
G	100	22.08	0.110

Table 1. Geometry of fundamental element plates.

4. Results

a. Fundamental Element Plates

As a plate size increases (i.e., from A to G), g increases while aspect ratio decreases. The increase of g is not due to the increase of size, but rather due to the aspect ratio decrease (see Figure 3).

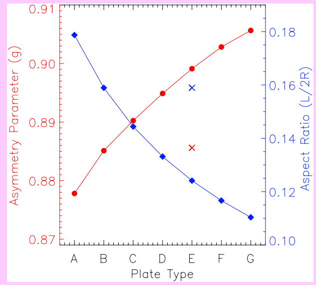

Figure 3. g and aspect ratio as a function of plate type. An extra plate, with the radius of type E and aspect ratio of type B is indicated by x.

b. Aggregation Effect

Up to ten of the same type of plates are attached together to show the aggregation effect. Figure 4 shows that g typically decreases as the number of attached plates increases but the rate of decrease is not linear.

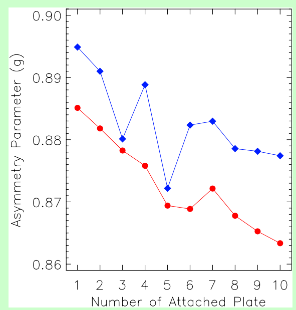

Figure 4. Up to ten type B (red) and type D (blue) plates are attached together and g for each is plotted as function of the number of attached plates.

c. Degree of Aggregation

In an attempt to explain the non-linearity in Figure 4 a new parameter, the ***"Aggregation Index (AI)"*** is introduced. The AI is defined as the distances between plates divided by the distances between plates when the plates lay on a straight line. Therefore, AI=1 means that element plates lay on a line. AI approaching zero means the distances between element plates are short and the shape is complex. The g as a function of AI is shown for seven type B plates attached together (Figure 5).

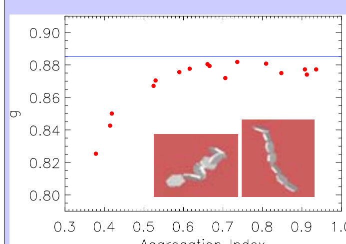

Figure 5. The g of aggregates of plates, (7 type B plates) as a function of AI. The g of the fundamental element plate (type B) is given by the blue line. The g can decrease by 7.3% due to aggregation shape. Two images of aggregates, AI=0.38 (left) and AI=0.94 (right), are embedded.

d. Aggregates of Plates

All seven types of plates are attached together to generate an idealized aggregates of plates model. In this model the distortion parameter (t), t=zenith tilt angle/90º, is used to represent the roughness of aggregates.

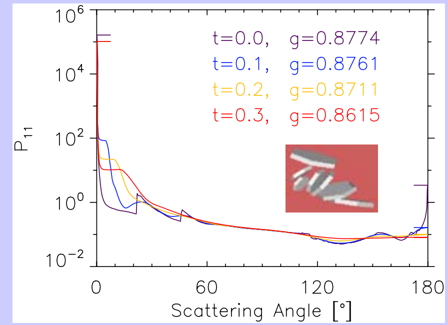

Figure 6. The g and P_{11} as a function of scattering angle and distortion parameter (t). An idealized model for aggregates of plates is indicated.

5. Summary

- Aggregates of plates were measured during TWP-ICE and in previous tropical field campaigns (i.e., TEFLUN-B, CRYSTAL-FACE, and EMERALD-II).
- The asymmetry parameter (g) is influenced more by the aspect ratio than by size at a non-absorbing wavelength.
- As the number of plates in an aggregate increases, g decreases non-linearly.
- The non-linear decrease of g can be explained by the morphology of the aggregates (i.e., Aggregation Index).
- Given the nature of the aggregation, g can differ by 7.3% due to morphology.
- The g value of the aggregates is reduced and the halos in the scattering phase function disappear when adding surface roughness to the aggregates.

Acknowledgements

This research was supported by the Office of Science (BER), U. S. DOE Atmospheric Radiation Measurement (ARM) Program Grant Numbers DE-FG02-02ER63337 and DE-FG02-07ER64378.

References

Connolly, P. J. et al, 2005: Aircraft observations of the influence of electric fields on the aggregation of ice crystals. *Quart. J. Roy. Meteor. Soc.*, 131, 1695- 1712.

Saunders, C. P. R. and N. M. A. Wahab, 1975: The influence of electric fields on the aggregation of ice crystals. *J. Meteor. Soc. Jpn.*, 53, 121-126.

Um, J. and G. M. McFarquhar, 2007: Single-scattering properties of aggregates of bullet rosettes in cirrus. *J. Appl. Meteor. Climatol., In press.*

Wahab, N. M. A., 1974: Ice crystal interactions in electric fields. PhD thesis, UMIST.