

Bastiaan van Diedenhoven,

Ann Fridlind, Jerome Riedi, Brian Cairns, Andrew Ackerman

Funded by NASA ROSES Aqua-Terra 2013; Submitted to JGR

### Large variability of ice properties



1 minute of Cloud Particle Imager data from the WB57 at ~ 11km on 8/8/07



Sensitivity of optical properties to shape

- Macro scale
  - 'habit'
- Meso scale
  - aspect ratios of components
- Distortion across scales
  - microscale roughness
  - Crystal complexity



van Diedenhoven, Springer Series in Light Scattering, 2018



Sensitivity of optical properties to shape

- 1. Meso scale
  - aspect ratios of components
- 2. Distortion across scales
  - microscale roughness
  - Crystal complexity
- 3. Macro scale
  - 'habit'



van Diedenhoven, Springer Series in Light Scattering, 2018



Sensitivity of optical properties to shape

- Meso scale:
  - aspect ratios
- Distortion
  - parameterized crystal distortion (Macke et al. 1996)



van Diedenhoven, Springer

### Retrieval approach

- Observations: polarized reflectances at 865 nm within 120°-150° scattering angle
- Forward model: Geometric optics, Doubling-Adding, Rayleigh (cloud top height), here  $\tau > 5$
- Fit parameters: aspect ratios and distortion of proxy hexagonal plates or columns
- **Derived**: ice asymmetry parameter of retrieved ice model





van Diedenhoven et al. 2012, 2013, 2014, 2016

# Ice shape and asymmetry parameter from 2007 POLDER

- Filters applied (>84 million valid retrievals):
  - Goodness of fit
  - Optical thickness > 5
  - MODIS/POLDER phase flags + cloudbow 'liquid index' (van Diedenhoven et al., JAS, 2012)







### Effective radius from MODIS C6 product





Asymmetry parameter



### Correct r<sub>eff</sub> for assumed ice model







$$r_{e,corr} = r_{e,C6} * \frac{(1 - g_{C6})}{(1 - g_{POLDER})})$$

### Global variation of ice properties









# Vertical variation of ice properties over Land



# Vertical variation of ice properties over **ocean**



#### Vertical variation of effective radius



Ice growth by vapor deposition:

Mass growth rates approximately scale with

- saturation pressure e<sub>s.i</sub>
- saturation ratio wrt ice S<sub>i</sub>:

$$\frac{dm}{dt} \sim (S_i - 1) \times e_{s,i}$$



Ice supersaturation in clouds **increases** with decreasing temperature: parameterization by Korolev & Isaac (2006)



Ice saturation pressure decreases with decreasing temperature

#### Vertical variation of effective radius



# Vertical variation of ice properties over Land



### Vertical variation of aspect ratio



Ice growth by vapor deposition:

- Laboratory grown crystals show temperature variation
- Pronounced dip at ~-15°C or 258K
- Empirical fit by Chen & Lamb 1994; Hashino & Tripoli 2008



### Vertical variation of aspect ratio



Ice growth by vapor deposition:

- Laboratory grown crystals show temperature variation
- Pronounced dip at ~-15°C or 258K
- Empirical fit by Chen & Lamb 1994; Hashino & Tripoli 2008



# Vertical variation of ice properties over Land



#### Variation of ice crystal distortion



### Variation of ice crystal distortion



# Variation of ice crystal distortion & asymmetry parameter



#### Current ice optical models do not take into account distortion varying with size and temperature



### Conclusions

- Variation of ice shape and size with temperature surprisingly consistent with simple vapor growth, despite many possible other ice processes
- Asymmetry parameter:
  - Global averaged g ~0.75 consistent with MODIS model
  - variation with size and temperature not represented in MODIS retrievals and commonly used radiation models
- Power of polarimetry for ice clouds studies:
  - Very robust filtering for super-cooled liquid clouds
  - Unique information on ice crystal shape and scattering properties
  - polarimetry+VIS/SWIR constrains ice cloud radiation: optical thickness, effective radius and asymmetry parameter
- Ice shape+size retrievals method can be applied to
  - POLDER+MODIS
  - Airborne RSP
  - future missions: 3MI, PACE polarimeters + Ocean Color Imager, A&CCP, ....
- Data files available: <u>https://osf.io/c7g58/</u>
  - compatible with existing POLDER-MODIS product files
  - currently 2007, but plans to process all 5 years of PARASOL in A-train