D1: Development of single-particle databases from in situ data

- use in-situ data acquired by several different instruments during several different field projects to develop a database that describe aspect ratio, particle habit and projected area and mass
- McFarquhar, Mitchell, Um, Dong
- years 1-2 and continuing

- Status
  1. Development of single-particle database from multiple flights during ISDAC, TWP-ICE and SPARTICUS to describe how dimensions, habits and aspect ratios vary with temperature and geographical location (Um et al. 2014, ACPD)
  2. Intercomparison of several different optical array processing codes to assess differences in projected area and particle size derived from the same data set (McFarquhar et al. 2015, In preparation for AMT)
  3. Intercomparison of different automated habit classification schemes from different groups (Um et al. 2015, In preparation)

Dimension and aspect ratio database of ice crystals

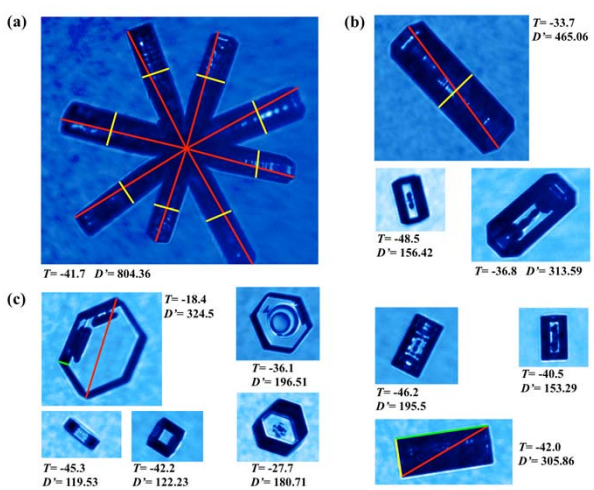
Junshik Um & Greg McFarquhar / University of Illinois

Science Question

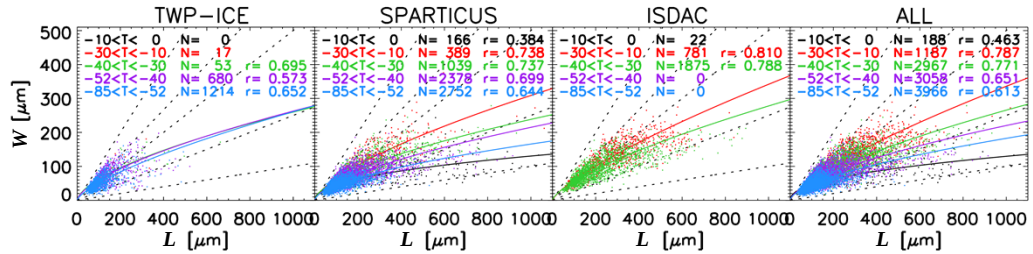
How microphysical properties (e.g., dimension & aspect ratio) of ice crystals vary as a function of temperature, habit, and geophysical location?

Approach

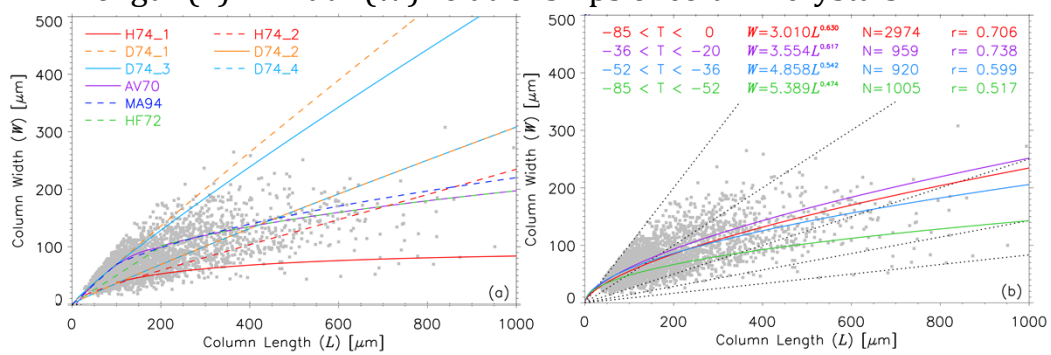
- Use high resolution images of ice crystals acquired by state-of-the-art cloud probes installed on aircraft flying through ice clouds during TWP-ICE, ISDAC, and SPARTICUS
- Determine dimensions & aspect ratios of ice crystals using newly developed software, the Ice Crystal Ruler (IC-Ruler)



Measured dimensions using IC-Ruler



Length (L) – Width (W) relationships of column crystals



L–W relationships from previous studies (left) and newly determined (right) using current data (gray dots)

Key Accomplishment

The first time to show *L*-*W* relationships from previous studies are within the range of current data obtained from the same probe and analyzed in consistent manner. All dimensions and *L*-*W* relationships of ice crystals depend heavily on temperature, but aspect ratio depends weakly on temperature.

Publications

Um and McFarquhar, ACPD (2014)

Comparing derived measures of particle morphology from different probe processing algorithms

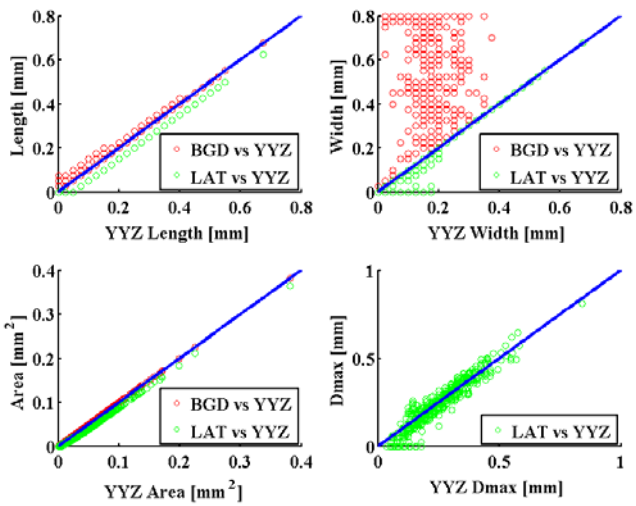
Greg McFarquhar and several others, University of Illinois

Science Question

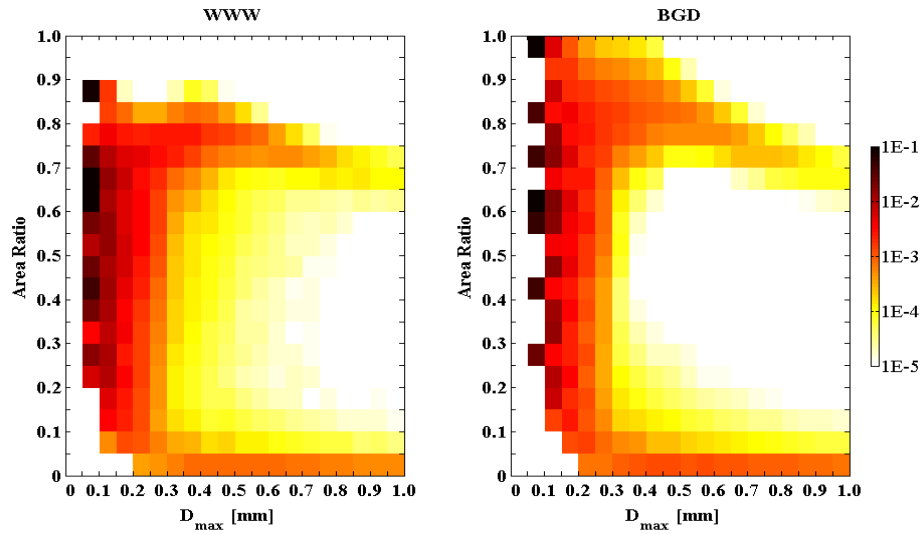
How do morphological measures of ice crystals (maximum size, projected area, etc.) vary with algorithm used to process data, and what are uncertainties in derived parameters

Approach

- Process data file obtained during field project with codes developed by several groups and compare derived particle morphology
- Do same for data file developed to describe simulated spherical particles



Measured dimensions of simjulated spherical particles



Frequency of occurrence of particles with given D_{max} and area ratio for 2 different processing codes; differences associated with differing definitions of D_{max}

Key Accomplishment

The first time to differences in particle morphology from different processing codes, which places uncertainty on derived dimensions; effect of different definitions of D_{max} on particle sizing, and on derived *m-D* and *A-D* relations also illustrated

Publications

McFarquhar et al. 2015 AMT; Wu and McFarquhar 2015 JAOT

Uncertainties in habit distributions of ice particles

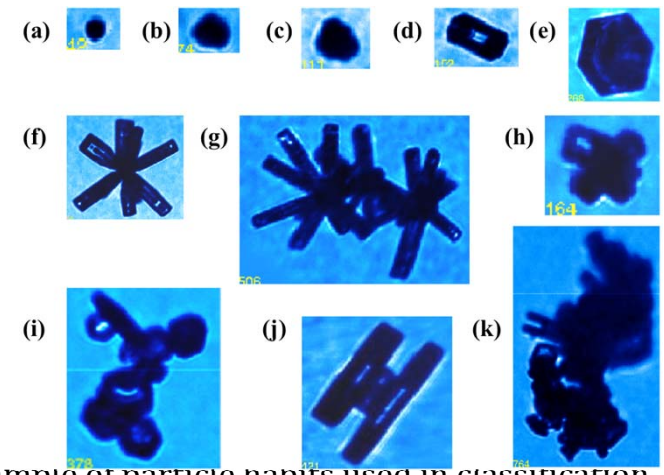
Junshik Um & Greg McFarquhar and others University of Illinois

Science Question

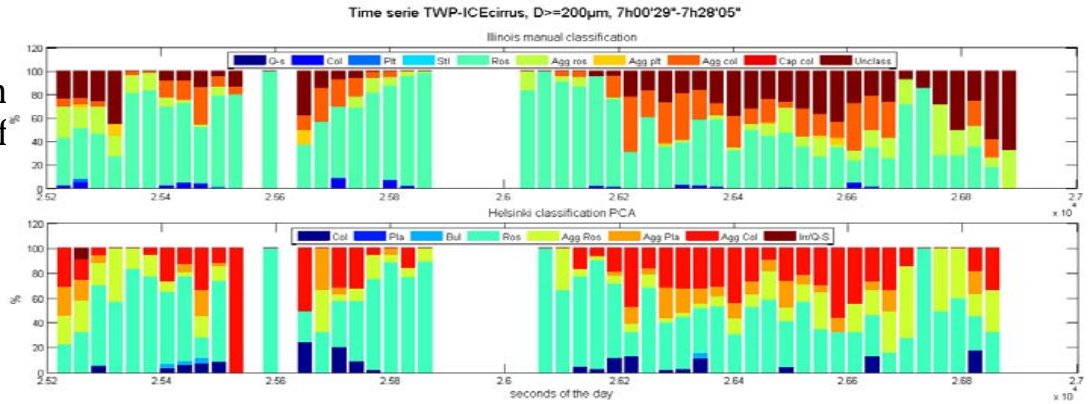
How well can automated shape recognition techniques determine the habit distributions of ice particles from CPI and OAP probe data?

Approach

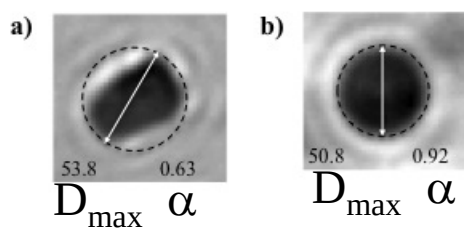
- Use CPI ice crystal images from various field campaigns in different habit recognition schemes, and determine differences in habit distributions
- Use CPI images in mixed-phase clouds to determine size/focus threshold to distinguish liquid from ice based on particle shape

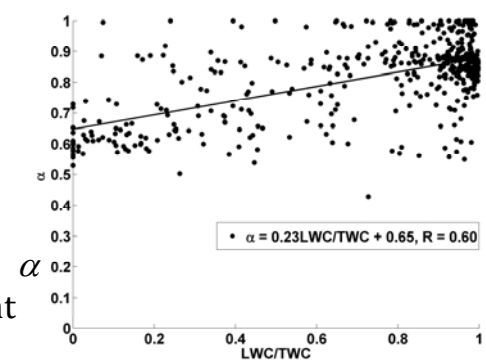


Example of particle habits used in classification schemes: spheres (a-c), columns (d), plates (e), bullet rosettes (f), aggregates (g-i) , capped columns (j), irregular (k)



Example of difference in habit classification of Illinois and Université Blaise Pascal schemes





(left): Difference in area ratio α between ice & liquid; (right) mean α increases with liquid water content (LWC)/total water content (TWC)

Key Accomplishment

Uncertainty in phase identification better understood, as well as showing liquid vs. ice can be distinguished for D > 35 µm and focus > 40 for CPI probe.

Publications

Um et al. 2015 ACD; McFarquhar et al. 2013 JAOT

D2: Characterization of ice particle properties on environmental conditions

- Characterize how mean and distribution functions of PSDs, mass-dimension relations, area-dimensional relations, IWC, β, mean aspects ratios and total ice particle concentrations vary with environmental conditions, as well as characterizing uncertainties in these relationships and uncertainties due to processing/measuring of microphysical quantities
- McFarquhar, Mitchell, Um, Dong
- continuing all 5 years owing to large amount of past and future data

- Status

1. Development of m-D and A-D expressions that capture the non-linear dependence of log m & log A on log D. Expressions depend on temperature and cloud type.
   - Relevance to modeling & QUICR
2. Evaluation of the accuracy and uncertainty of these m-D and A-D expressions.
   - Relevance to modeling & QUICR
3. Translation of these expressions into m-D & A-D power laws based on PSD moments of interest.

ICEPRO Deliverable D2 (continued)

4. New treatment for modifying the m-D and A-D power law terms (prefactor & exponent) as a function of riming, based on field measurements of unrimed and heavily rimed dendrite masses, and hexagonal graupel masses.
   - Relevance to mixed phase clouds focus group
5. Use of area-ratios to evaluate consistent changes in ice particle shape (which occur around -55°C) in synoptic and anvil cirrus clouds.
6. Development of new technique for quantifying uncertainty in representation of PSDs as gamma functions by describing (N_0, λ, μ) as volume of equally realizable solutions based on statistical uncertainty in measured SDs
7. Assessment of uncertainty in PSDs derived from optical array probes through comparison of processing algorithms applied to same dataset and to artificially simulated spherical particles
8. Derivation of how mean morphological properties (D, aspect ratio) of ice crystals vary with environmental conditions for SPARTICUS/TWP-ICE/ISDAC
9. Derivation of how PSDs, representations of PSDs and bulk parameters vary with environmental conditions for MC3E data

Dependence of cloud properties on environmental properties: results from MC3E

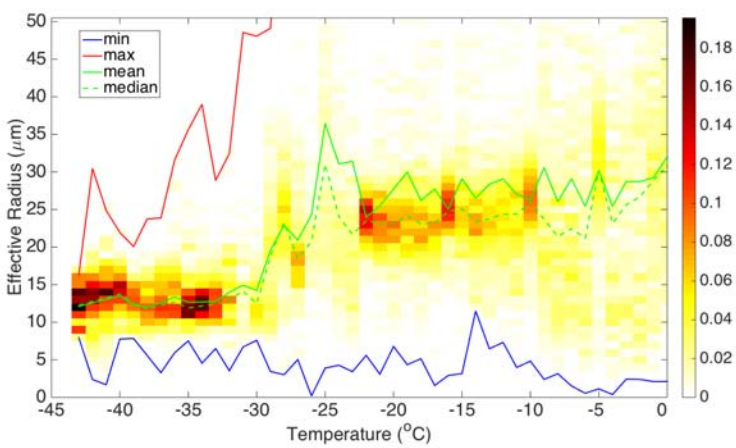
Wei Wu & Greg McFarquhar / University of Illinois

Science Question

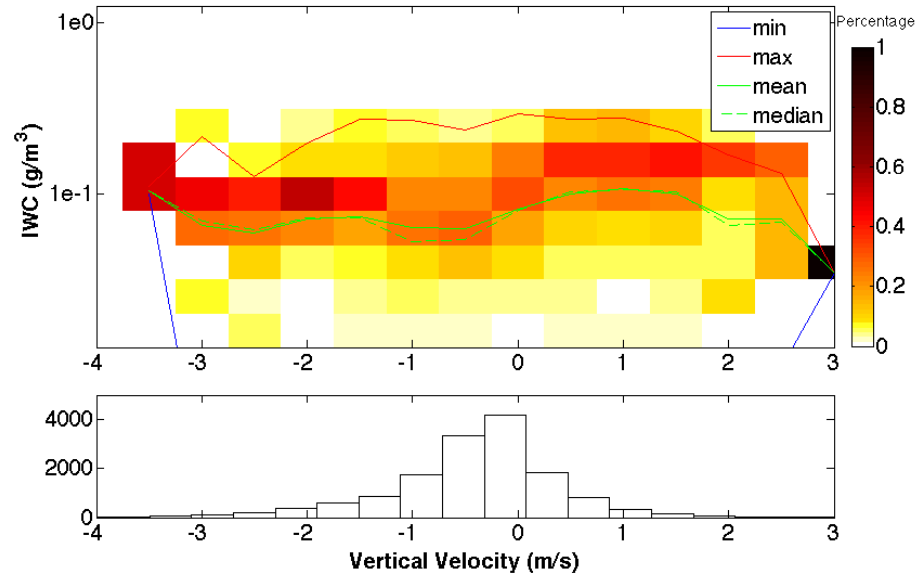
How do bulk microphysical properties (e.g., *IWC*, r_e, N_{ice}) vary with environmental conditions (e.g., temperature, supersaturation, vertical velocity, turbulence) during MC3E flights?

Approach

- Use data from 4 MC3E flights (18, 20, 23 and 24 May) to show how statistics of bulk cloud properties vary with environmental parameters
- Compare with results from other field projects, and with results of model simulations



Dependence of frequency distribution of r_e on temperature



Dependence of IWC distribution on vertical velocity

Ongoing Activities

Integrating work from PSD intercomparison project to have more accurate PSD estimates; deriving volumes of equally realizable solutions to characterize PSDs as gamma distributions in (N_0,λ,μ) phase space; this will also allow estimates of *m-D* and *A-D* relations, and determination if PSD/bulk parameter dependence on environmental conditions consistent between models and observations

Riming treatment in a snow growth model

Ehsan Erfani & David Mitchell / Desert Research Institute & U. Nevada, Reno

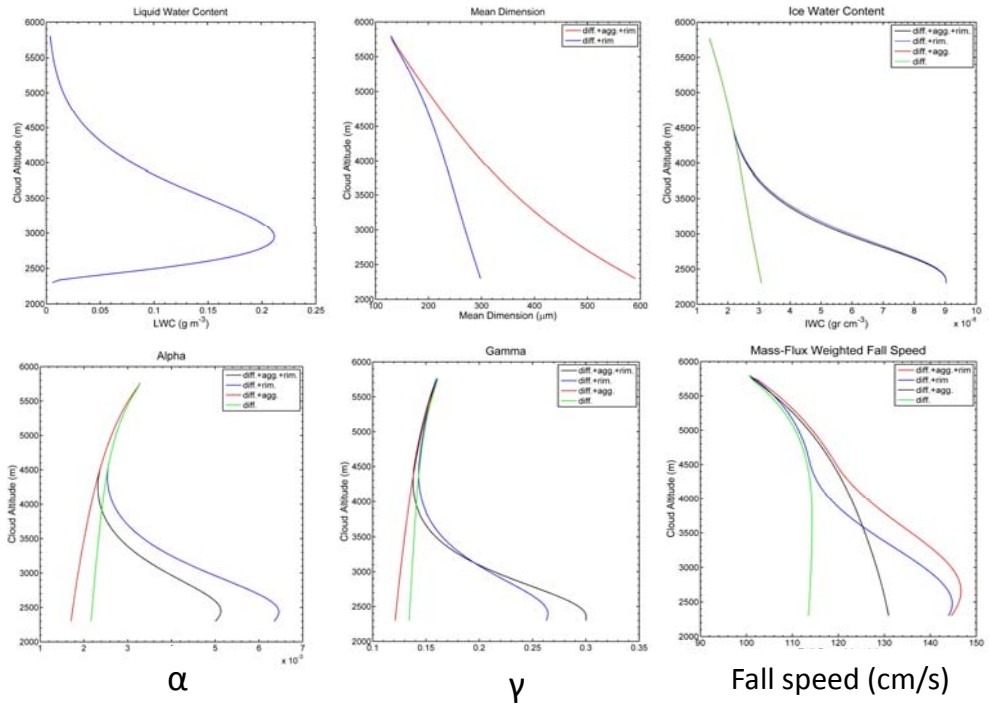
Science Question

How can ice particle mass- and area-dimension (m-D & A-D) power laws be expressed as a function of riming?

Approach

- Used m-D field measurements to show that only α is affected by riming, where $m = \alpha D^{\beta}$.
- Used m-D field measurements to show that maximum projected area from riming is attained at hexagonal graupel stage where $m_r / m_u \approx 3.5$ (r => rimed; u => unrimed).

- $\alpha/\alpha_u = IWC/IWC_u$ (D > 150 μm)
- $A = (A_{max} - A_u)R + A_u$; $R = (M-M_u)/(M_{max}-M_u)$
- $M_{max} = 3.5\ M_u$; $M \leqslant M_{max}$
- $A_{max} = k\ (\pi/4)\ D^2$; k = attenuation factor
- $A = \gamma D^{\delta}$; if $\delta_r = \delta_u$ then $\gamma = A/D^{\delta}$



Results from the snow growth model featuring the new treatment of ice particle riming. Different curves show different combinations of growth processes (diffusion, diff. + aggregation, diff. + riming, & diff. + agg. + riming.

Key Accomplishment

New riming treatment was incorporated into a snow growth model that can be used in conjunction with radar reflectivities to retrieve the IWC in ice clouds.

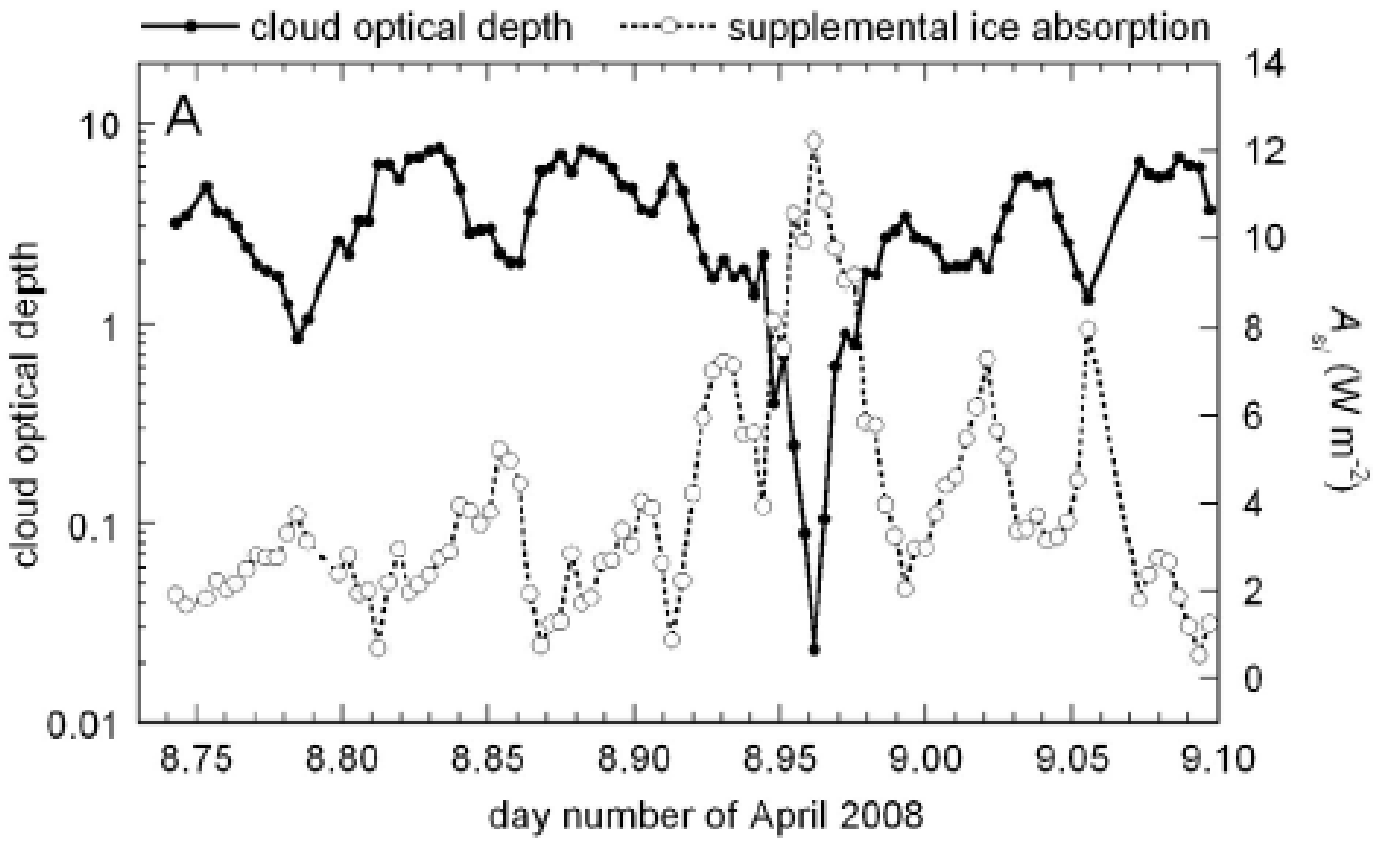
D3: Radiative closure studies from ISDAC

- rigorously determine degree to which radiative closure exists using available ISDAC cloud microphysical data and surface shortwave irradiance measurements at NSA
- Lubin, McFarquhar, Fridlind, van Diedenhoven, Mitchell
- years 1-2

- Status
  - DISORT-based radiative transfer model configured for mixed-phase clouds and 179 bands in shortwave, clear-sky fluxes validated against MODTRAN.
  - ISDAC April 8 “Golden Day” selected for first radiative closure study.
  - Code is ready to ingest NASA-GISS microphysical simulations and complete study by early 2015.

ISDAC 08 APR 2008 Spectroradiometer Retrievals

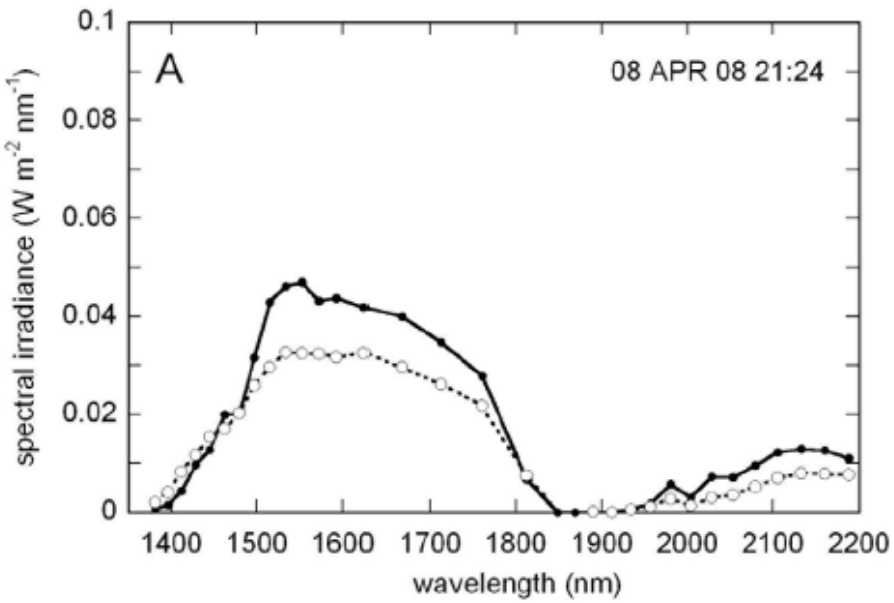
- Moderate cloud optical depth, *N* = 435 spectra once per minute
- Supplemental ice absorption is relative to liquid water cloud with same optical depth

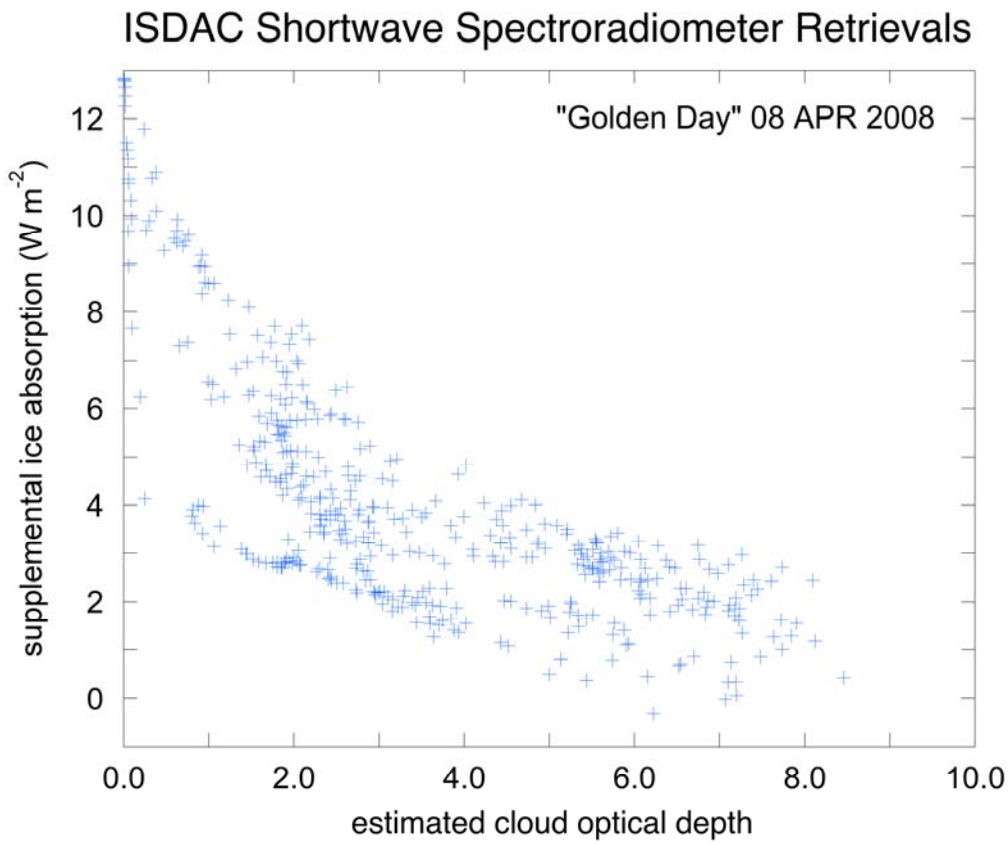


Lubin and Vogelmann, JGRd, 2011

ISDAC 08 APR 2008 Spectroradiometer Retrievals

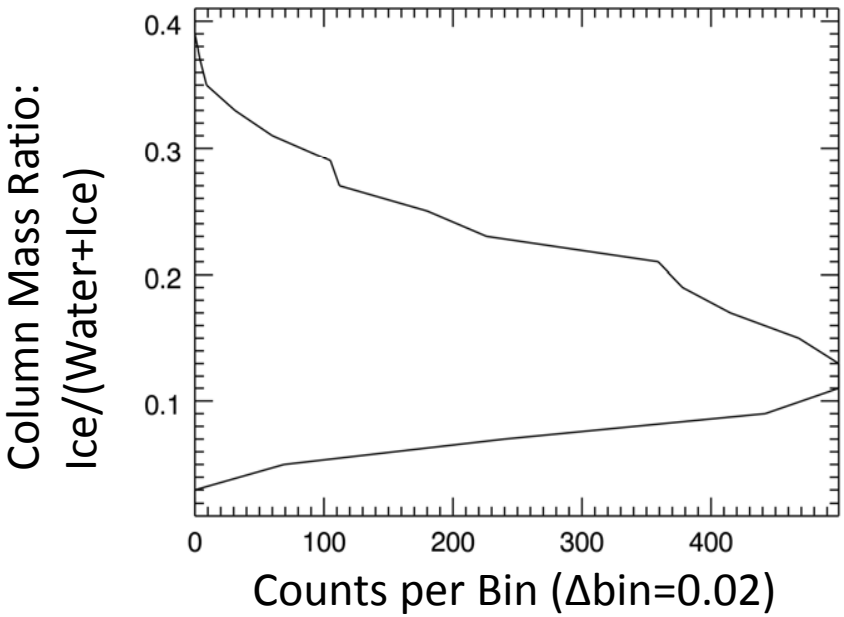
- Supplemental absorption by ice occurs in the NIR
- Ice absorption inversely proportional to total optical depth

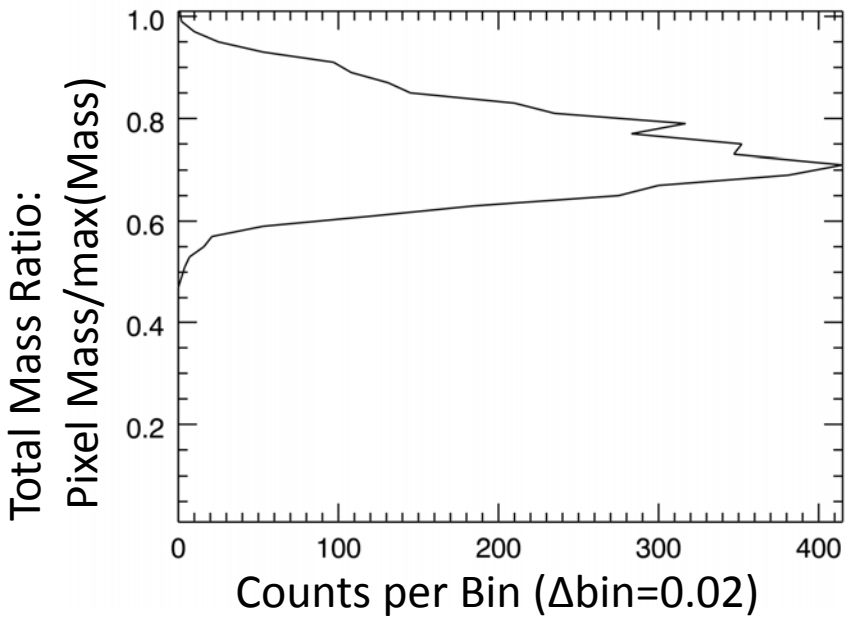




Lubin and Vogelmann, JGRd, 2011

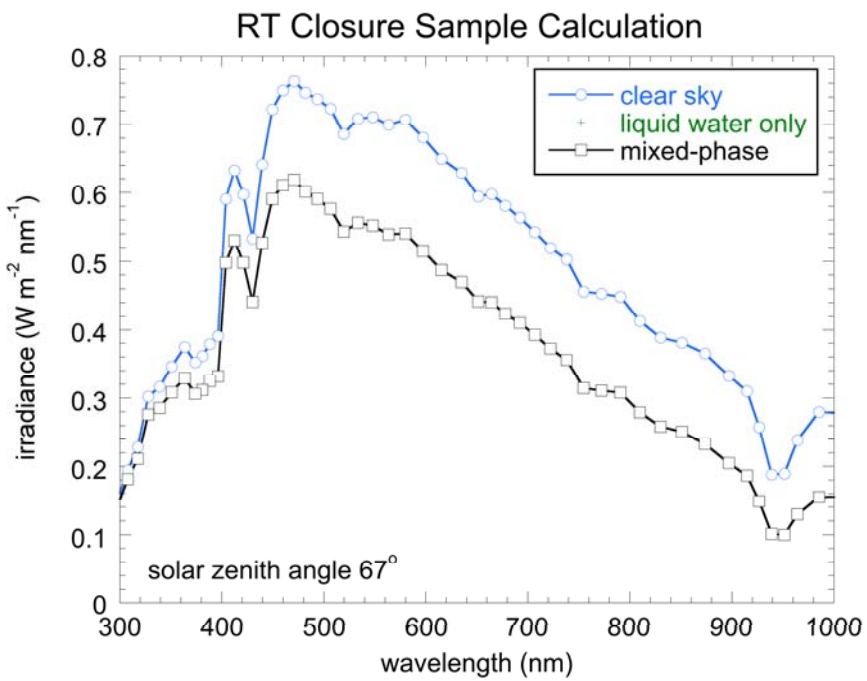
Microphysical Simulation for "Golden Day"

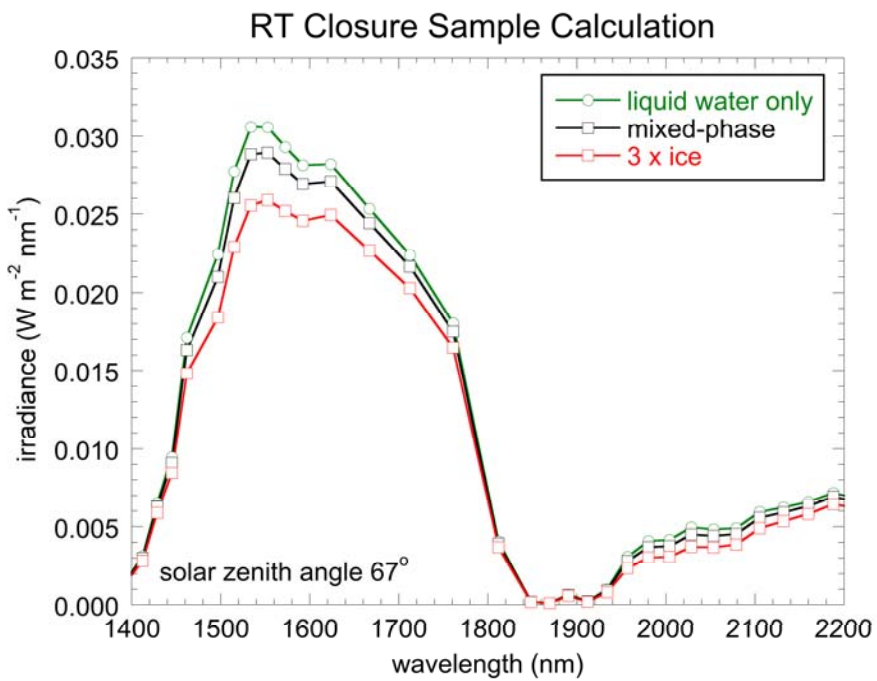




- Mode Ice abundance is ~10% of cloud total water content by mass
- Simulated cloud is somewhat uniform in total water content
- Ice optical properties from van Diedenhoven et al., 2014, J. Atmos. Sci.
- Liquid water properties directly from Mie theory

Test RT Result Using Simulation Input





- Single "test pixel" selected for being near mode in ice abundance
- Liquid water cloud optical depth 11.4, high compared with spectroradiometer retrievals
- Liquid water r(eff) increases from 3 to 8 microns between 820 ➔ 1100 m altitude
- Ice water optical depth ~0.43; ice extends from 1100 m (cloud top) nearly down to surface
- In this sample, total supplemental ice absorption only ~1.3 W m^{-2}, is it representative?
- One spectral calculation runs in 14.5 s on MacBook Pro

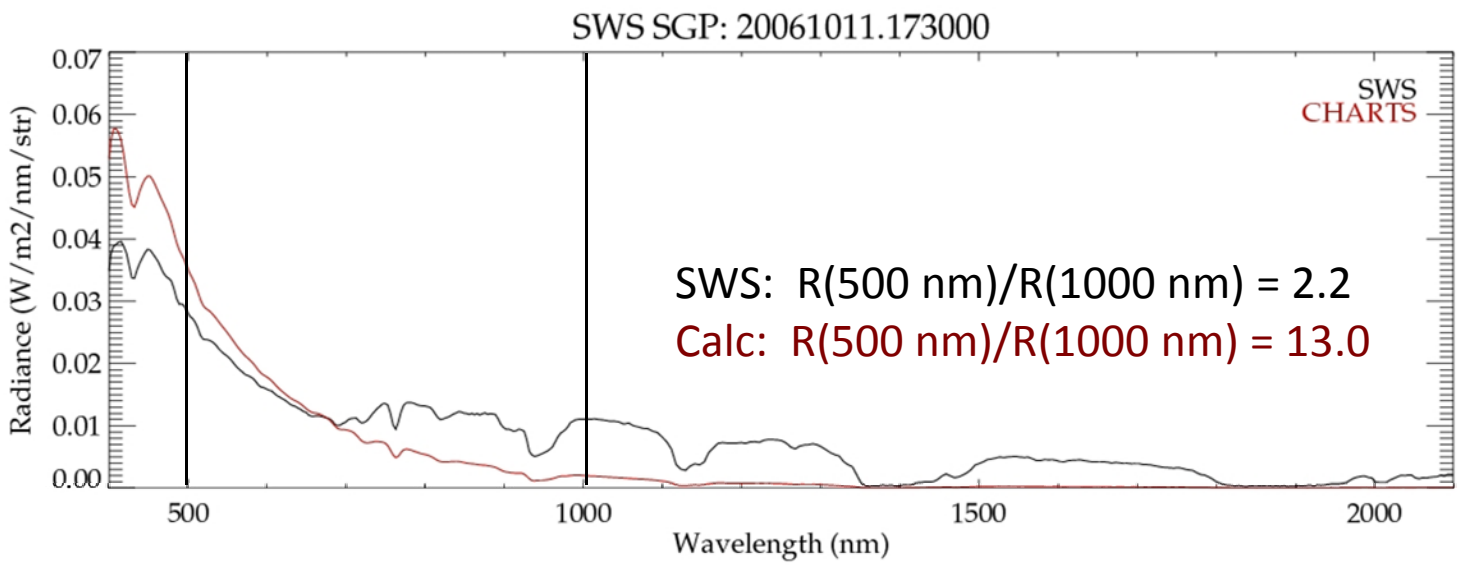
D4: Radiative closure studies using data from SGP

- rigorously determine degree to which radiative closure exists using available surface, remote sensing and in-situ measurements collected over the SGP site
- Mlawer, Mitchell, and Dong
- begin in year 1, most work in years 2 and 3 and continuing as data becomes available

- Objectives of our study
  - Use newly deployed zenith-pointing shortwave radiometers (SAS-Ze, SWS) at SGP for spectral closure studies
  - Evaluate ice optical property parameterizations (e.g. Yang, Mitchell)
- But first ...
  - Instruments must be calibrated, characterized, and validated
  - Clear-sky radiative closure
  - Aerosol radiative properties need to be better understood
- Current status
  - SAS-Ze, SWS, SAS-He clear-sky measurements for 3/9/14 and 3/19/14 received 2 weeks ago, supporting data being gathered for initial closure study

D4: Importance of clear-sky validation

- Clear-sky radiative closure determined that original SWS had serious design flaw (stray light from direct solar beam)



from presentation by Delamere et al. (2008)

- In response, a sun shade was added to the SWS after 2011.
- And ARM deployed new hyperspectral instruments: SAS-Ze and SAS-He measuring zenith radiance (SAS-Ze) and direct and diffuse hemispheric irradiances (SAS-He) from 350-1700 nm.

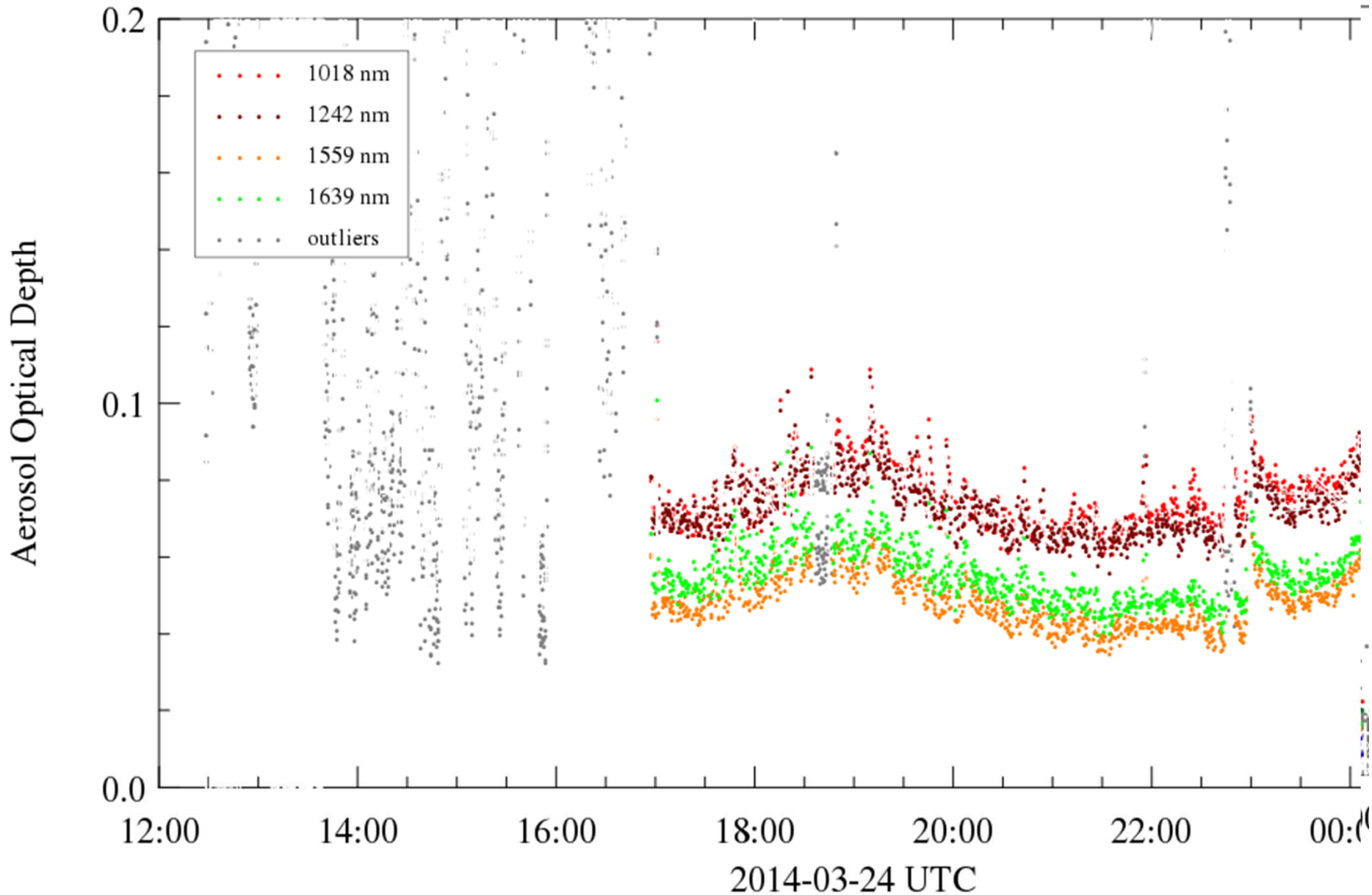
D4: SAS-Ze and SAS-He deployments

Year	SGP He	SGP Ze	AMF1 He	AMF1 Ze	AMF2 Ze
2011	SGP	SGP	PGH	PGH	
	SGP	SGP	PGH	PGH	
2012	SGP	SGP	PGH	PGH	
	SGP		PVC	PVC	MAG*
2013	SGP		PVC	PVC*	MAG*
	SGP		MAO	MAO*	MAG*
2014	SGP	SGP*	MAO	MAO*	
	SGP	SGP*	MAO	MAO*	
2015	SGP	SGP**	MAO	MAO**	

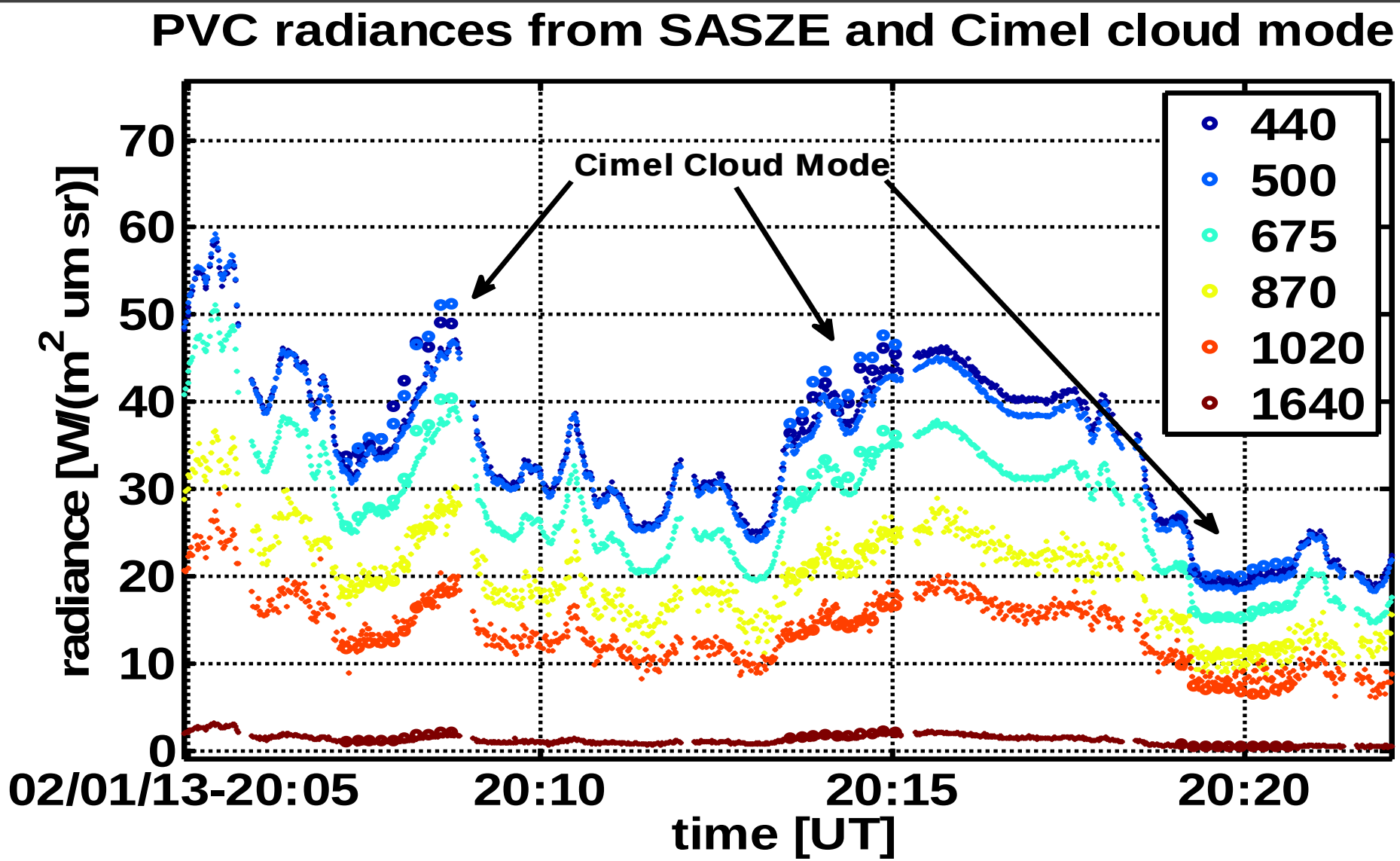
* SASZe with baffle tube

** SASZe with shorter baffle

SASHe QA, “filterband” irradiances, AODs

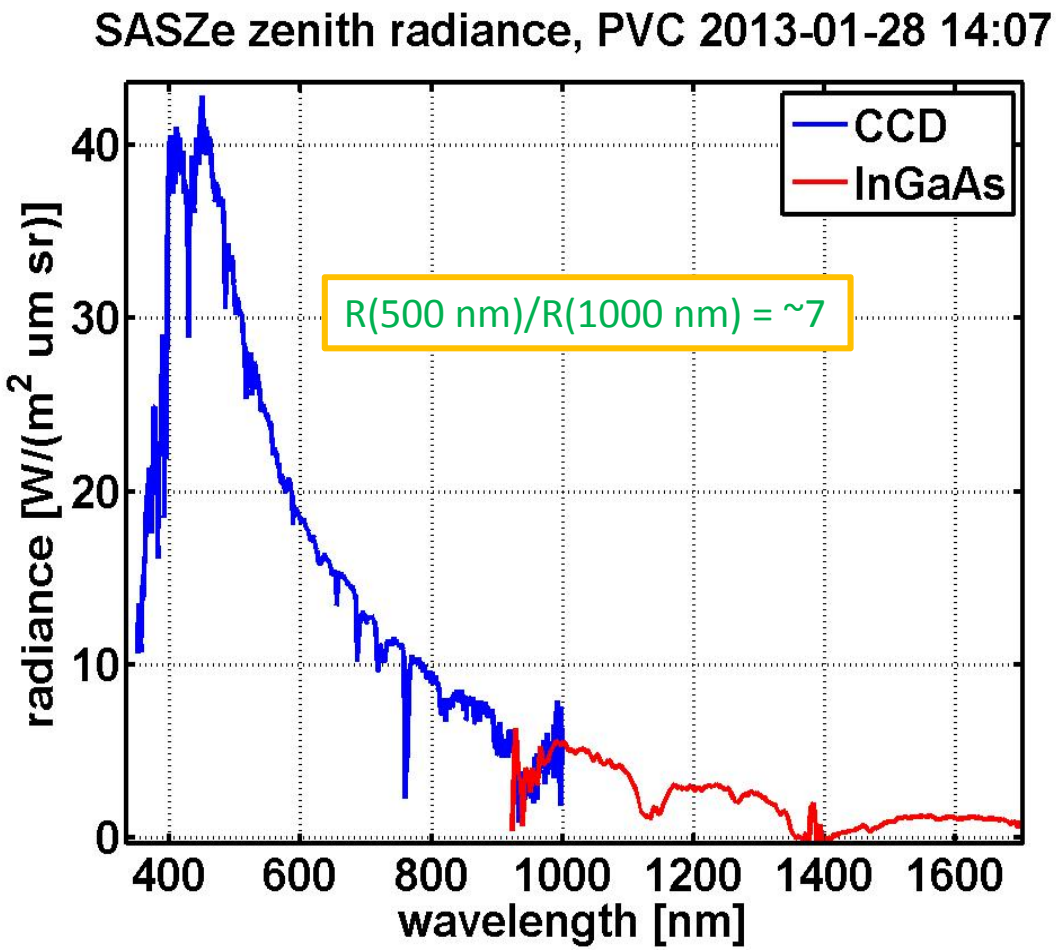


SASZe QA: compare with NFOV, Cimel radiances



D4: Better SAS-Ze QA? Closure study with model!

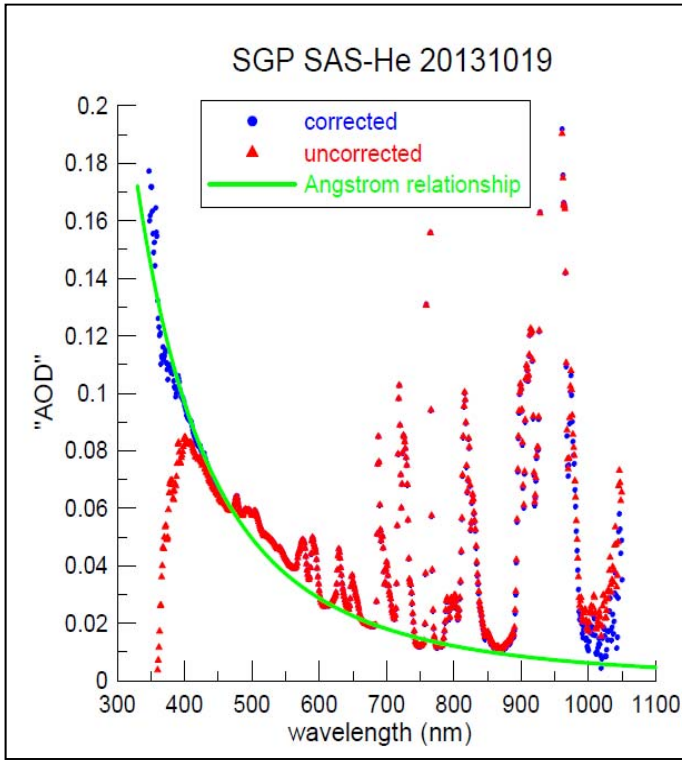
Previous comparison at SGP:
SWS: R(500 nm)/R(1000 nm) = 2.2
Calc: R(500 nm)/R(1000 nm) = 13.0



D4: SAS QA, known and potential issues

Most of the instrument characterizations could be improved.

The following limitations are acknowledged:



Both systems:

- Linearity vs well-depth: measured, not applied
- Wavelength registration could be refined
- Stray light within spectrometer: corrected?

SASHe only:

- Diffuser temp effects: measured, not applied
- Irradiance calibration ignores gases

SASZe only:

- Radiance calibration frequency too sparse
- Observed discrepancies in collocated radiances during MAG. (Vibration?)

Radiative **closure** analysis will be important in ensuring and improving measurement quality and establishing confidence thresholds.

D5: Demonstrate impact of improved ice properties on retrievals

- use aircraft in-situ measurements to evaluate ground- and space-based retrieved ice cloud microphysical properties
- Dong
- ground-based retrievals in year 1, satellite retrievals in years 1 and 2

Status

- The ice cloud microphysical properties of the DCS cases during MC3E have been collected by the University of North Dakota Citation II research aircraft and processed by Xiquan Dong's group at UND.

What the deliverable was

- The best-estimated ice cloud Dm, Nt, IWC, and PSD, as well as the empirical relations (gama-distribution) for remote sensing and modeling community.

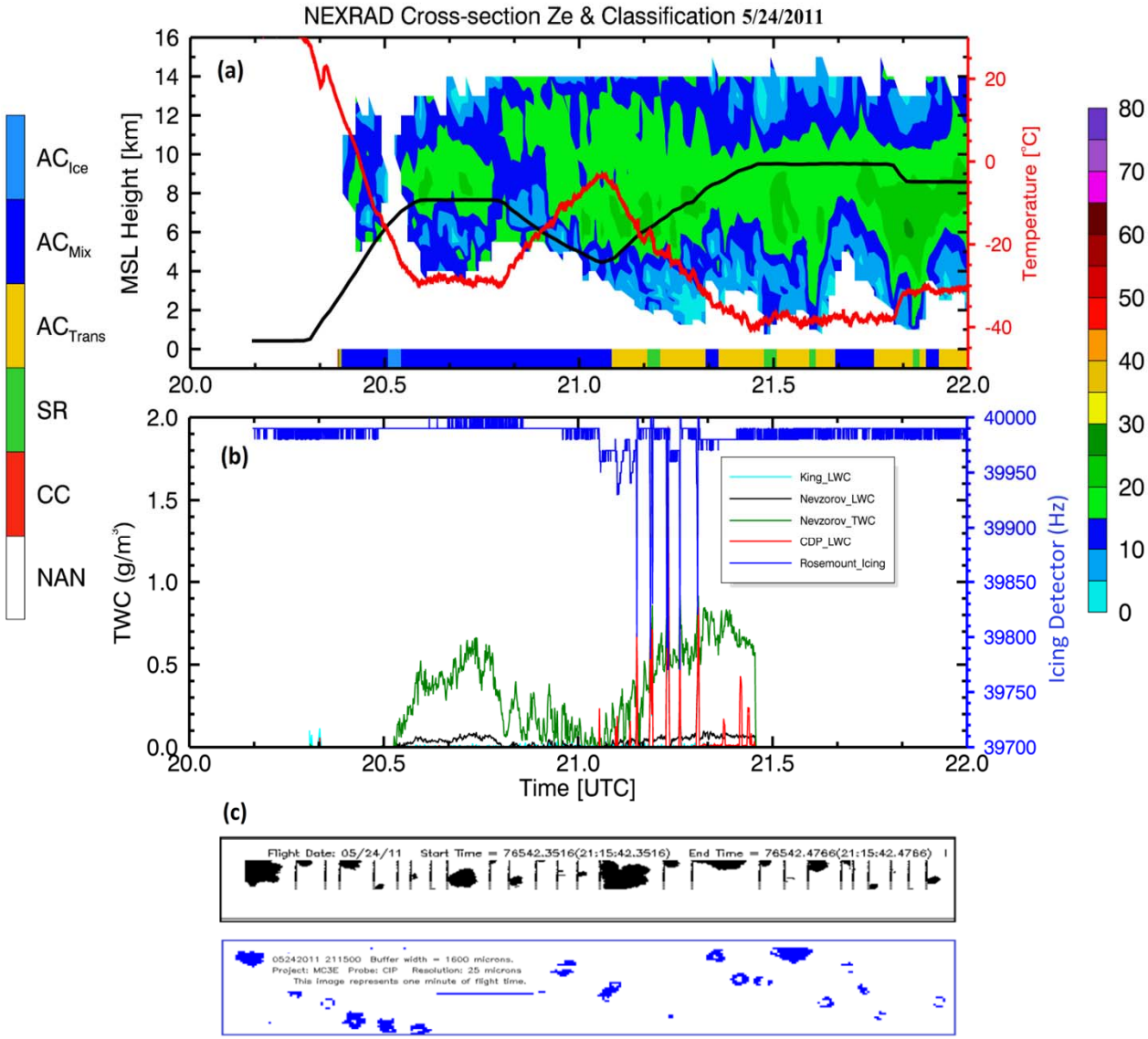
What can be improved

- If DMT Counterflow Virtual Impactor (CVI) were available, then a more reliable IWC could be provided because CVI can account for a broader range of PSDs.
- If Cloud Particle Imager (CPI) probe worked well, then more ice crystal images would be observed.

What are the plans for the future

- We will work on mixed-phase clouds, and quantitatively estimate LWC/IWC, re/Dm, N values of mixed-phase layer of DCS using aircraft data during MC3E.

Using multi-sensor measurements to determine Ice Phase

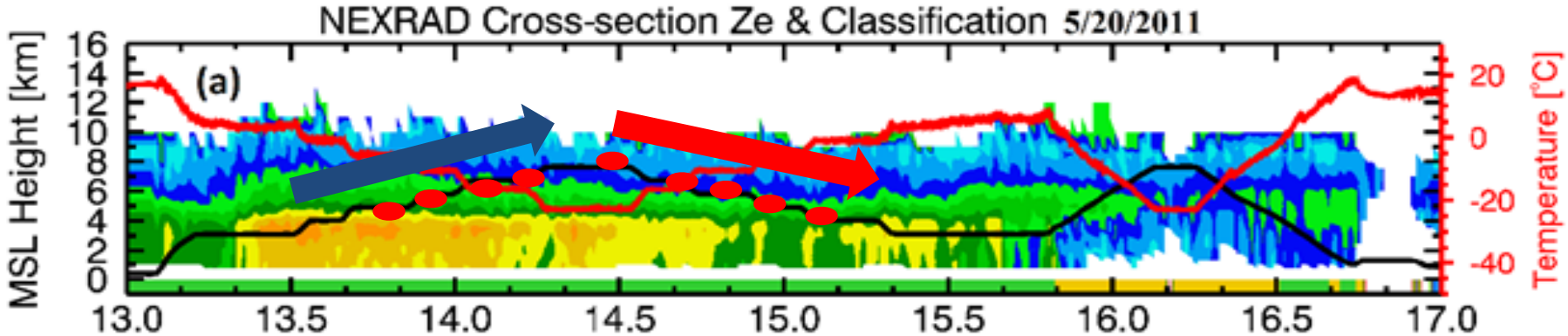


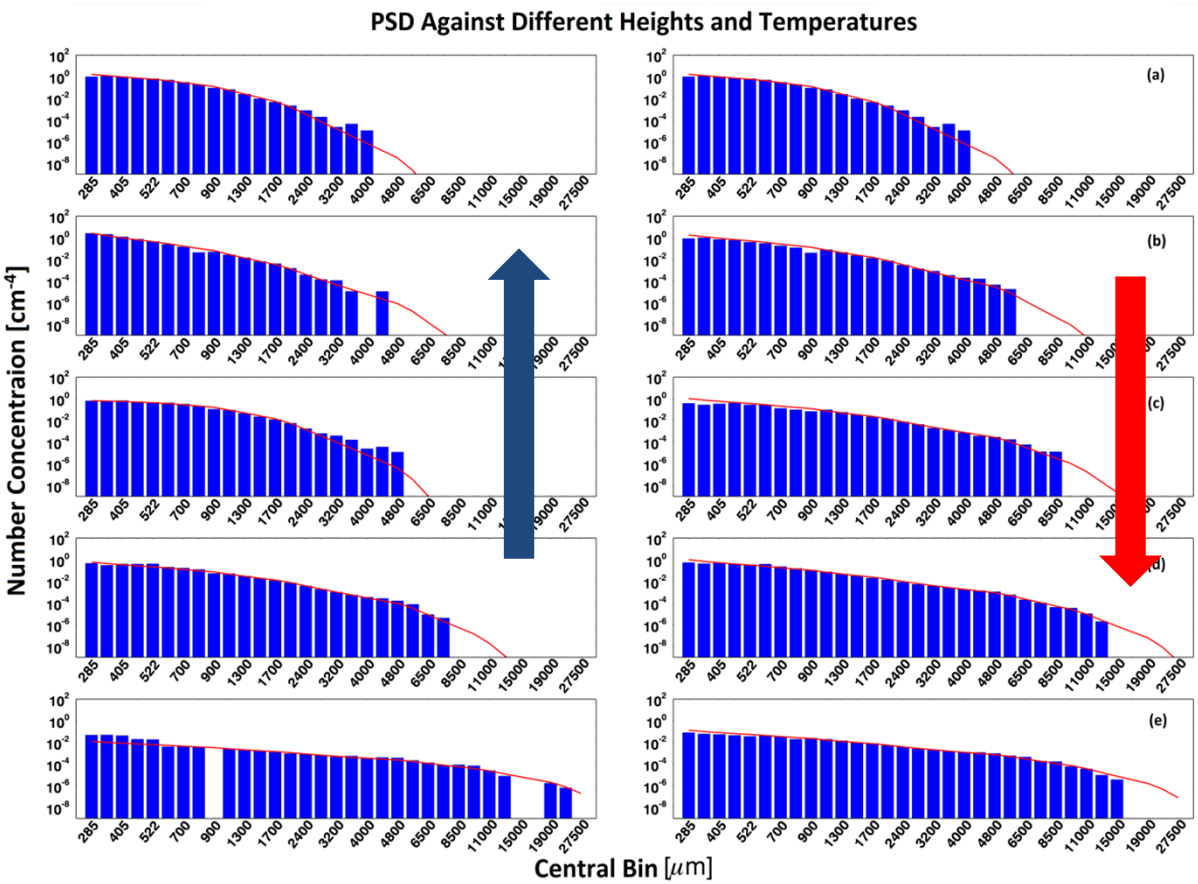
(a) NEXRAD radar reflectivity cross-section along the aircraft track (contour), aircraft altitude (black, 5-10 km) and temperature (red, -40 – o °C).

(b) Super-cooled liquid water content (*SLWC*) was identified by one of the following measurements: a Rosemount Icing Detector (RID, a sudden drop in frequency due to *SLWC* occurrence), by King Probe (high *LWC*), and CDP probe (high *LWC*), accounting for particles with *D* < 50 µm.

(c) 2DC and CIP images for particles with *D* > 50 µm.

Constructed a full spectrum of PSDs and derived Gama-Dist.





1. **The maximum diameters decrease from 27,500 μm to 4,000 μm, whereas the total number concentrations increase about 100 times when the aircraft ascended from 4 km to 7.3 km**
2. **Gamma-type-size-distributions have been derived from original PSDs as**

$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

Developing a new mass-dimension relation

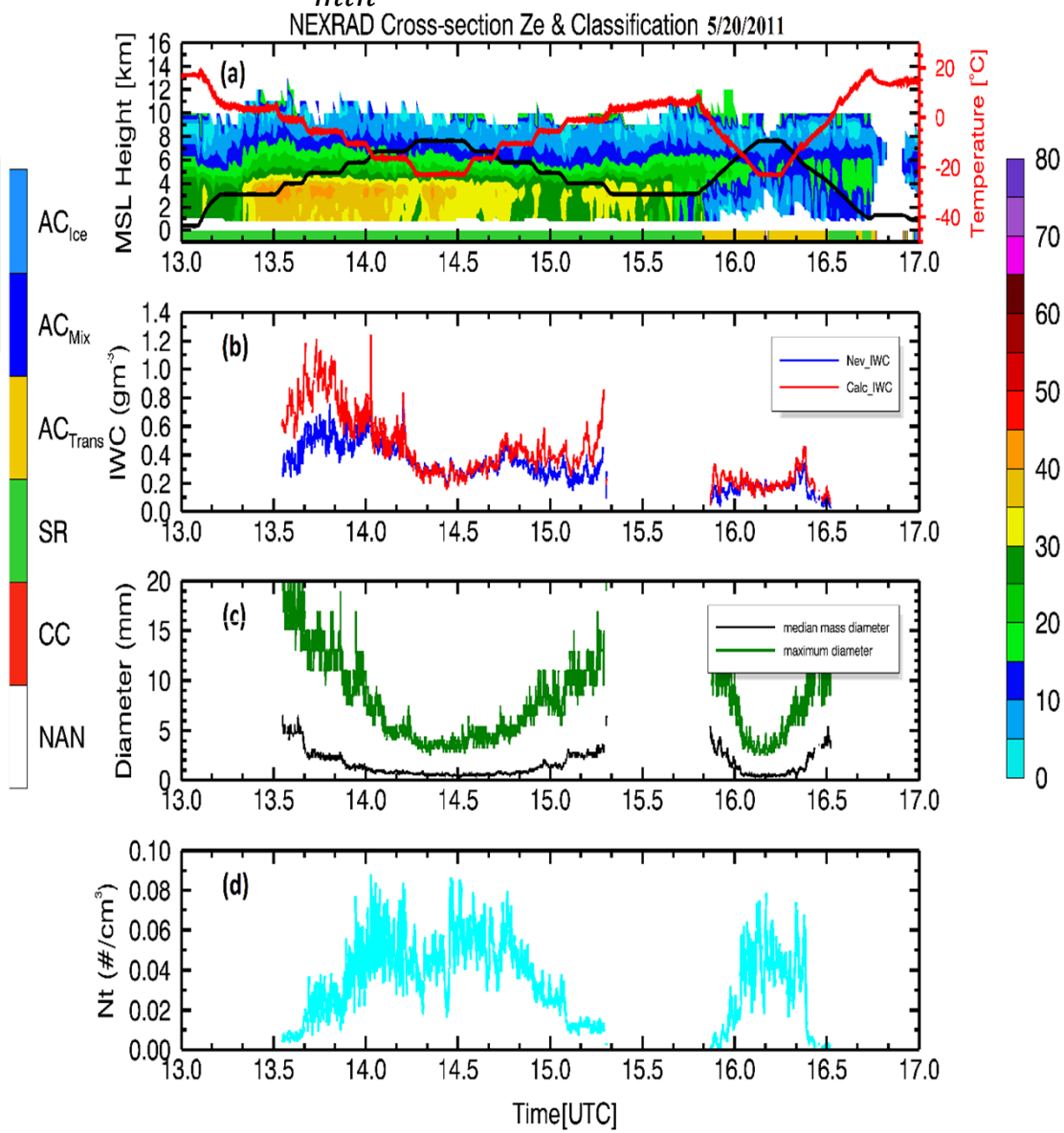
$$\mathbf{IWC} = \int_{D_{min}}^{D_{max}} N(D)m(D)dD = \int_{D_{min}}^{D_{max}} N(D) \cdot a \cdot D^b dD$$

Steps:

1) Using the conclusions from Heymsfield et al. [2010] (exponent b=2.1) and Korolev et al. [2013] (Nevzorov-measured IWCs are reliable for D_{max}<4,000 um).

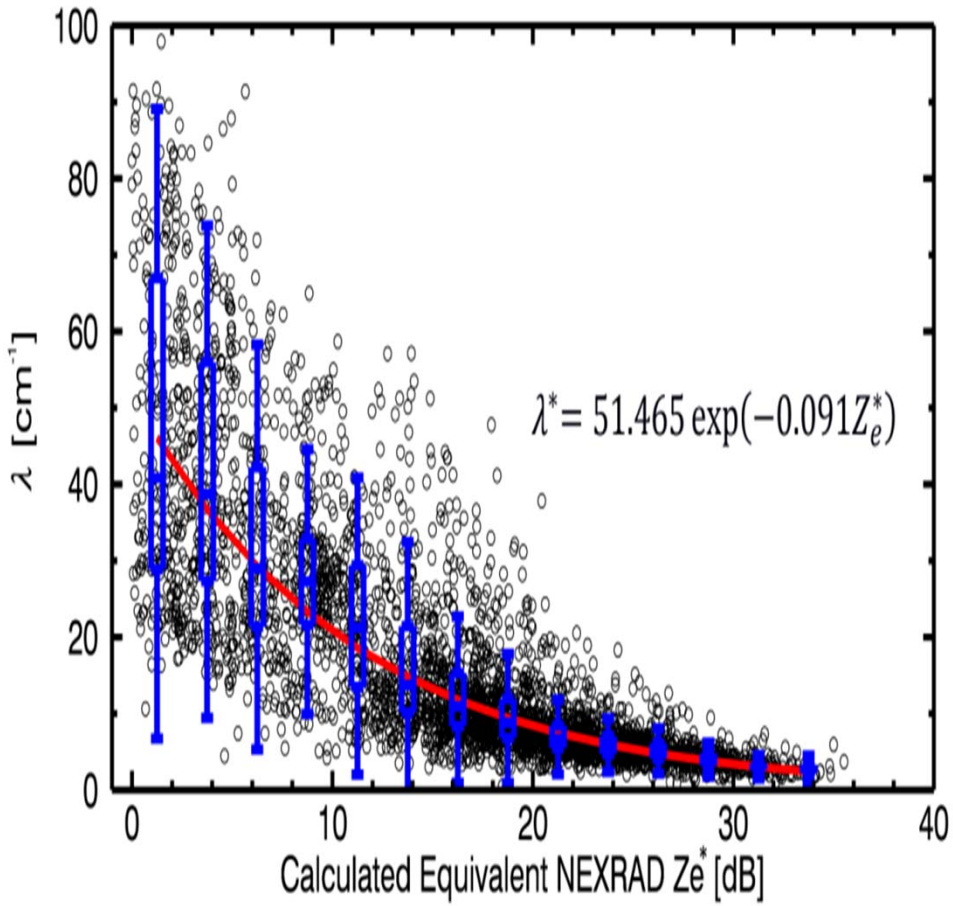
2) Nevzorov-measured IWCs at D_{max} < 4,000 μm are used as a ground truth to determine the coefficient *a* values for each 5-s sample during the MC3E. a =3.65×10^{-3} (1,097 5-s samples for D_{max} < 4000 μm).

3) The newly derived mass-dimension relation(a=0.00365, b=2.1) has been applied to a full spectrum of PSDs (90-30,000 μm) constructed from both 2DC and HVPS measurements to calculate the "best-estimated" IWCs of DCSs during MC3E.



Developing empirical relations for remote sensing community

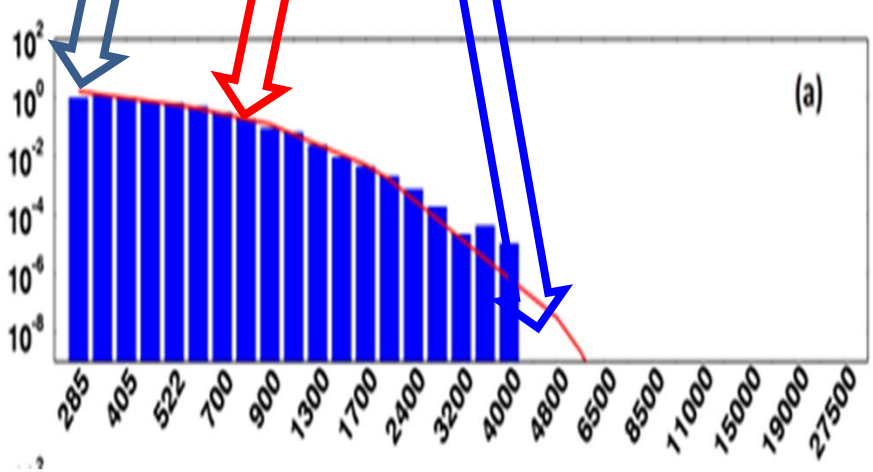
For application of observed PSDs to remote sensing and modeling community (such as, development of retrieval algorithm), a series of empirical relationships between fitted parameters and Z_e values has been derived as follows:



$$N(D) = N_0 D^{\mu} e^{-\lambda D}$$

Gama-type-size-distribution

No: Intercept of PSD
μ: Dispersion of PSD
λ: Slope of PSD



D6: Development of ground-based remote sensing techniques to infer ice particle habit information

- Improve assumptions that go into ground-based remote sensing retrievals and determine impact on ability to infer particle habit information
- Dong
- years 1-2

Status

- A new method has been developed to retrieve ice cloud properties of DCSs during MC3E using NEXRAD reflectivity and aircraft derived empirical relations.

What the deliverable was

- Preliminary 3D ice cloud properties (Dm, IWC) are available for ASR community, and these retrievals have been validated by aircraft results.

What can be improved

- The new method will be modified through T-Matrix and updated relation: Nt vs. cloud temperature and other variables.

What are the plans for the future

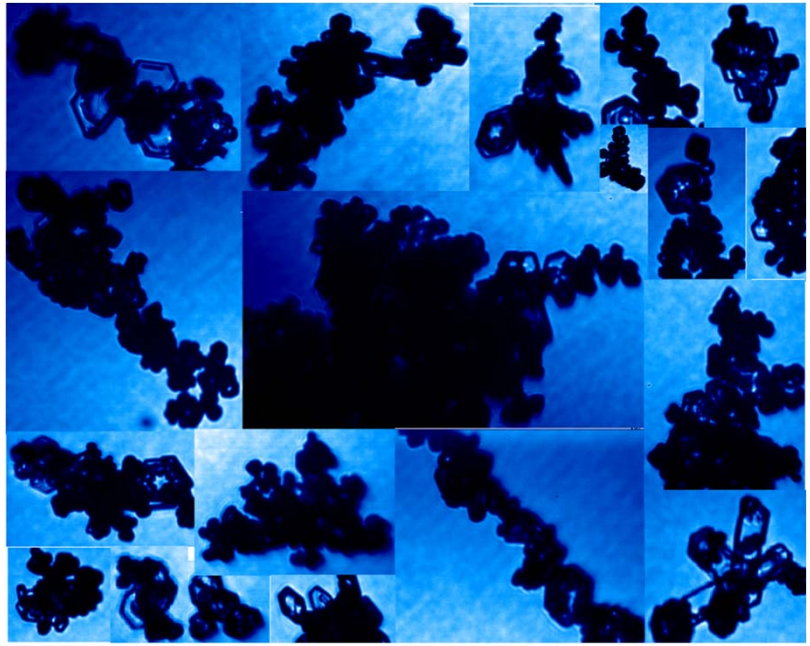
- How to use radar reflectivity and Doppler velocity to infer ice particle habit. Question: Can we determine air velocity?

How can we use aircraft results to improve ground-based retrievals

During the retrieval process, people have to assume one of the ice crystal shapes.

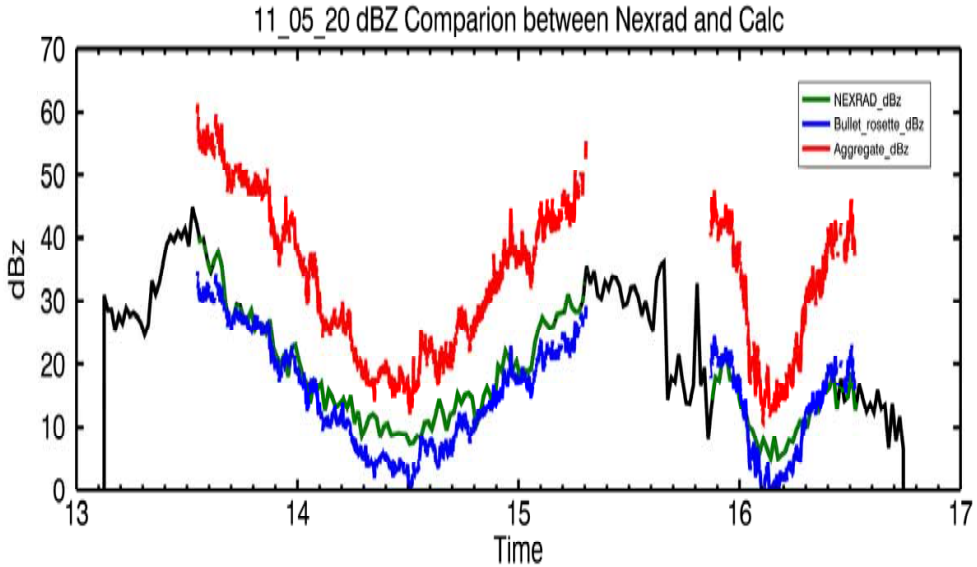
From aircraft CPI images (May 23/24 case), aggregates of bullet rosettes, planes, and columns were observed to be the dominant ice crystal habits.

Therefore we need to determine which one should be used in ground-based retrievals.

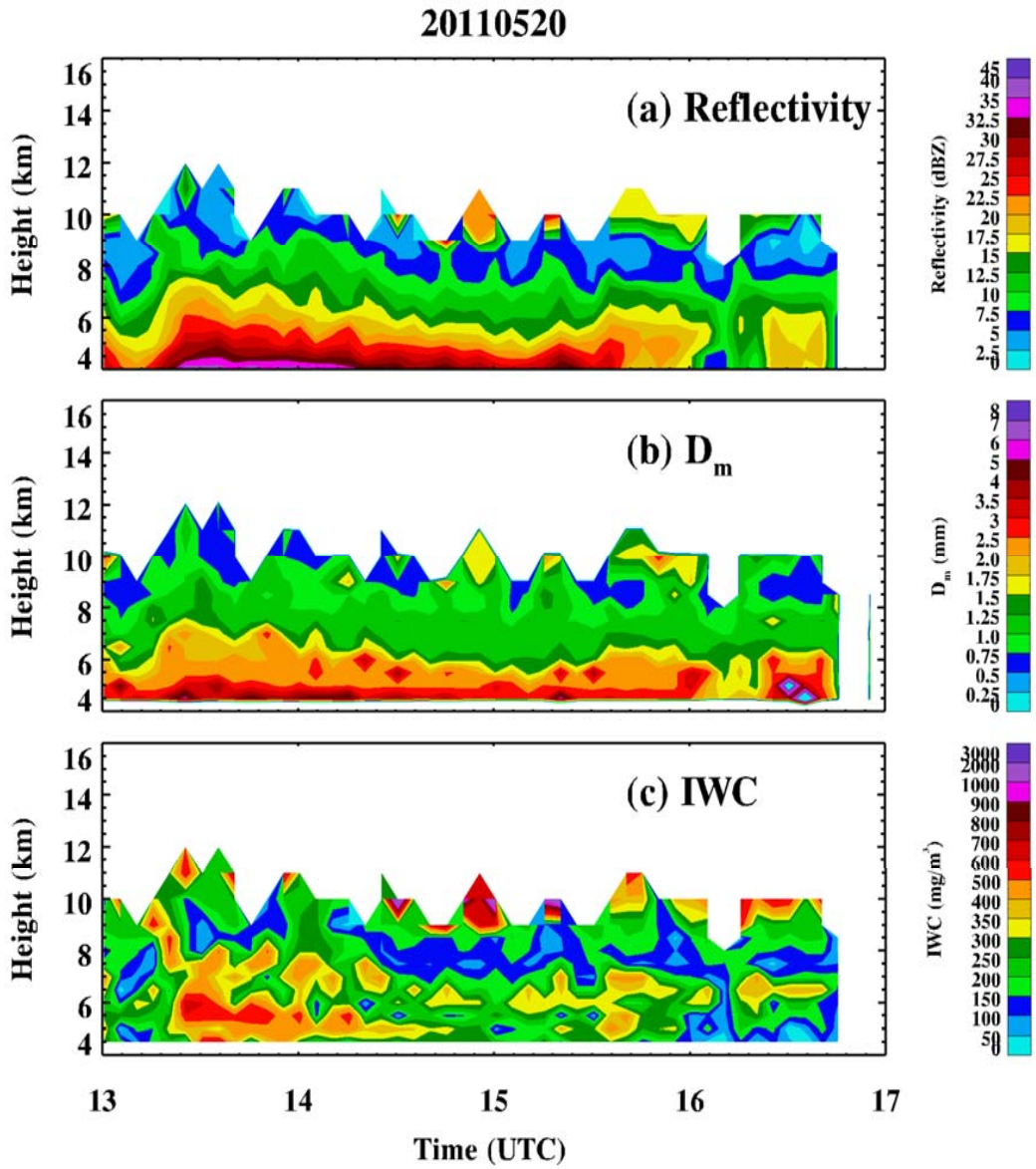


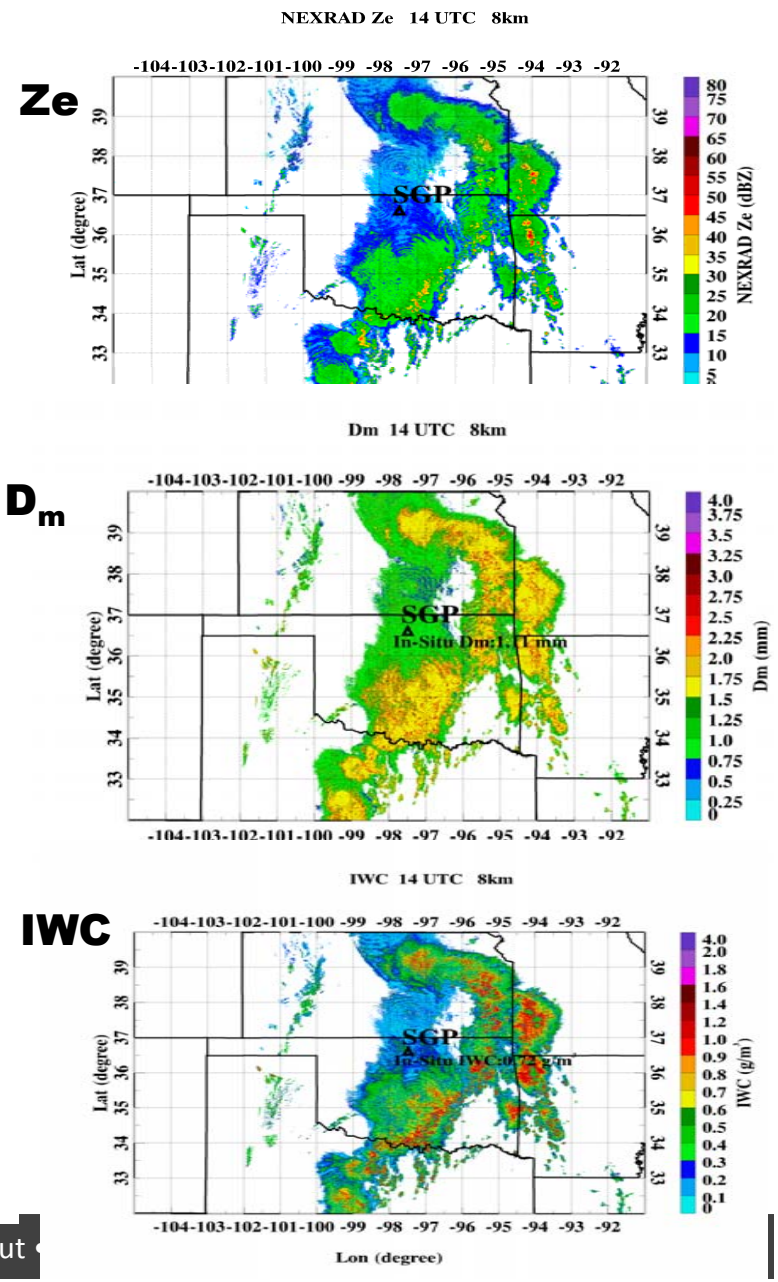
⟷ 100 microns

- **NEXRAD reflectivity**
- **Calculated NEXRAD Ze using aircraft measured PSDs and Bullet Rosette backscattering relation, and aggregate.**
- **Conclusion: Bullet Rosette backscattering relation is used in radar retrievals.**



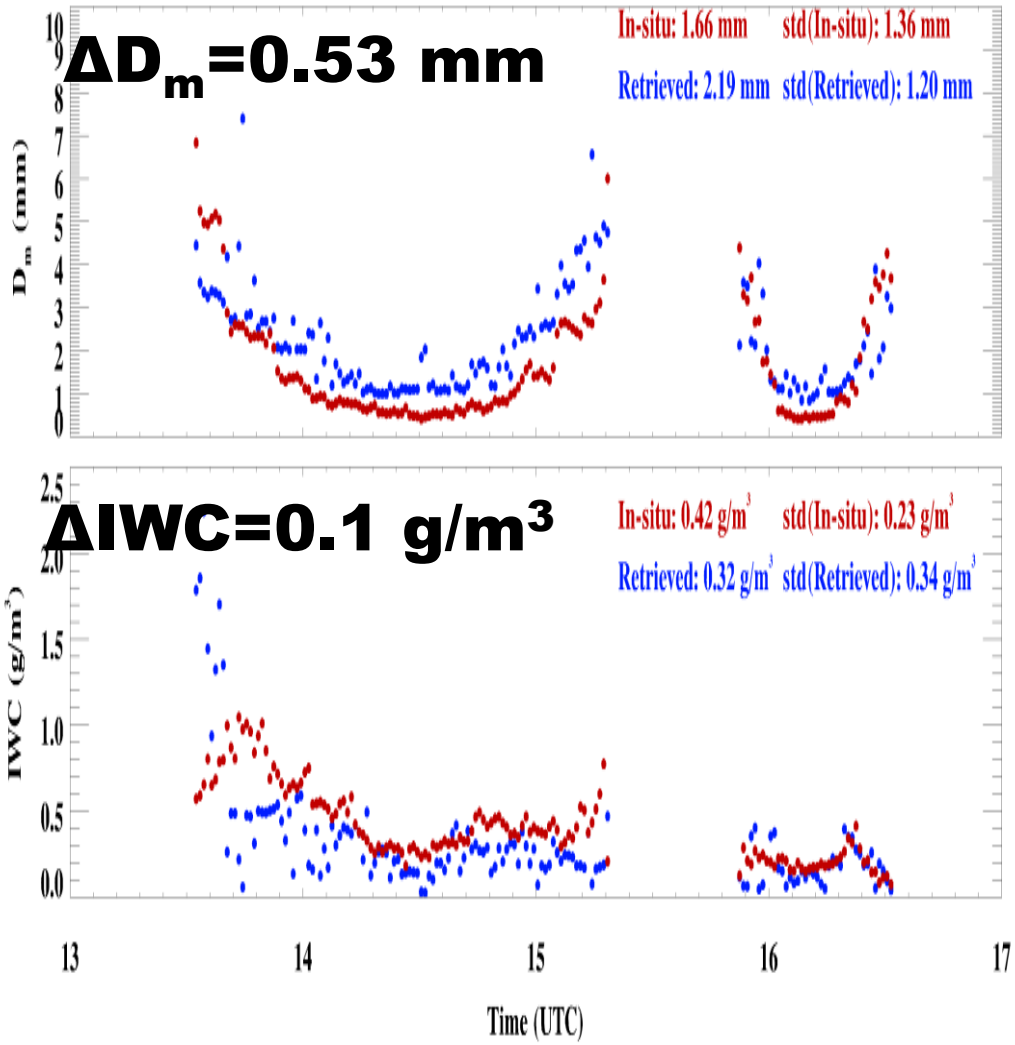
3D ice cloud Dm and IWC retrievals from NEXRAD



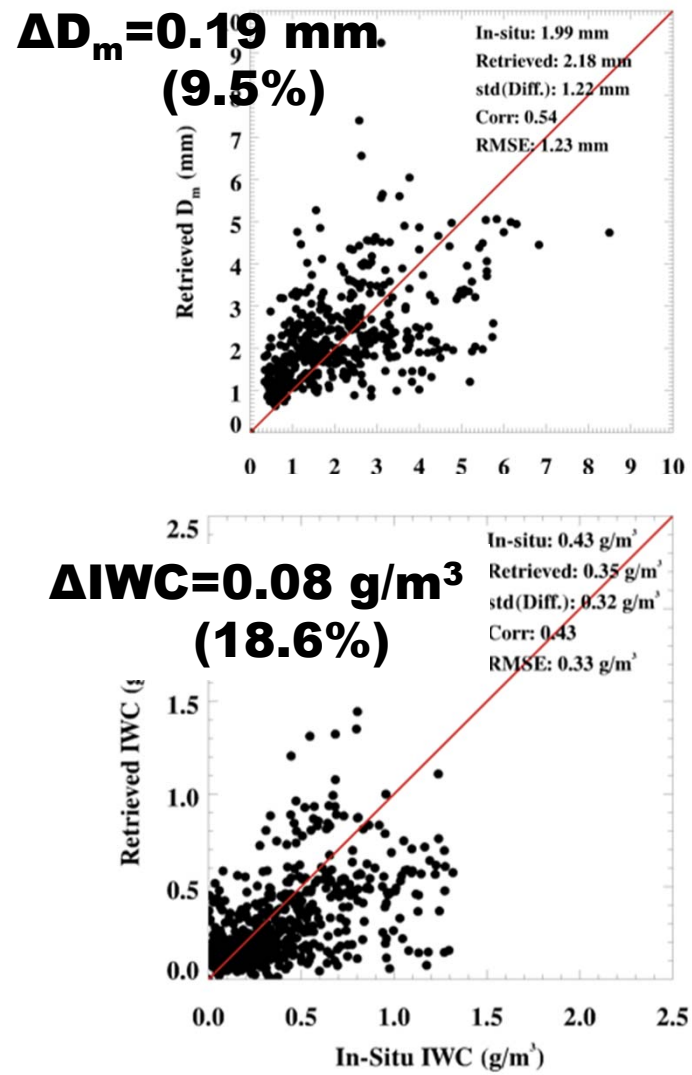


Validation of radar retrievals using aircraft results

May 20 Case



6-Case Comparison



Using Doppler cloud radar to study microphysics and dynamics of ice clouds

Observation: Doppler velocity V_d + radar reflectivity Z of ice clouds with 35 GHz cloud radar (MMCR)

↓

Decomposition: V_d into particle terminal fall velocity V_t and in-cloud vertical air motion w ($V_d = V_t + w$)

↓

Climatology: V_t and w at SGP (1997-2010) & Manus (1999-2010) as daily netcdf at www.arm.gov/data/pi/76
(see Kalesse & Kollias, J. Clim., 2013)

↓ V_t

- Variability of profiles of $V_t = a\ Z^{\wedge}b$ indicate different microphysical regimes (nucleation + deposition, aggregation, riming)
- Exponent b can be expressed in terms of PSD moments M
- b>0 (<0): larger moments grow more rapidly (slowly) than reflectivity-corresponding moment (M_6)
- $b \leq 0$ is radar-observed near cloud top where nucleation + deposition occur

→ Empirical relations in microphysical parameterizations do not reproduce $b \leq 0$ and could thus be adjusted to better represent conditions near cloud top

(see Kalesse, Kollias, Szyrmer, JGR, 2013)

w ↓

- Statistical comparison (PDFs) of w and dissipation rates ε derived from MMCR and in-situ aircraft measurements
- two SPARTICUS anvil cirrus cases (SGP, 2010) studied, serves as validation of radar-derived dynamics
- w : good agreement for w < 0.5 m/s
- ε: agreement within 1 order of magnitude
- more detailed and direct comparisons are needed for various environmental conditions at tropics and midlatitudes

(Muhlbauer, Kalesse, Kollias, revised version submitted to GRL)

McGill
www.clouds.mcgill.ca

D7: Upgrade CAM5 microphysics to make it self-consistent

- make the CAM5 microphysics self-consistent by using improved mass-diameter and area-diameter expressions to formulate the processes
- Morrison, Mitchell, Eidhammer
- emphasized in years 2 and 3

- Status
  - Modified CAM5 microphysics to combine cloud ice and snow into a single ice category *(done)*
  - Incorporated observed particle m-D and A-D relationships to calculate all relevant processes and parameters using a lookup table approach *(done)*
  - Add an additional dependency of the m-D and A-D relationships to temperature *(ongoing)*
  - Test in single-column and global model frameworks against observations: microphysics + standard climate diagnostics *(ongoing)*

Motivation

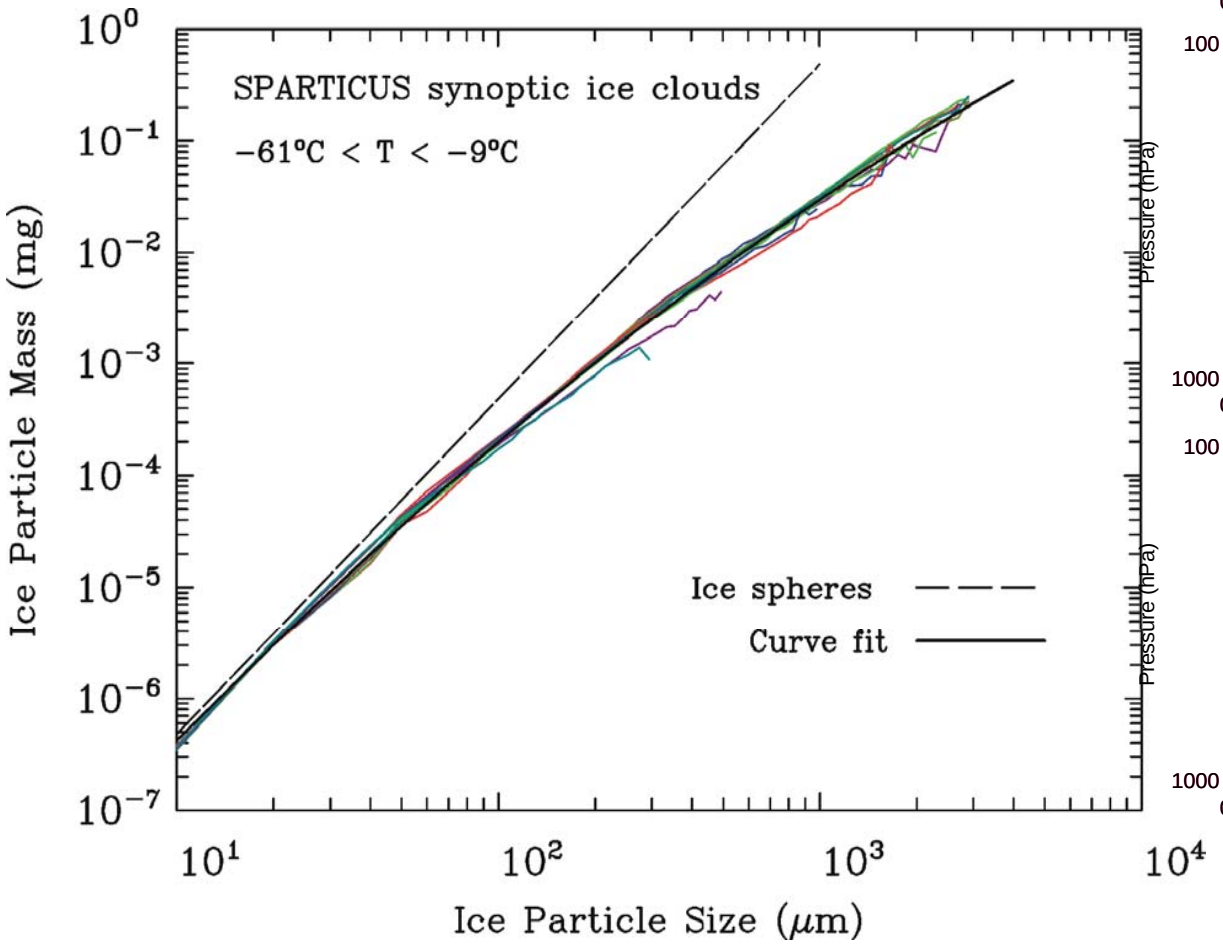
- Point 1: Having cloud ice and snow as separate categories is inherently artificial and necessitates having an "autoconversion" process representing growth of ice particles from vapor deposition, riming, aggregation → the autoconversion size threshold (Dcs) is one of the important tuning knobs in CAM5 but is not constrained by theory or observations

- Point 2: The particle m-D, A-D, and V-D relationships are not self-consistent → model assumes reduced density spheres for some processes but other habits for others (fallspeed)

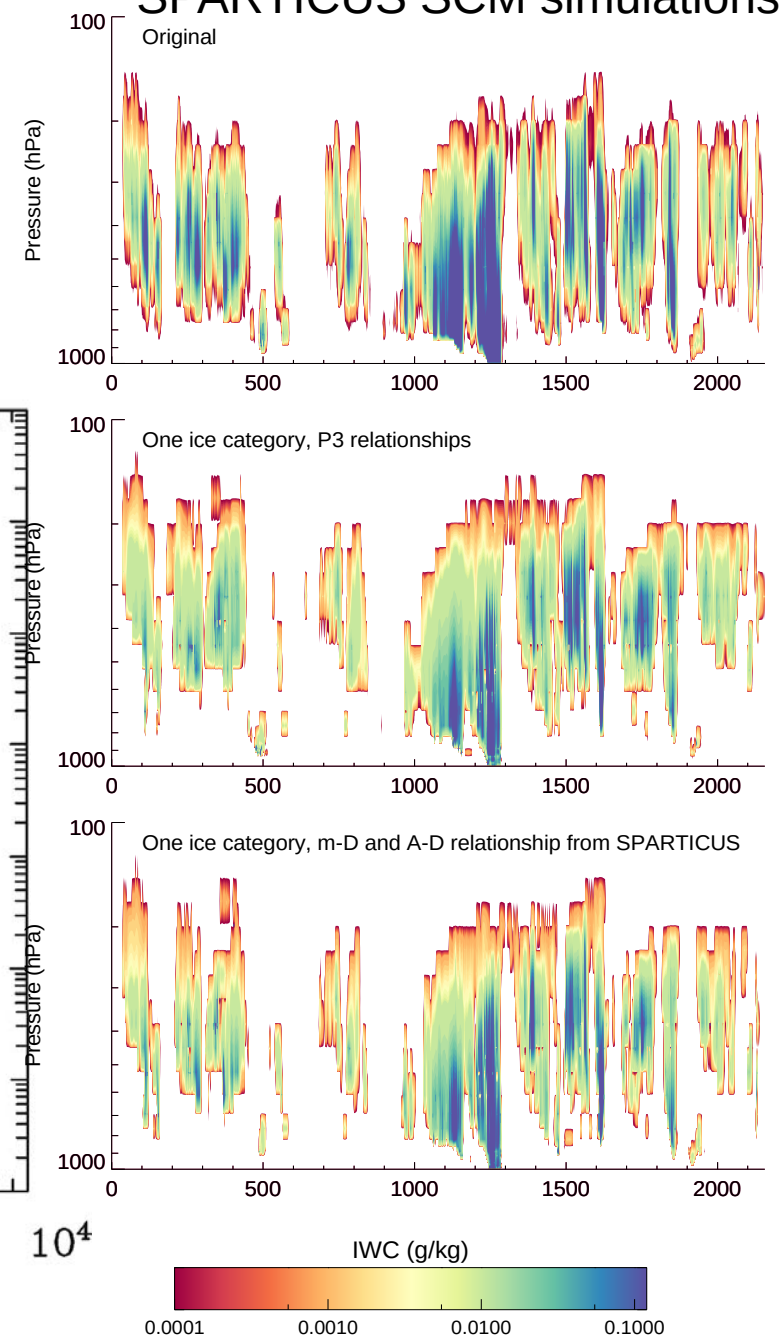
Description of the approach

- Combine cloud ice/snow into a single ice category
- Use m-D and A-D relationships from observations (Mitchell et al. 2014) as a function of temperature and apply self-consistently for all processes and parameters for all particle sizes
- Because of the form of the m-D and A-D relationships, analytic integrations over the PSD are no longer possible → use numerical integration to calculate relevant PSD moments and store values in a lookup table as a function of qi, Ni, and temperature
- Represents part a broader trend in microphysics schemes improving representation of ice particle properties and moving away from pre-defined categories (Hashino and Tripoli 2007; Morrison and Grabowski 2008; Harrington et al. 2013; Sulia et al. 2013; Morrison and Milbrandt 2014)

Observed m-D relationships (Mitchell et al. 2014)



SPARTICUS SCM simulations



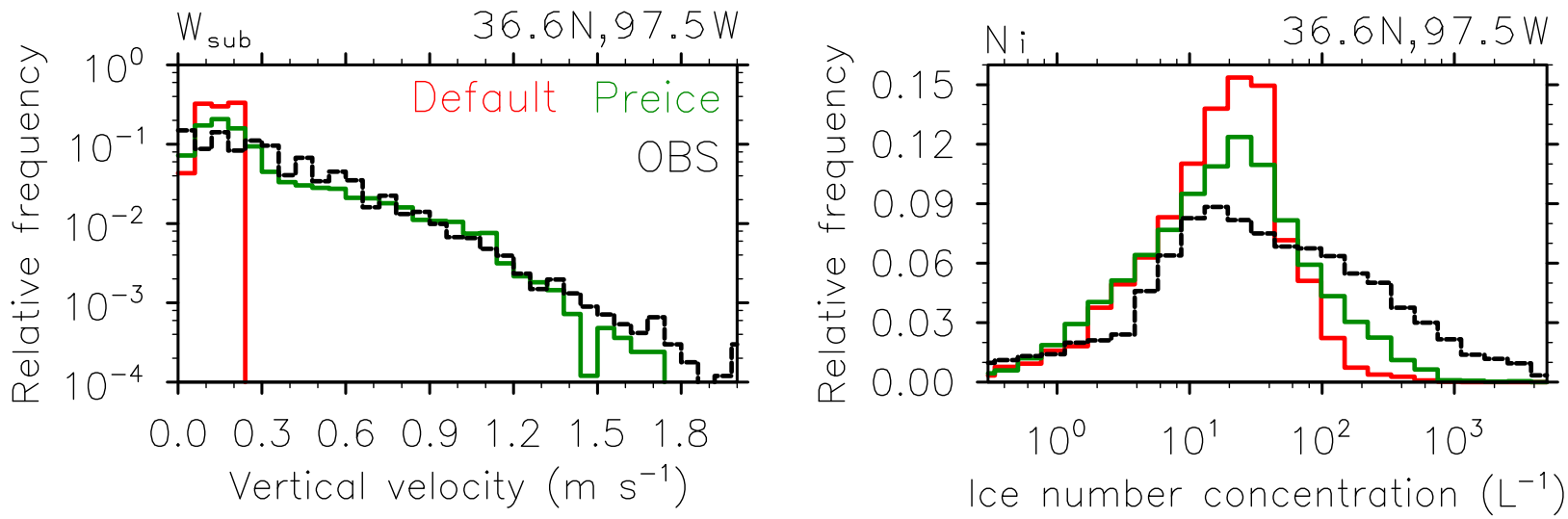
Refining ice nucleation parameterization in CAM5

Shi X., X. Liu et al., ACPD, 2014

- Consider preexisting ice crystal effect on ice nucleation in cirrus clouds
- Introduce in-cloud variability of ice saturation ratio due to temperature fluctuation
- Remove two limiters (upper limit of subgrid updraft velocity and lower limit of sulfate aerosol size) used in the ice nucleation parameterization in cirrus clouds

Results:

Improve comparison with ice microphysics observations (e.g., SPARTICUS) with small mean climate state changes from the default CAM5 model



Comparison of PDF of sub-grid updraft velocity (W_{sub}) & in-cloud ice number (Ni) with **SPARTICUS** observations (OBS) over ARM SGP. Model results output 3 hourly from Default & updated model (Preice)

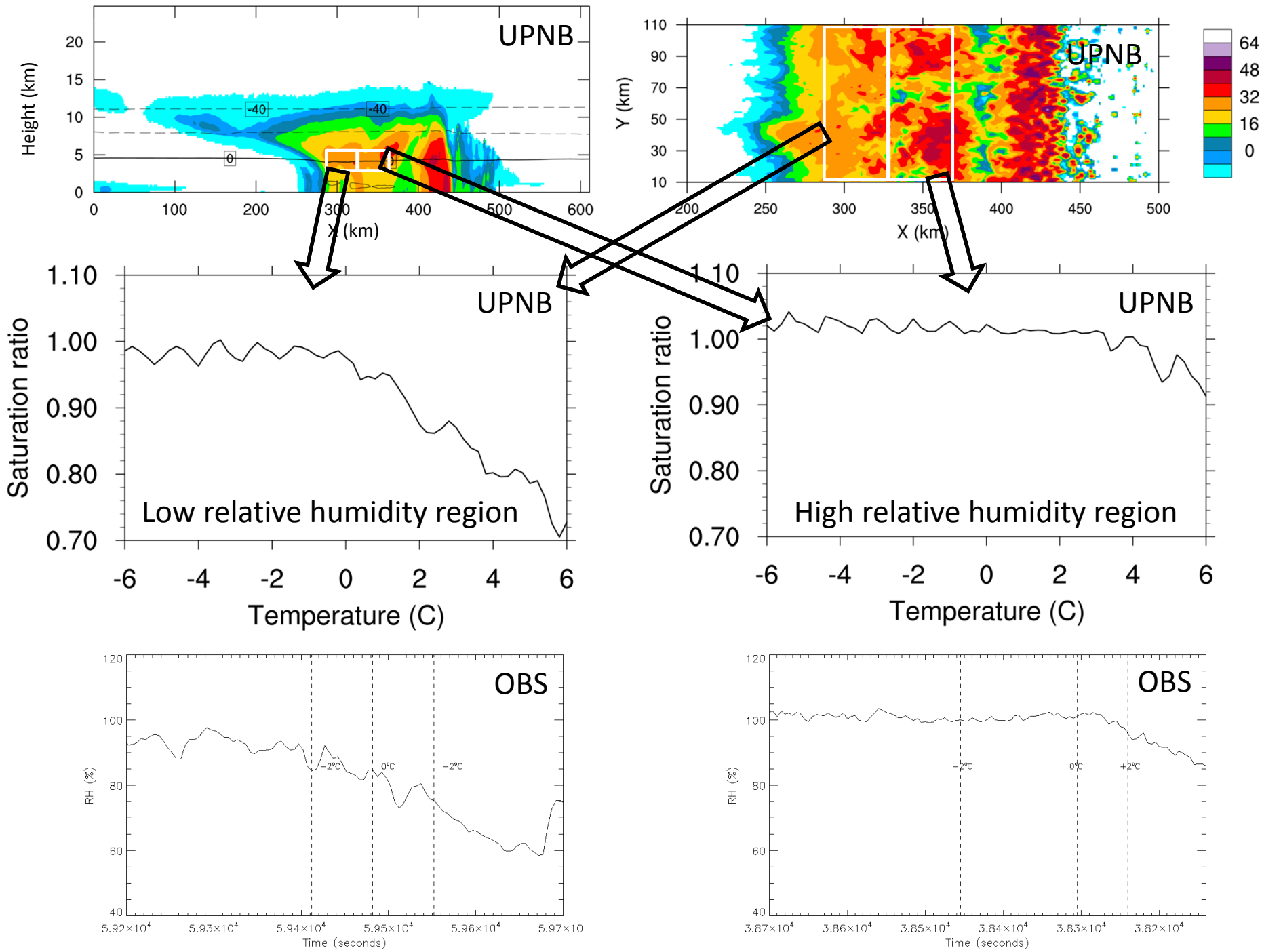
Outlook and issues for discussion

- Adding prediction of particle properties, e.g., crystal axis ratio and density following Harrington, Sulia et al., rime mass, etc.
- Coupling with other aspects – improved ice nucleation, microphysics in convection parameterization (and detrained ice), coupling with macrophysics
- What existing datasets do we have for model evaluation and further parameterization development, that are not being used?
- What observations are still needed – both in terms of 1) additional particle properties we aren't currently measuring, 2) better characterizing the properties that we're already measuring?
- What is the role of variability in ice parameters, both locally (in a grid box) and regionally?

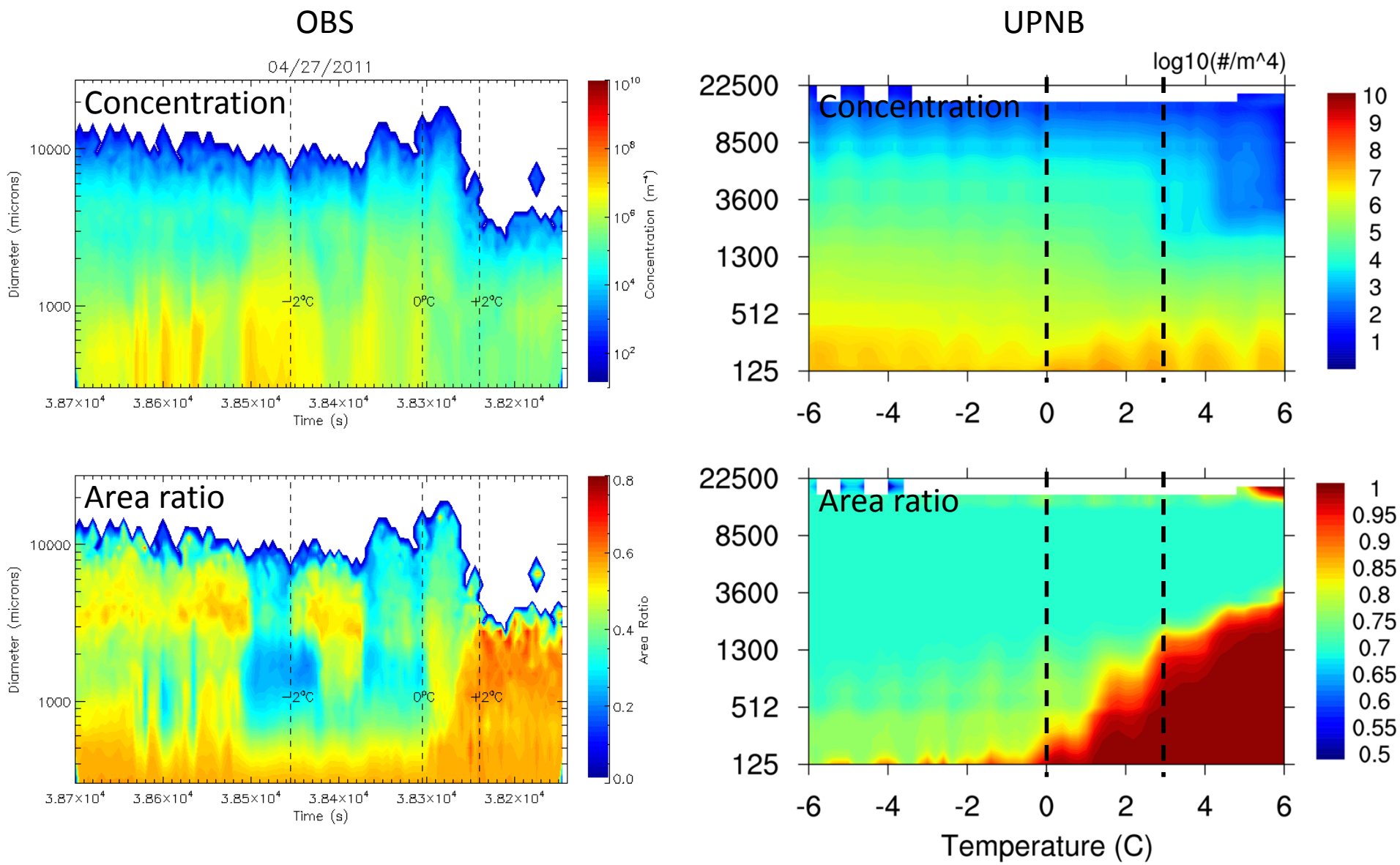
D8: Evaluate high-resolution simulations of MC3E systems

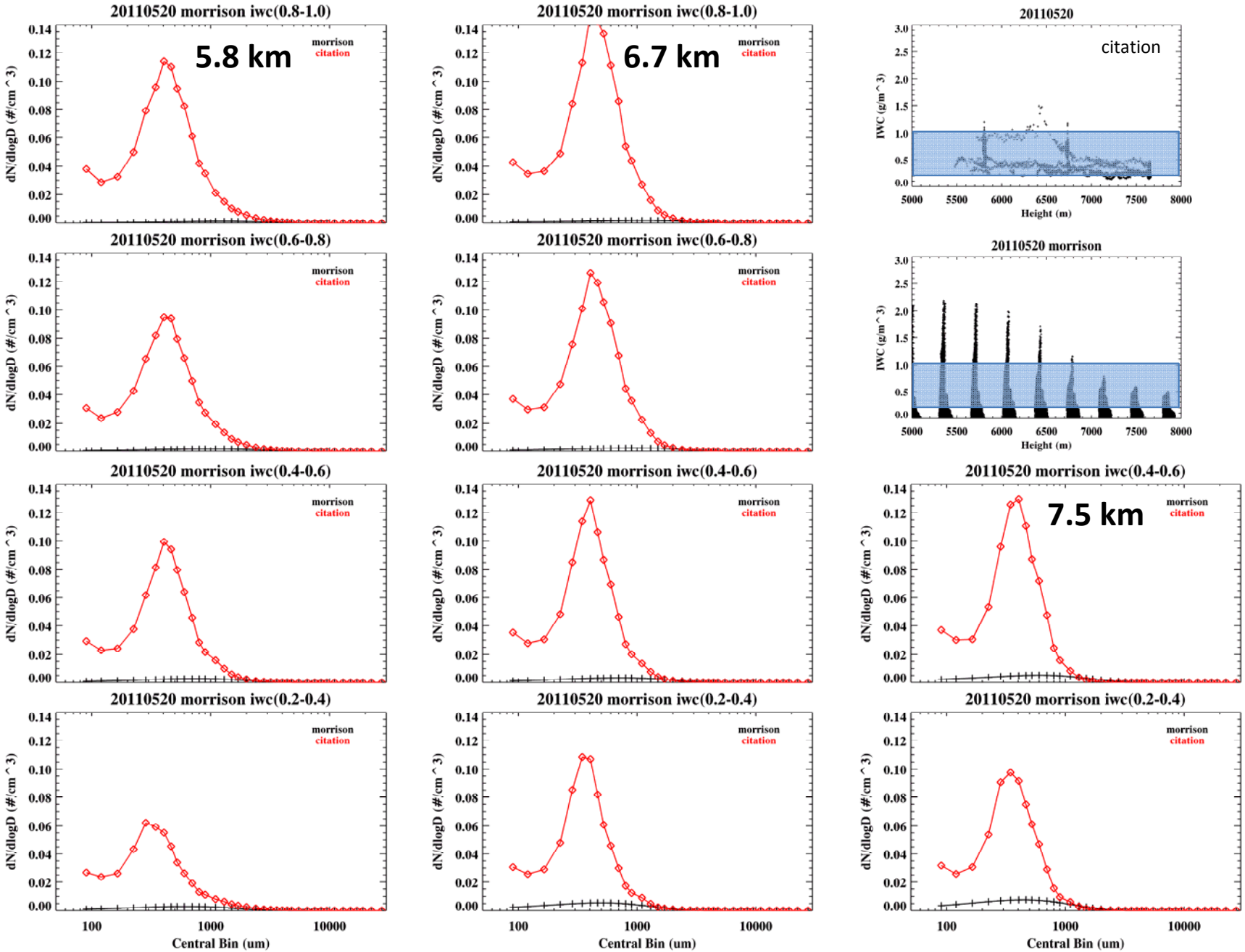
- compare high-resolution model simulations of MC3E deep convective precipitation systems with radar and aircraft measurements
- Tao, McFarquhar, Fridlind, Dong
- emphasized in years 1 and 2

- Status
  - 3D simulation groups have some differing focus areas
  - team with simulated ice particle melting studying roundness (MC3E 4/27)
    - Xue, Lebo, Fan, Bansemer, Geresdi, North, Morrison, Rasmussen, Thompson, Grabowski, Kollias, Heymsfield
    - roundness as an indicator of meltwater content
  - team using fixed ice properties focused on outflow PSDs (MC3E 5/20)
    - Fridlind, Wu, Li, Tao, Ackerman, Dong, Wang, McFarquhar, Wu
    - PSDs in large stratiform areas during MC3E (well sampled)
    - establishing ice properties as a fn of size (difficult)


UPNB
Height (km)
X (km)
-40
0
UPNB
Y (km)
X (km)
64
48
32
16
0
UPNB
Saturation ratio
Temperature (C)
Low relative humidity region
UPNB
Saturation ratio
Temperature (C)
High relative humidity region
OBS
RH (%)
Time (seconds)
-2°C
0°C
+2°C
OBS
RH (%)
Time (seconds)
-2°C
0°C
+2°C

High relative humidity region




20110520 morrison iwc(0.8-1.0)
5.8 km
6.7 km
morrison
citation
20110520
IWC (g/m^3)
Height (m)
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20110520 morrison
20110520 morrison iwc(0.4-0.6)
7.5 km
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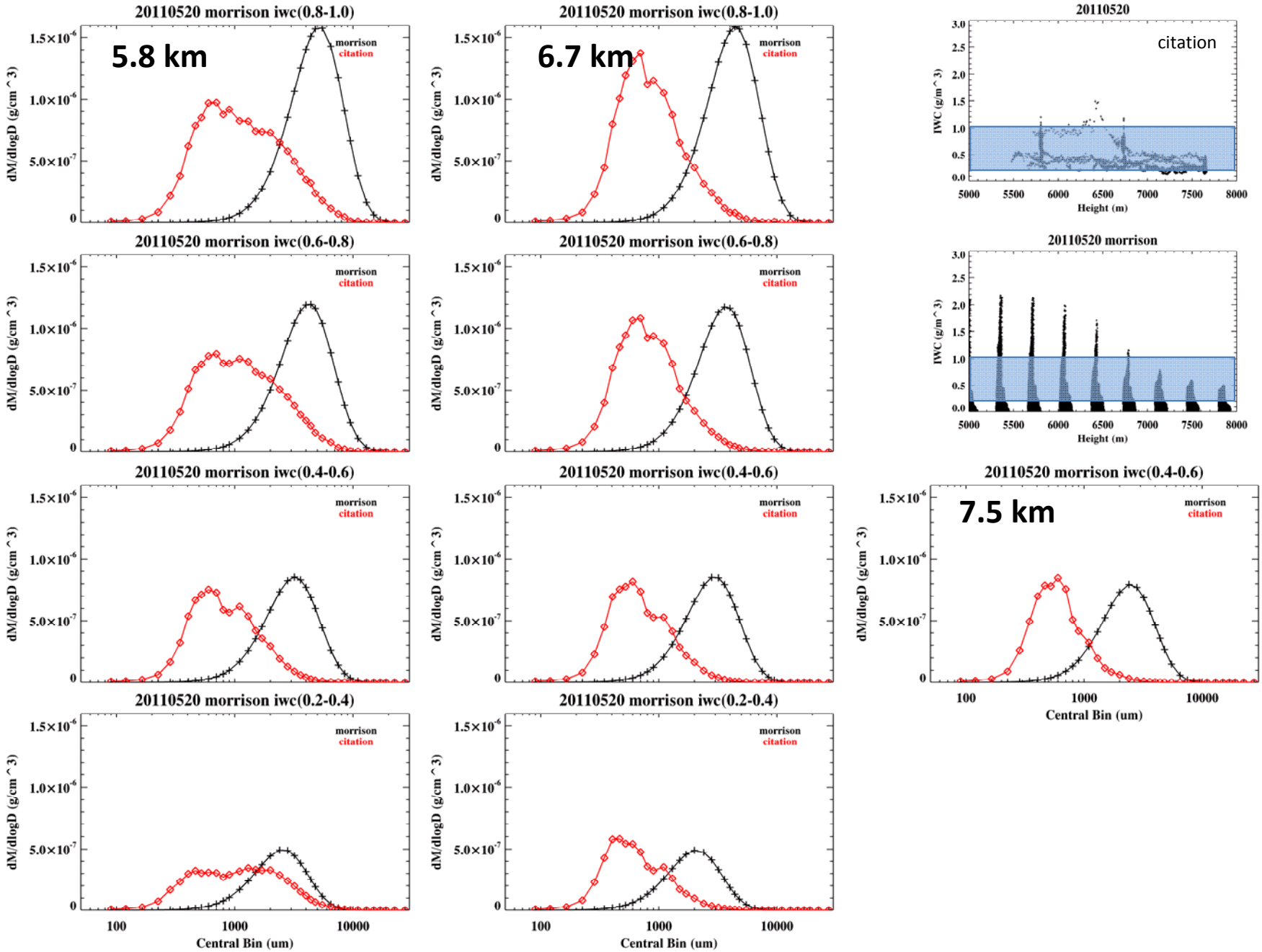
dN/dlogD (#/cm^3)
Central Bin (um)


20110520 morrison iwc(0.8-1.0)
5.8 km
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citation
dM/dlogD (g/cm ^ 3)
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IWC (g/m ^ 3)
Height (m)
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20110520 morrison iwc(0.4-0.6)
7.5 km
20110520 morrison iwc(0.2-0.4)
Central Bin (um)

D9: Determine modeling impact of new ice property parameterizations

- implement the new parameterizations of ice particle properties into models targeting various scales and report impact of new schemes on cloud microphysical and radiative properties and radiative forcing
- Fridlind, Harrington, Morrison
- all 5 years with concentration on different environments in different years

- Status
  - Kara Sulia/Matt Kumjian: Evolving ice habits, comparisons with radar.
  - Anders Jensen/Harrington/Morrison: Evolving ice habits during riming
  - Hugh Morrison: Determining impact of new ice parameterizations
  - Ehsan Erfani/David Mitchell: Riming in a snow growth model

- Ice Habit and Density Evolution in LES -

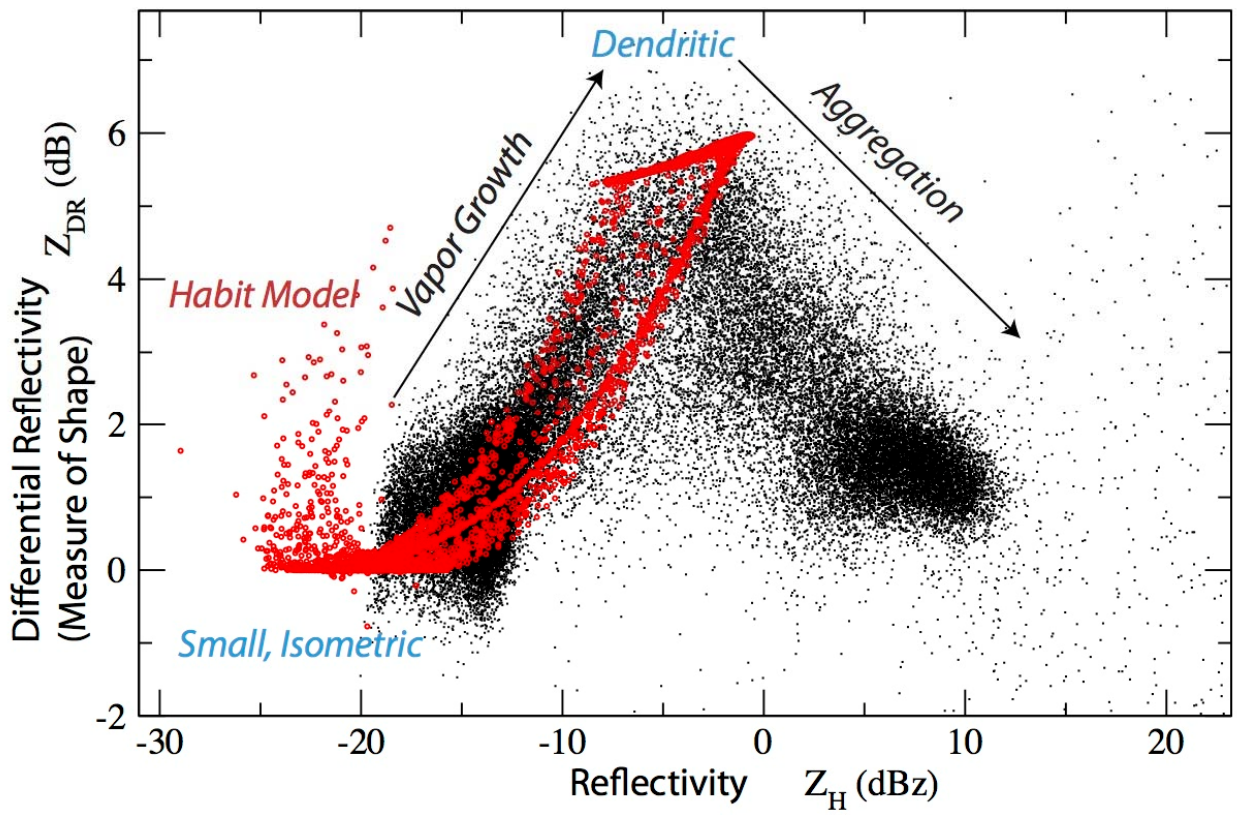
Kara Sulia (ASRC/SUNY-Albany)
Matt Kumjian (Penn State)

Approach:

• Using polarimetric radar data to test a bulk habit evolution model that evolves aspect ratio, mean density, size, and fall-speed instead of separating ice into a cloud ice and snow category as in most models.

Unique Features:

• Smooth evolution of aspect ratio (isometric to developed habit) and density that are tied to mass and fall-speed evolution
• Differential reflectivity dependent on density (dielectrics). Important test of model's density prediction.
• Captures the parameter space of reflectivity (size) and differential reflectivity (shape).



- Riming Prediction for Evolving Habits -

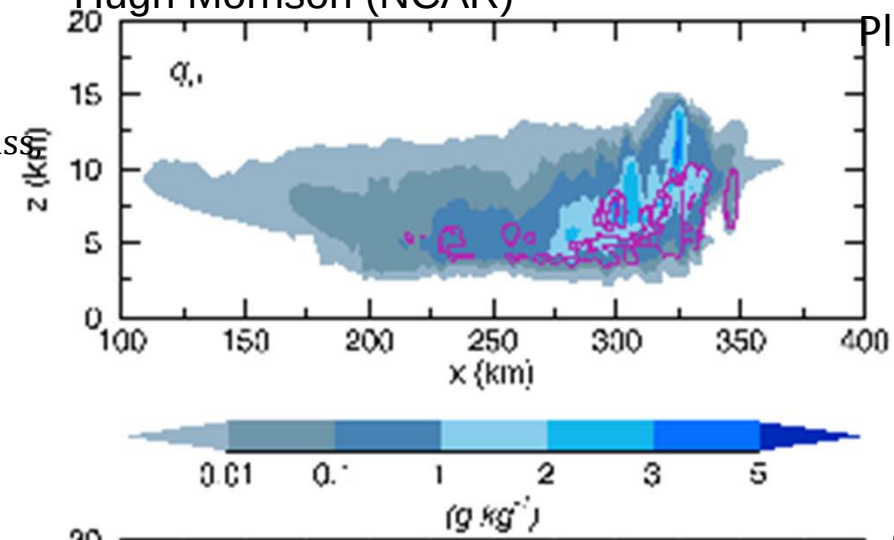
Jerry Harrington, Anders Jensen (Penn State)
Hugh Morrison (NCAR)

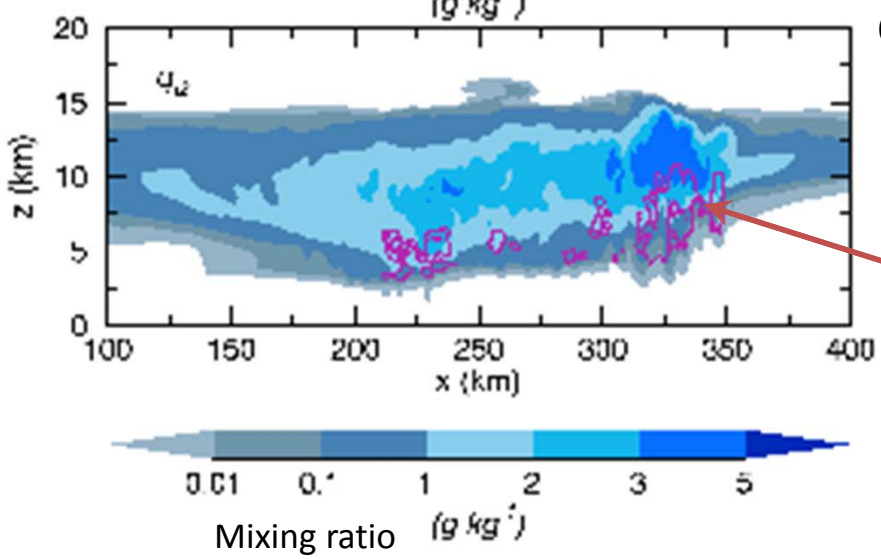
Approach:

- Extend habit prediction model for riming. Instead of a separate rimed category, model evolves particle mass, aspect ratio, density, and fall-speed during riming.
- Theory developed that compares well to wind tunnel riming measurements.

Unique Features:

- Smooth evolution of aspect ratio (isometric to developed habit), density, mass, and fall-speed during riming.
- Captures habit effect and transitional states of riming.
- Allows natural "habit delays" in riming during precipitation production.





Riming rates (1×10^{-5} g/kg/s)

Hugh Morrison / National Center for Atmospheric Research

Grants: DOE ASR DE-SC0008648 (PI: Wojciech Grabowski, NCAR)
DOE ASR DE-SC0005336 (PI: Eric Jensen, NASA)

ICEPRO Deliverable D9:
Determine modeling impact of new ice property parameterizations

Approach

• Further develop a *conceptually different approach for parameterizing microphysics* by predicting the properties of ice (mean density, size, fallspeed) instead of separating ice into categories with fixed properties (cloud ice, snow, graupel, etc.) as in traditional schemes.

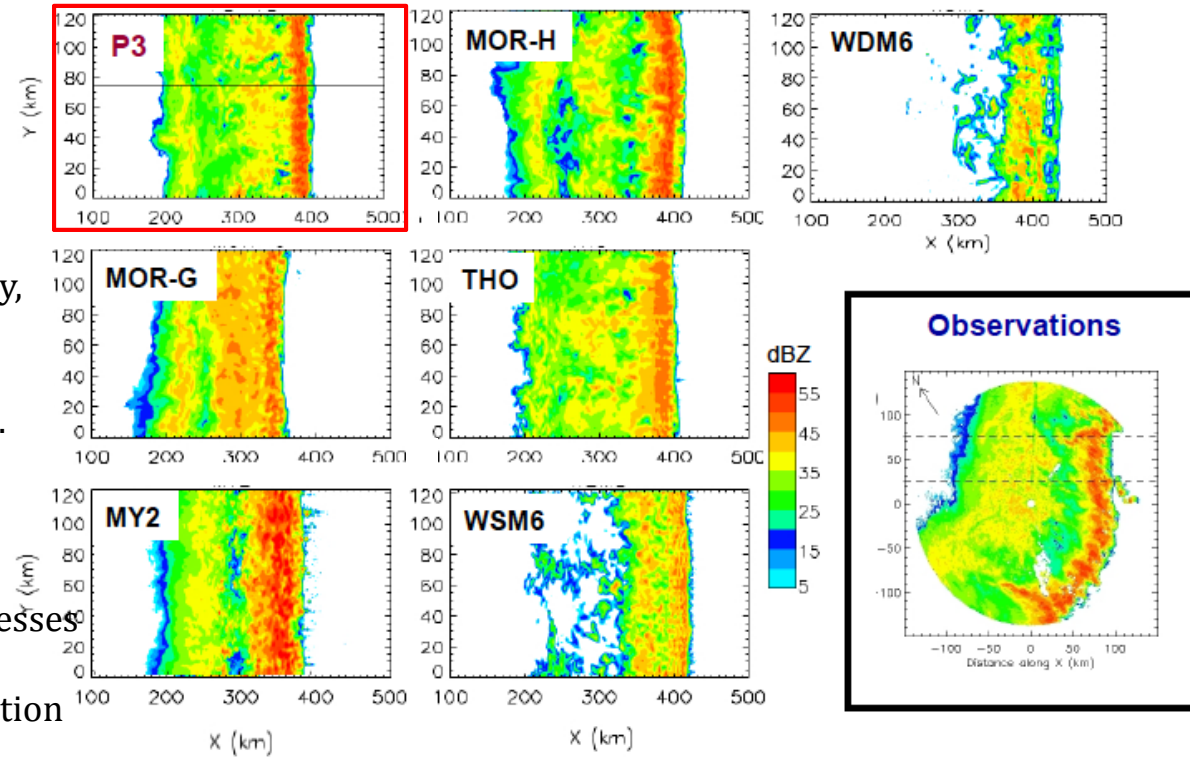
Advantages compared to traditional schemes:

• Avoids unphysical/ad-hoc conversion processes and parameters
• Smooth evolution instead of discrete transition of the particle properties
• Better coupling with observations
• Computationally efficient

Future work

• Test for ARM case studies (MC3E, GO-AMAZON); couple with polarimetric radar simulator

Horizontal cross-sections of radar reflectivity at t= 6 h for quasi-idealized simulations with various microphysics schemes in WRF and observations for the 20 June 2007 Oklahoma squall line



References

Morrison, H., and J. A. Milbrandt: Parameterization of cloud microhpysics based on the prediction of bulk ice particle properties. Part I: Scheme description and idealized tests. *J. Atmos. Sci.* (in press)

Morrison, H., J. A. Milbrandt, G. H. Bryan, K. Ikeda, S. A. Tessendorf, and G. Thompson: Parameterization of cloud microhpysics based on the prediction of bulk ice particle properties. Part II: Case study comparisons with observations and other schemes. *J. Atmos. Sci.* (in press)

Riming treatment in a snow growth model

Ehsan Erfani & David Mitchell / Desert Research Institute & U. Nevada, Reno

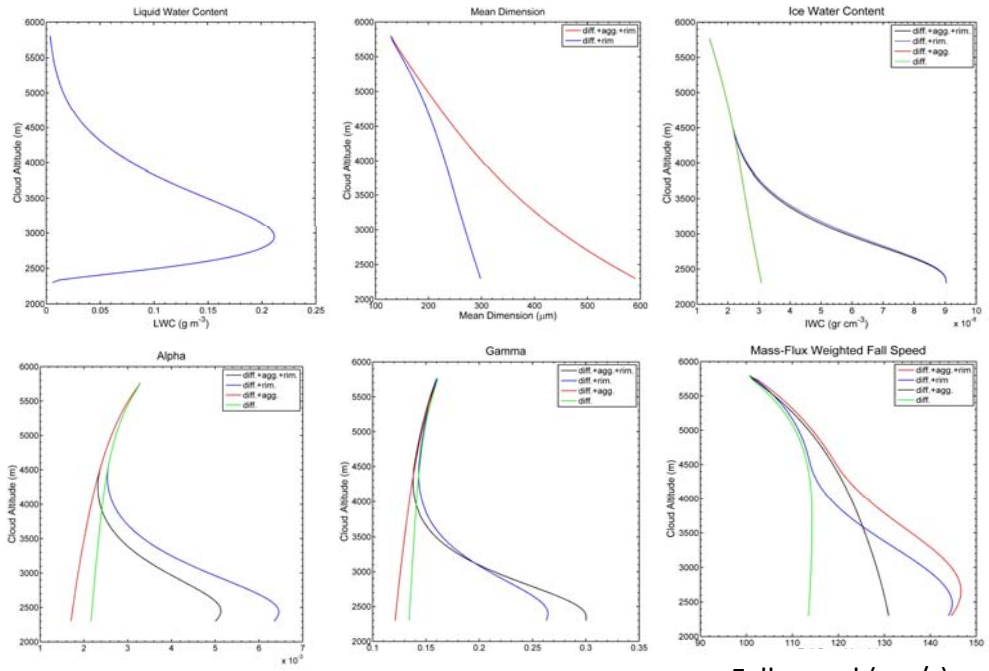
Science Question

How can ice particle mass- and area-dimension (m-D & A-D) power laws be expressed as a function of riming?

Approach

- Used m-D field measurements to show that only α is affected by riming, where $m = \alpha D^{\beta}$.
- Used m-D field measurements to show that maximum projected area from riming is attained at hexagonal graupel stage where $m_r / m_u \approx 3.5$ (r => rimed; u => unrimed).

- $\alpha/\alpha_u = IWC/IWC_u$ (D > 150 μm)
- $A = (A_{max} - A_u)R + A_u$; $R = (M-M_u)/(M_{max}-M_u)$
- $M_{max} = 3.5\ M_u$; $M \leqslant M_{max}$
- $A_{max} = k\ (\pi/4)\ D^2$; k = attenuation factor
- $A = \gamma D^{\delta}$; if $\delta_r = \delta_u$ then $\gamma = A/D^{\delta}$



α γ Fall speed (cm/s)

Results from the snow growth model featuring the new treatment of ice particle riming. Different curves show different combinations of growth processes (diffusion, diff. + aggregation, diff. + riming, & diff. + agg. + riming.

Key Accomplishment

New riming treatment was incorporated into a snow growth model that can be used in conjunction with radar reflectivities to retrieve the IWC in ice clouds.

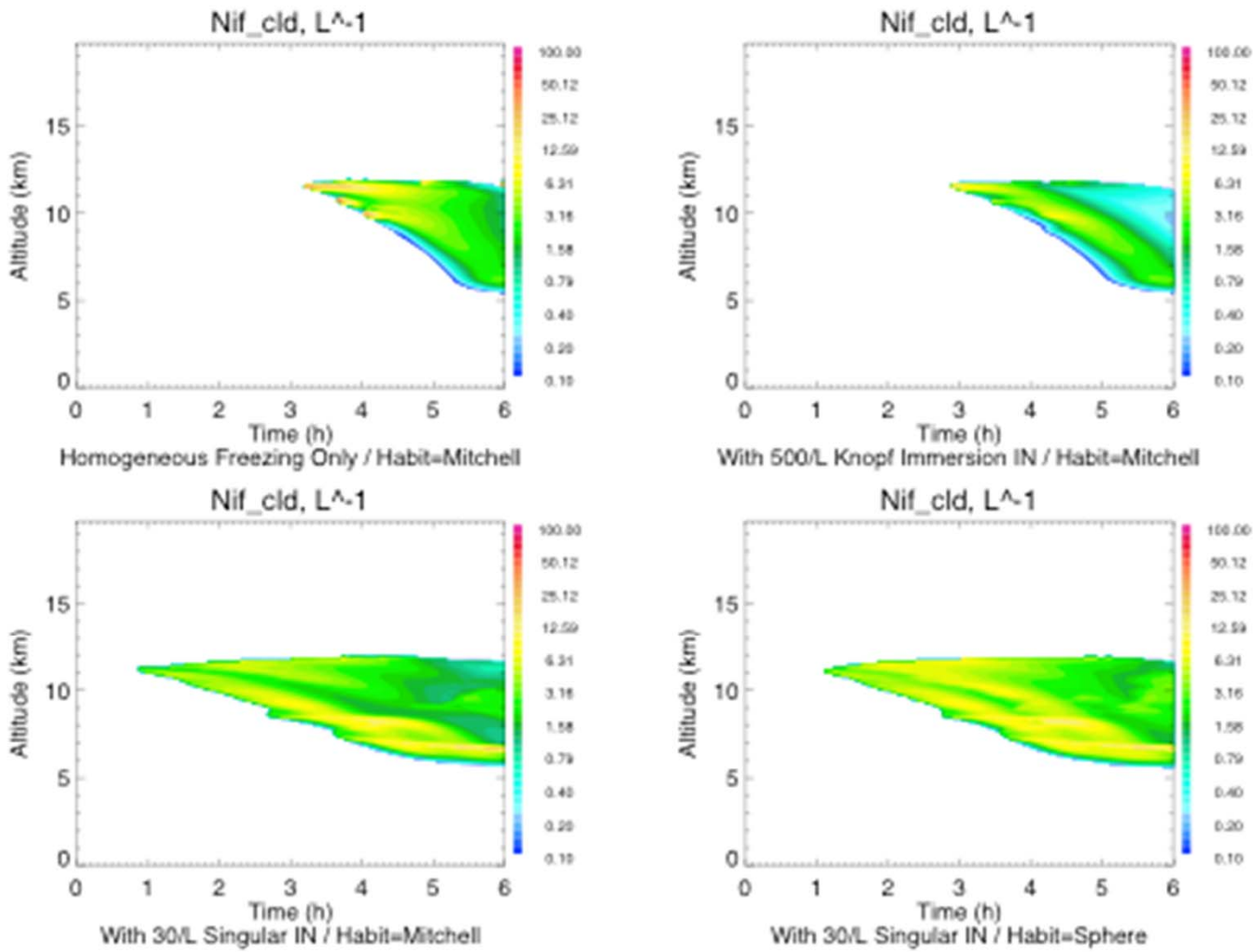
D10: Develop framework for translating uncertainties in ice particle properties to model output

- develop a framework for translating uncertainties in ice particle properties to uncertainties in modeled cloud and radiative properties and radiative forcing
- Fridlind, Harrington, Morrison, McFarquhar, Dong and Mitchell
- develop of framework in years 1-2, testing in subsequent years

- Status
  - preliminary studies using bin microphysics in SPARTICUS case (Fridlind et al.) use typical and perhaps inadequate approach of varying ice properties using a single case study
  - Framework for quantifying uncertainties developed to quantify fit parameters as surfaces of equally realizable solutions (McFarquhar et al. 2014 for gamma distributions)

SPARTICUS bin microphysics (Fridlind in prep.)

— ice properties and ice nucleation scheme both influence cirrus number concentration



Representing uncertainty of PSDs in a gamma function

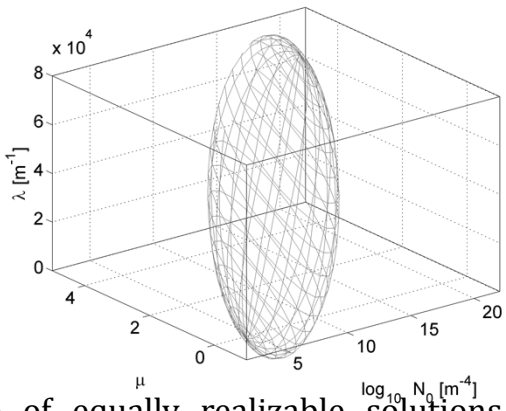
Greg McFarquhar / University of Illinois

Science Question

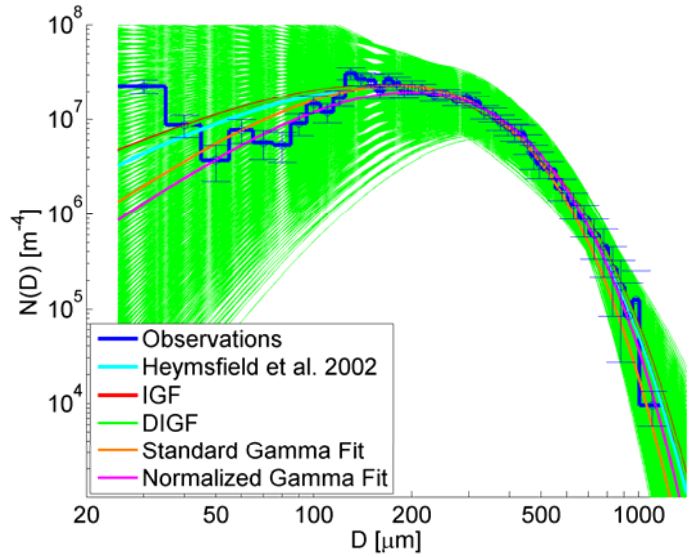
How can we describe the uncertainty in the gamma function $N(D)=N_0D^{\mu}e^{-\lambda D}$ that is used to represent PSDs in models & retrieval schemes?

Approach

- Using ISDAC & NAMMA data developed IGF technique that identifies all (N_0,λ,μ) within $\Delta\chi^2$ of χ_{min}^2 minimizing difference of fit and observed moments, as equally realizable solutions
- Represent intersection of solutions from individual PSDs as ellipse in (N_0,λ,μ) phase space in order to apply in Monte Carlo simulations using random gamma parameters



Volume of equally realizable solutions in (N_0,λ,μ) phase space for all PSDs measured during ISDAC



Single PSD measured during ISDAC, together with different fits randomly taken from volume of equally realizable solutions (green lines); other lines represent PSD representation using different fit techniques

Key Accomplishment

Method developed for representing uncertainty in fit gamma functions that can easily be applied in models, and that forces integrated moments of PSD to match those observed as close as possible; technique being applied to PSDs measured in many campaigns to see how PSDs vary with meteorological conditions

Publications McFarquhar et al. JAS (2014)

D11: Linking ice optical properties with microphysical observations

- link ice optical properties computed from models and scattering codes with microphysical observations such as PSDs
- Williams, Nesbitt, McFarquhar, van Diedenhoven, Fridlind, and Dong
- starting in year 1 and continuing

- Status
  - team using bin microphysics
    - Fridlind, van Diedenhoven, Ackerman, McFarquhar, Um, et al.
    - getting past power law relations through direct analysis of single-particle databases starting with SPARTICUS
    - integrating geometric models with available data (expanding but still limited in handling of single-particle mass, irregularity, small crystals)
    - deriving differing aspect ratios relevant for microphysical process rates versus optical properties

A flexible parameterization for shortwave optical properties

Bastiaan van Diedenhoven, Ackerman, Brian Cairns and Ann M. Fridlind
J. Atmos. Sci., **71**, 1763-1782, doi:10.1175/JAS-D-13-0205.1.

- Yields single scattering albedo and asymmetry parameter for **single** ice crystals with any combination of
  - Volume
  - Projected Area
  - Aspect ratio of crystal components
  - Crystal distortion/roughness level
  - At any wavelength in the shortwave (0.2 – 4 micron)
- Uses only 88 coefficients
- Accuracy is comparable or better than existing, less flexible schemes
- Computes optical properties consistent with ice microphysical properties assumed in models

Computer code available at
http://www.columbia.edu/~bv2154/parameterization.html

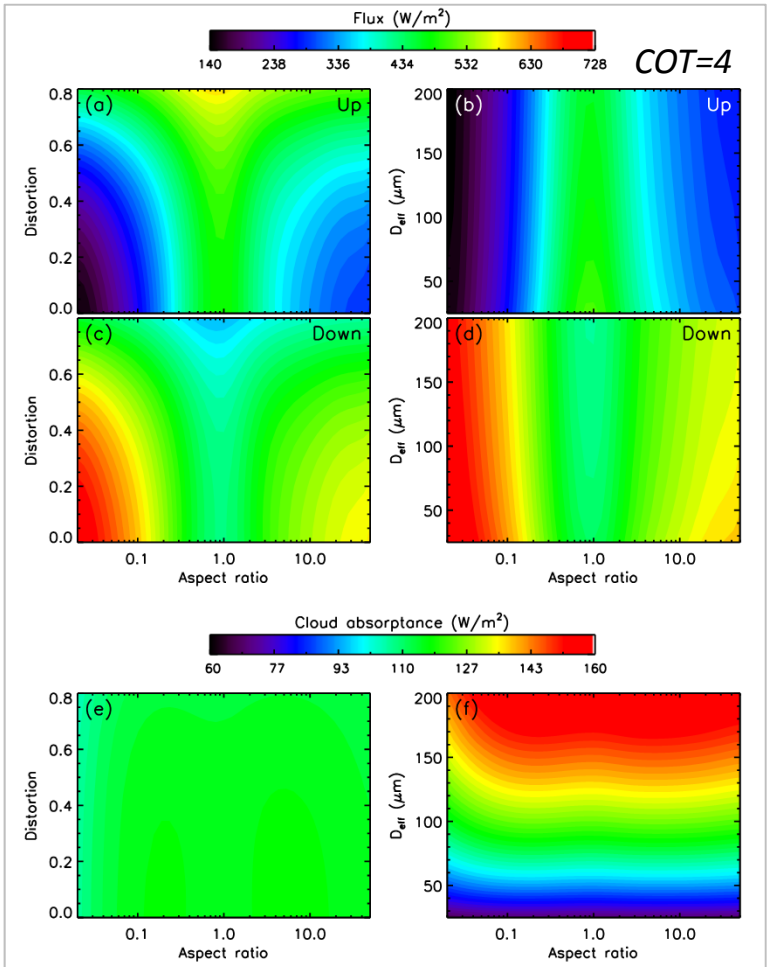
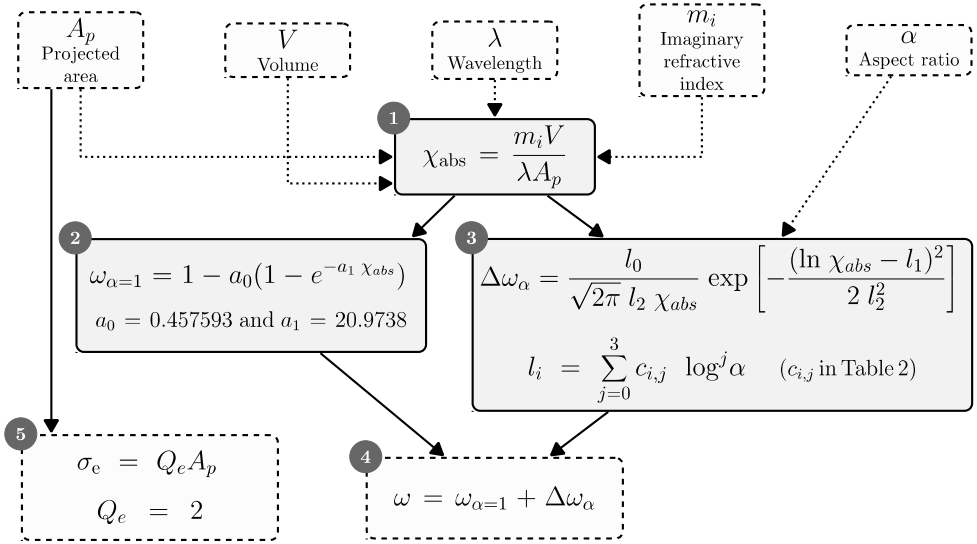


Figure shows variation of fluxes for clouds with varying crystal aspect ratio, distortion and effective diameter calculated using new scheme

van Diedenhoven et al. (2013)

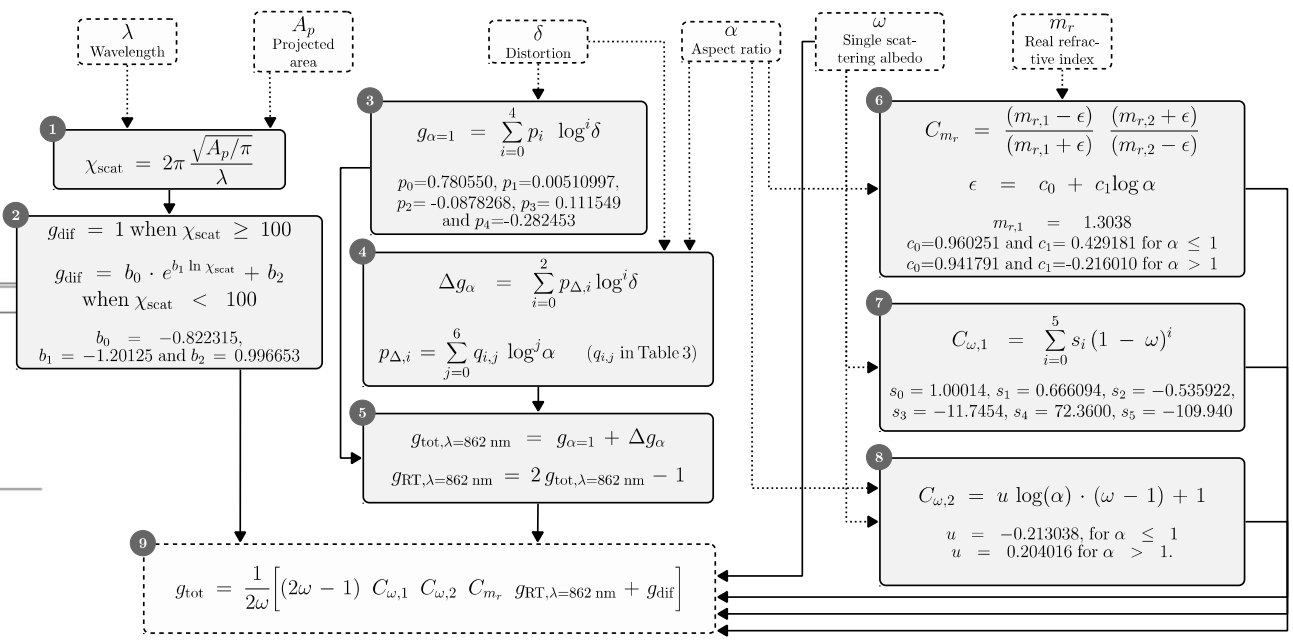


Single scattering albedo and extinction

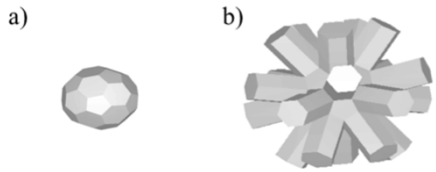
	j	$c_{0,j}$	$c_{1,j}$	$c_{2,j}$
Plates	0	0.000527060	0.309748	-2.58028
	1	0.00867596	-0.650188	-1.34949
	2	0.0382627	-0.198214	-0.674495
	3	0.0108558	-0.0356019	-0.141318
Columns	0	0.000378774	0.390452	-2.36821
	1	0.00463283	0.420040	1.07603
	2	0.00593106	-0.0848059	-0.729980
	3	-0.00117167	0.0186601	0.232446

Asymmetry parameter

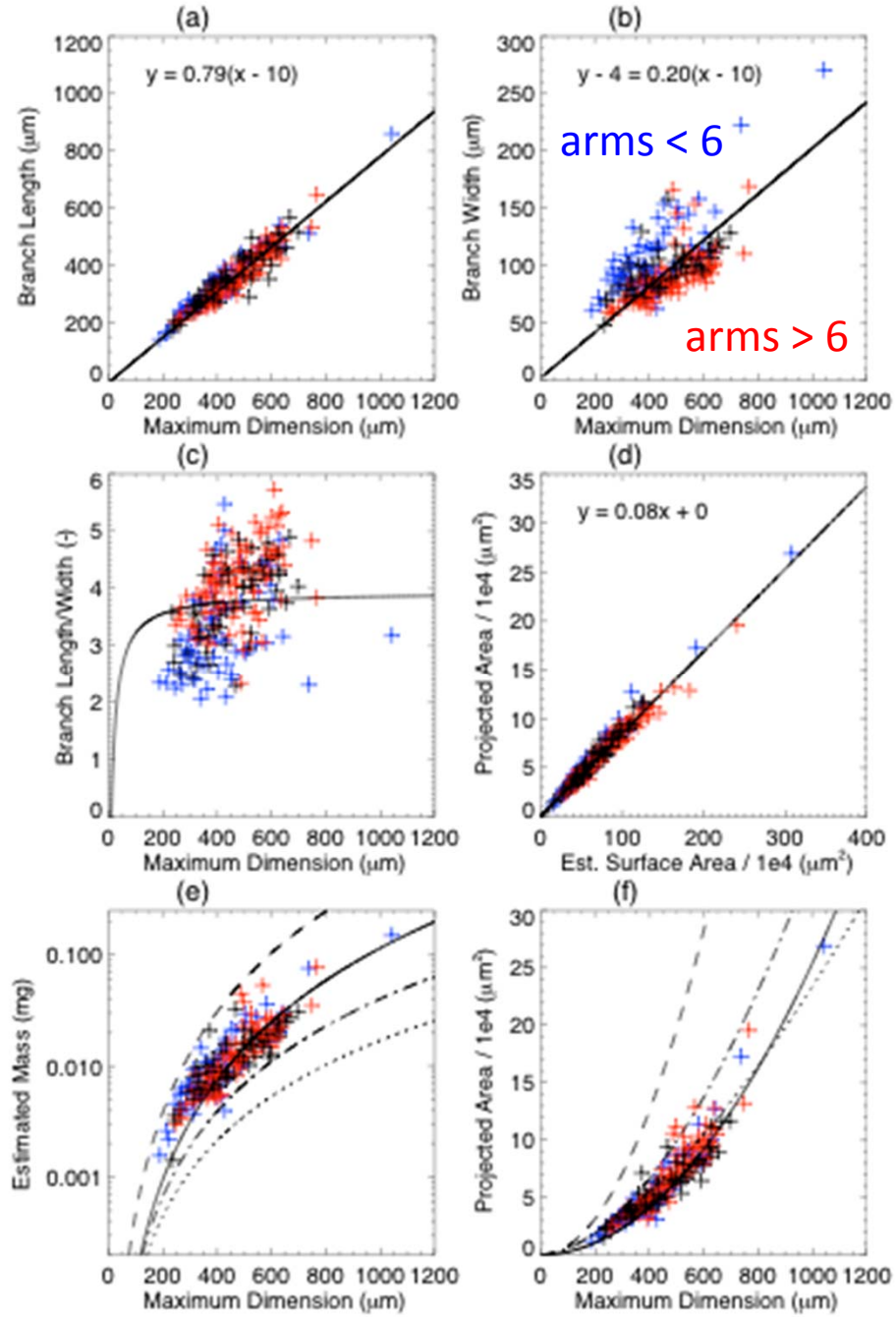
	j	$q_{0,j}$	$q_{1,j}$	$q_{2,j}$
Plates	0	-0.00133106	-0.000782076	0.00205422
	1	0.0408343	-0.00162734	0.0240927
	2	0.525289	0.418336	-0.818352
	3	0.443151	1.53726	-2.40399
	4	0.00852515	1.88625	-2.64651
	5	-0.123100	0.983854	-1.29188
	6	-0.0376917	0.187708	-0.235359
Columns	0	-0.00189096	0.000637430	0.00157383
	1	0.00981029	0.0409220	0.00908004
	2	0.732647	0.0539796	-0.665773
	3	-1.59927	-0.500870	1.86375
	4	1.54047	0.692547	-2.05390
	5	-0.707187	-0.374173	1.01287
	6	0.125276	0.0721572	-0.186466



SPARTICUS

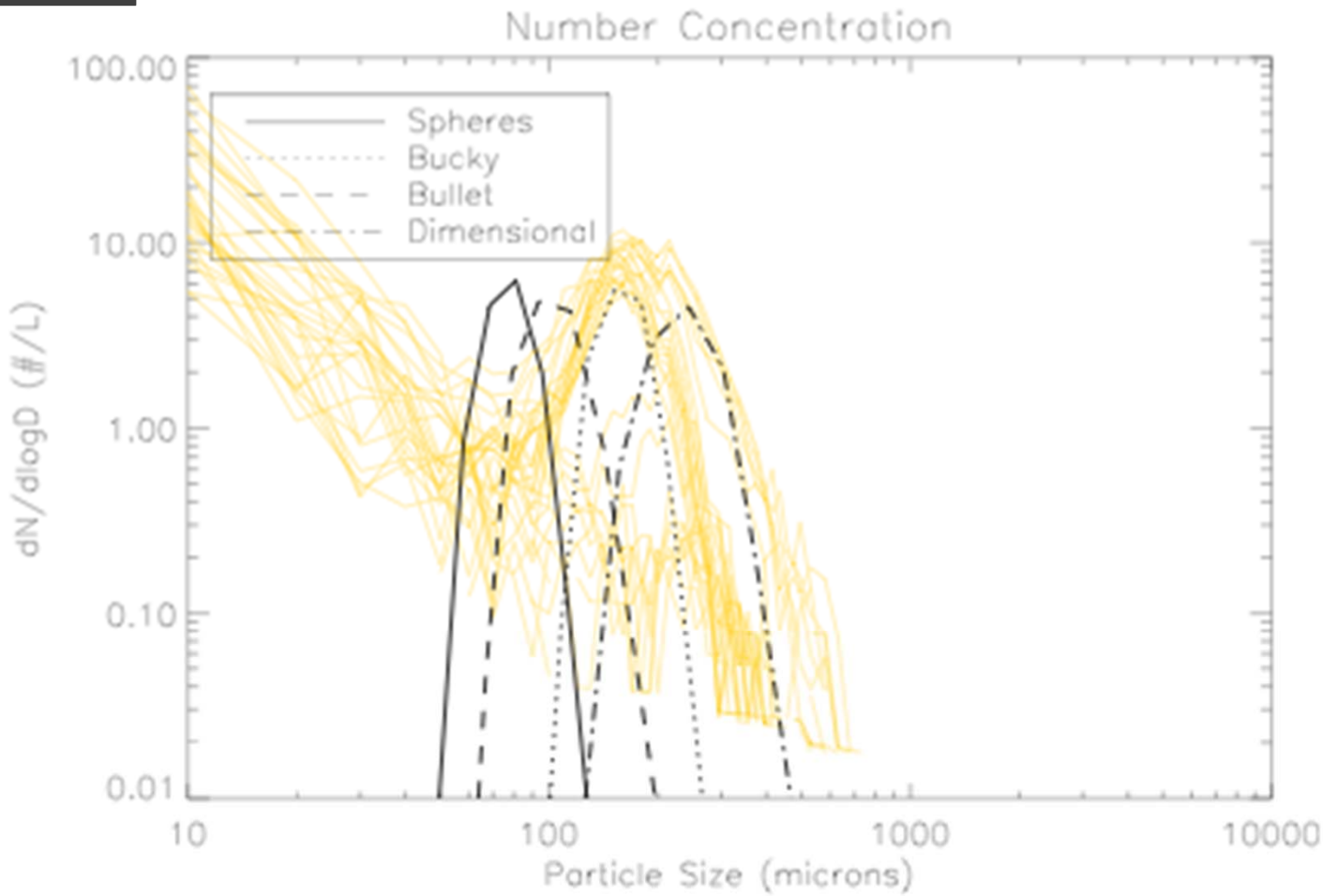


- Bullet rosettes
  - force branch width to zero at a fixed "core" size
  - assume that early branch width increases linearly from *same number of branches*
  - A < 0.25*SA (as expected)
  - *calculate* mass
  - solid line mass, area for 6 arms
  - compare with bulk spheres (dashed), Mitchell et al. [1996] (dotted), Heymsfield et al. [2002] (dash-dotted)
  - *randomly oriented* D



Preliminary data courtesy
Greg McFarquhar, Jun Um, and Sun Kim

SPARTICUS



Preliminary parcel model results
Rachel Atlas, Ann Fridlind, Andy Ackerman

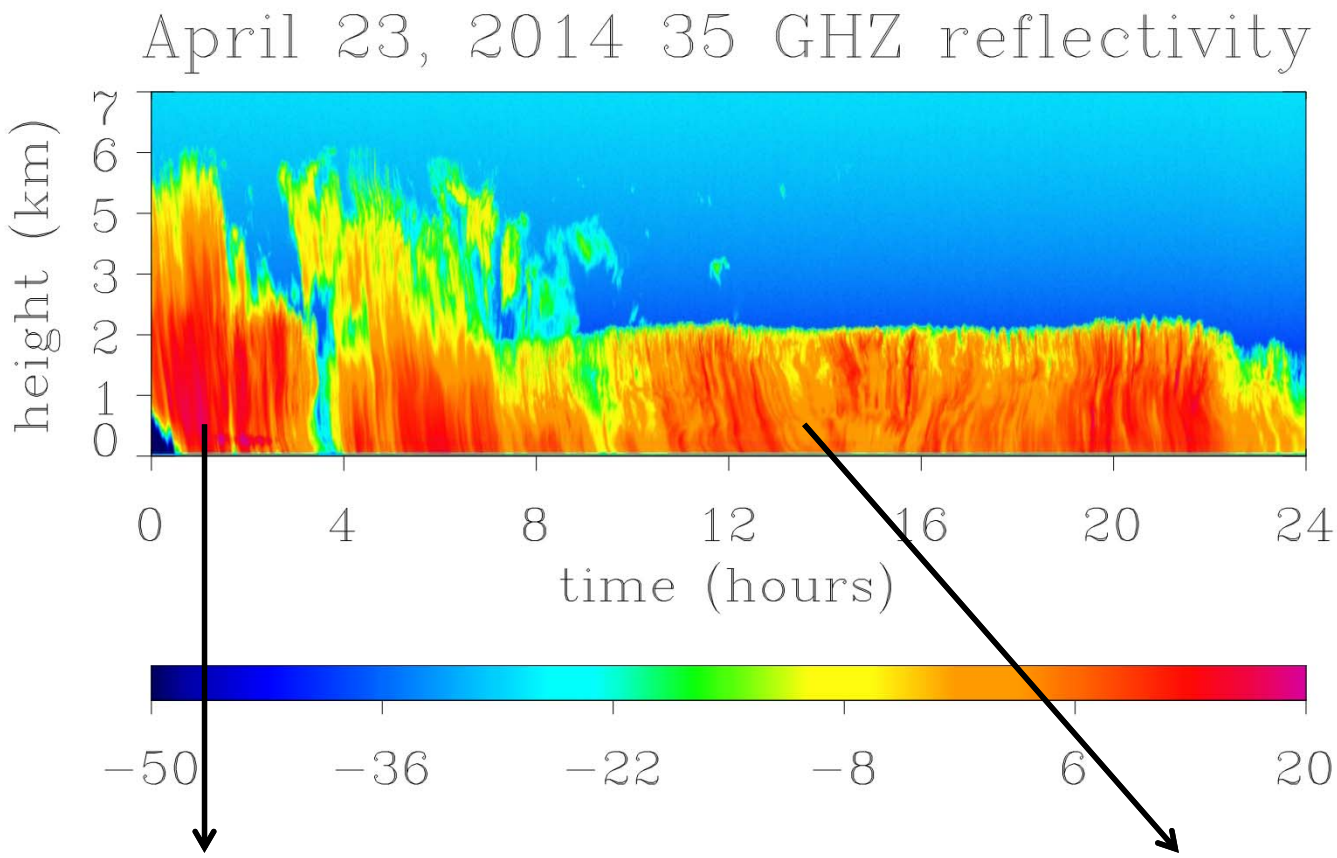
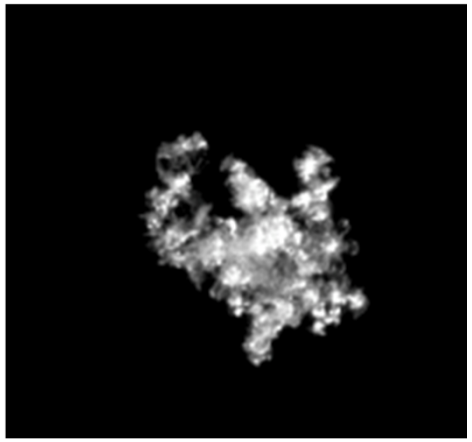
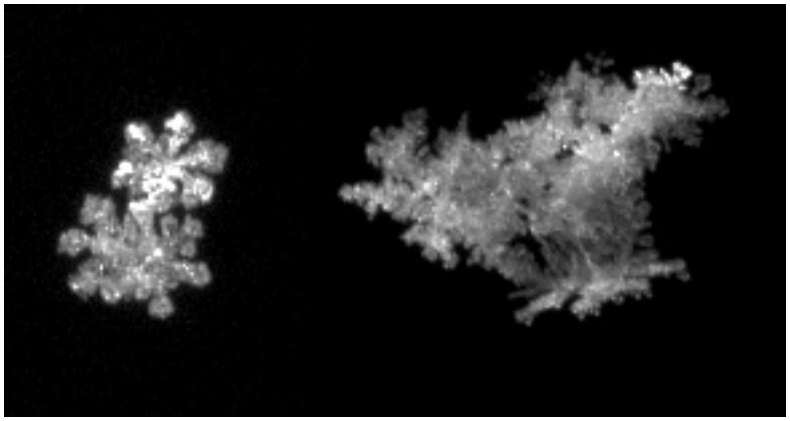
D12: Determine gaps in existing microphysics databases

- identify any gaps that still exist in ice cloud property database and parameterization, possibly conducting or proposing additional field or laboratory measurements that are needed to fill in these gaps
- all participants
- ongoing through year 5

- Status
  - team using bin microphysics focused on extracting additional data from past field experiments relevant to processes
    - Fridlind, van Lier-Walqui, van Diedenhoven, Ackerman, McFarquhar, Um, Wu, Dong, Wang, et al. (MC3E, SPARTICUS)
    - fraction of aggregates as a function of size and distance from cloud top
    - aggregate component properties (size-dependence of aggregation?)
    - multi-mode PSD fits
    - complete and quantitative ice properties as a function of ice type (not power laws, may include dispersion as a fn of mass): mass, maximum dimension, projected area, total and component aspect ratios

New and future field activities

- **Polar Ocean campaigns (MOSAiC, SOCRATES)**
  - high frequency of mixed-phase clouds, but only sparse measurements
  - seasonally varying aerosol conditions may impact ice and liquid nucleation
  - low concentrations of classic ice nuclei (e.g. dust), with hemispheric differences
- **Arctic cirrus**
  - gap in ice property measurements of clouds colder than -40°C
  - need this information together with aerosol measurements
  - may expect more homogeneous freezing away from dust sources
- **Ground-based MASC instrument**
  - continuous ice property measurements at NSA
  - improved multi-instrument retrievals
  - expanded single-particle data for model development


April 23, 2014 35 GHZ reflectivity
height (km)
0
1
2
3
5
6
7
0
4
8
12
16
20
24
time (hours)
−50
−36
−22
−8
6
20