Observation Error Characterization for Radiance Assimilation of Clouds and Precipitation

Ralf Bennartz
Oceanic & Atmospheric Sciences, University of Wisconsin - Madison

Tom Greenwald
CIMSS, University of Wisconsin

Andy Heidinger
NOAA/NESDIS/ORA

Mark Kulie
Oceanic & Atmospheric Sciences, University of Wisconsin

Goals

- Integrate Successive Order of Interaction (SOI) radiative transfer solver and its TL and AD models into the CRTM

- Provide quantitative estimates of observation error covariances attributed to uncertainties in microwave ice optical properties

SOI Integration Status

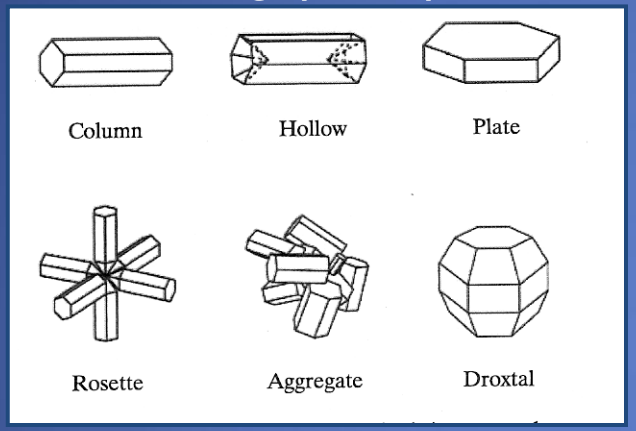
- For a more effective interface with the CRTM, the SOI solver and its TL and AD were rewritten from scratch to take advantage of CRTM routines
- SOI solver and its TL have been successfully integrated and tested in an experimental branch of the software repository; AD has been coded but not tested
- Plans are to test the AD model, merge the experimental branch into the trunk, and make the SOI solver available for CRTM V2.1

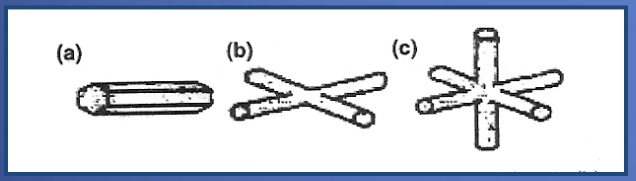
Uncertainties in Microwave Ice Optical Properties

- Active and passive observations are used via a physically consistent method to quantify errors
- Collocated CPR(94 GHz), MHS(89-190 GHz) and AMSR-E (6-89 GHz) dataset (Chen et al. 2008)
- Forward model framework:
  - IWC retrieved from observed CPR attenuation-corrected reflectivities
  - LWC: Cloud (CloudSat/AMSR-E); precipitation (L'Ecuyer & Stephens 2002) W-band Z-R relationship
  - Surface emissivity (FASTEM-2)
  - Atmospheric profiles: ECMWF analyses
  - Slant path version of SOI solver (8-stream)
- Particle types: DDA (nonspherical); soft spheres
- Errors/correlations classified according to cloud/precipitation conditions

Microwave Optical Properties Database

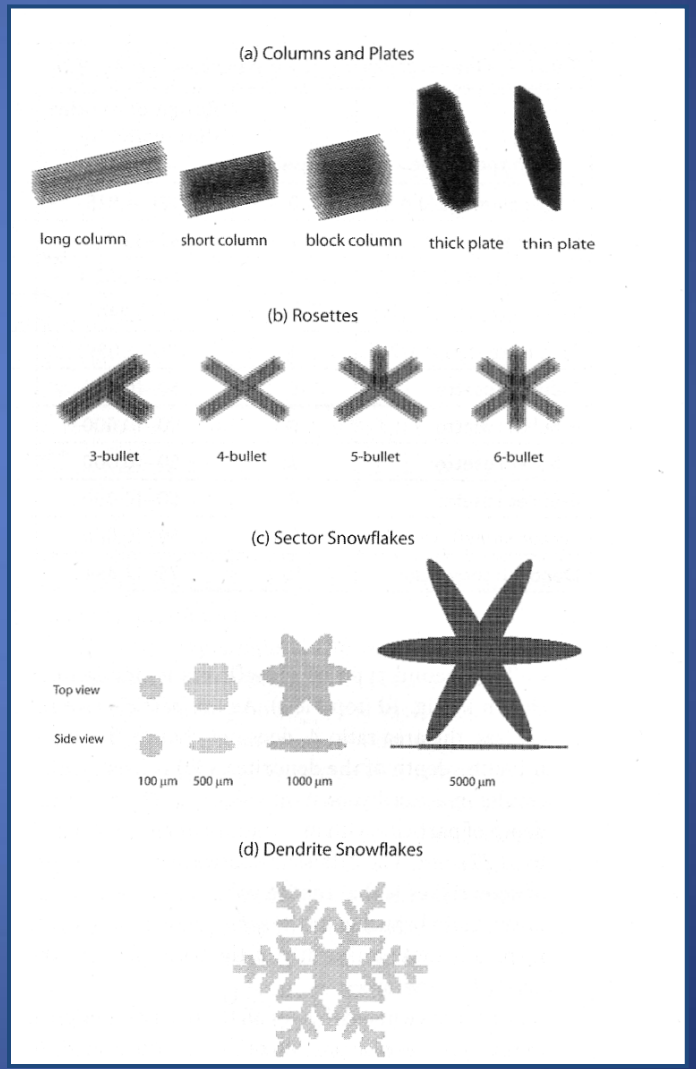
Hong (2007)

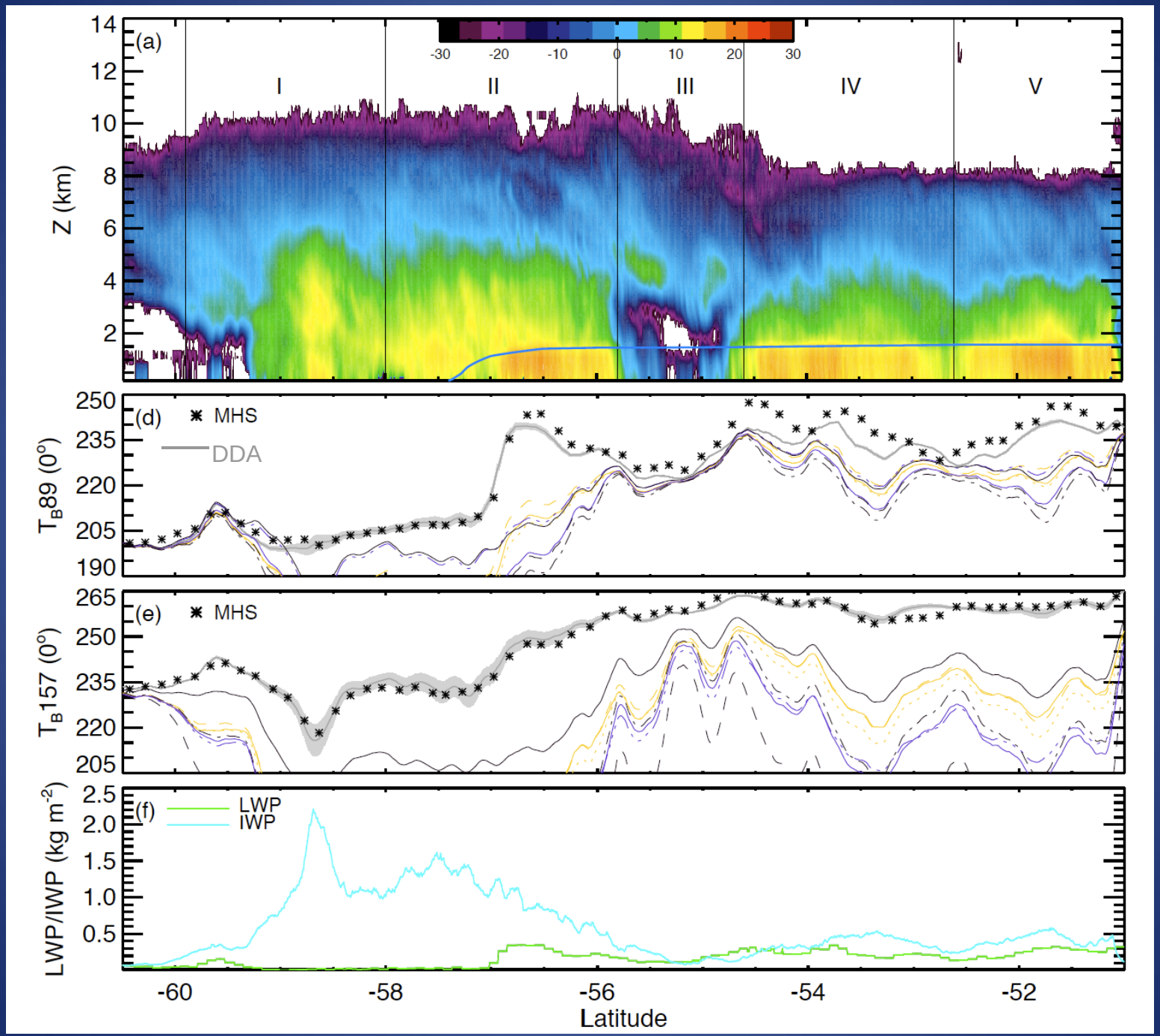




Kim et al. (2007)

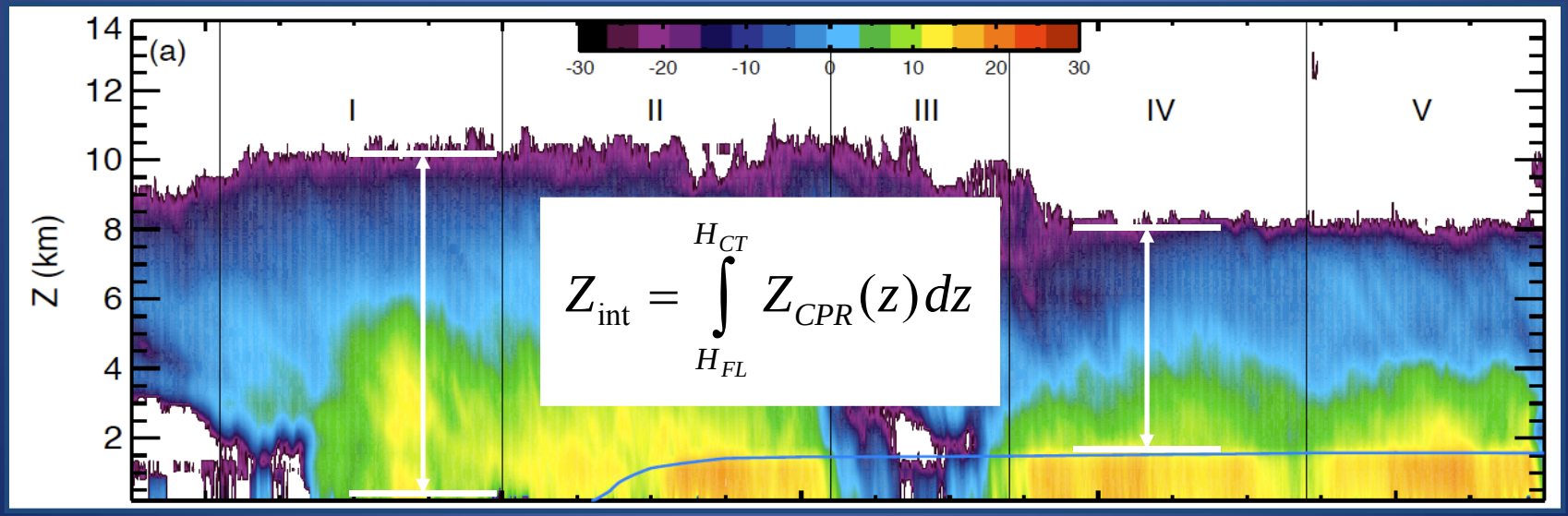
Liu (2004,2008)



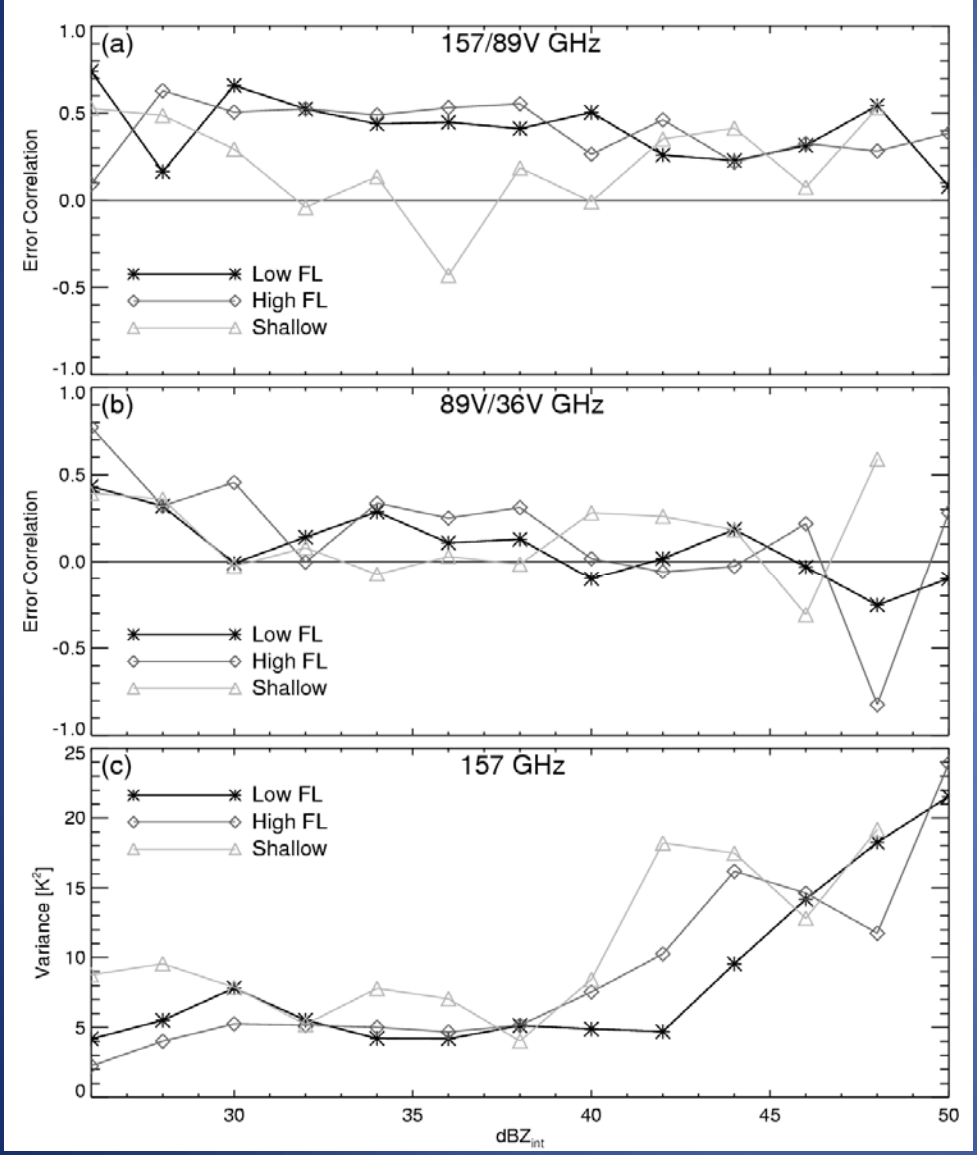

(a)
-30
-20
-10
0
10
20
30
I
II
III
IV
V
Z (km)
14
12
10
8
6
4
2
(d)
MHS
DDA
T_B89 (0°)
250
235
220
205
190
(e)
MHS
T_B157 (0°)
265
250
235
220
205
(f)
LWP
IWP
LWP/IWP (kg m^{-2})
2.5
2.0
1.5
1.0
0.5
-60
-58
-56
-54
-52
Latitude

Global Results - DDA Models Only

Cloud/Precip Category	Label	N_{obs}	Description
All clouds	AC	9043	All clouds, no precipitation.
Cold clouds	CC	2494	Cold clouds only (< 0 C), no precipitation.
Warm clouds	WC	2894	Warm clouds only (> 0 C), no precipitation.
All precipitation	AP	5153	All precipitation occurrences.
Stratiform (mid-lat)	SML	1911	Mid-latitude (lat. > $\|30^o\|$) stratiform precipitation.
Stratiform (low FL)	SLFL	916	Mid-latitude stratiform, freezing level < 1 km.
Stratiform (high FL)	SHFL	583	Mid-latitude stratiform, freezing level > 1 km.
Stratiform (brightband)	SBB	412	Mid-latitude stratiform with obvious brightband.
Low-topped convection	LTC	1148	Shallow, higher latitude (lat. > $\|45^o\|$) convection.



Error Correlations



157/89V Error Correlations

89V/36V Error Correlations

157 GHz Variance

Error Covariance Matrix

Low Freezing Level Stratiform*

	18V	23V	36V	89V	157
18V	**1.99**	0.85	0.74	0.06	0.25
23V	**1.70**	**1.99**	0.75	0.13	0.24
36V	**1.42**	**1.44**	**1.84**	0.13	0.11
89V	**0.18**	**0.43**	**0.40**	**5.21**	0.41
157	**0.80**	**0.75**	**0.33**	**2.13**	**5.13**

High Freezing Level Stratiform*

	18V	23V	36V	89V	157
18V	**4.51**	0.93	0.82	0.07	0.13
23V	**3.52**	**3.17**	0.81	0.05	0.09
36V	**5.86**	**4.87**	**11.39**	0.31	0.13
89V	**0.57**	**0.35**	**4.17**	**15.79**	0.55
157	**0.60**	**0.35**	**1.00**	**4.99**	**5.15**

*For the 40 dBZ_{int} data bin

Accomplishments

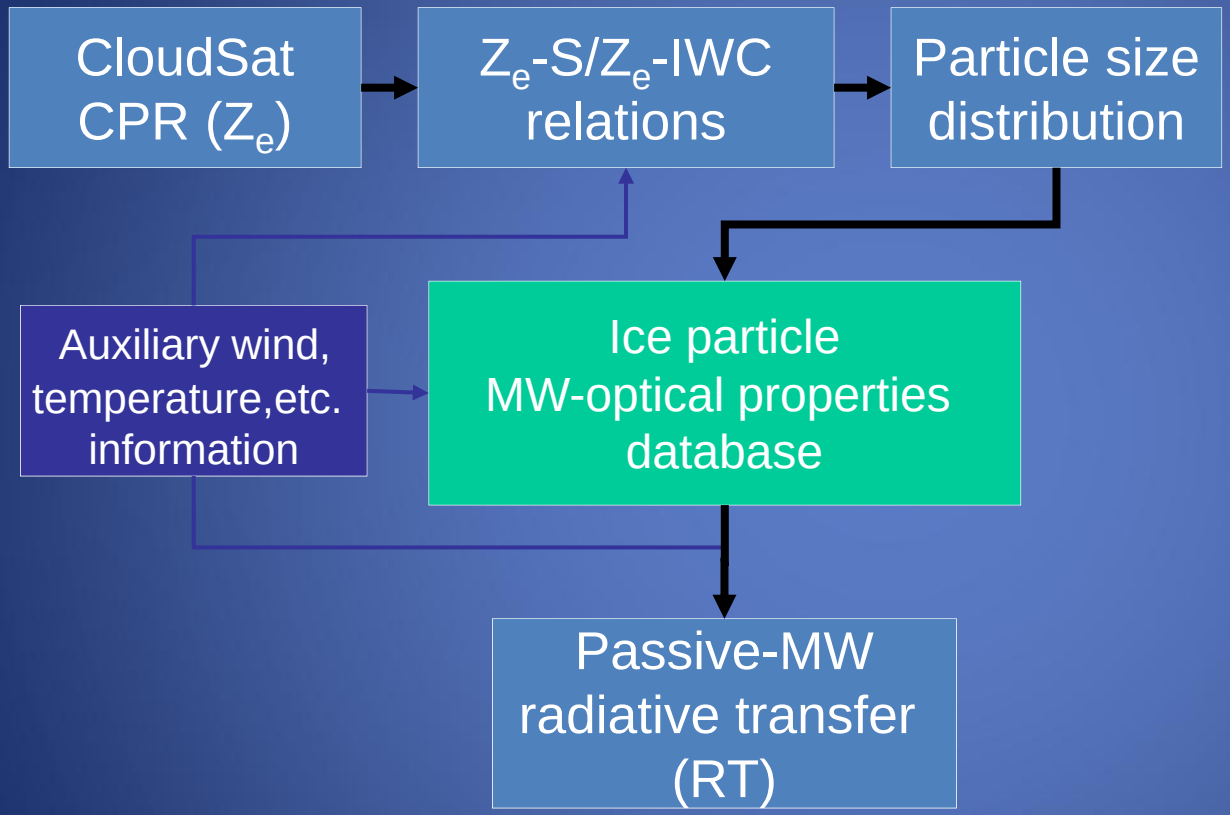
- SOI solver and its TL have been successfully tested and integrated into the CRTM

- Provide, for the first time, quantitative estimates of observation error covariances due to ice optical property uncertainties (a major source of error) for potential use in data assimilation
  - Errors found to be a function of IWP/Z_{int}, precipitation type, zenith angle

- Manuscript submitted to JAS: *Uncertainties in Microwave Optical Properties of Frozen Precipitation: Implications for Remote Sensing and Data Assimilation - Kulie, Bennartz, Greenwald, Chen and Weng.*

Extra Slides

Combined Active/Passive Modeling System



1. Closure with MHS AMSR-E passive microwave T_B
2. Assessment of ice scattering models
3. Radar IWC/IWP retrievals and uncertainties
4. Consistent proxy simulations of GMI and DPR

Evaluation of ice scattering models (MW)

- DDA (non-spherical)
  - ✓Liu (2004/2008)
  - ✓Kim (2006)/Kim et al. (2007)
  - ✓Hong (2007)
- Spheres
  - ✓JCSDA (snow, hail, graupel)
  - ✓Surussavadee and Staelin (2006)

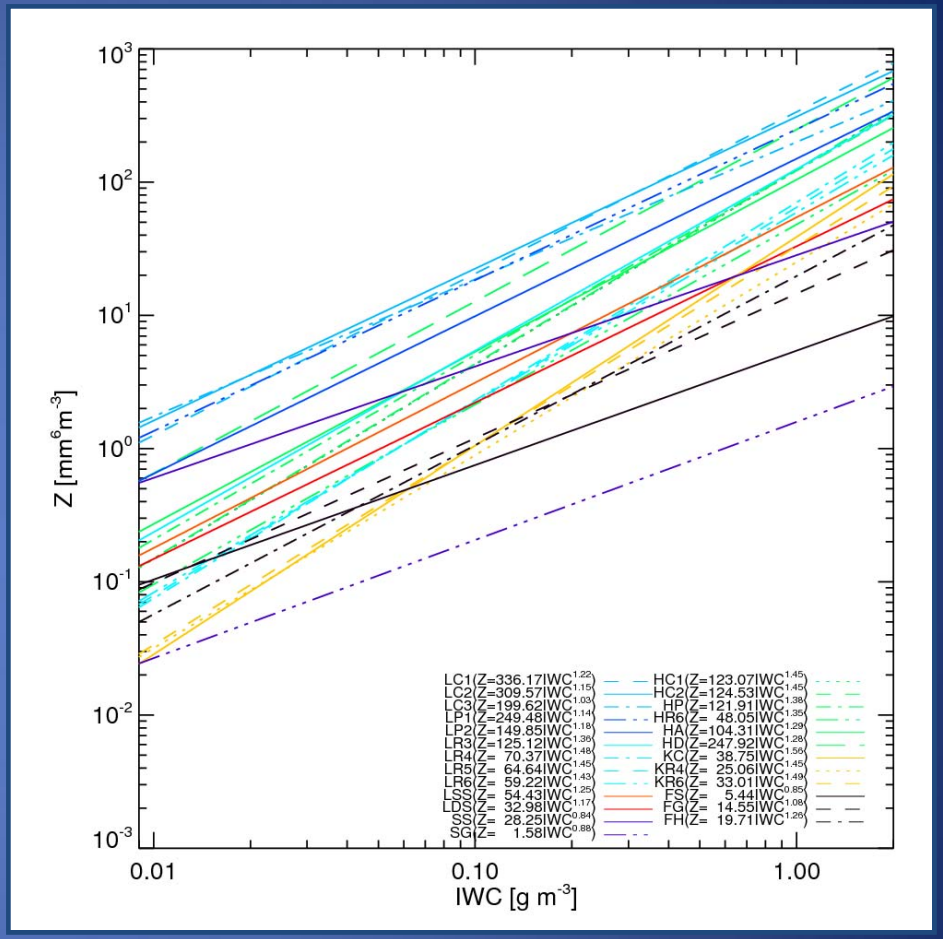
Database	Habit	Abbreviation	D_{max} (μm)	R_e (μm)
Hong (2007)	Hexagonal Column	HC1	100-5500	42-610
Hong (2007)	Hollow Hex Column	HC2	100-5500	40-574
Hong (2007)	Hexagonal Plate	HP	100-5500	29-793
Hong (2007)	6-Bullet Rosette	HR6	100-5500	27-625
Hong (2007)	Aggregate	HA	100-5500	26-1416
Hong (2007)	Droxtal	HD	100-5500	45-2469
Liu (2008)	Long Hex Column	LC1	242-3626	55-771
Liu (2008)	Short Hex Column	LC2	166-2477	56-772
Liu (2008)	Block Hex Column	LC3	132-1974	55-766
Liu (2008)	Thick Hexagonal Plate	LP1	163-2434	57-767
Liu (2008)	Thin Hexagonal Plate	LP2	253-3794	53-769
Liu (2008)	3-Bullet Rosette	LR3	100-5000	30-666
Liu (2008)	4-Bullet Rosette	LR4	100-5000	37-591
Liu (2008)	5-Bullet Rosette	LR5	100-5000	40-635
Liu (2008)	6-Bullet Rosette	LR6	100-5000	42-674
Liu (2008)	Sector Snowflake	LSS	50-10000	61-502
Liu (2008)	Dendrite Snowflake	LDS	75-12453	40-506
Kim et al. (2007)	Hexagonal Column	KC	60-3000	23-590
Kim et al. (2007)	4-Bullet Rosette	KR4	60-3000	29-766
Kim et al. (2007)	6-Bullet Rosette	KR6	60-3000	33-875
SS06	Snow (soft sphere)	SS	100-15000	30-2968
SS06	Graupel (soft sphere)	SG	100-15000	23-2251
Snow	Snow (soft sphere)	FS	100-15000	24-2389
Graupel	Graupel (soft sphere)	FG	100-15000	38-3791
Hail	Hail (soft sphere)	FH	100-15000	50-4969

Z_e-IWC Relationships

IWC

PSD

$$Z_{e,\lambda} = \frac{\lambda^4}{\pi^5 |K|^2_\lambda} \int_D^D \sigma(D)_{b,\lambda} N(D) dD$$

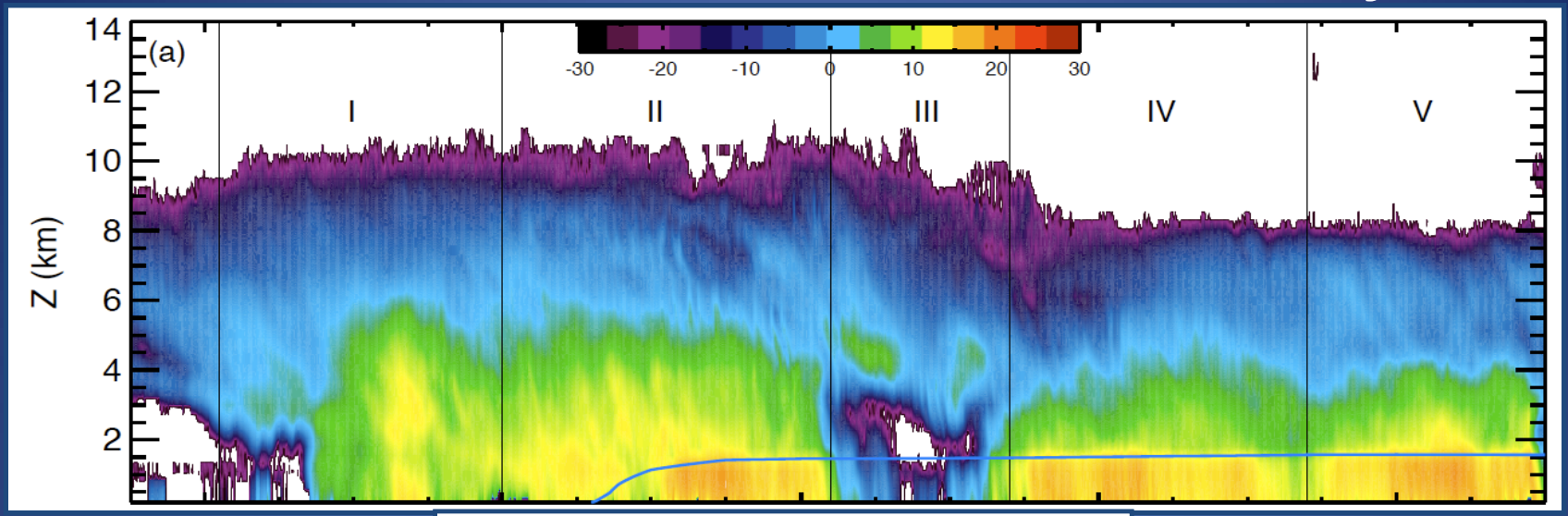


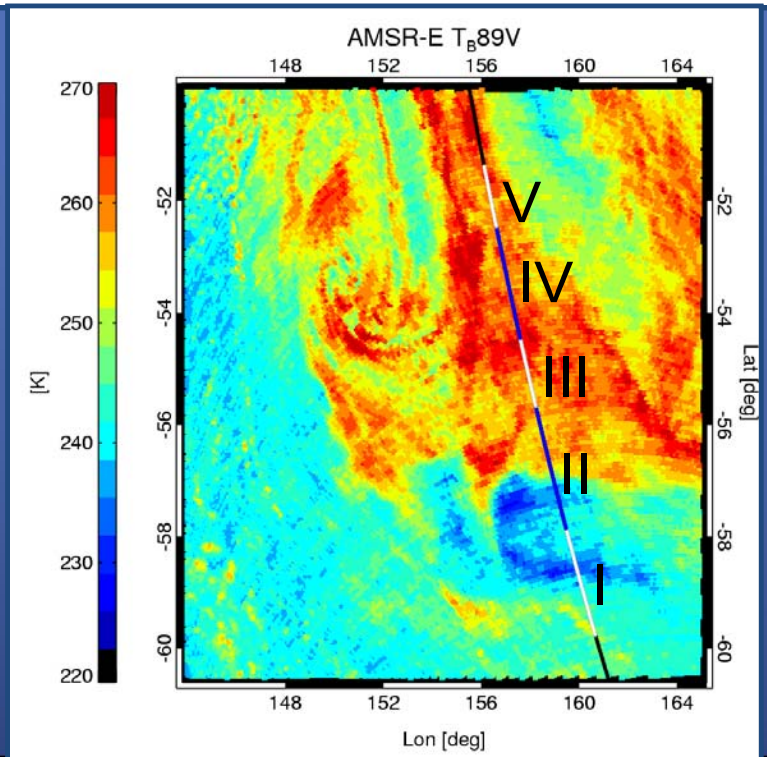
Temp = -7.5°C

Combined Active/Passive Modeling

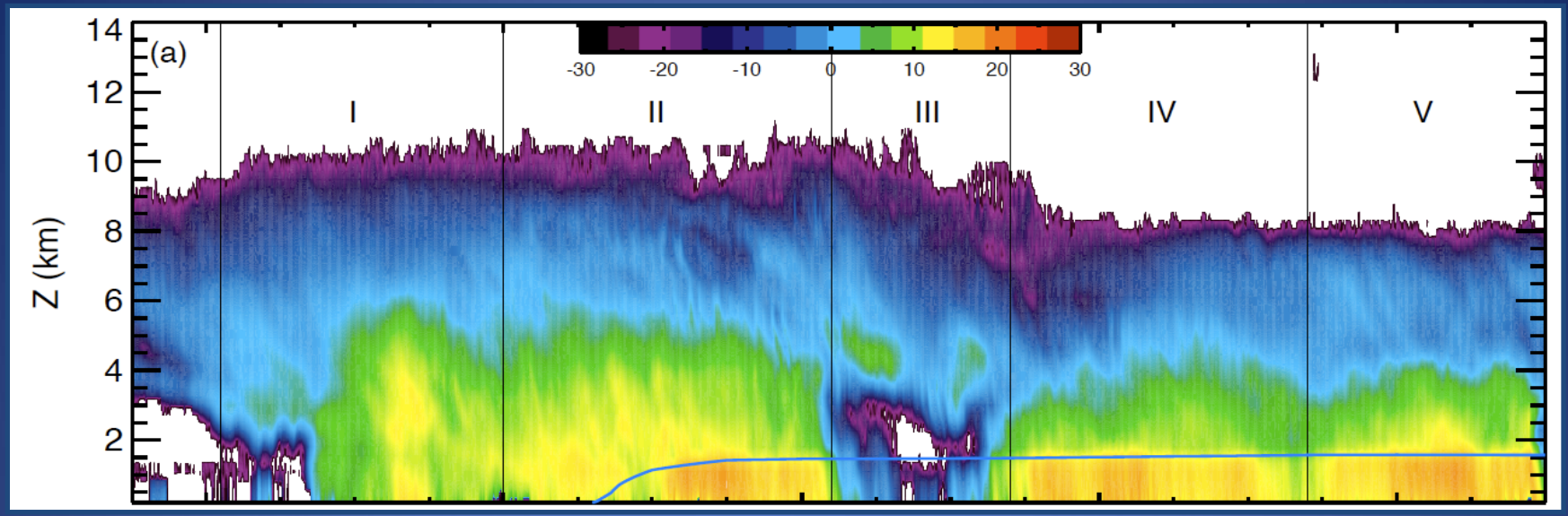
- Cloud liquid water
  - ✓ CloudSat products + AMSR-E LWP
  - ✓ Liebe (1991) parameterization
- Water vapor & temperature
  - ✓ Co-located ECMWF model output
  - ✓ Rosenkranz (1998) parameterization
- Liquid precipitation
  - ✓ L'Ecuyer and Stephens (2002) W-band Z-R relation
- Ocean emissivity
  - ✓ FASTEM-2 surface emissivity model (DeBlonde and English 2001)
- RT Solver
  - ✓ Successive Order of Interaction (SOI)
  - ✓ Heidinger et al. (2006), O'Dell et al. (2006)

Ice Model Assessment Case Study





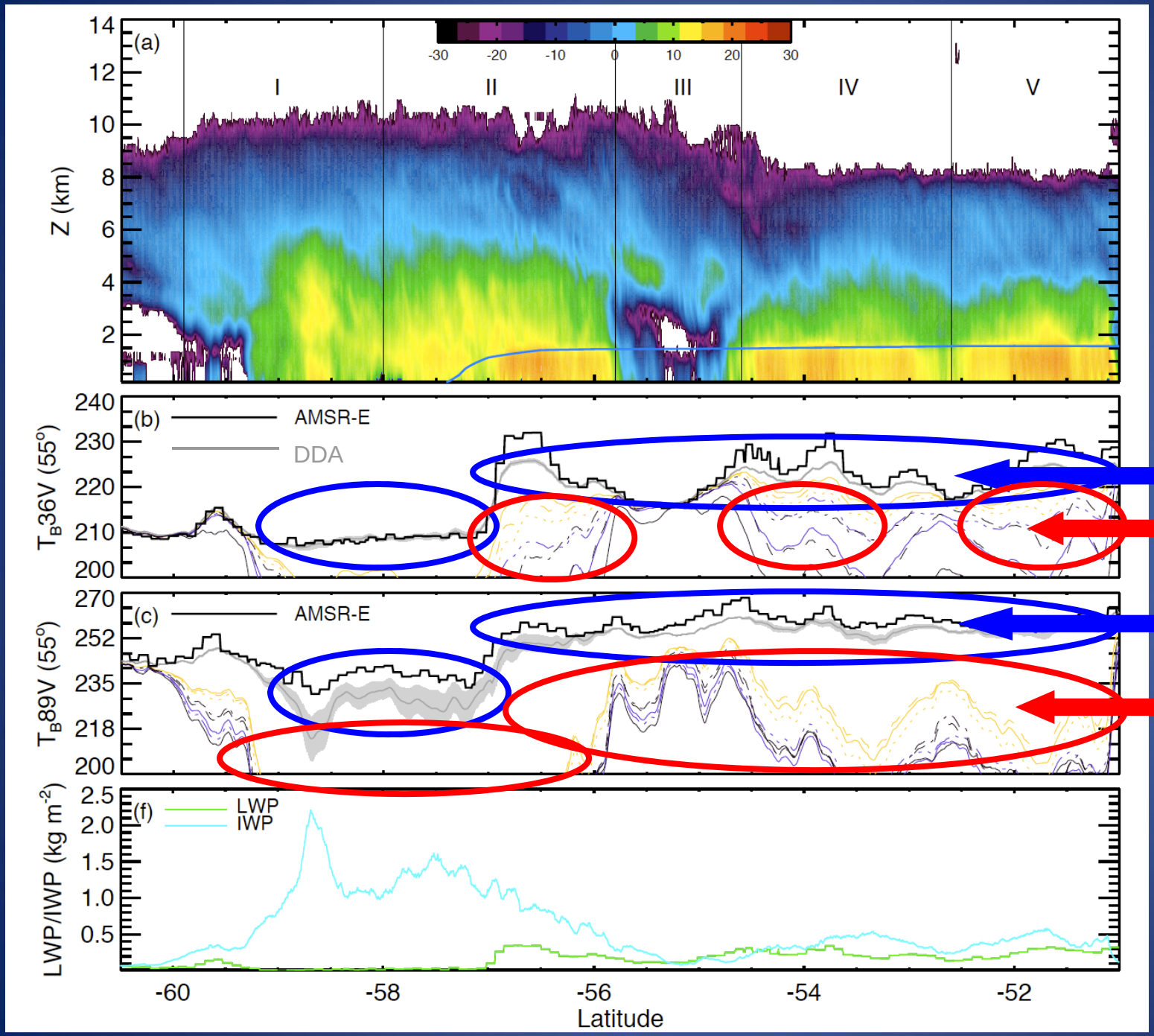
Individual Ice Model Biases



LSS (0.25 K) LC2 (0.40 K) HR6 (-0.48 K) LP2 (0.08 K) HR6 (0.31 K)

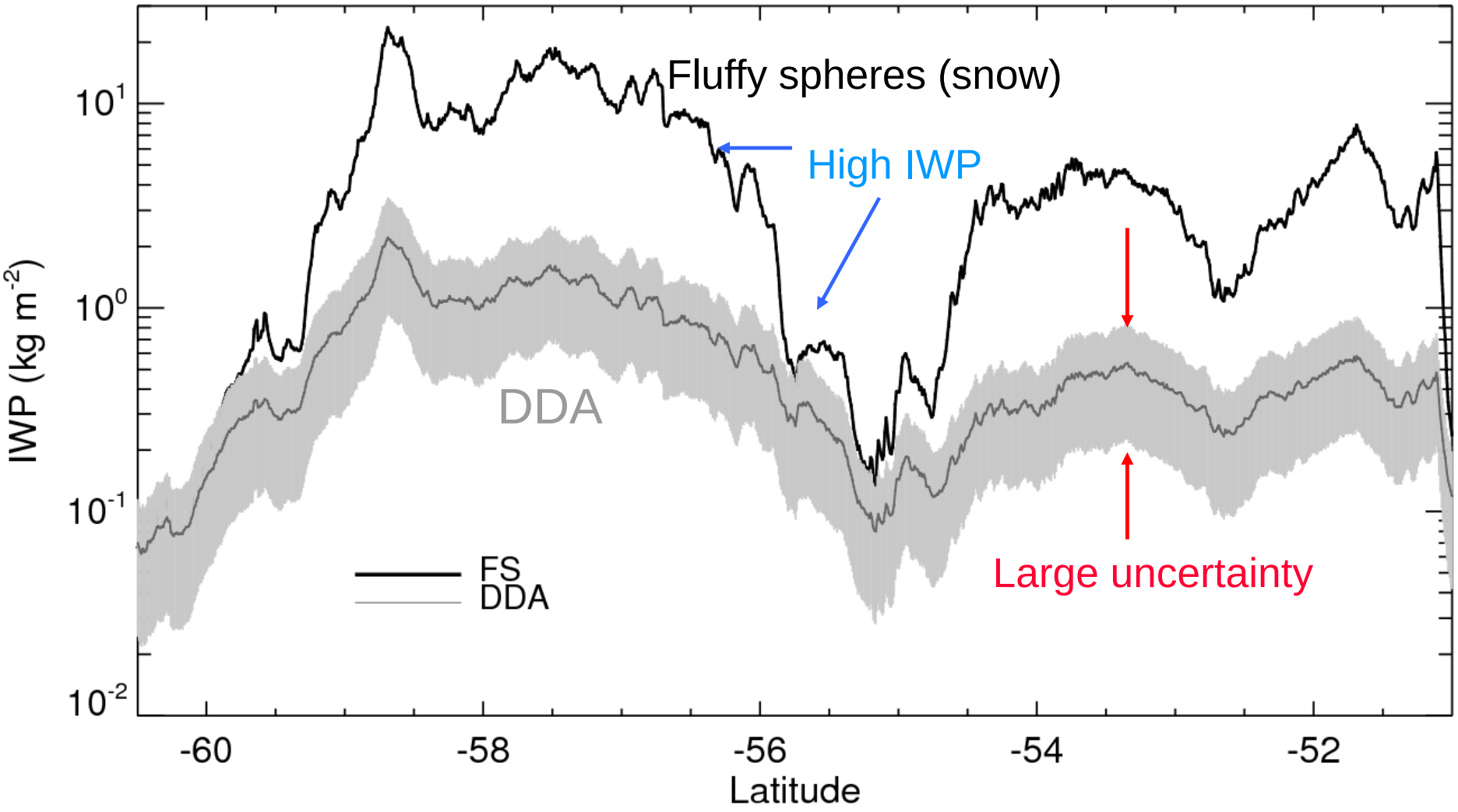
Entire Domain: LC1 (-0.09 K)

- Variability across the frontal system
- Column, plate, rosette ice habits compare well in precipitation
- Ice water path: Better metric to study uncertainties, biases, etc.?



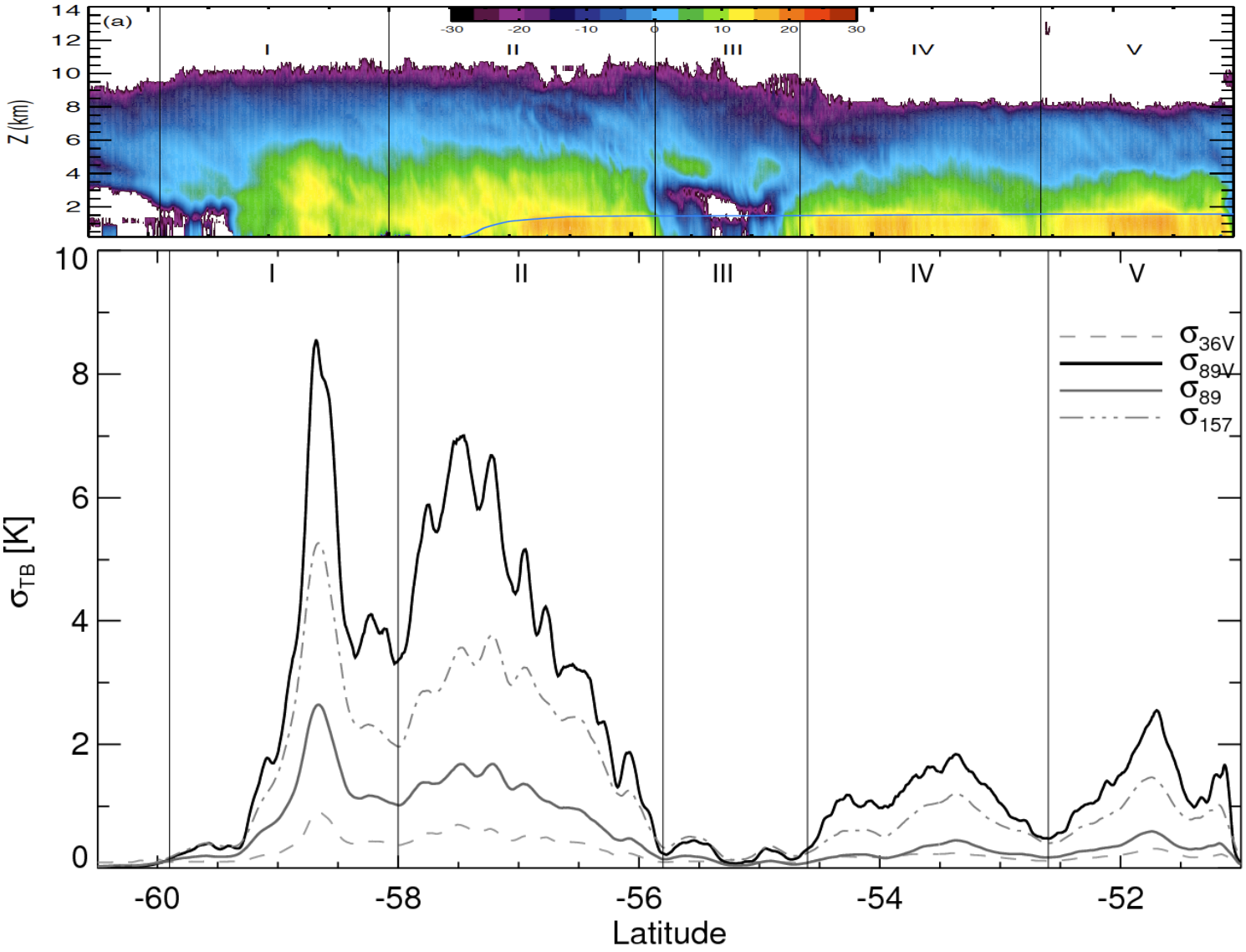
DDA produces

Unrealistic results - spheres



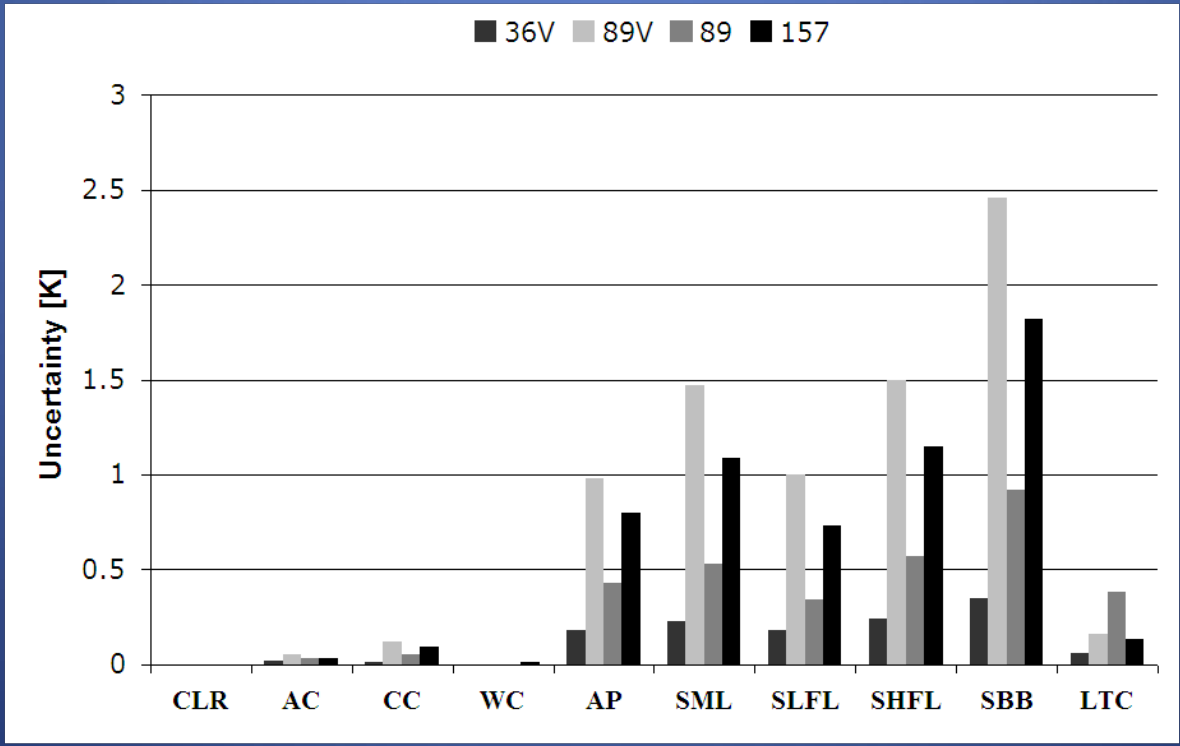
IWP (Z_e-IWC relationships)

Simulated T_B Uncertainty

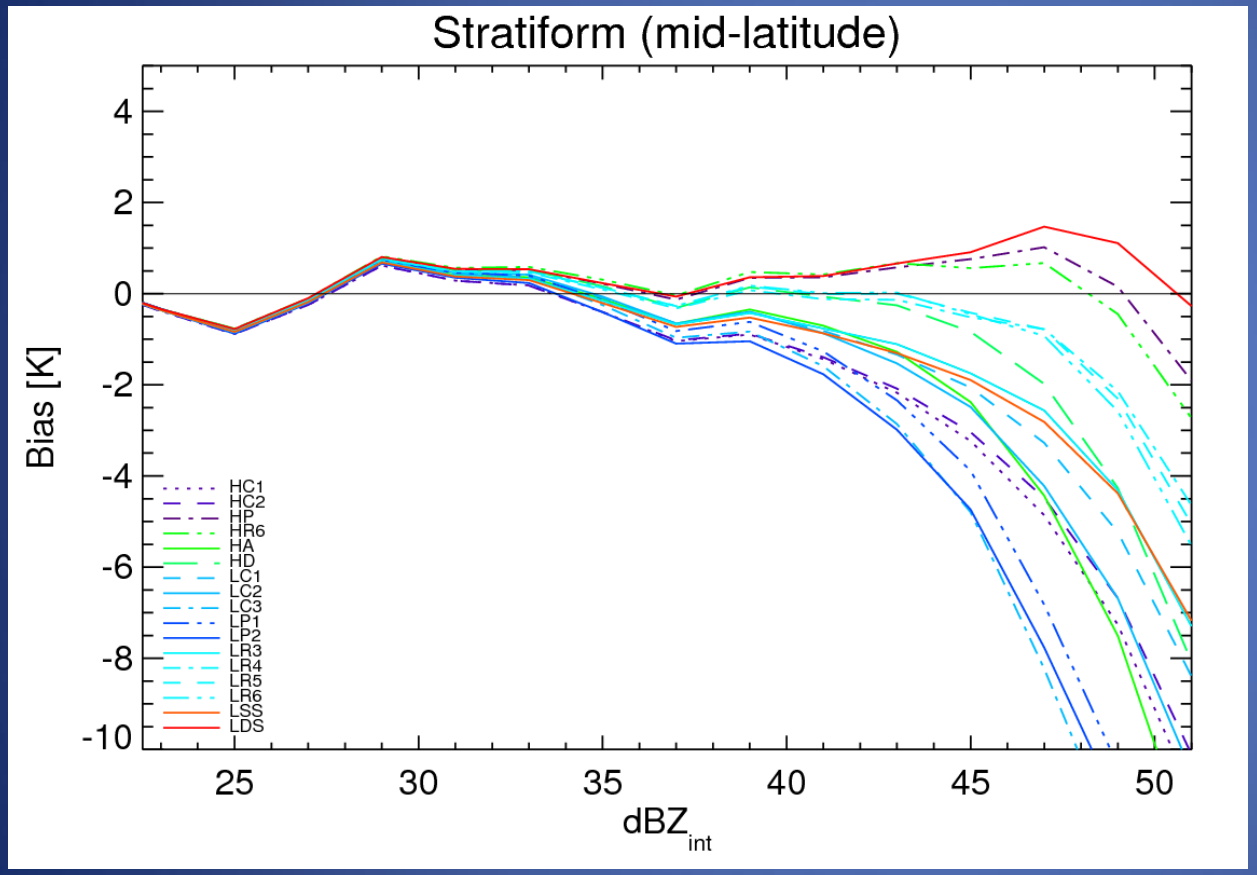


Global Results - DDA Models Only

Cloud/Precip Category	Label	N_{obs}	Description
All clouds	AC	9043	All clouds, no precipitation.
Cold clouds	CC	2494	Cold clouds only (< 0 C), no precipitation.
Warm clouds	WC	2894	Warm clouds only (> 0 C), no precipitation.
All precipitation	AP	5153	All precipitation occurrences.
Stratiform (mid-lat)	SML	1911	Mid-latitude (lat. > |30°|) stratiform precipitation.
Stratiform (low FL)	SLFL	916	Mid-latitude stratiform, freezing level < 1 km.
Stratiform (high FL)	SHFL	583	Mid-latitude stratiform, freezing level > 1 km.
Stratiform (brightband)	SBB	412	Mid-latitude stratiform with obvious brightband.
Low-topped convection	LTC	1148	Shallow, higher latitude (lat. > |45°|) convection.



Ice Model Assessment: Stratiform



- Z_{int} dependence
- Distinct 157 GHz biases at high Z_{int}
- Unrealistic for elevated IWP?