Rasmussen & Libbrecht / CalTech

BBHRP for Cloudy Situations

Mark Miller, Eli Mlawer,

Mike Jensen, Karen Johnson

ARM Atmospheric Radiation Measurement

BROOKHAVEN NATIONAL LABORATORY

Outline

1. Requirements
   - Local scale
   - GCM scales
2. Approach
3. Results
4. Perspective

The Cloud Field

- instantaneous broadband flux
  - Vertical distributions of:
    - fractional cloudiness
    - particle phase
    - particle size spectrum
    - Aerosol
- GCM-scale flux

Baseline Estimate Continuous Cloud Microphysics (MICRO_BASE)

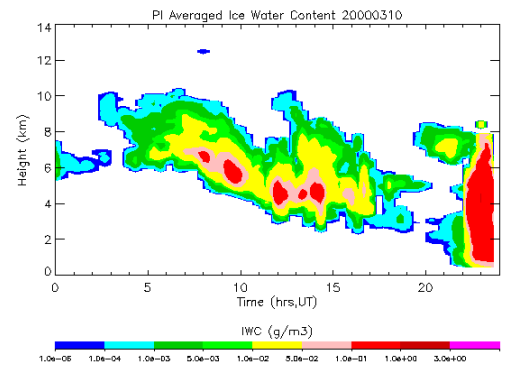
- *Continuous* microphysical structure from surface remote sensing
- Operational extensions of retrievals available in the literature
- Residual
  - *flux measurement minus calculations*

Water Content (g m^3)

14

Height (km)

0

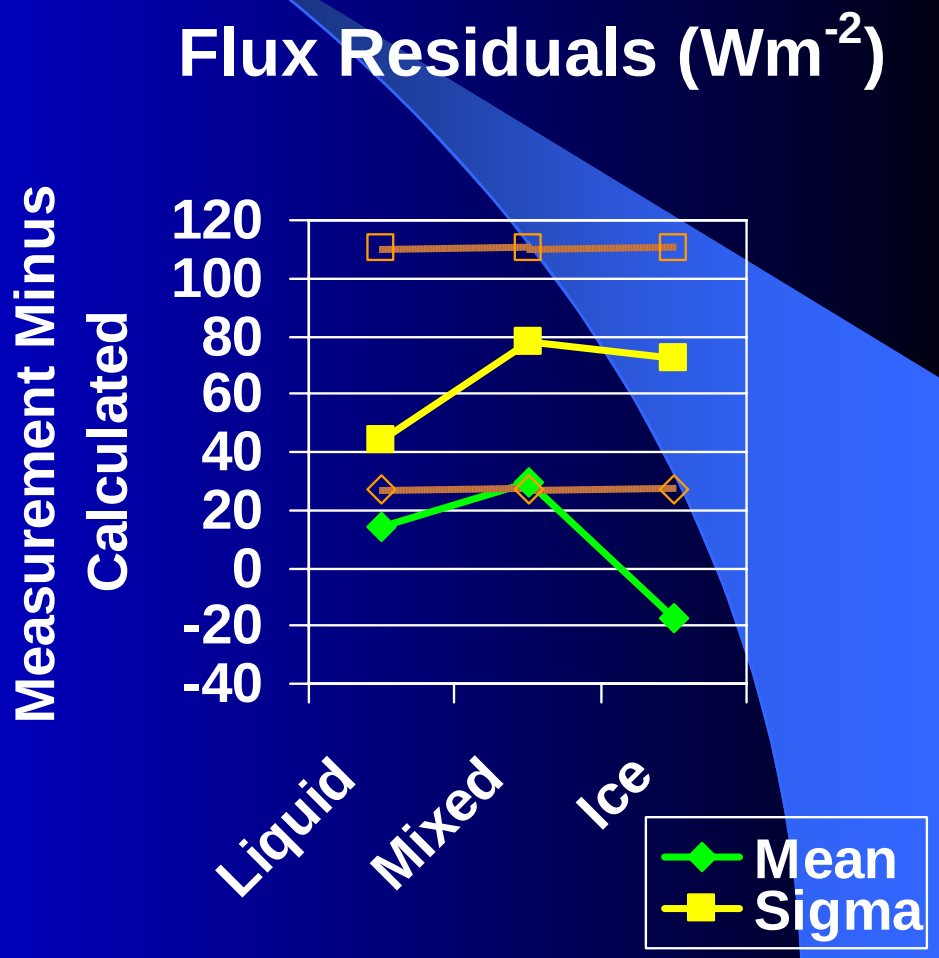


24 Hours

Liquid	**0.005**	**1.0**	**8-16**
Ice	**1e-6**	**0.01**	**0.1-3**

Proximity to Closure in Overcast Conditions at SGP

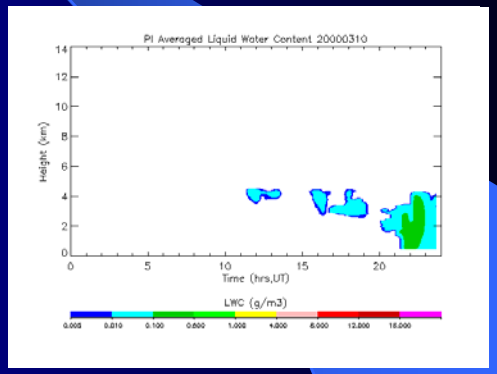
- Closure: Mean=Sigma=0
- Liquid clouds too optically thick and ice clouds too optically thin
- Variability in residuals is doubled in mixed and ice clouds



Deficiencies

- Liquid and liquid portion of mixed phase in overcast conditions
  - ***Ground-based remote sensing of information about cloud droplet size distribution is highly conditional***
    - ***single cloud layer in daytime***
    - ***low LWP***
  - ***Phase differentiation***
    - ***Temperature-based***

MIC_BASE_PI_LWC



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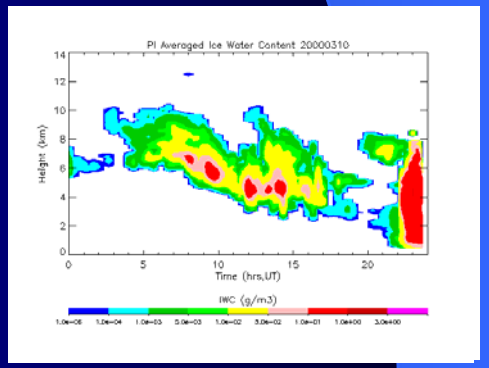
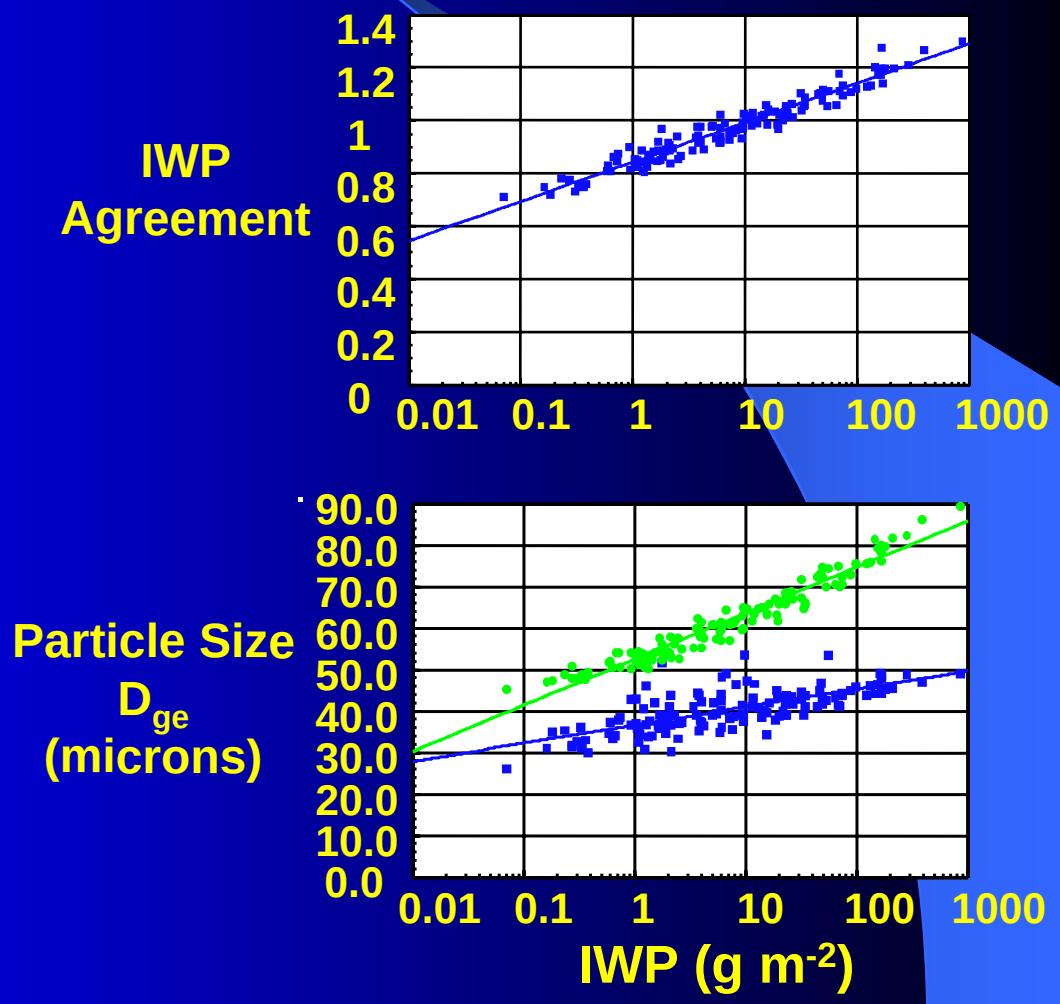


Deficiencies

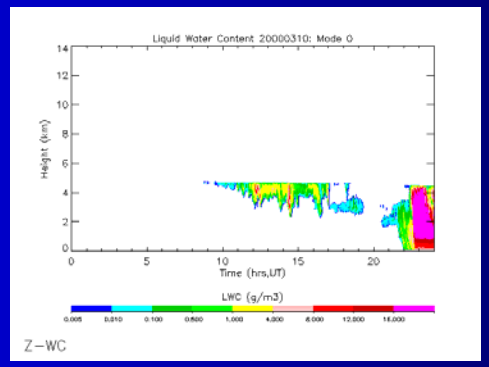
- **Ice phase in overcast conditions**
  - Uncertainties in IWP and ice particle size
  - Particle size differences related to existence of small ice crystals
    - FSSP shattering?



Deficiencies

- Complex cloud fields
  - Local variations in the vertical distribution of clouds
  - GCM-scale cloud properties
    - Challenge!

GCM-scale Cloud Properties?



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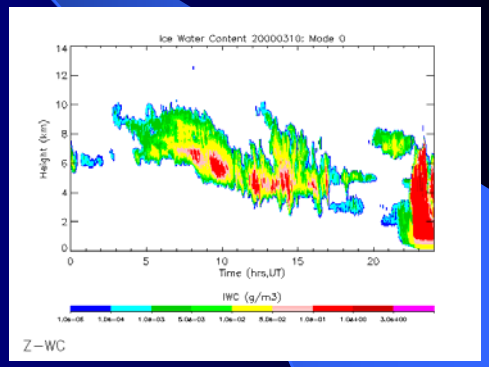

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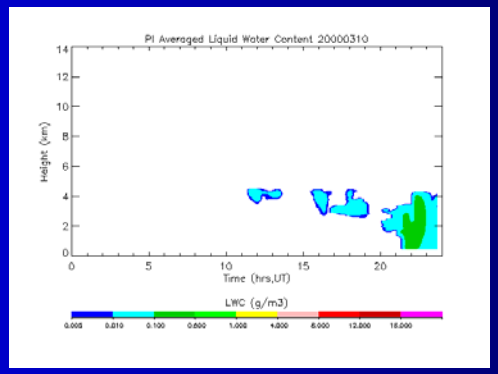
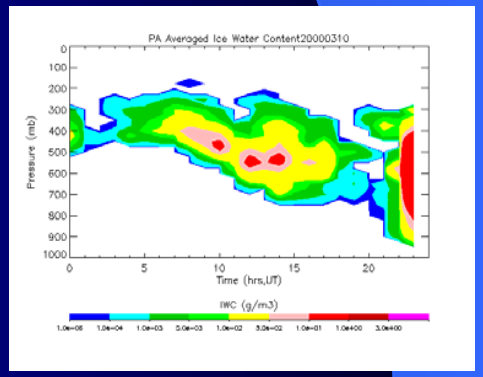


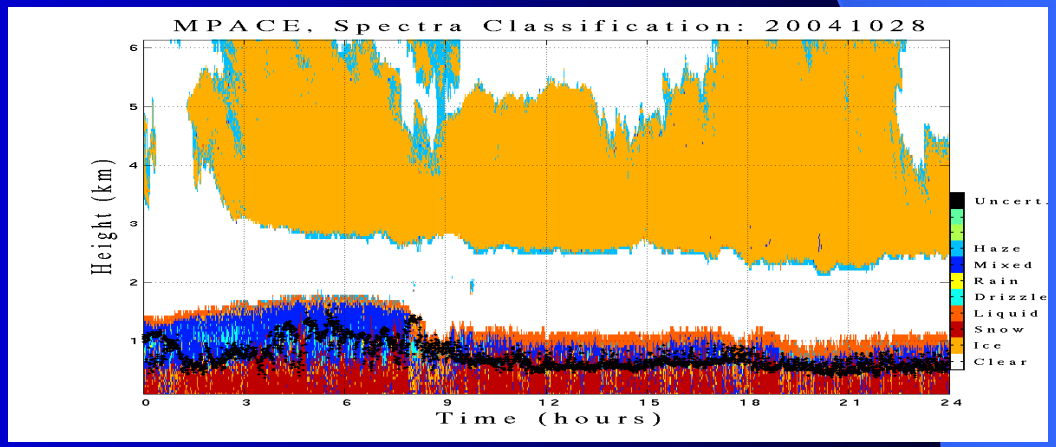


Potential Improvements

- Continuous closure testing-instrument problems
- Doppler spectra phase discrimination
- Routine aircraft sampling of cloud microphysics over ARM sites
- Targeted field deployments
- Scanning cloud radars

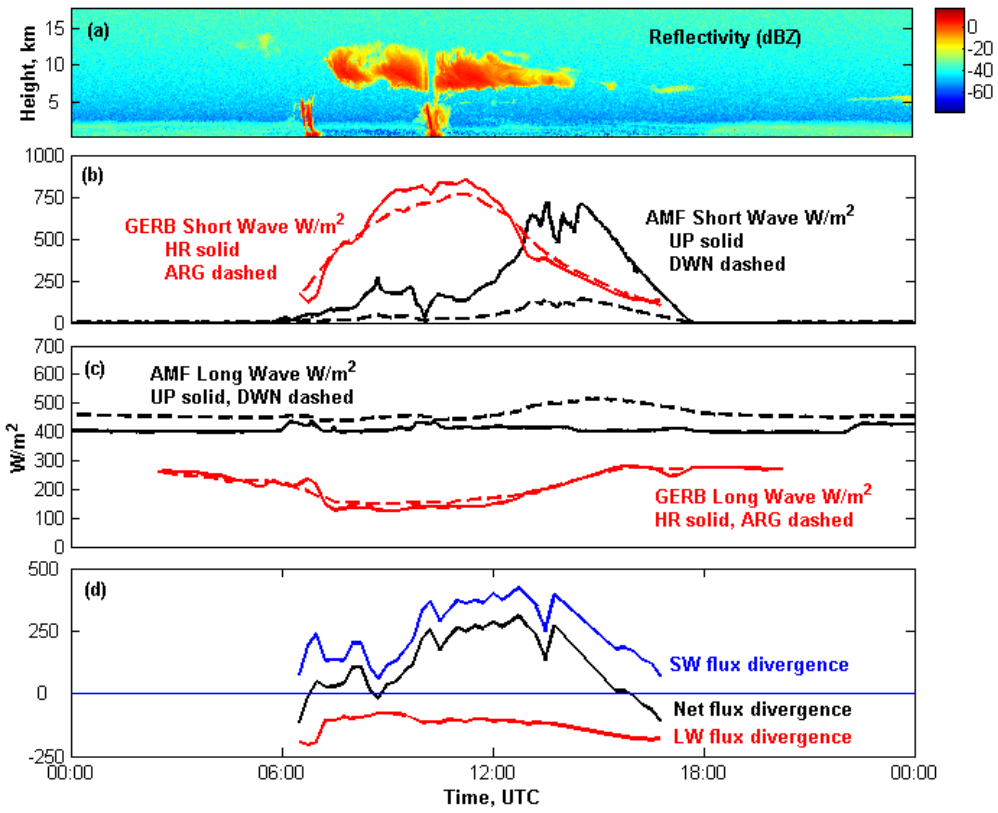
Cloud Phase Classification 256 FFT length Doppler spectra

Kollias and Luke, 2006



Potential Improvements

AMF Niamey, Niger, Africa



Contrast of Particle Size Distribution Techniques

- Microbase

  Ice Effective Radius:

  Ivanova et al.(2001): $D_e = (75.3 + 0.5895T)/2$

  Ice Crystal Size Distribution:

  Bimodal log-normal with large and small crystal populations

- Matrosov et al.

  - **Ice Effective Radius:**

  Matrosov et al. (2001): $D_0 = 420Z_e^{0.19}$
  and $D_e \sim 18D_0^{0.3}$ ($D_0 > 75\ \mu m$)

  - **Ice Crystal Size Distribution**

  Exponential (Mace et al., 2002)

Overcast Liquid-Only Cases (7) Shortwave Diffuse Flux Residual

Trial [Meas-RRTM]	Mean [Wm^{-2}]	Standard Deviation
1.0 Trial C: ***assumed N_d*** ***No MWR Scaling (9 cases)***	4.9	42.2
1.2.1 Trial A: ***assumed N_d*** ***MWR Scaling***	17.1	16.6
1.2.1 Trial D: ***retrieved N_d*** ***Frisch et al. 1995 (9 cases)***	7.5	87.9
1.2.1 Trial E ***Dong and Mace, 2003***	27.2	28.5

Overcast Mixed-Phase Cases (50) Shortwave Diffuse Flux Residual

Trial Meas-RRTM	Mean [Wm^{-2}]	Standard Deviation
1.0 Trial C: ***assumed N_d*** ***No MWR Scaling (58)***	34.1	80.4
1.2 Trial A: ***assumed N_d*** ***MWR Scaling***	18.8	68.4
1.2 Trial D: ***retrieved N_d*** ***Frisch et al. 1995 (58)***	29.8	80.4
1.2 Trial E ***Dong and Mace, 2003***	35.5	84.0

Overcast Ice-Phase Cases (35) Shortwave Diffuse Flux Residual

Trial Meas-RRTM	Mean [Wm^{-2}]	Standard Deviation
1.2 Trial A ***Microbase***	-16.2	73.0
1.2 Trial E ***Mace and Dong, 2003***	-18.0	71.0

Ice Retrievals and Parameterizations

- Cloudbase
  - **Ice Water Path**: Liu, C, and A.J. Illingsworth, 2000: Toward more accurate retrievals of ice water content from radar measurements of clouds, JAM, 39, 1130-1145.
  - **Ice Crystal Size Distribution:** Ivanova et al., 2001: A GCM parameterization for bimodal size spectra and ice mass removal rates in mid-latitude cirrus clouds, AR, 59-60, 89-113
  - **Scattering Properties of Ice Crystals**: Fu, Q., and K.N. Liou, 1993: Parameterization of the radiative properties of cirrus clouds, JAS, 50, 2008–2025.

Ice Retrievals and Parameterizations

- **Matrosov, Shupe, Heymsfield, and Zuidema**
  - **Ice Water Path:** Matrosov, S.Y., M.D. Shupe, A.J. Heymsfield, and P. Zuidema, 2003: Ice crystal optical thickness and extinction estimates from radar measurements, JAM, 42, 1584-1597.
  - **Ice Crystal Size Distribution:** Matrosov, S.Y., A.V. Korolev, and A.J. Heymsfield, 2002: Profiling cloud mass and particle characteristic size from Doppler radar measurements, JTECH, 19, 1018-1028.
  - Mace, G.G., A.J. Heymsfield, and M. Poellot, 2002: On retrieving the microphysical properties of cirrus clouds using the moments of the millimeter-wavelength Doppler spectrum, JGR, 107, 4815.
  - **Scattering Properties of Ice Crystals**: Fu, Q., and K.N. Liou, 2000: Parameterization of the radiative properties of cirrus clouds, JATMOS, 2008-2025.

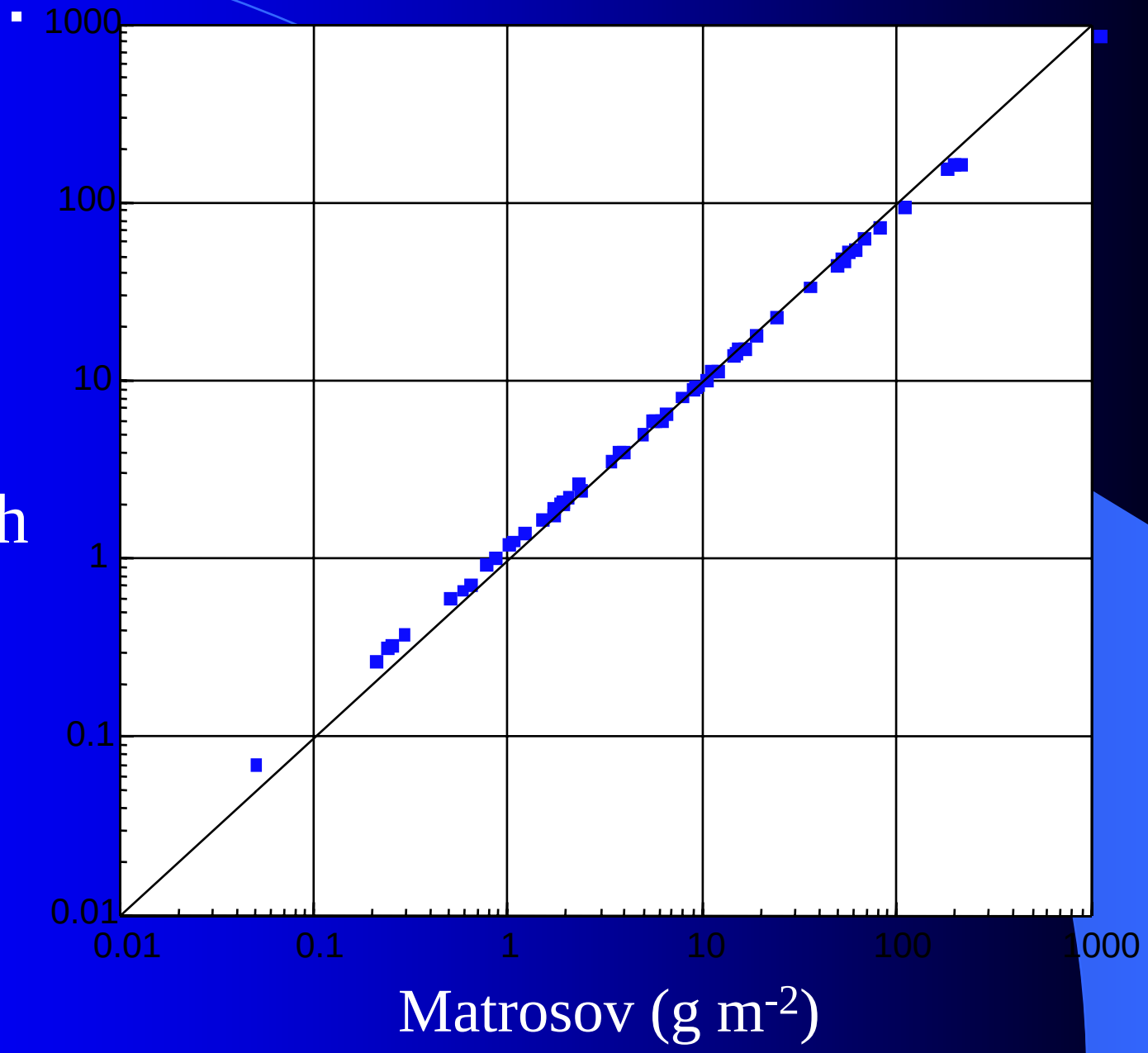
A look at how the retrieved parameters compare for the two approaches

IWP = Ice Water Path

D_{ge}= Generalized Effective Particle Size

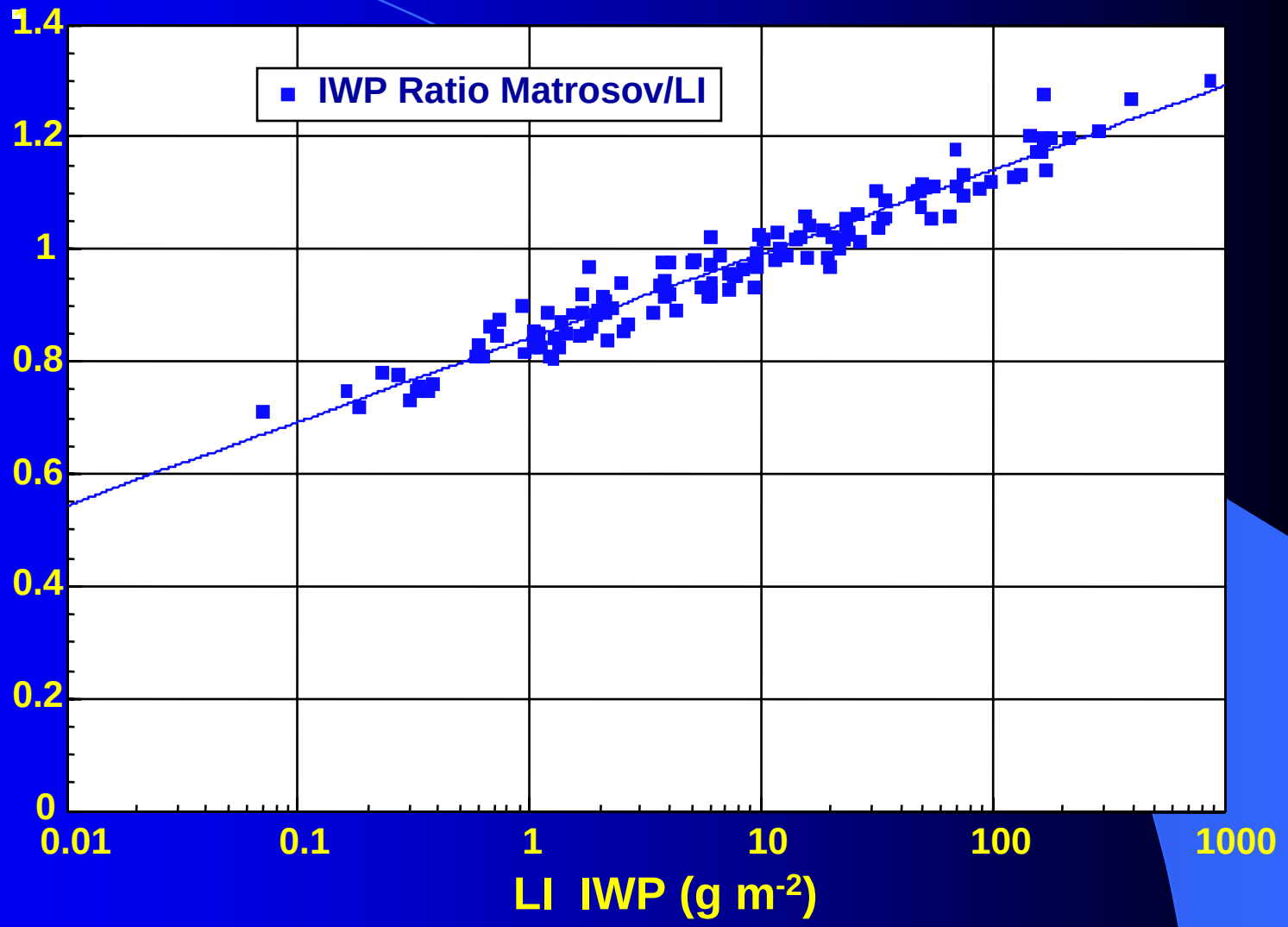
IWP Comparison

Liu and Illingsworth



LI=Liu and Illingsworth

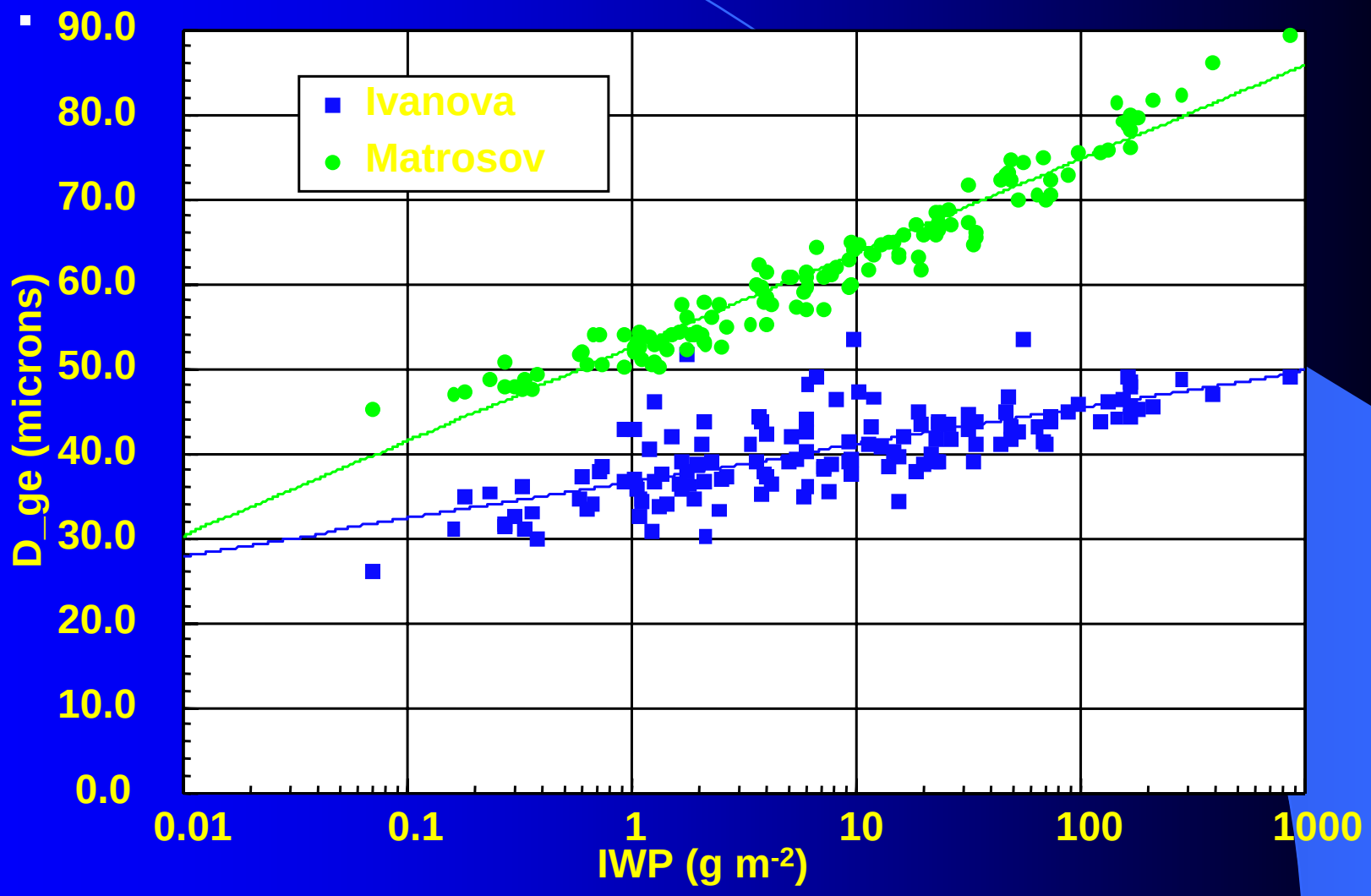
Ratio = 1 for IWP ~ 10 g/m^2



Equation of line:

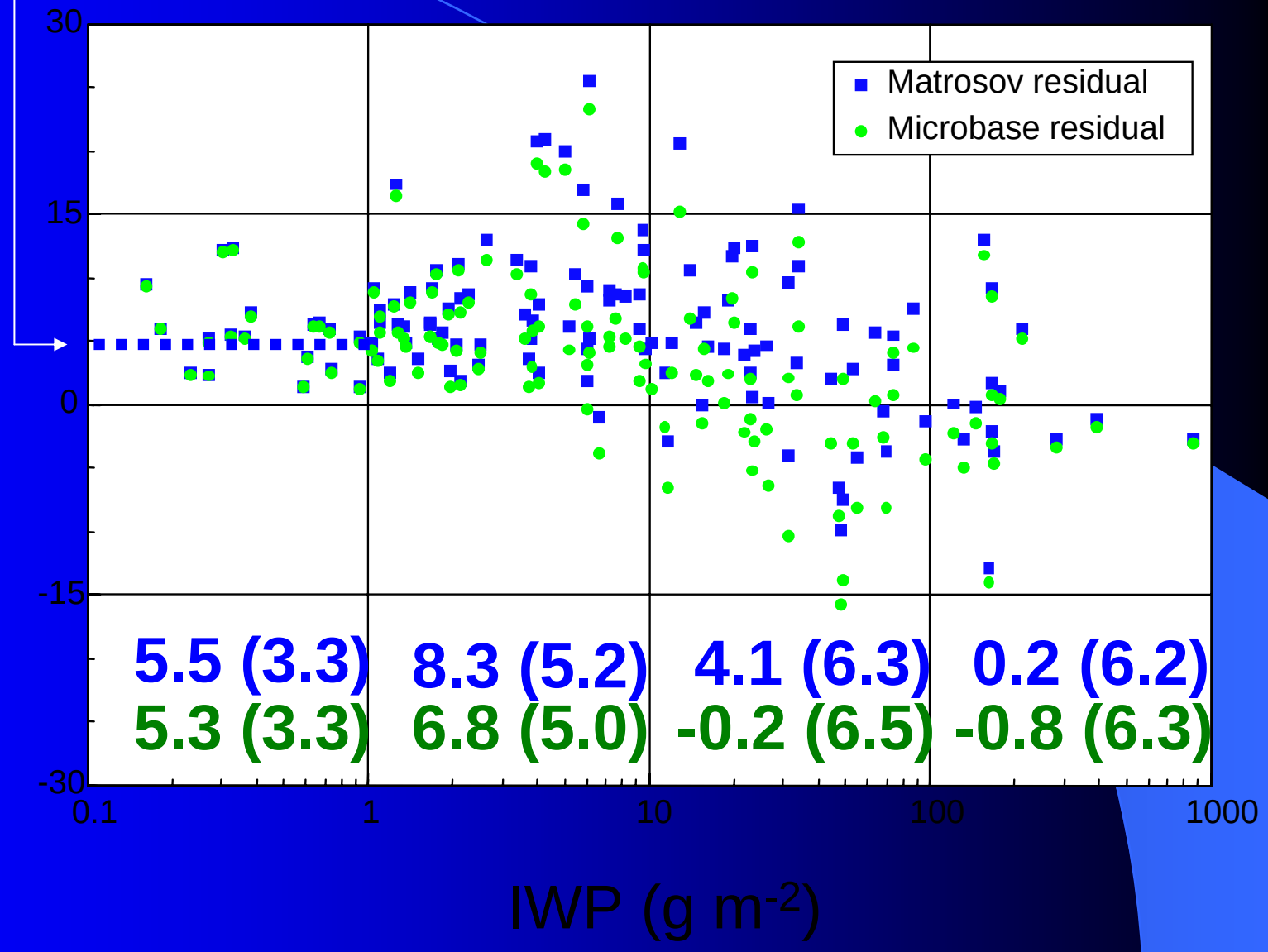
Matrosov /LI = 6.48e-2 * ln [LI (g/m^2)] + 0.843

Behavior of D_{ge} with IWP



LW results for all overcast ice cases

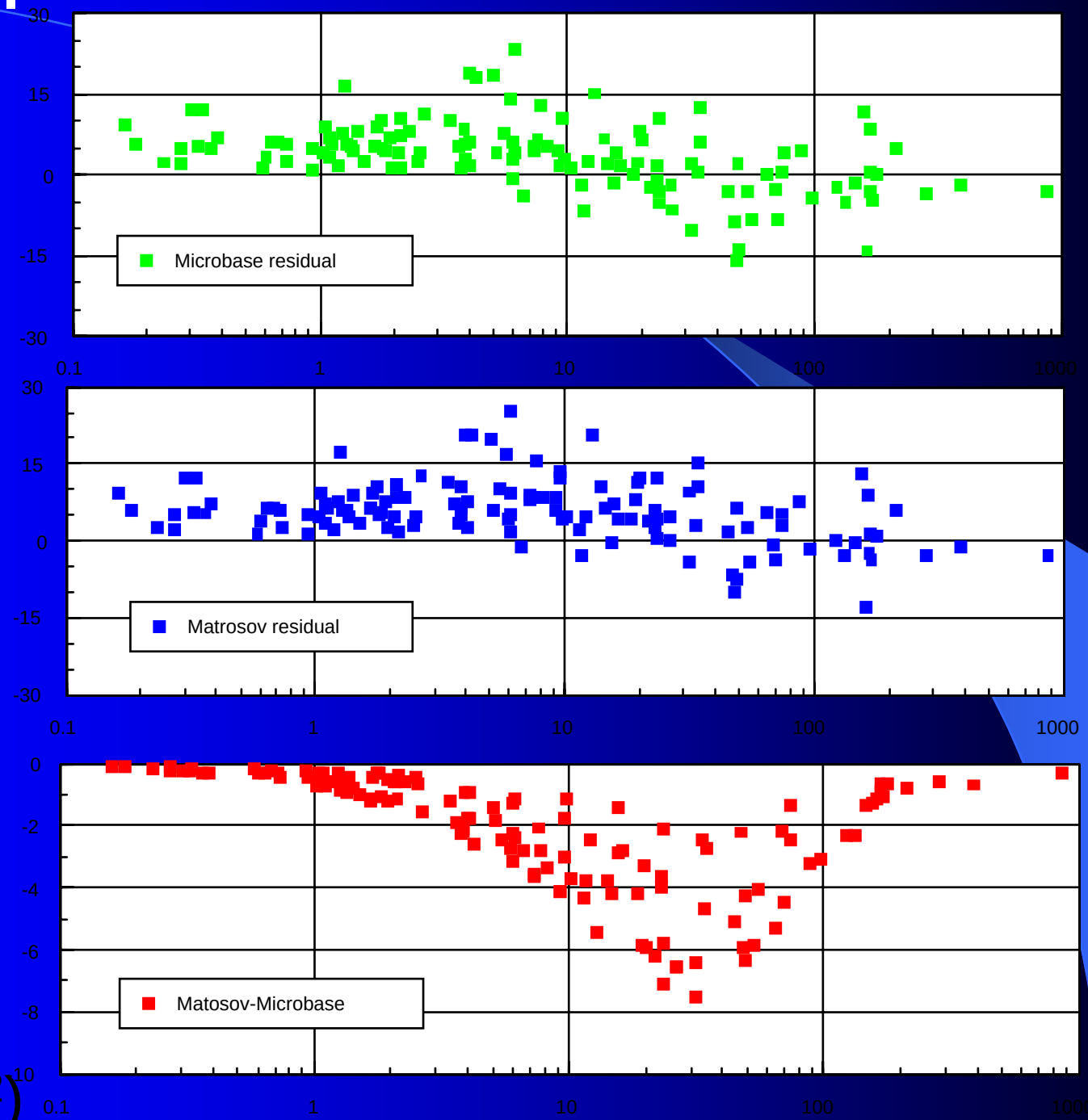
clear cases (mean residual =2.9 Wm^{-2}, stdev =2.7 Wm^{-2})



Flux Residual (W m^{-2})

LW results for all overcast ice cases

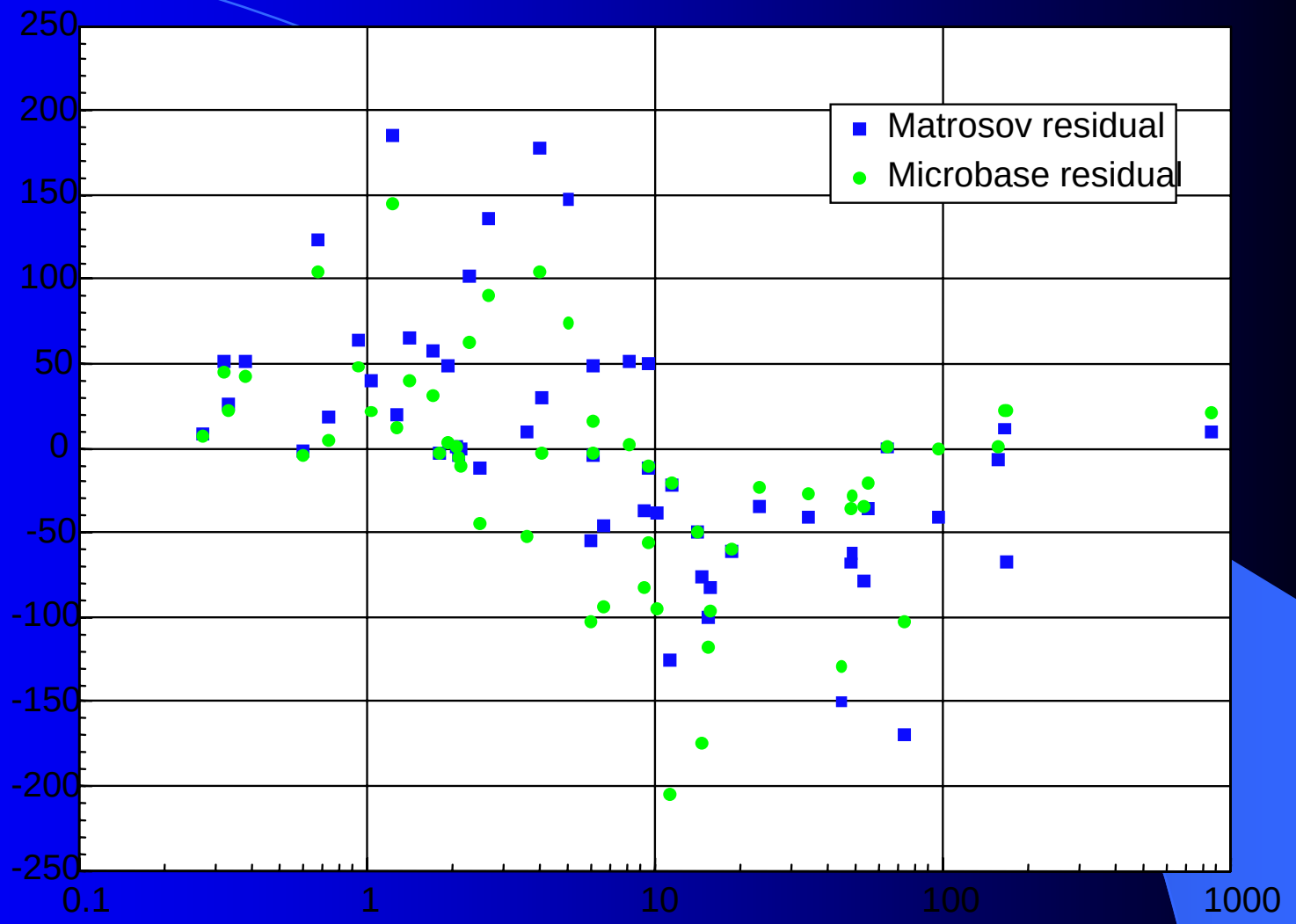
Flux Residual (W m^{-2})



IWP (g m^{-2})

SW results for all overcast ice cases

Flux Residual (W m^{-2})



IWP (g m^{-2})

No aerosols in the calculations

45.2	40.4	-68.0
36.9	5.9	-67.4

Trials

- Version 1.2.1—Trial A
  - Same as Version 1.0 Trial C except:
  - ***LWC linearly scaled to match MWR LWP***
  - LWC=>mode radius, r, using lognormal distribution **assuming** ***Nd=200 cm^{-3}*** and width=0.35
  - Algorithm modification and bug fixes
- Version 1.2.1—Trial D: Frisch et al., 1995
  - ***N retrieved from ratio of integrated Z and MWR LWP***
  - Lognormal to compute LWC(z) and r
  - May test Frisch et al. 2002

Trials

- Version 1.2.1—Trial E: Dong and Mace, 2003

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Profiles of Low-Level Stratus Cloud Microphysics Deduced from Ground-Based Measurements

XIQUAN DONG* AND GERALD G. MACE

Meteorology Department, University of Utah, Salt Lake City, Utah

- Ice and ice portion of mixed phase
  - Original version still used

Describing the Cloud Field

Compare the broadband diffuse flux residual for overcast cirrus conditions during the year 2000 using two ice cloud retrieval methods that use fundamentally different approaches to define crystal particle size.

- Matrosov (P_i v1.2.2tG)
- Microbase (P_i v1.2.2)

- Residual= *flux measurement minus flux calculation from a radiation transfer model (RRTM)*

Overcast Ice-Phase Cases (35) Shortwave Diffuse Flux Residual

Trial Meas-RRTM	Mean [Wm^{-2}]	Standard Deviation
1.2 Trial A ***Microbase***	-16.2	73.0
1.2 Trial E ***Mace and Dong, 2003***	-18.0	71.0

The End?

Why aren't the LW residuals for the thinnest ice clouds (IWP < 1 g/m^2) closer to those of clear cases (mean residual -2.9 W/m^2, stdev - 2.7 W/m^2) ?

Possible answer: In the BBHRP dataset (with outliers removed), it is more likely that there would be cloudy cases (relative to clear) for which the piece of sky directly above the site would not be particularly representative of the entire sky. In the category of IWP < 1 g/m^2, these inaccuracies would tend to be underestimations of the actual IWP, resulting in positive residuals. If one were to remove from this subset those cases with residuals furthest from the mean residual, then the mean residual would be much closer to the clear mean (~ 4.2 W/m^2).

All cases have higher computed fluxes from Microbase than from Matrosov. This is because the cloud OD is increased by ~35% due to the smaller particle sizes in Microbase while the IWPs differ by less than 20%. (For IWP < 10 g/m^2, these two effect both lead to Microbase having more OD, while for IWP > 10 g/m^2 the two effects pull in opposite directions, with the size effect being larger.)

For 1 < IWP < 10, Microbase has better results. For 10< IWP < 100, Matrosov appears to be better (assuming the goal is to get close to clear sky results). What would be the simplest way of explaining this?

(note to MM: I can't come up with a great explanation, either for this, the SW (see next slide), or both together. It does seem as though for IWP > 10 that Microbase has too much optical depth.)

Baseline Estimate Continuous Cloud Microphysics (MICRO_BASE)

- Continuous estimate of microphysical structure.
- Optional extensions of retrievals available in the site.
- Temperature-reflectivity mixed-phase deterization
- Scaling of Z-LWC (Liu and Sassen)
  - Optional extension of Frisch et al., 1995
  - Wet Window Flag
- ΔLWC(z), r_e(liquid and ice), cloud fraction (f (z))
- Instantaneous(P_I) and P_averaged (P_A)
- Beta versions: running

MICRO_BASE Parameterizations

Fractionating:

simple LWC/IWC fractionating scheme is used, where T = interpolated sounding temperature:

- For T <= -16C, all ice
- For T >= 0 C, all liquid
- For -16 < T < 0 C, ice fraction = linear fraction with no ice at 0 and all ice at -16

•Sassen and Liao(1994) Z-LWC
•MWR LWC Scaling (Frisch et al., 1995)
•Latest MWR Retrieval (Liljegren and Turner; Variable Coefficient)
•Liu and Illingworth(2000) Z-IWC.

Radius:

log-normal droplet distribution.

Radius:

Ivanova et al.(2001): ice effective radius = (75.3 + 0.5895T) / 2

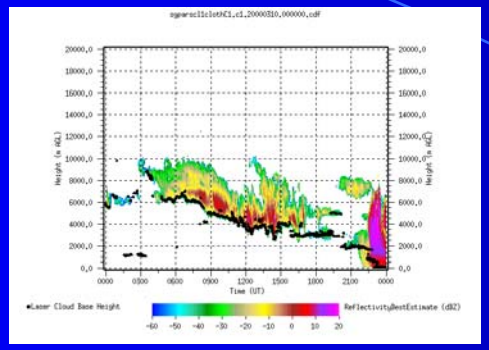
Size Distribution:

Bimodal log-normal with large and small crystal populations

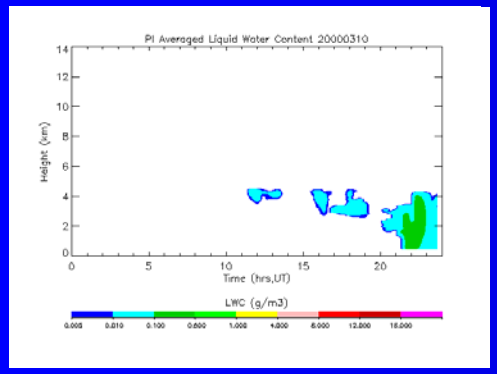
MICRO_BASE Status and Availability

- **SGP**
  - Year 2000 available
  - Instantaneous
    - 30 minute averaging period
    - MMCR Cloud Fractions
  - Averaged
    - 1 hour averaging period
    - MMCR Cloud Fractions
  - Raw
    - 10 second data available
- **TWP**
  - Selected Months
  - MMCR (Jensen et al., 2001)
- **Additional Retrievals**

ARSCL



MIC_BASE_PI_LWC



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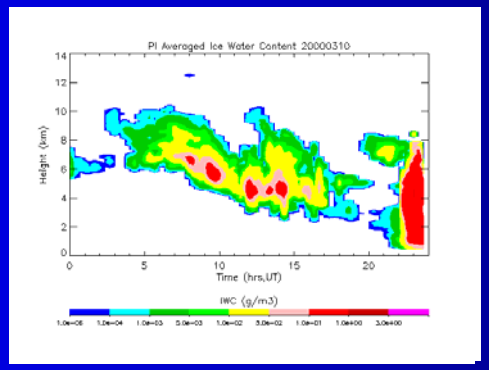

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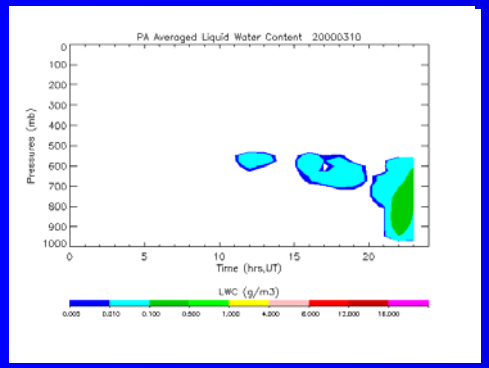

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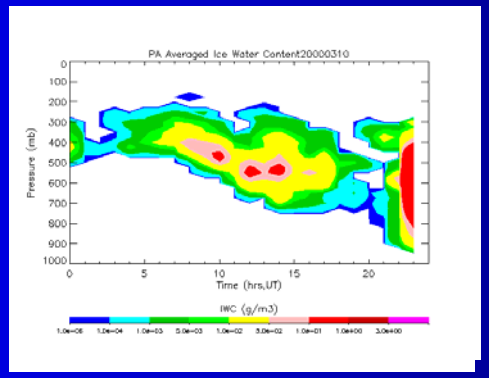
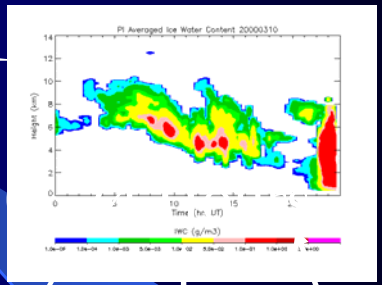


LEGEND

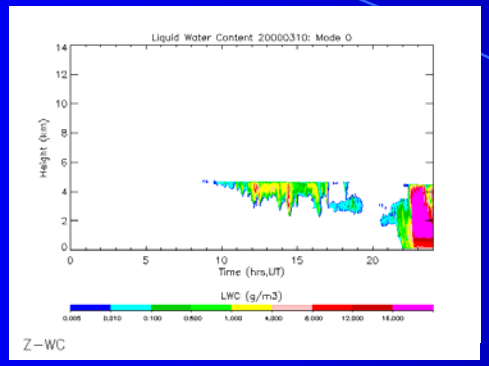
Water Content (g/m3)

Height (km)

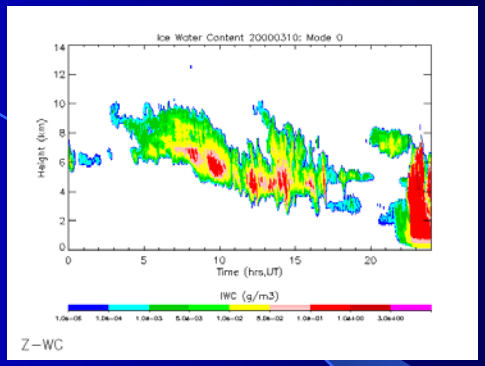


Liq	0.005	1.0	8-16
Ice	1e-6	0.01	0.1-3

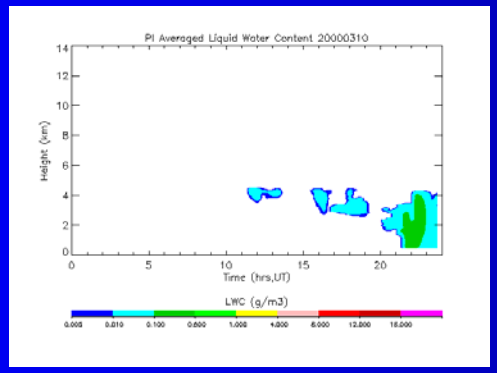
Improved PA Resolution



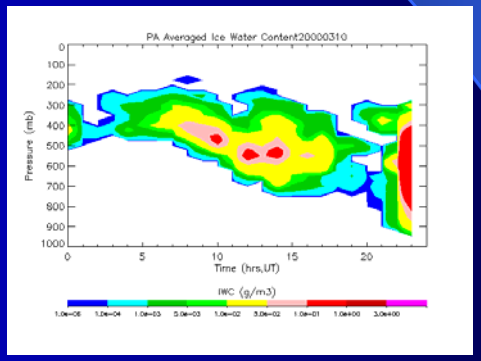
MIC_BASE_PI_LWC



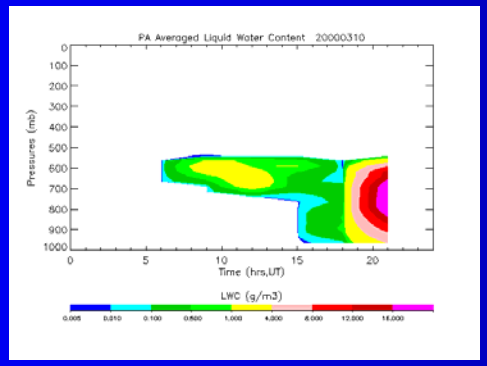
MIC_BASE_PI_IWC

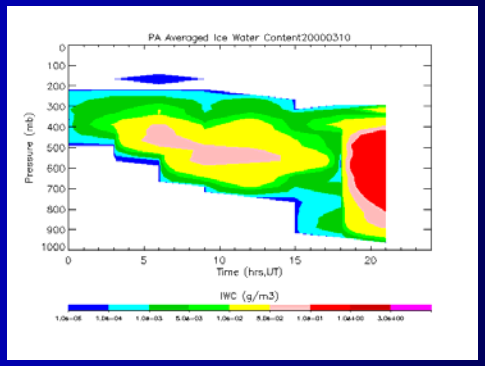


MIC_BASE_PA_OLD



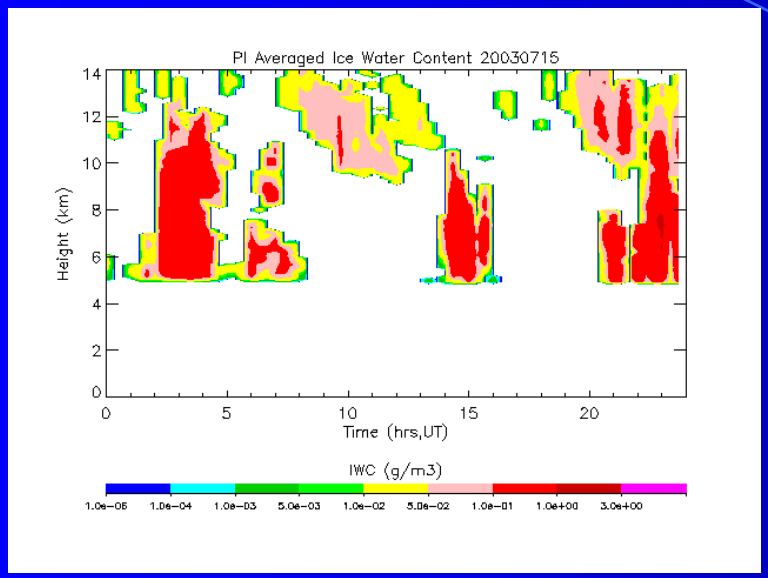
MIC_BASE_PA_OLD



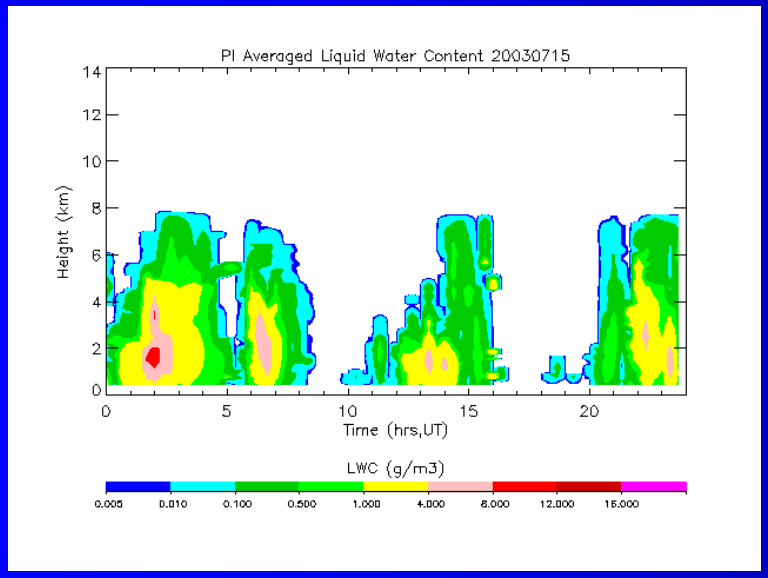


TWP Beta Microbase

Ice



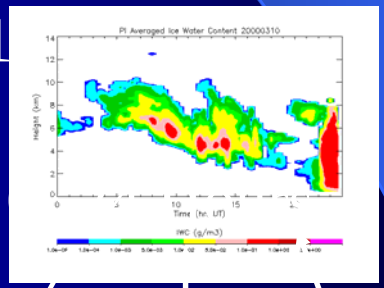
Liq



- Vogelmann
- Mather, Long, Ackerman
- Z-IWC (Jensen et al., 2001)

Water Content (g/m3)

Height (km)



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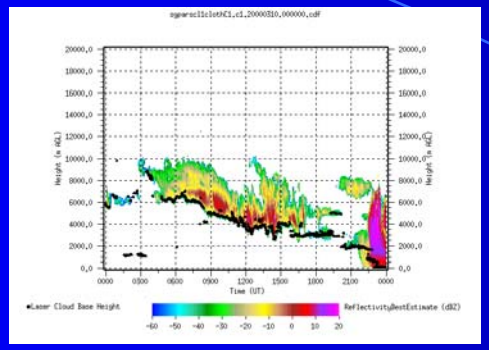

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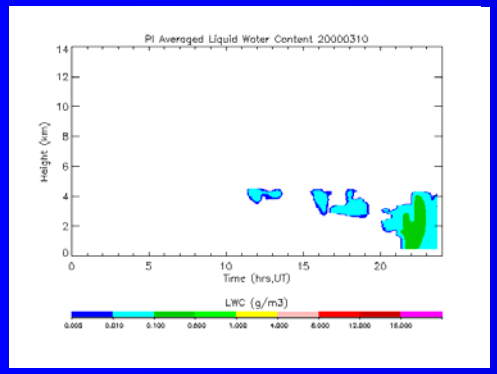

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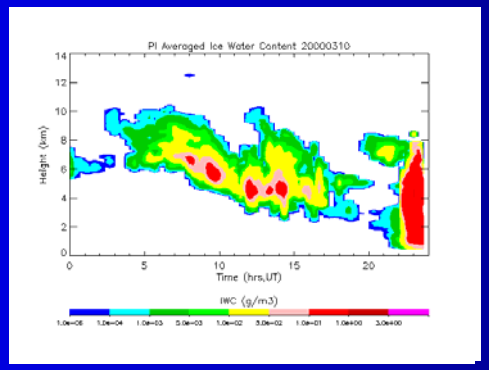
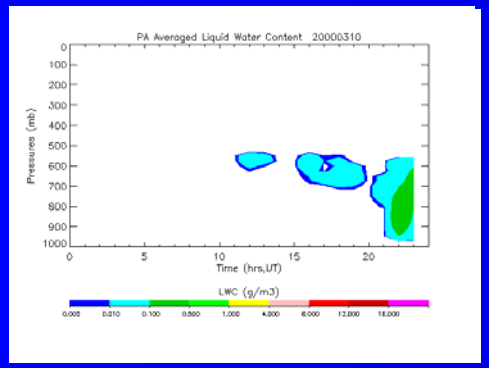
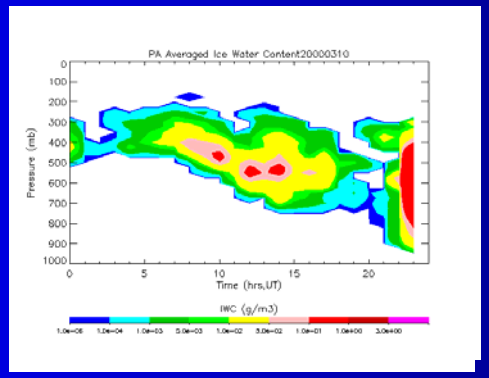


MIC_BASE_PA_LWC



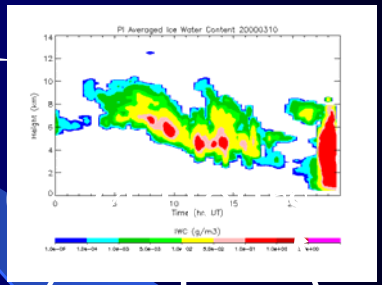
MIC_BASE_PA_IWC



LEGEND

Water Content (g/m3)

Height (km)



Liq	0.005	1.0	8-16
Ice	1e-6	0.01	0.1-3