Multi-Variate Density Functions with Dynamics: Mixed-Phase Clouds, FASTER and ASR Interactions

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Overview

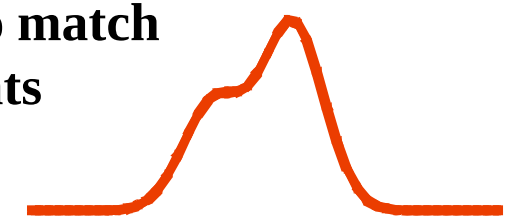
- Using multi-variate probability density functions with dynamics to parameterize boundary layers and clouds
- Application to mixed phase clouds
- ASR, FASTER interactions

Building a PDF-based parameterization

Advance prognostic moment equations

$\overline{w}$, $\overline{\theta_l}$, $\overline{q_t}$, $\overline{w'^2}$, $\overline{w'^3}$, $\overline{q_t'^2}$, $\overline{\theta_l'^2}$, $\overline{q_t'\theta_l'}$, $\overline{w'q_t'}$, $\overline{w'\theta_l'}$

Select PDF from functional form to match moments



Diagnose cloud fraction, liquid water, droplet number from PDF

Δt

Use PDF to close higher-order moments, buoyancy terms

$\overline{w'q_t'^2}$, $\overline{w'\theta_l'^2}$, $\overline{w'q_t'\theta_l'}$, $\overline{w'^2q_t'}$, $\overline{w'^2\theta_l'}$, $\overline{w'^4}$, $\overline{q_t'\theta_v'}$, $\overline{\theta_l'\theta_v'}$, $\overline{w'\theta_v'}$, $\overline{w'^2\theta_v'}$

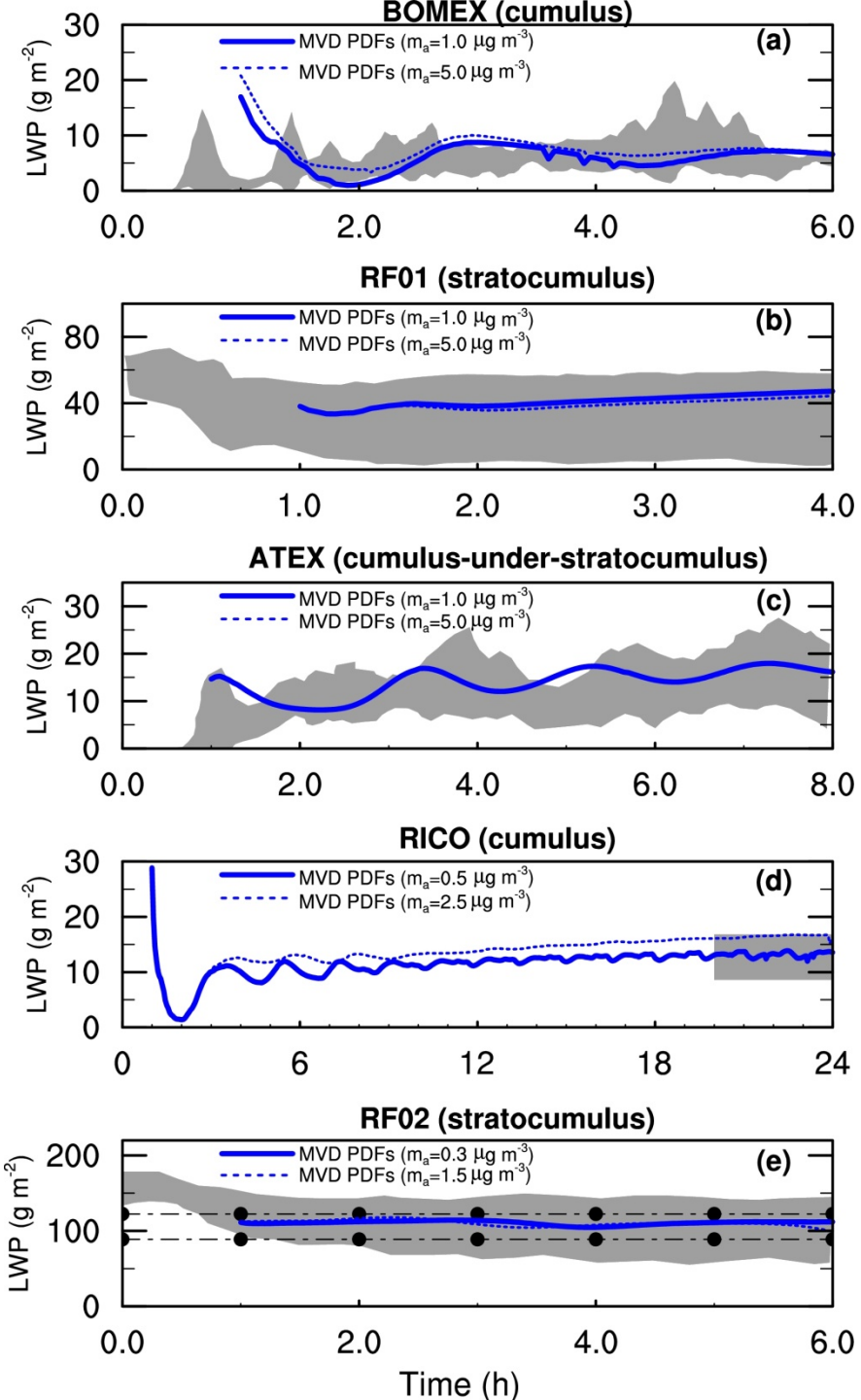
Adapted from Golaz et al. 2002a,b (JAS)

Five warm cloud cases

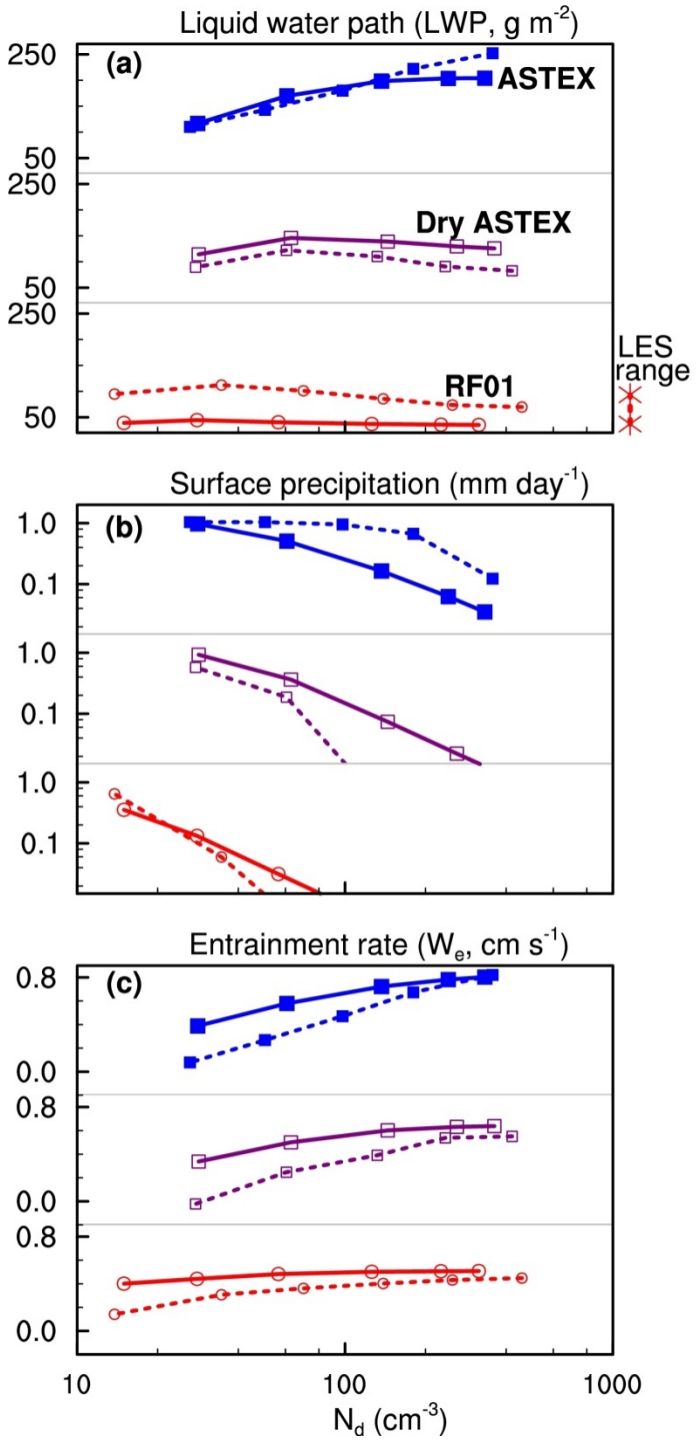
Non-precipitating
- BOMEX (cumulus)
- RF01 (stratocumulus)
- ATEX (cumulus-under-stratocumulus)

Precipitating
- RICO (cumulus)
- RF02 (stratocumulus)

AM3 Single Column Model using Multi-Variate Probability Density Function with Dynamics, Aerosol Activation, and Double-Moment Microphysics



from *Guo et al.* (2010, *Geosci. Model Dev.*)



Solid: MVD PDFs

Dashed: LES from Ackerman *et al.* (2004, *Nature*)

LES range from Guo *et al.* (2010, *GMD*)

from Huan Guo, GFDL

Two mixed-phase cases

Precipitating

- MPACE-B (pristine, warmer)
- SHEBA (polluted, colder)

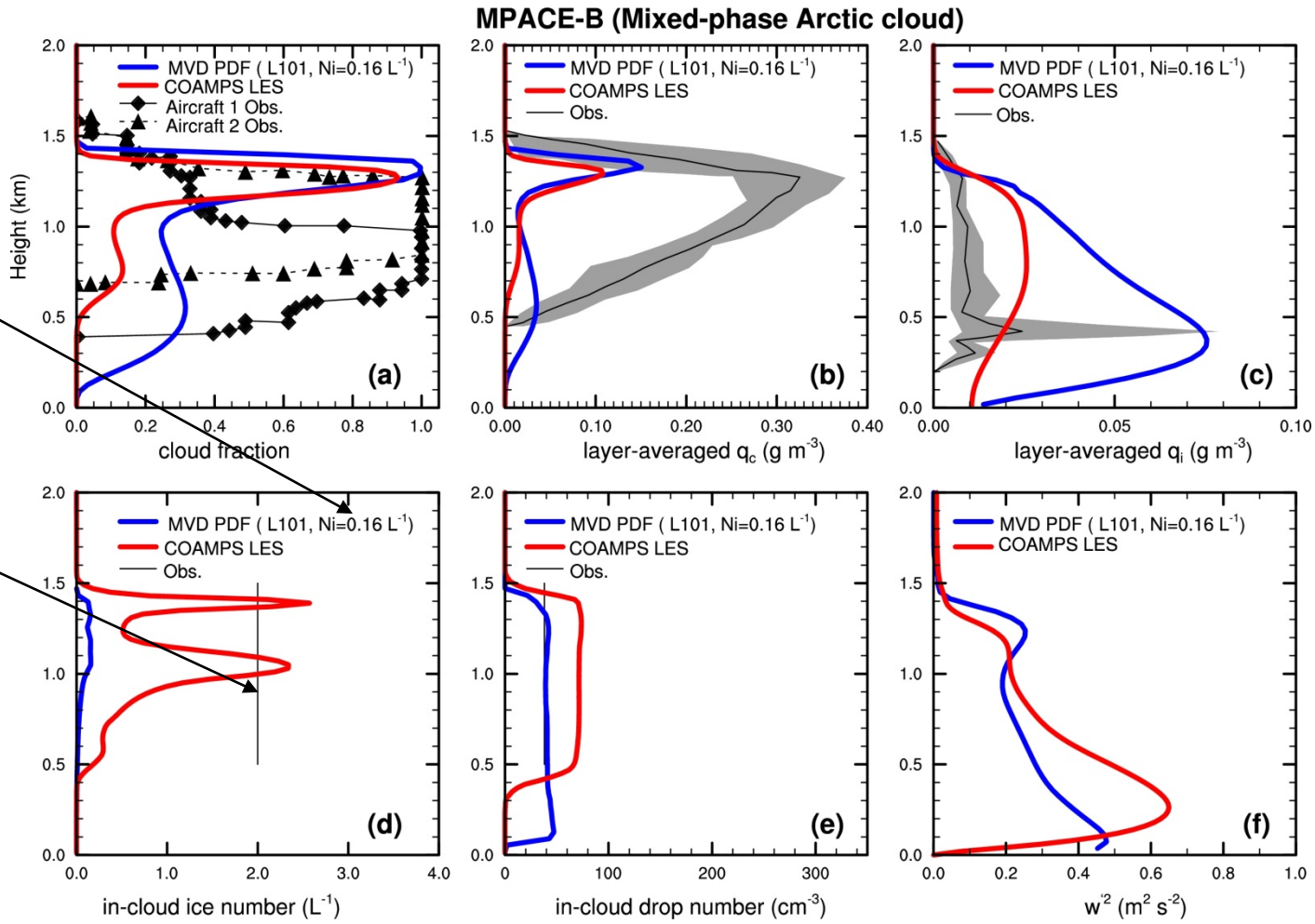
MPACE-B: profiles

ice nuclei (0.16/L)

<

ice number (2/L)

ice multiplication



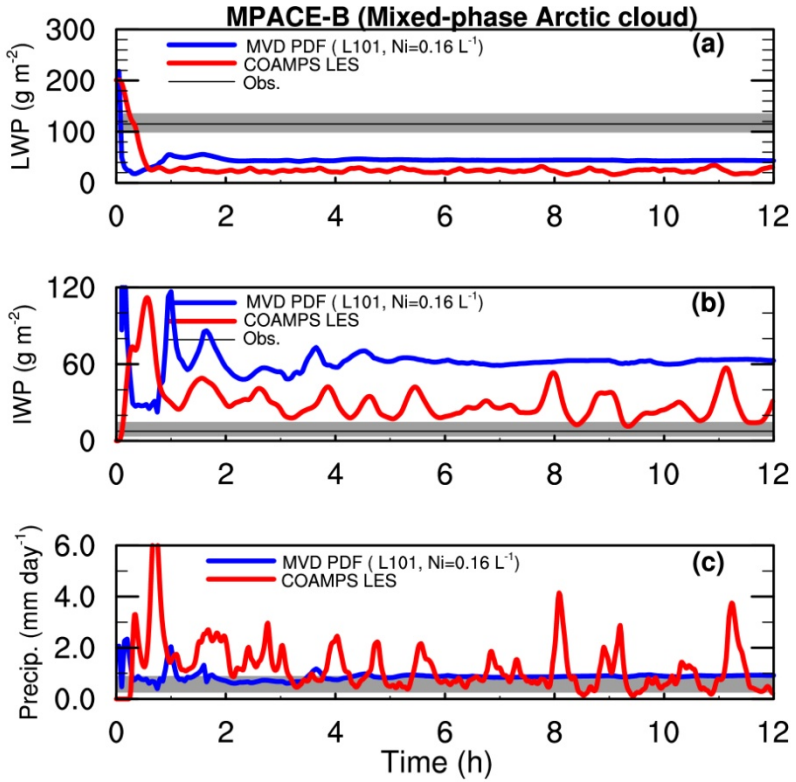
Mar 2011

ASR/FASTER

Aircraft obs, cf. Klein *et al.* (2009, *QJRMS*)

from Huan Guo, GFDL

MPACE-B: time series



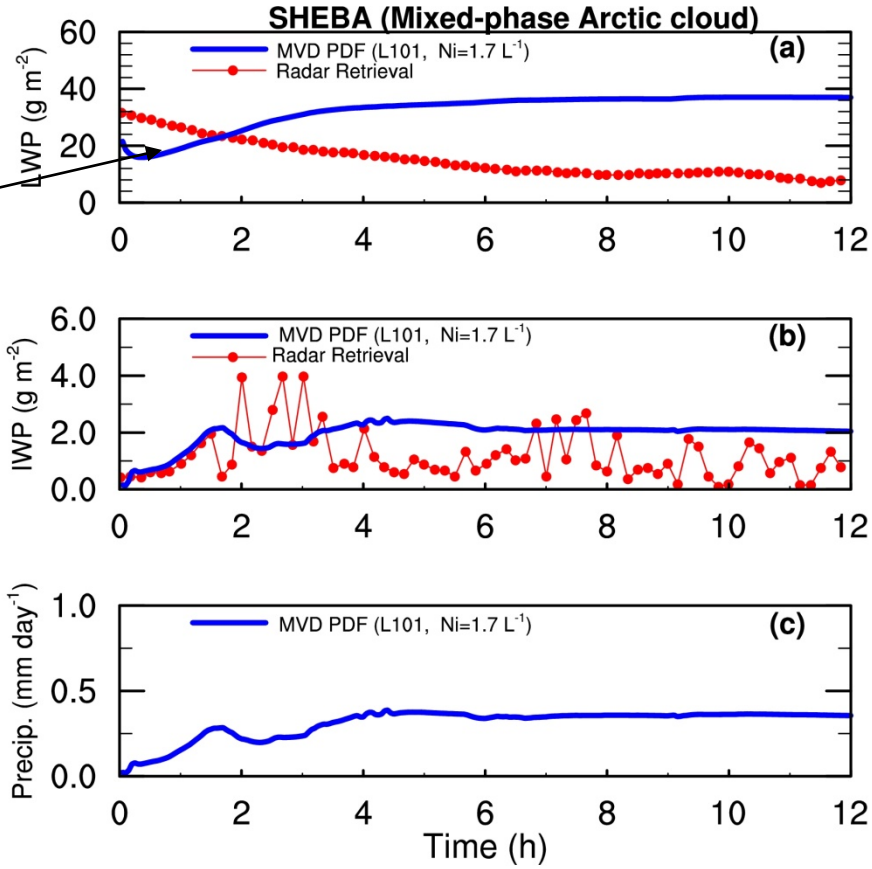
avg. over 4-12 hour

	LWP (g/m2)	IWP (g/m2)	Precip. (mm/day)
MVD PDF	44.2546	61.9714	0.8779
COAMPS LES	23.8739	26.2158	1.0155
Obs. Esti.	115.3000	7.6000	0.9000

SHEBA (Time series)

overestimate

LWP

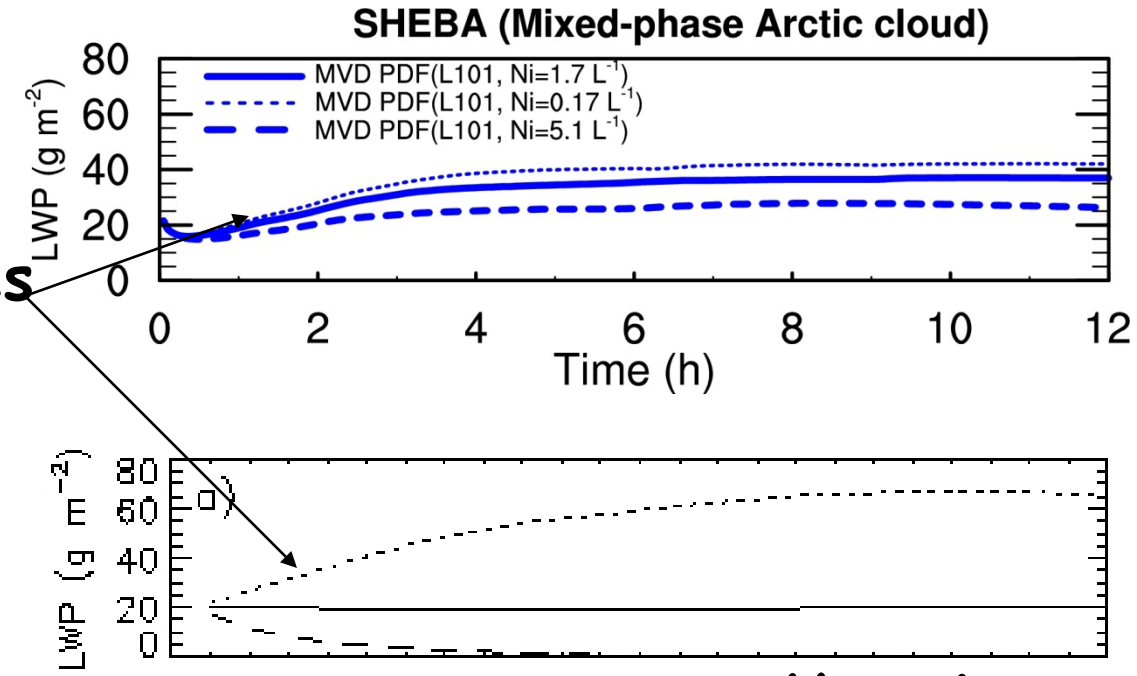


avg. over 4-12 hour

	LWP (g/m2)	IWP (g/m2)	Precip. (mm/day)
MVD PDF	35.6580	2.1440	0.3530

SHEBA: sensitivity to IN

LWP decreases with IN

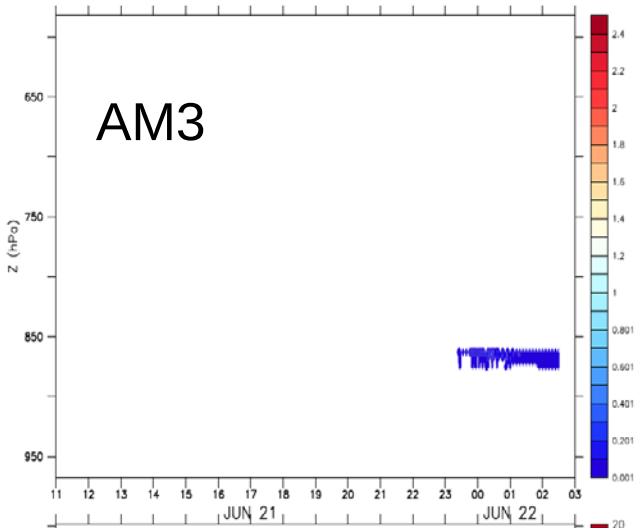


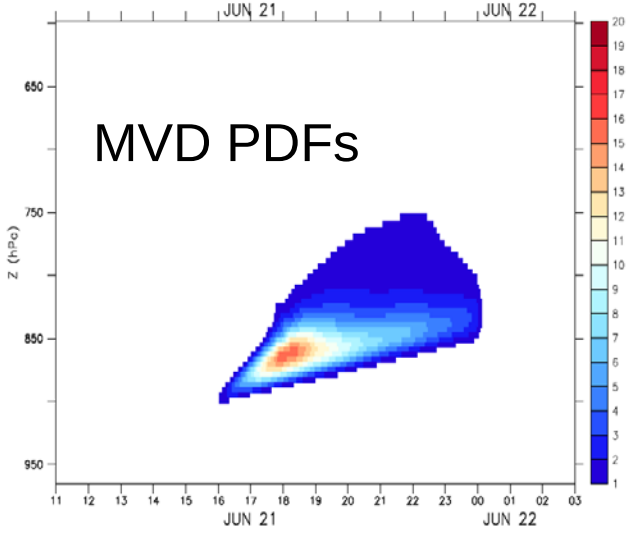
Morrison et al., 2011

FASTER Interactions

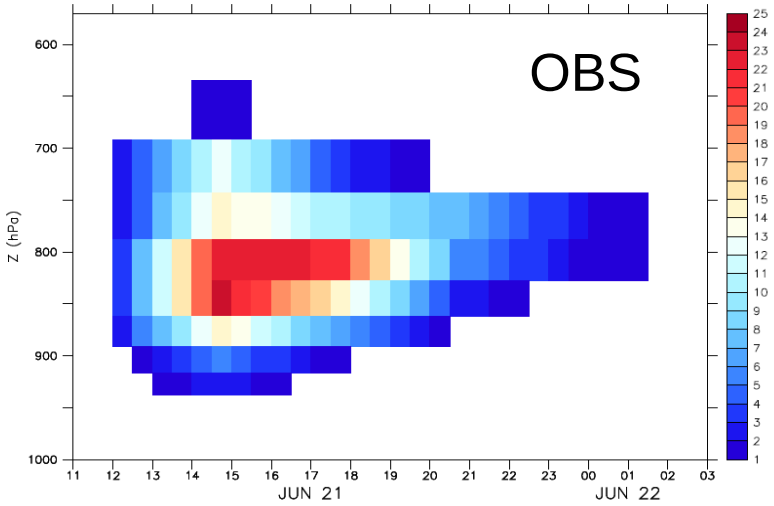
- Important to assess MVD PDF method for cases beyond RF01 and ASTEX
- SCM and LES runs for ARM cases with well-characterized aerosols
- Both mean and PDFs important
- Proposal: GFDL does SCM runs, LES from FASTER for comparable periods

GCSS ARM case



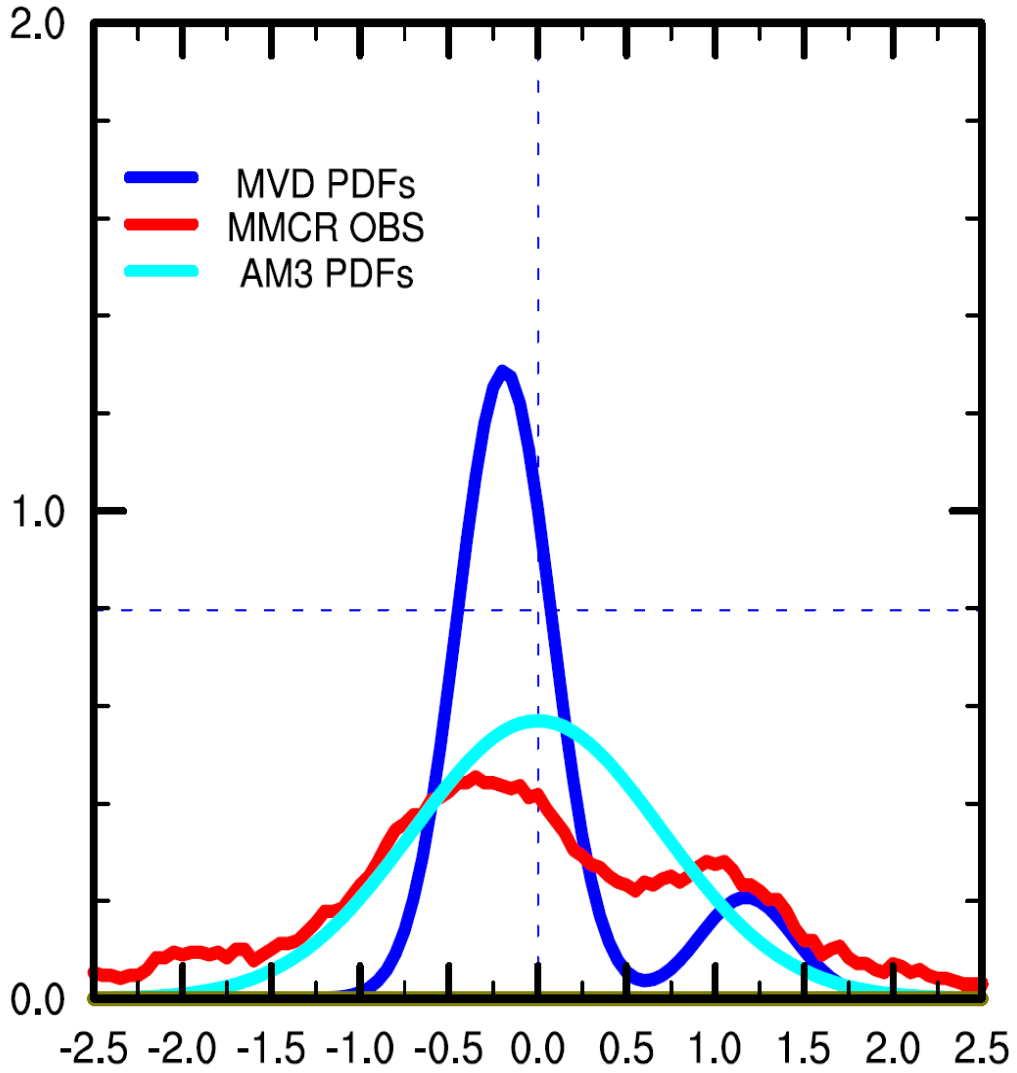


Cloud fraction



Vertical motion PDF comparison

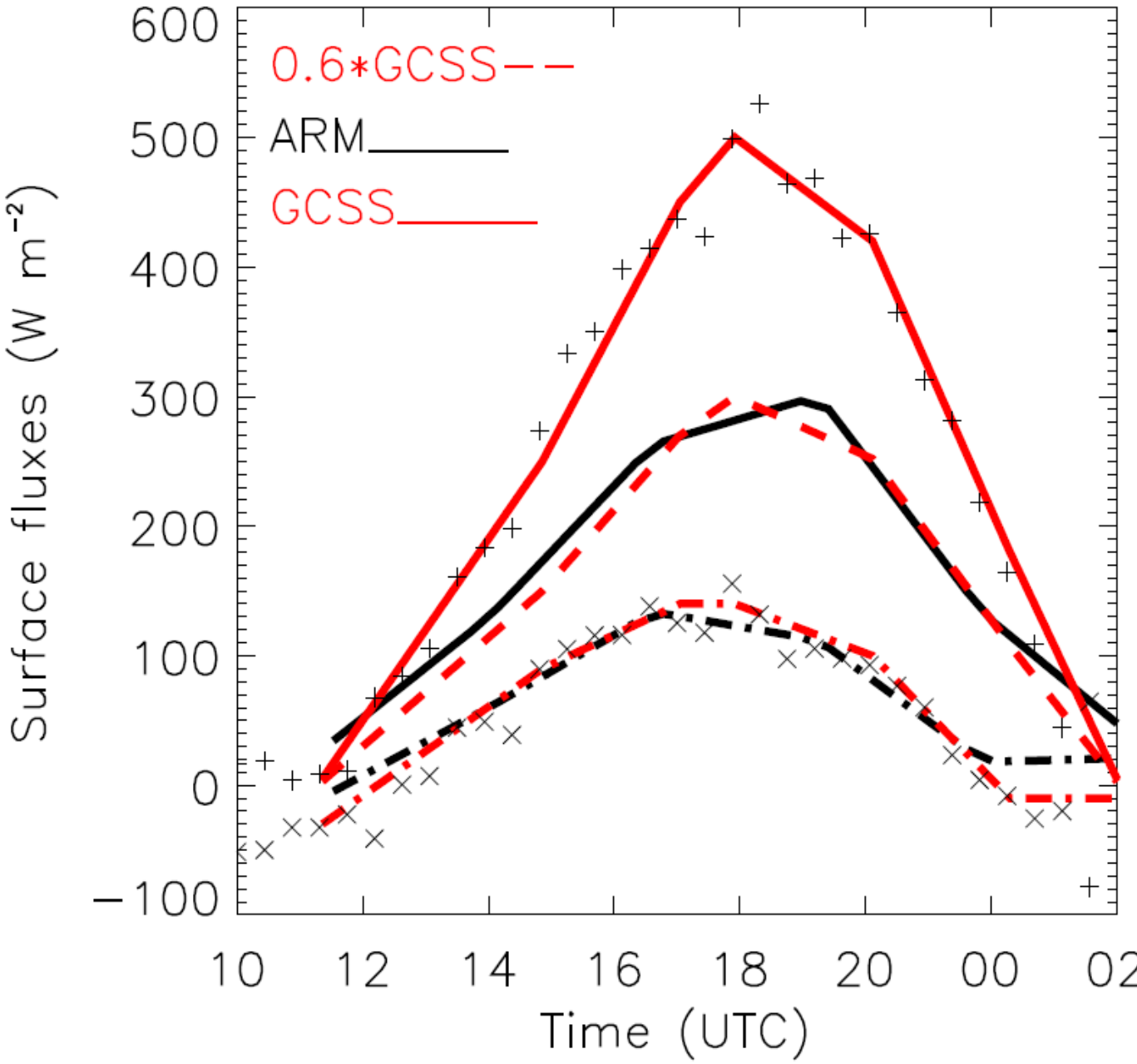
ARM GCSS
21 June 97
Brown *et al.*
(*QJRMS*,
2002)



Surface latent and sensible heat flux from ARM variational analysis and GCSS forcing

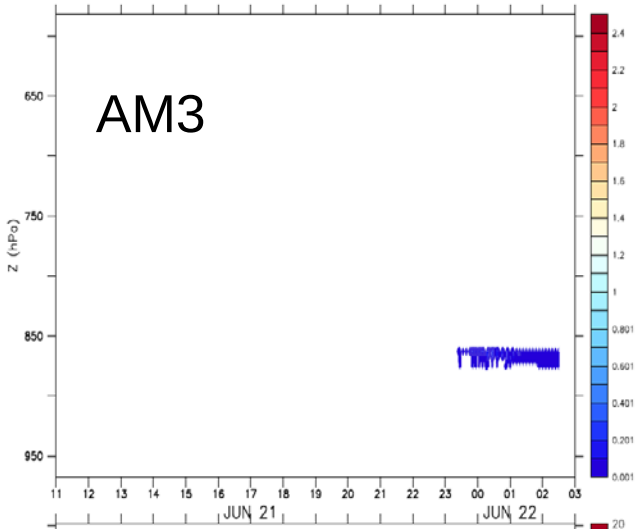
LH: solid line
SH: dashed lines

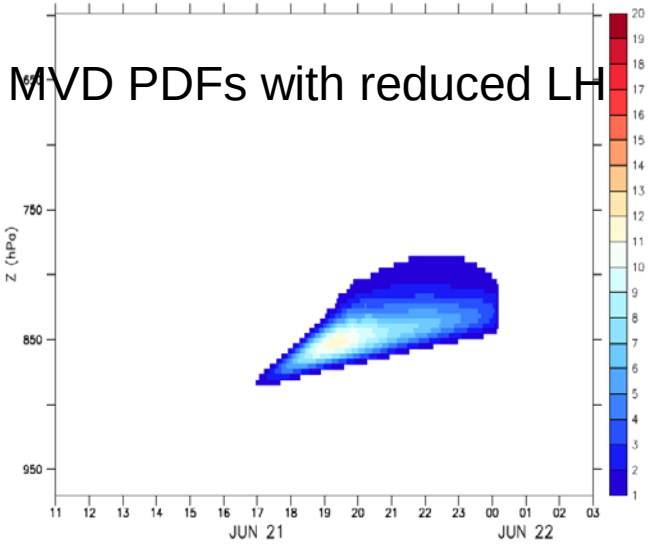
Symbols are fluxes at the central facility.

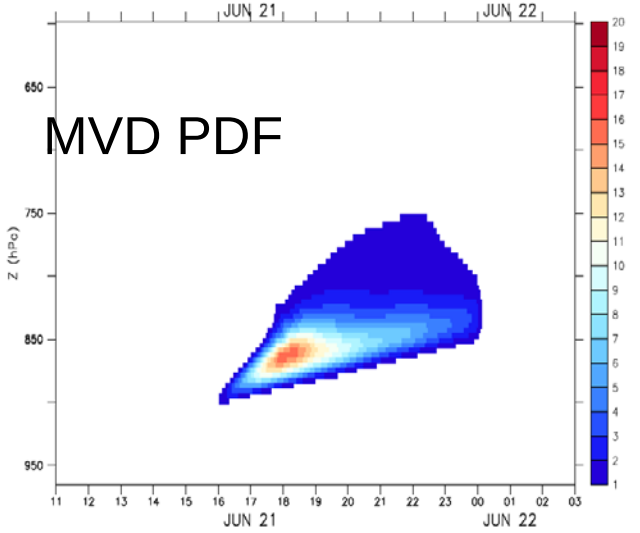


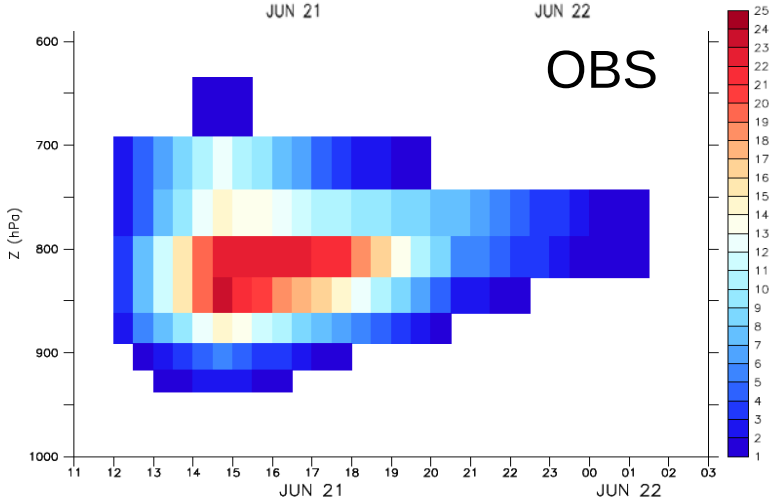
GCSS ARM case

Cloud fraction

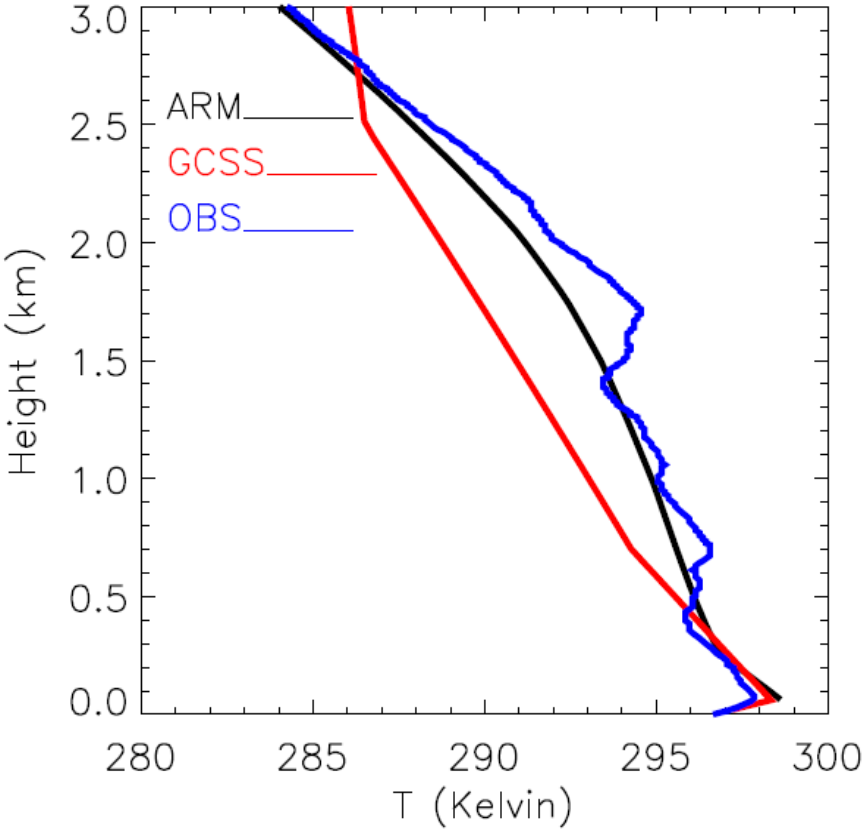


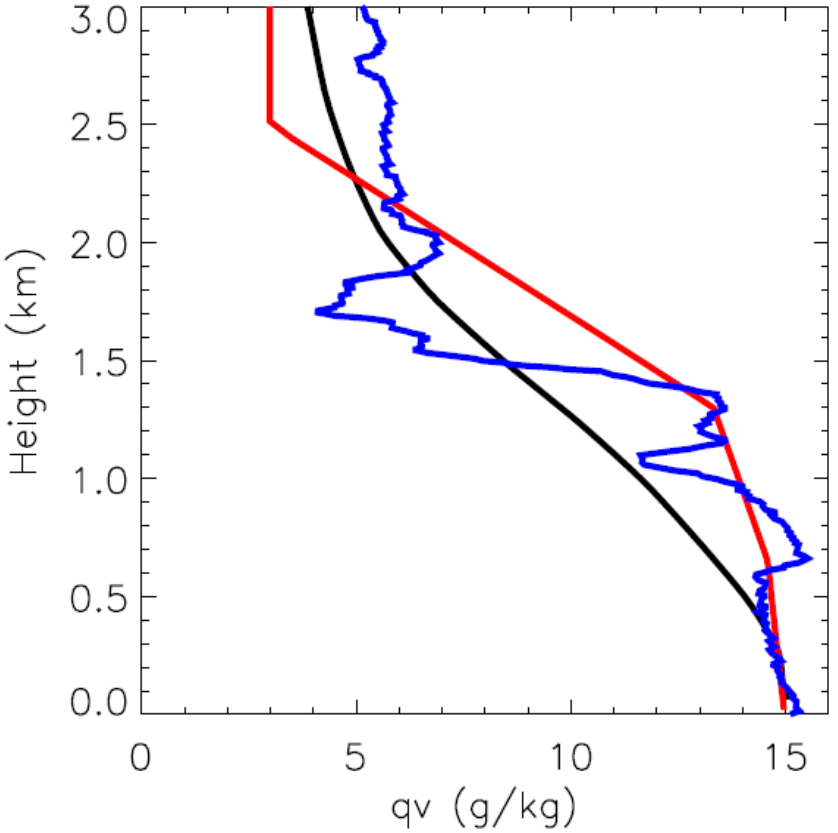






Initial T and Qv

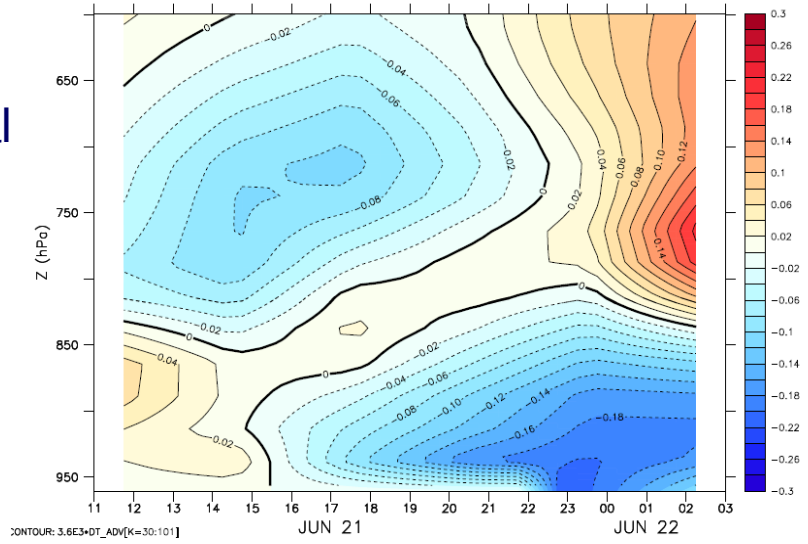


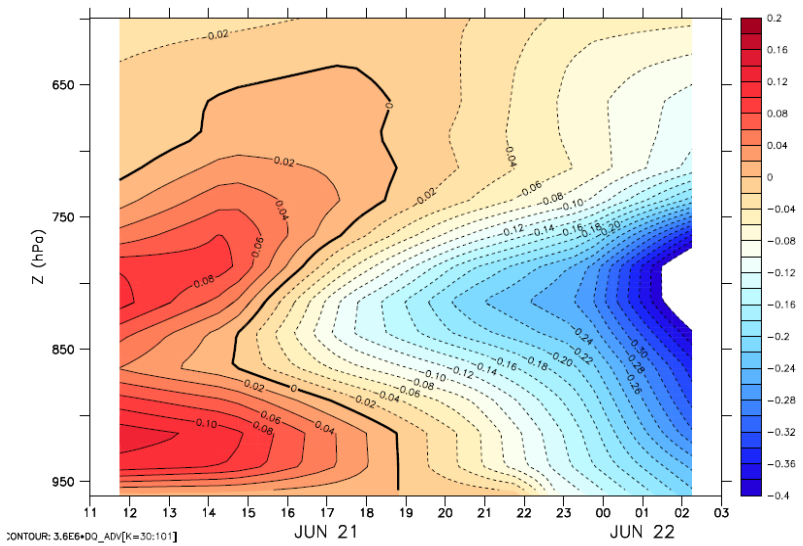


T adv

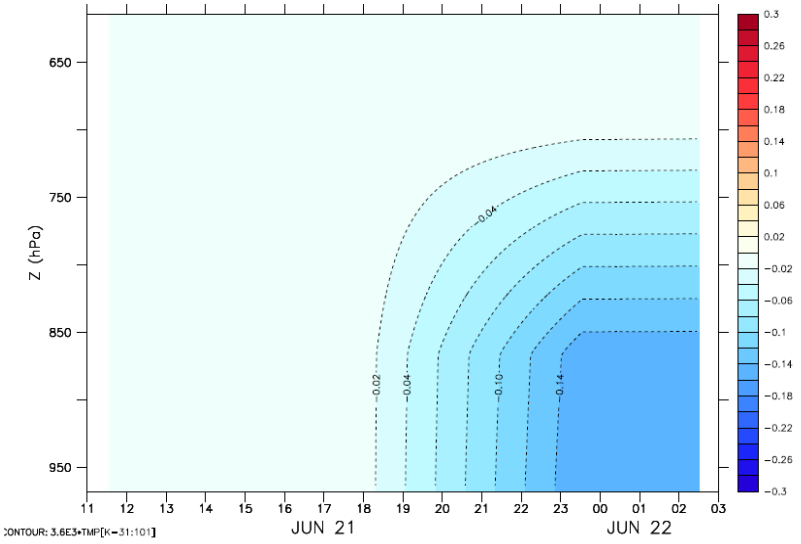
qv adv

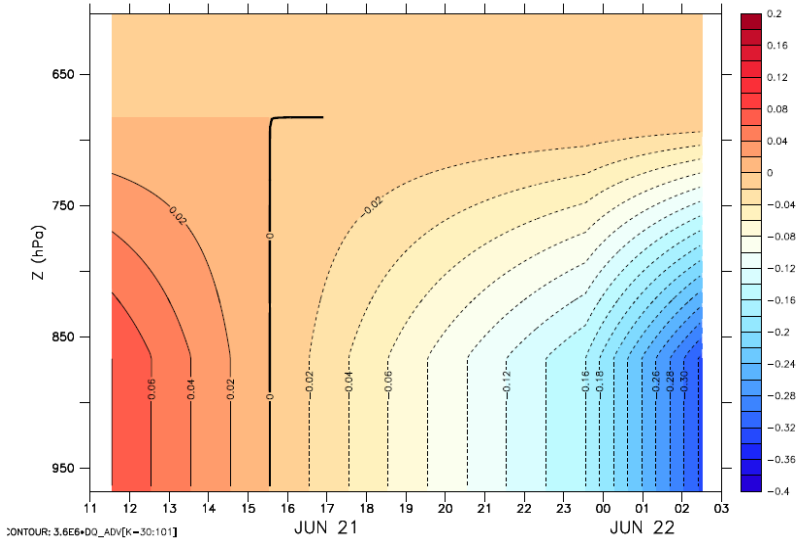
GATE Variational





GCSS





MVD PDF fails to produce cloud using ARM variational analysis

Summary

- MVD PDFs successfully simulate cloud fraction, water path, and droplet numbers for Sc and shallow Cu GCSS cases
- MVD PDFs simulation of mixed-phase clouds raises ice microphysics issues
- MVD PDFs indicate both positive and negative indirect effects on LWP
- Entrainment change as control on LWP change with aerosol loading consistent between LES and MVD PDFs
- Critical issues regarding observations…strong difference in MVD PDFs using ARM variational analysis and GCSS forcing for same case