Continental and Marine Low-level Cloud Processes and Properties (ARM SGP and AZORES)

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Outline

1) Statistical results from SGP and AZORES
2) Challenge and Difficult for modelers to simulate low-level clouds

Question to be partially answered

What processes determine the formation, persistence and evolution of cumulus, stratocumulus and stratus clouds in both WARM and cold climates?

➔Radiation-turbulence-entrainment-microphysics-drizzle-precipitation interactions

➔Role of large-scale vs. local-scale

➔Impacts of aerosols (AIE, such as CCN vs. cloud re/Nd.....)

➔Similarities and differences between Marine and continental low clouds.

➔Key instruments at SGP, AZORES, NSA ......

➔Relevant focus groups: Entrainment, VV, QUICR....

Similarities and differences between Marine and continental Low clouds

➔Del Genio and Wolf (2000) explained and discussed this topic and concluded that the formation-dissipation processes of marine boundary layer clouds can be mostly applied to continental boundary layer clouds.

➔Dong et al. (2005) documented 6-yr of low-level cloud properties over the ARM SGP site, and also discussed this topic (following DW2000 paper).

➔Marine boundary clouds during ASTEX (June 1992, Albrecht et al. 1995, Miller et al. 1995, Dong et al. 1997).

➔The ARM AMF deployment at AZORES (Wood et al. 2011, 2012) during May 2009-Dec. 2010 provided a great opportunity for us to investigate this topic.

Similarities and differences between Marine and Continental low clouds

Over the water, the moisture comes directly from the surface, which also maintains a relatively stable temperature throughout the day. The cloud layer undergoes a coupling and decoupling with the surface air over the diurnal cycle (DW2000)

Over land areas, the water vapor is typically advected into the region with an air mass except when the surface is moist. The stratus is often formed as part of a cyclonic system. It is not surprising that the moisture and cloud layer over the SGP can be decoupled from the surface (DW2000)

A conceptual model of midlatitude Marine Boundary Layer (MBL) Clouds

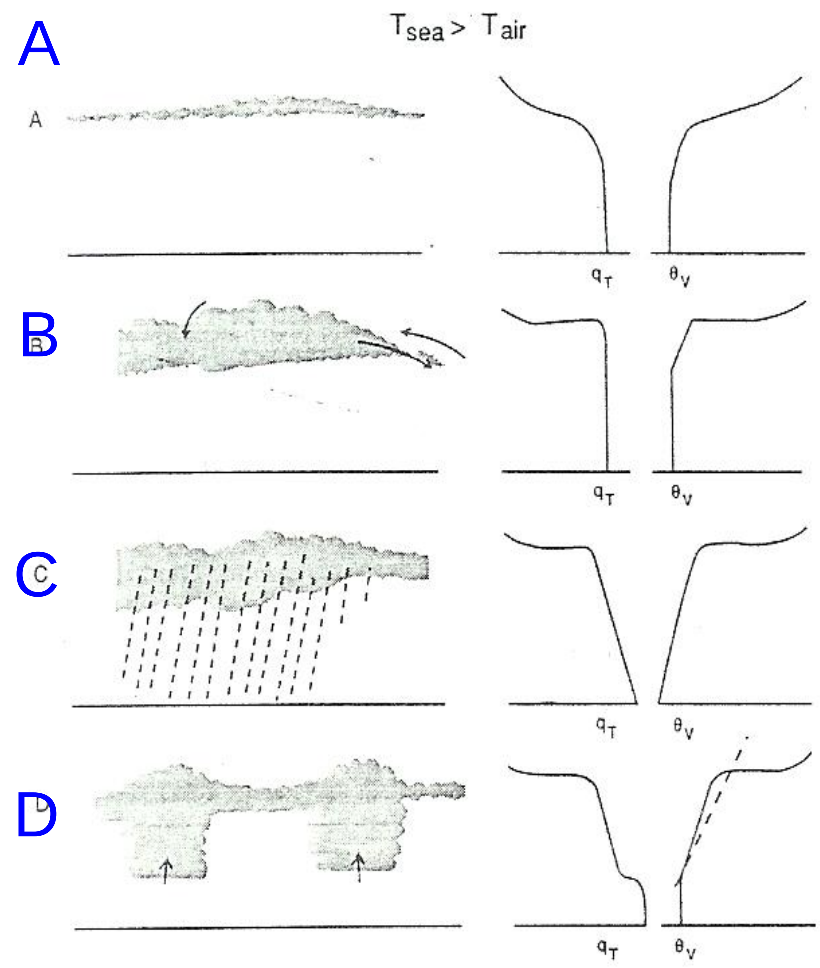
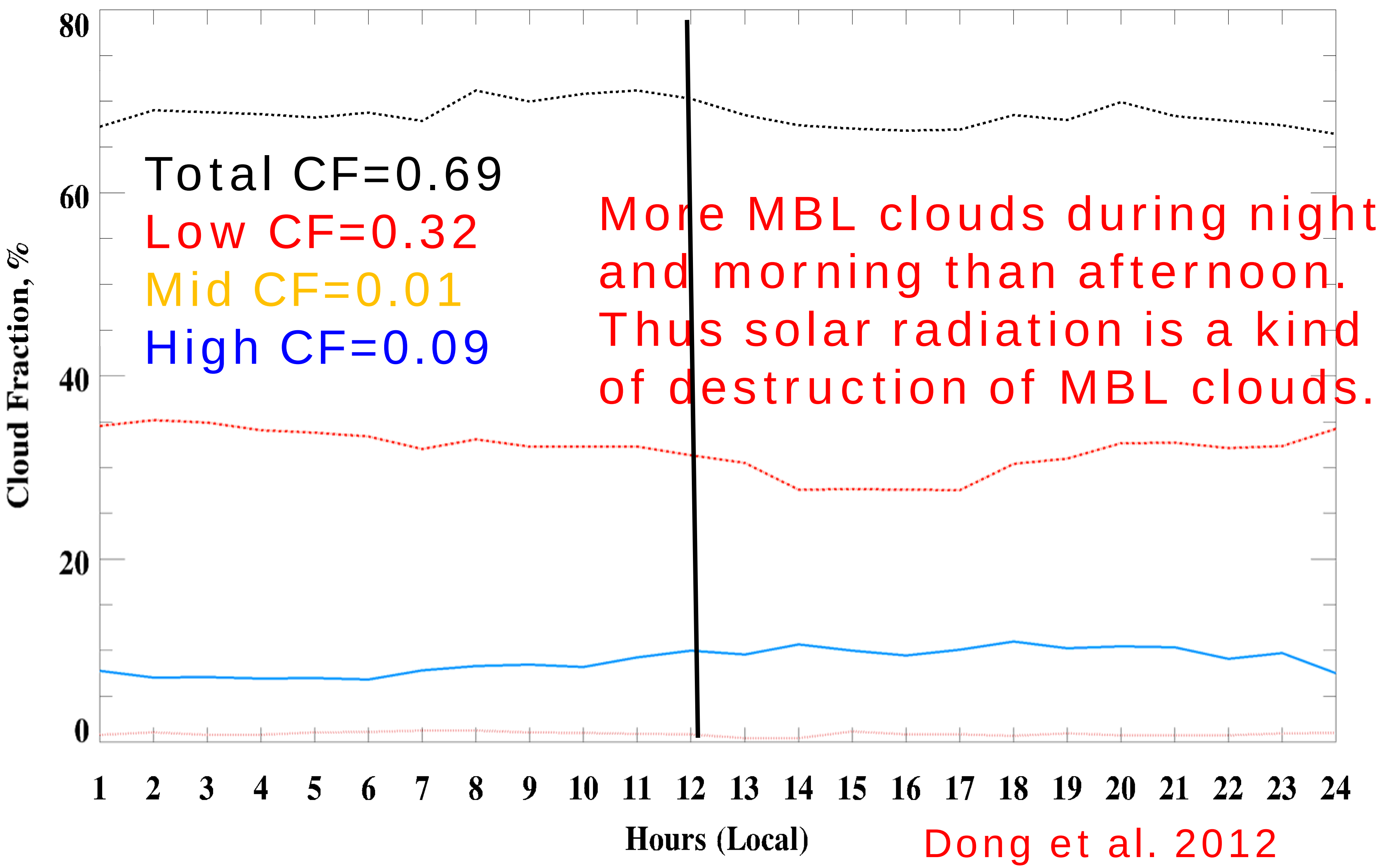


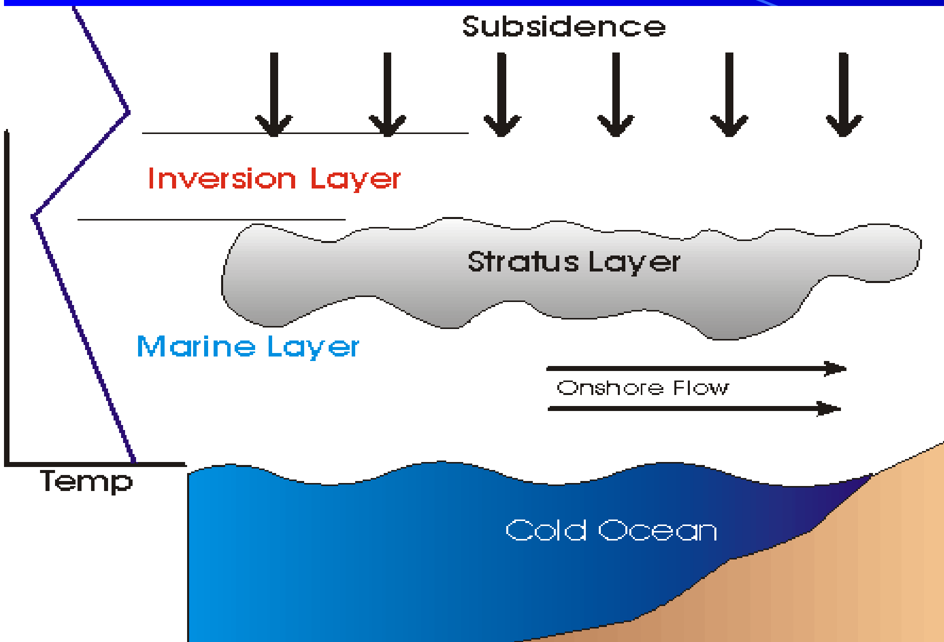
FIG. 15. Life cycle of a marine stratus layer as it forms in the presence of surface heating with corresponding profiles of total-water (q_t) and virtual potential temperature (θ_v). The dashed line in (d) represents the wet adiabat.

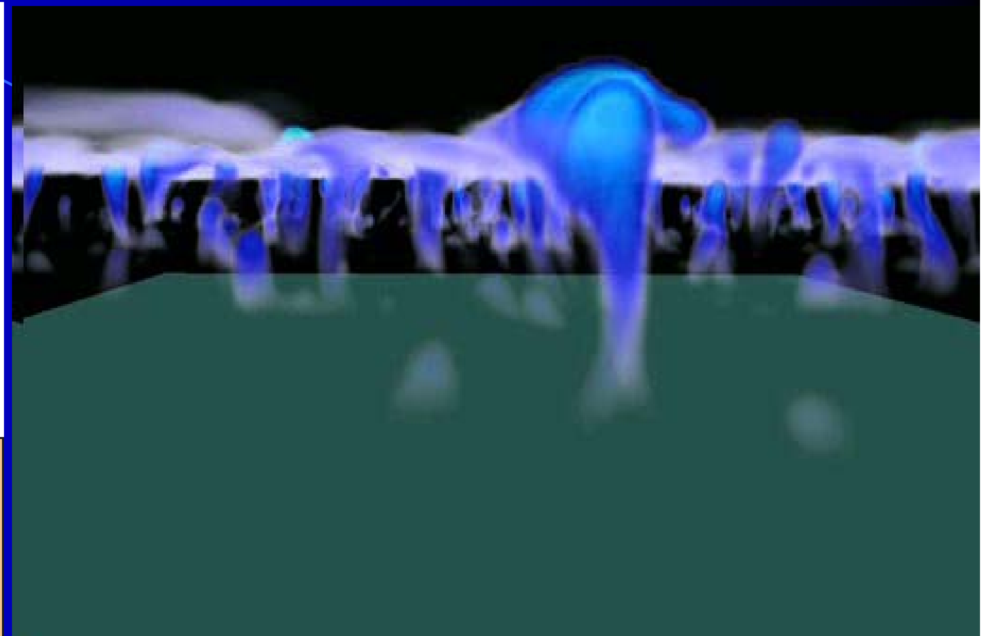
- Based on aircraft in situ data, Paluch and Lenschow (1991) developed a conceptual model of the life cycle of MBL in the midlatitudes.
- It starts initially as a thin, homogenous layer (A), then grows thick and becomes patchy with time and produces precipitation (B & C).
- This stage is followed by the formation of small cumuli below (D) and eventually disintegrates, leaving a field of cumuli behind.

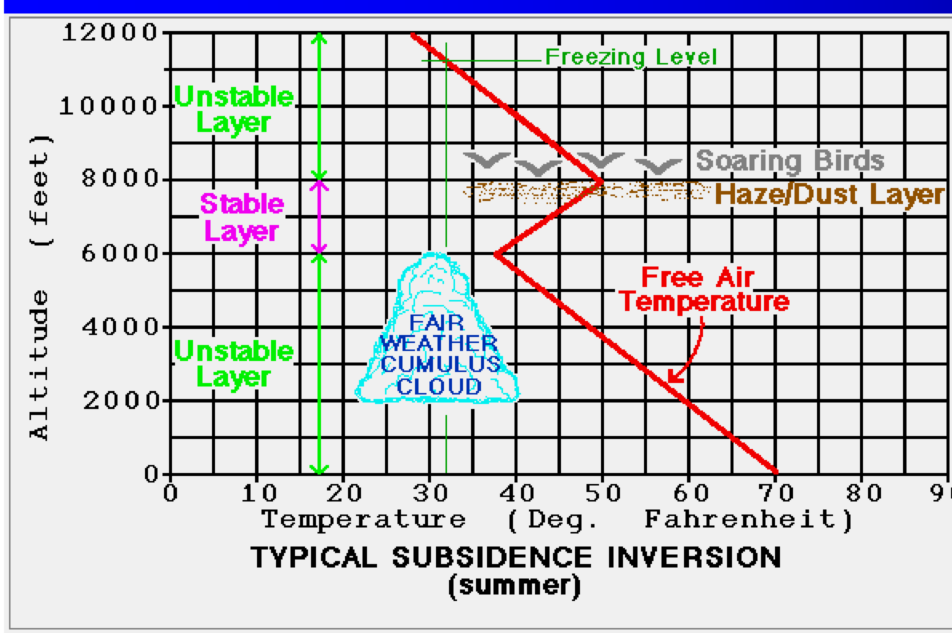
19 months of AZORES radar-lidar data

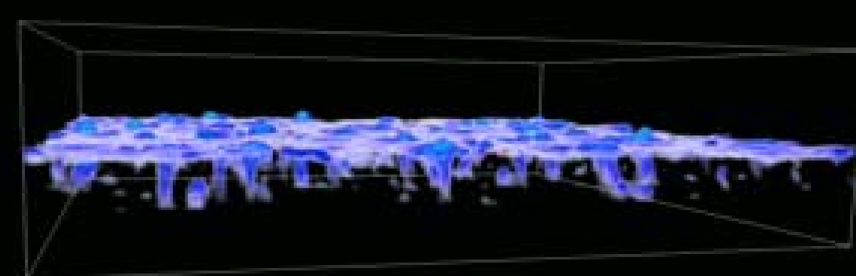


MBL cloud formation process



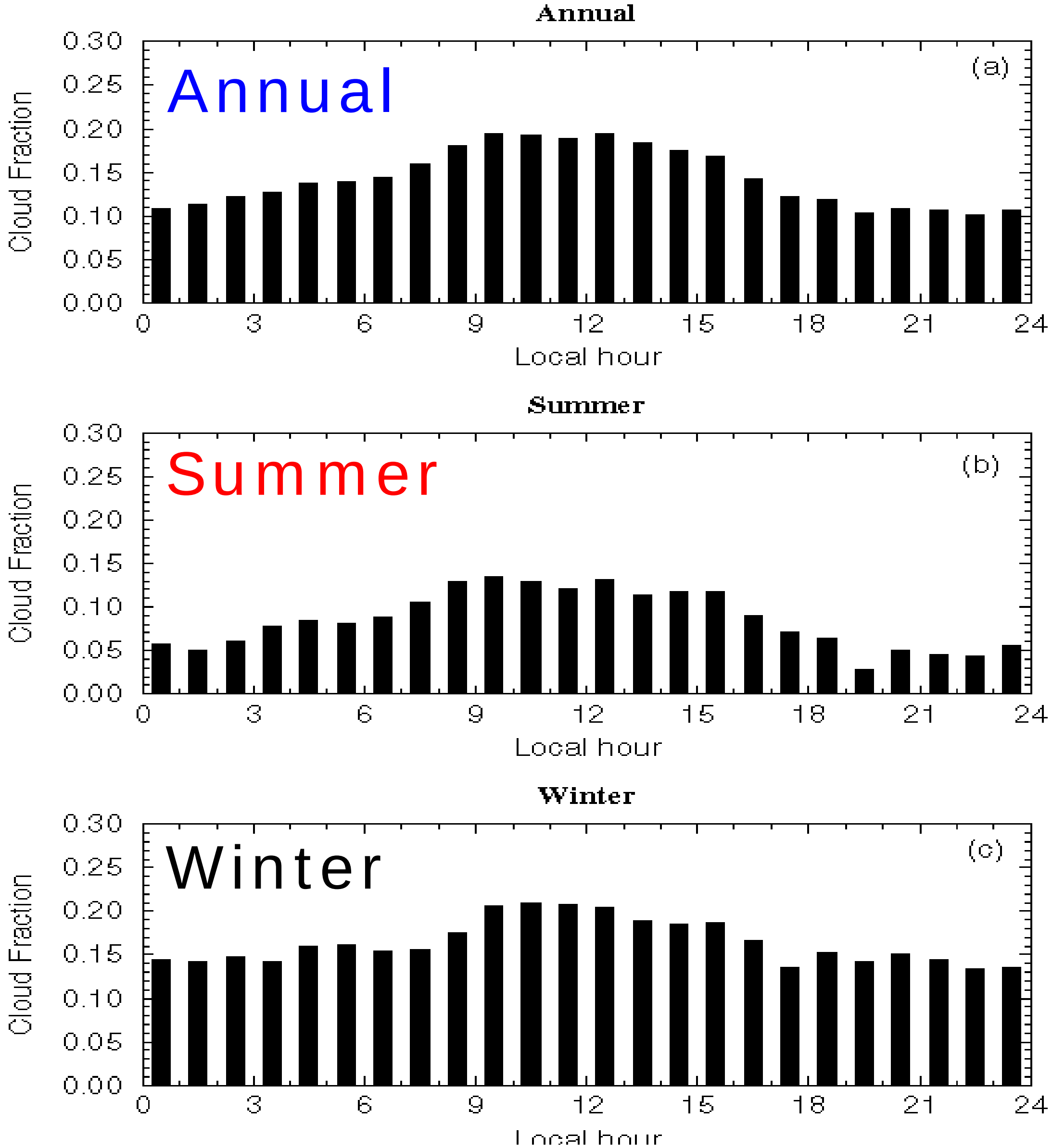






Courtesy:
Dr. Dave Stevens, LLNL

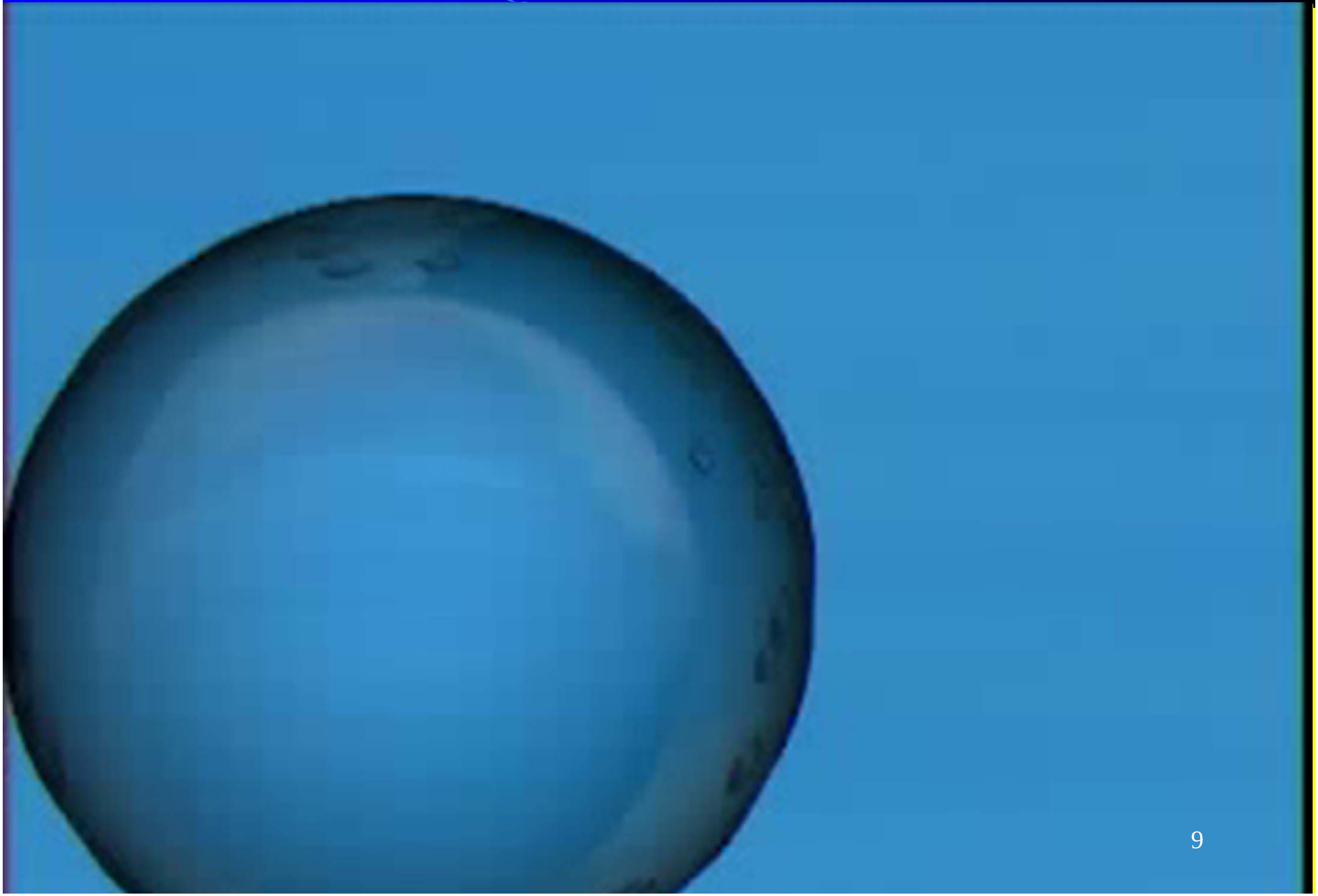
A NEW conceptual model of Continental Low-Level clouds (ARM SGP, Dong et al. J Clim 2005)



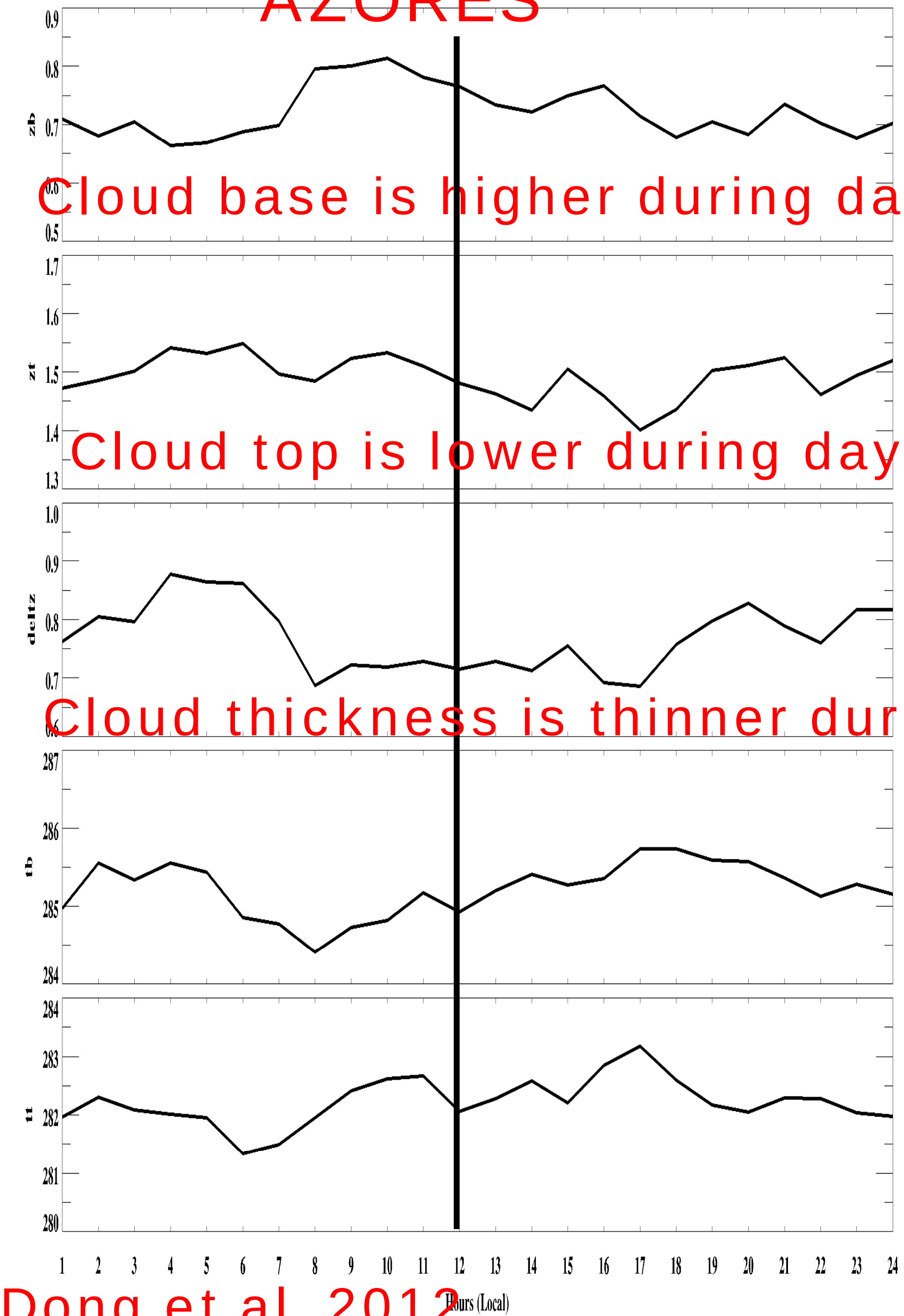
The low stratus cloud amount monotonically increases from midnight to early morning (0930 LT), and remains at a maximum until around local noon, then declines until 1930 LT when it levels off for the remainder of the night.

The diurnal cycle during the summer is much stronger than during the winter due to the summertime local convection.

Low cloud formation process over land

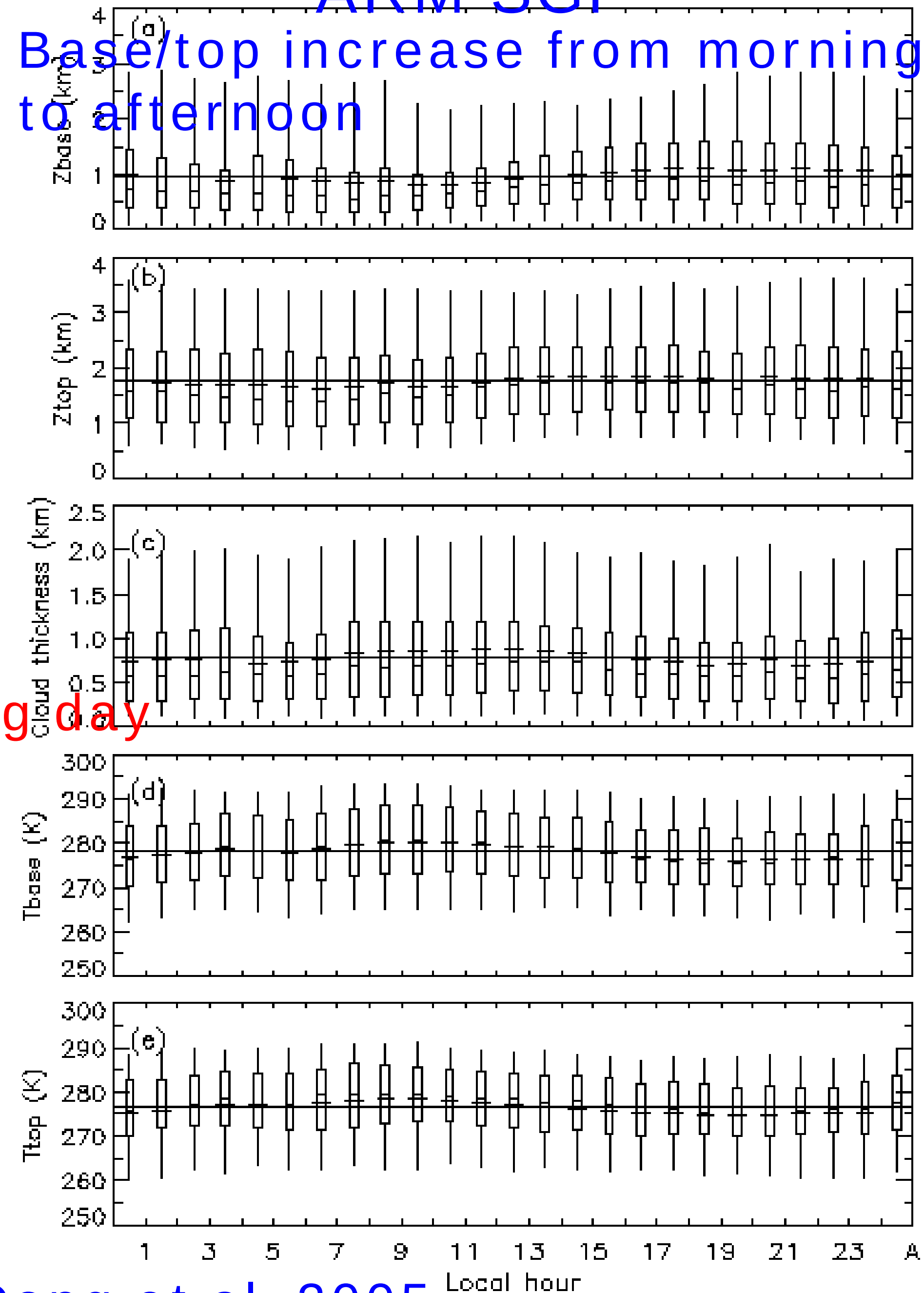


AZORES



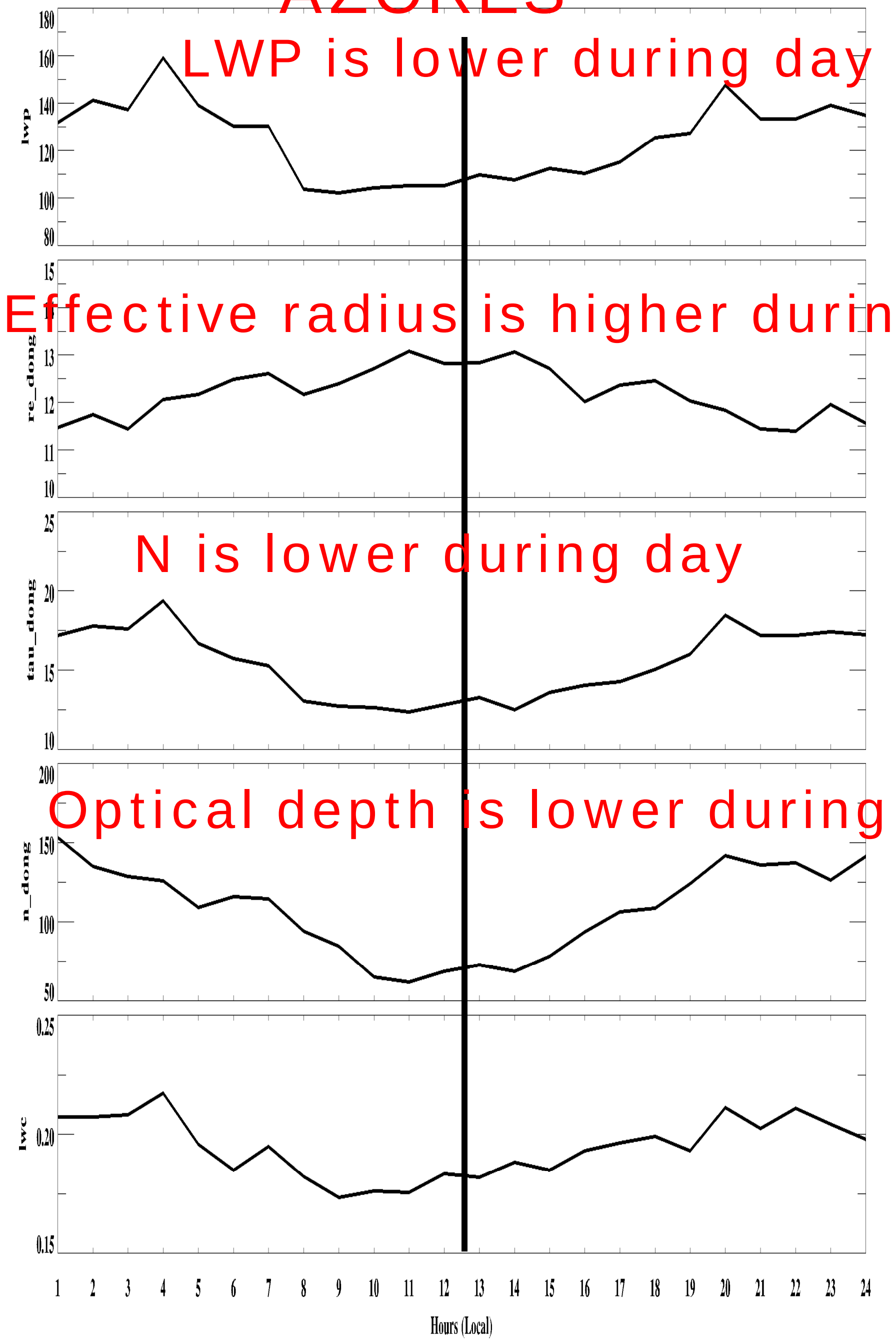
Dong et al. 2012

ARM SGP

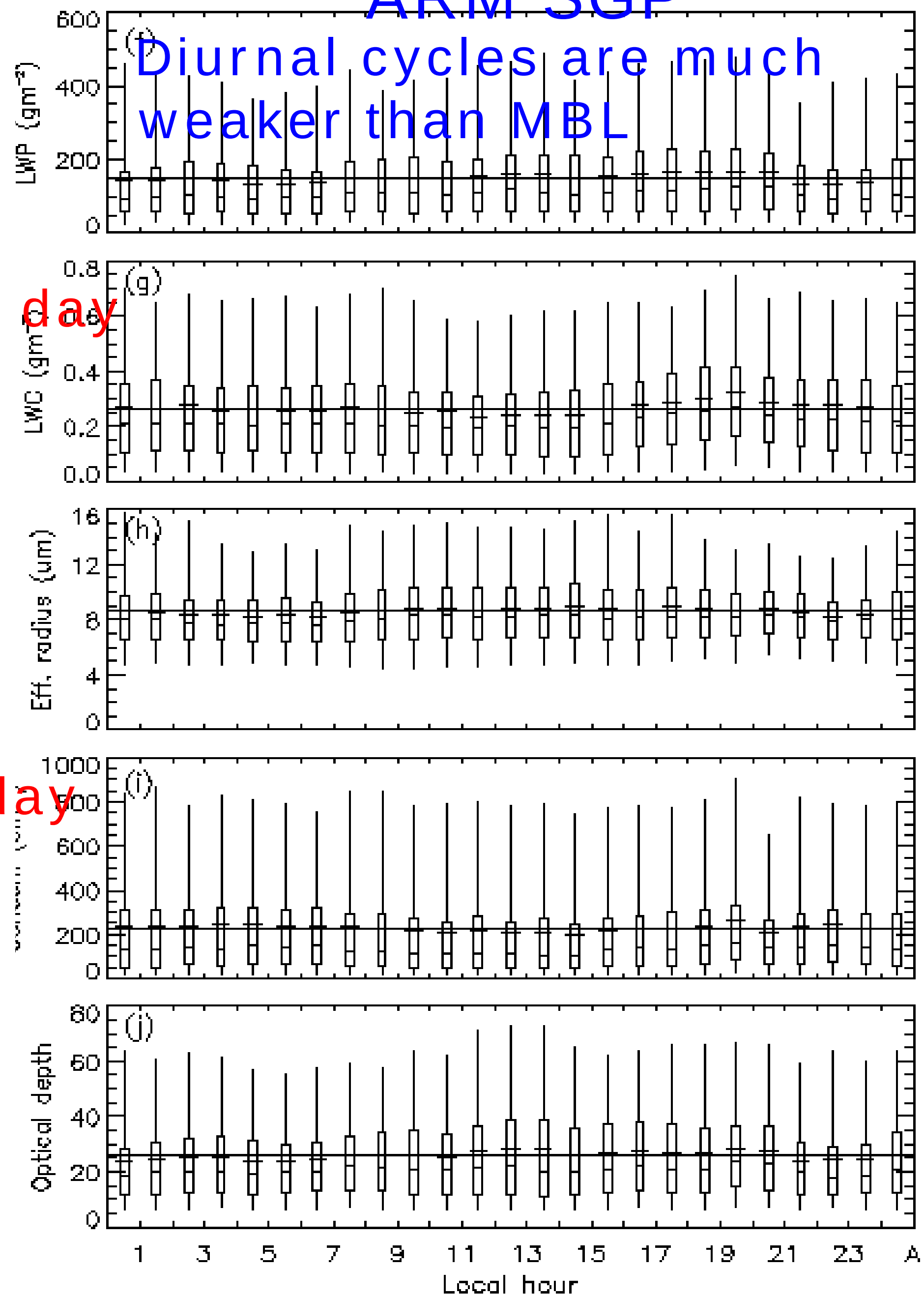


Dong et al. 2005

AZORES



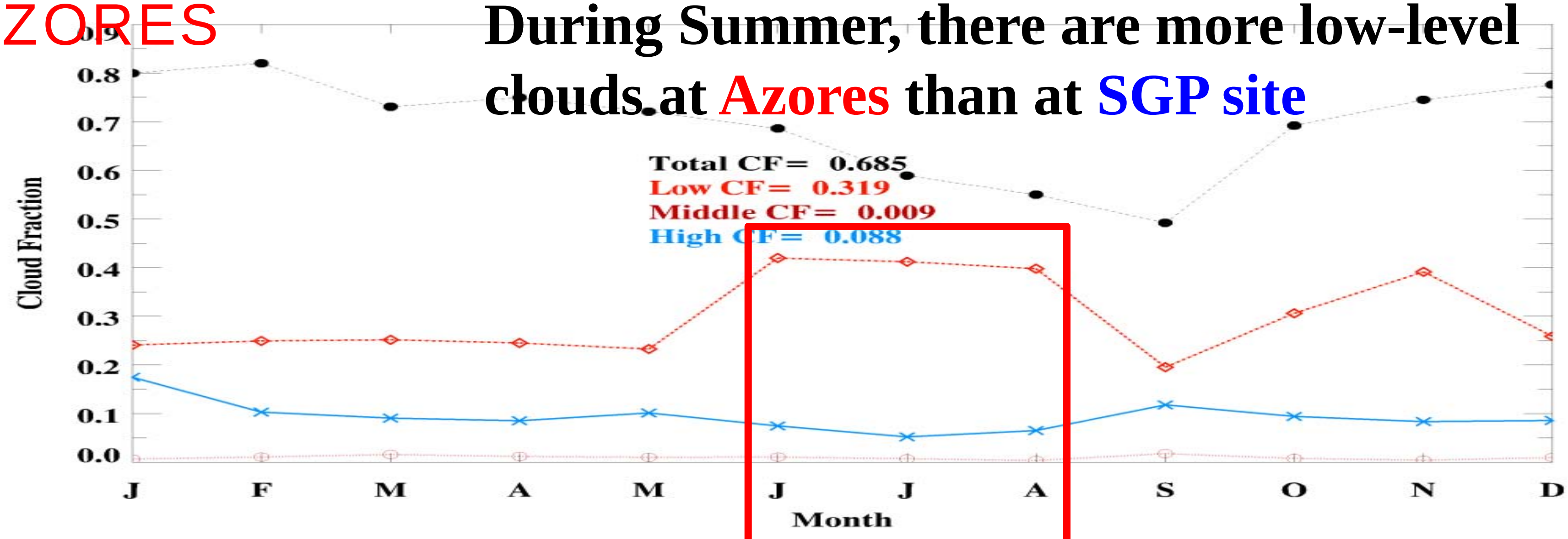
ARM SGP



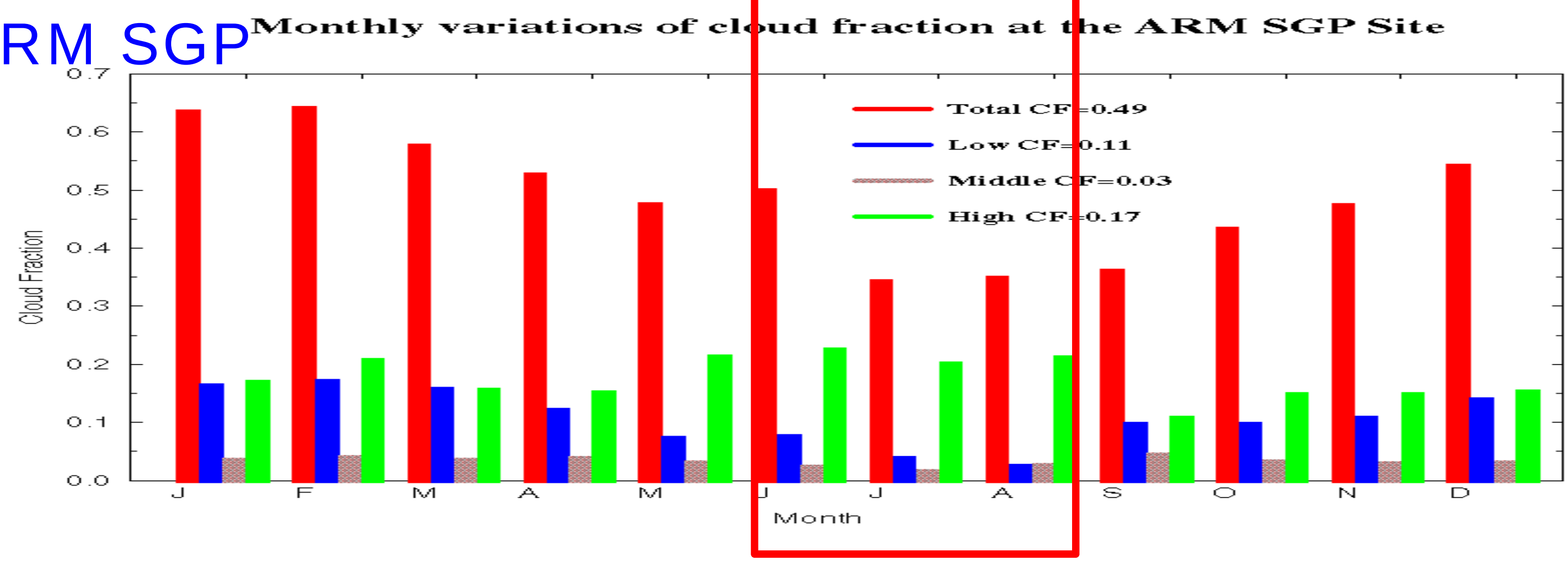
Seasonal Variations of CFs

AZORES

During Summer, there are more low-level clouds at Azores than at SGP site

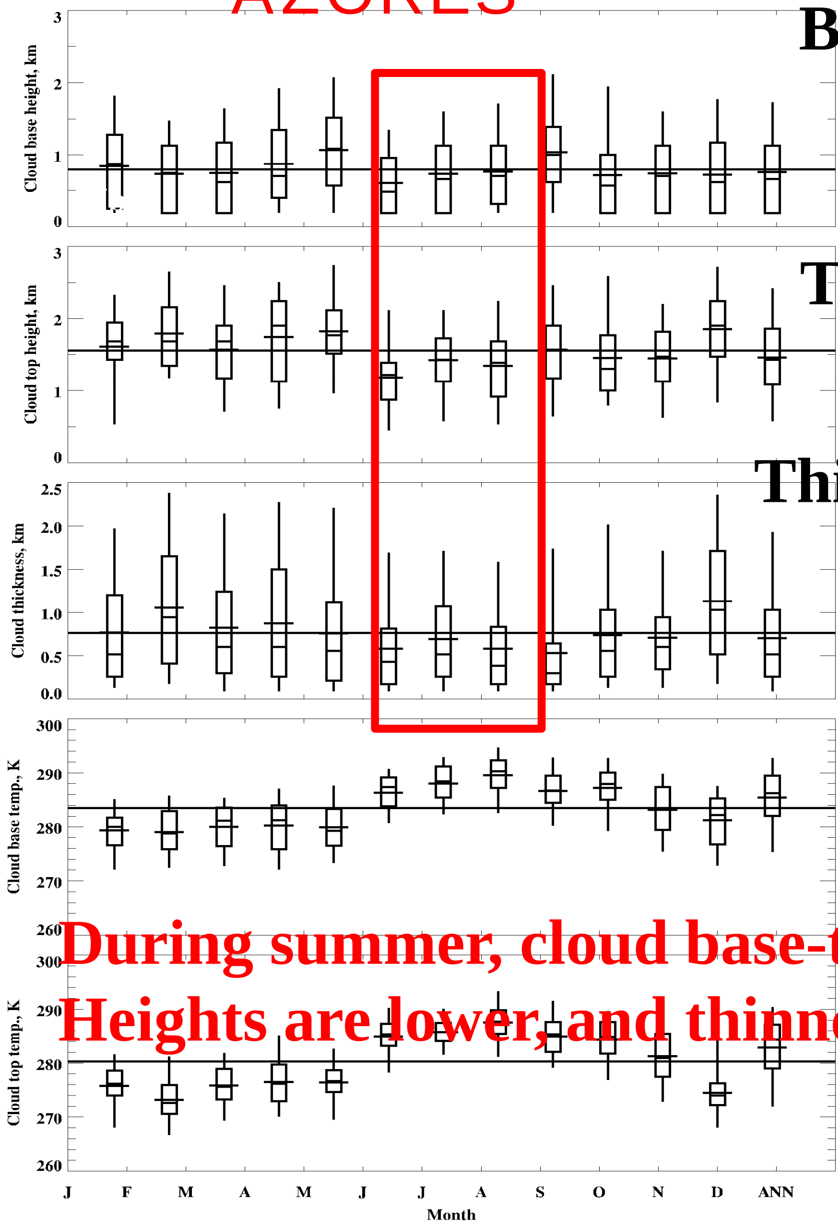


ARM SGP

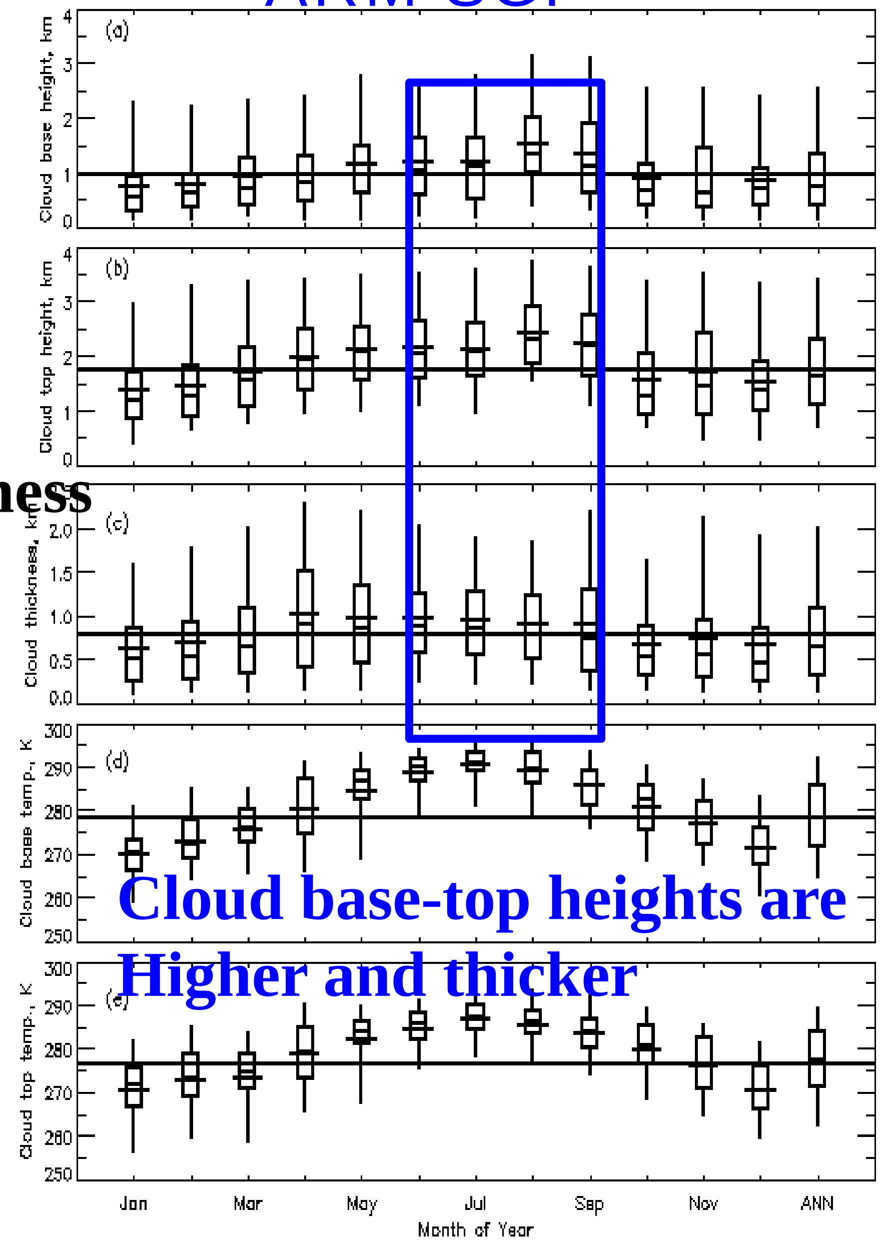


Seasonal Variations of height/temp

AZORES



ARM SGP



Base

Top

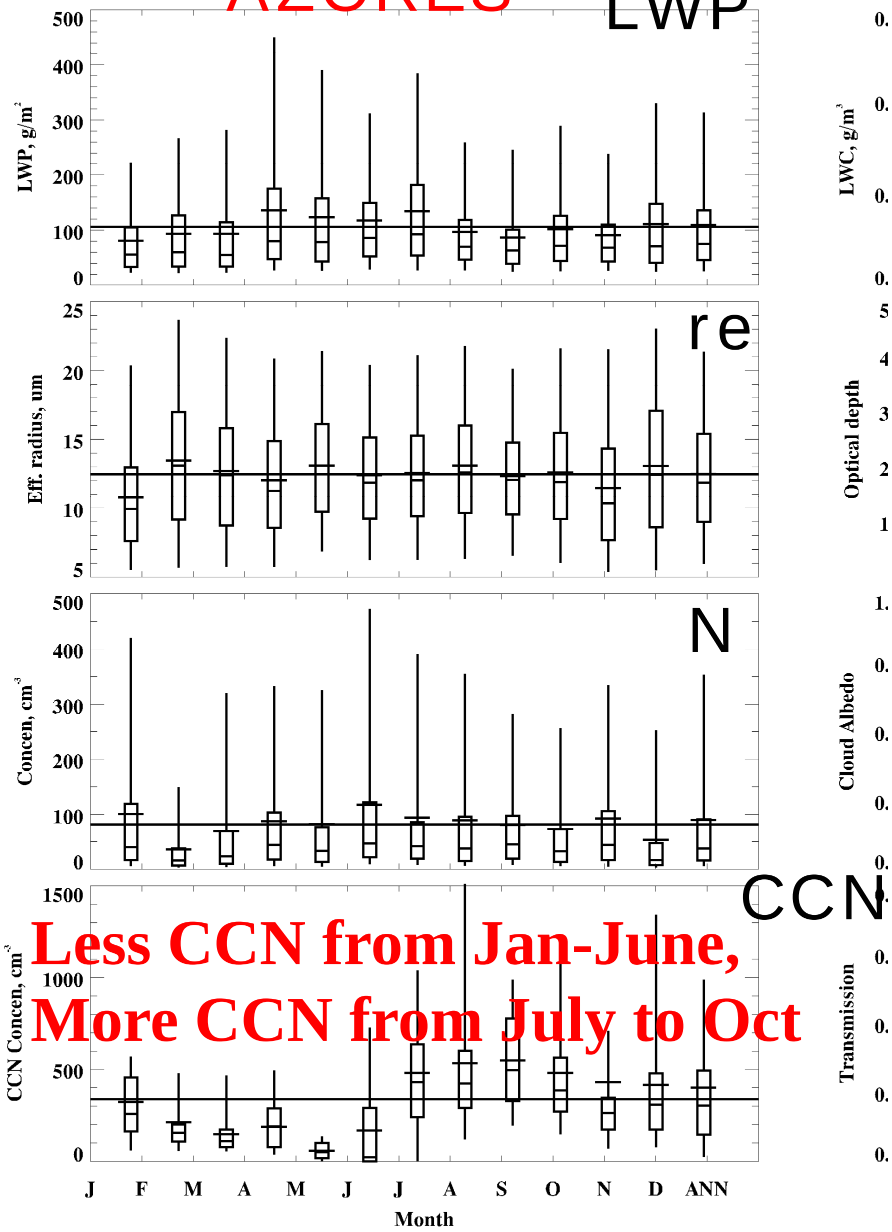
Thickness

During summer, cloud base-top Heights are lower, and thinner

Cloud base-top heights are Higher and thicker

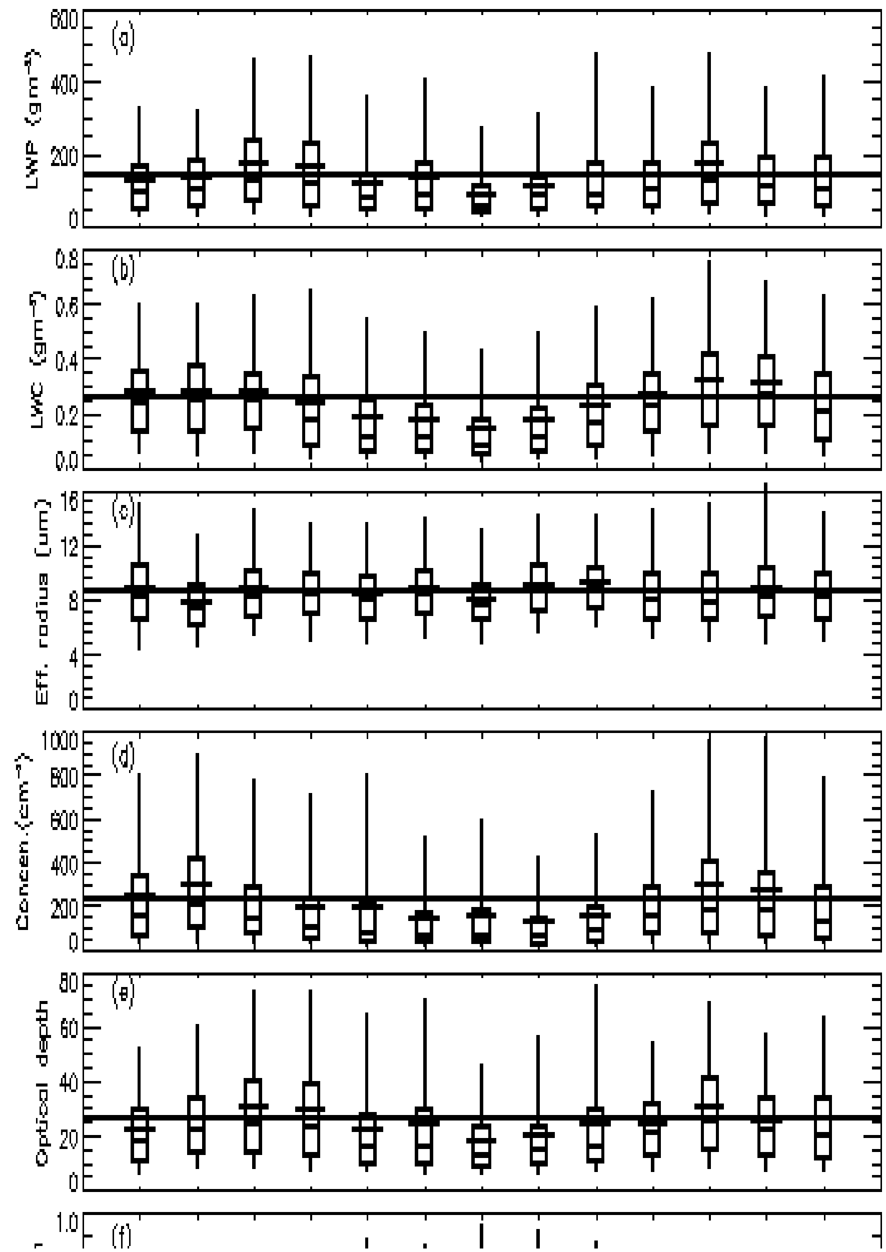
Seasonal Variations of LWP/re/N/tau

AZORES



Less CCN from Jan-June, More CCN from July to Oct

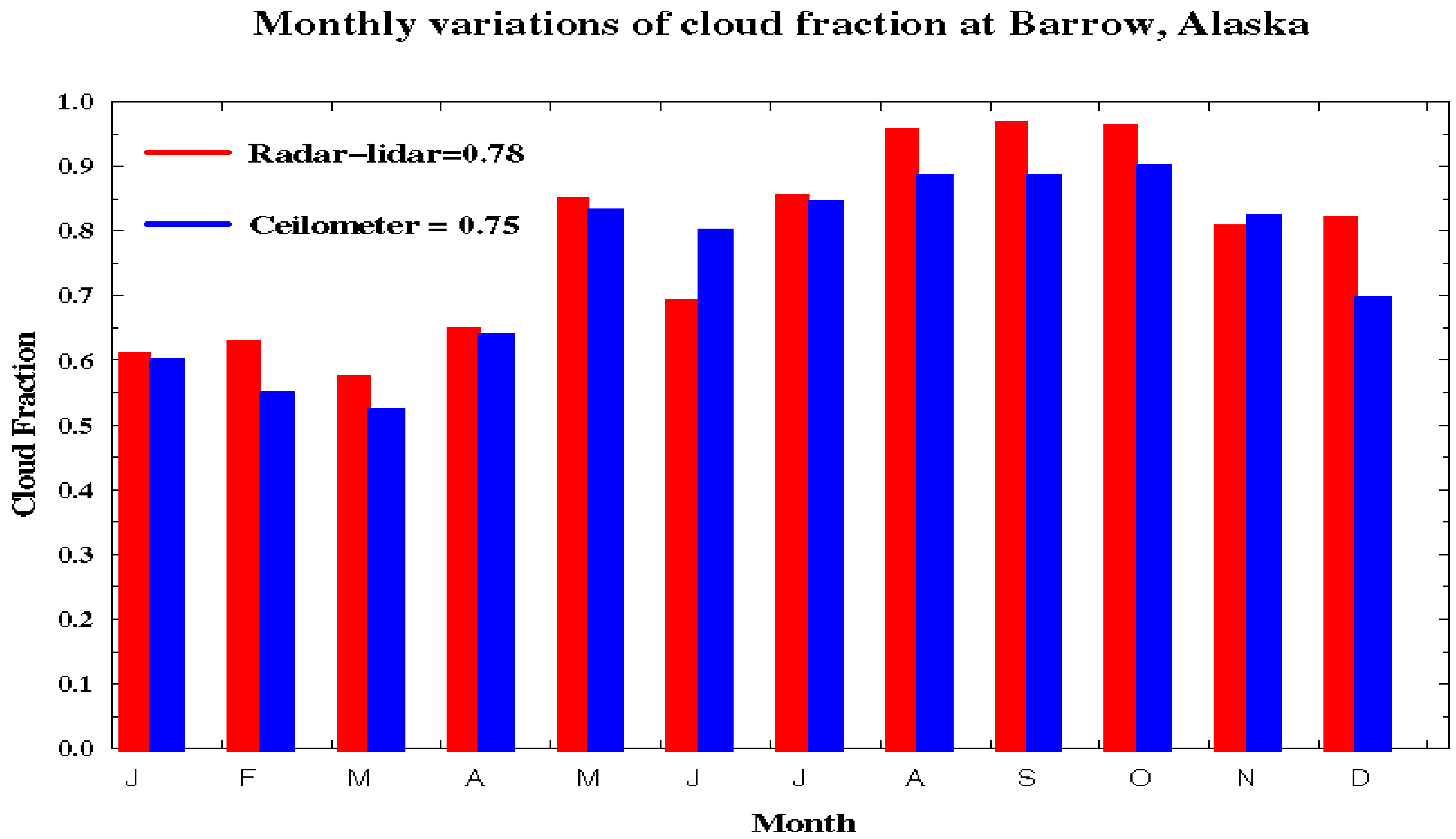
ARM SGP



Summary of AZORES and SGP clouds

Parameter	AZORES	SGP
Total CF	0.69	0.49
Low CF	0.32	0.14
Base height, km	0.72	0.97
Top Height, km	1.49	1.75
Thichness, km	0.77	0.78
LWP, gm^{-2}	124	144
LWC, gm^{-3}	0.19	0.26
re, um	12.2	8.6
N, cm^{-3}	108	226
Tau	15.4	26

What about Arctic Stratus clouds similarities and differences to warm clouds (Dong and Mace 2003, Dong et al. 2010)



More clouds from May to October at the ARM NSA site

What about Arctic Stratus clouds similarities and differences to warm clouds (Dong and Mace 2003, Dong et al. 2010)

➔**Arctic stratus clouds tend to last at least a few days, and even more than 10 days because the formation, maintenance, and dissipation processes of Arctic stratus clouds are significantly different from what typically occurs at the SGP site.**

➔**Arctic stratus clouds are formed very near the sea-ice surface if warm moist air advects over the cold Arctic Ocean (stable inversion layer), or by a convective-type process if cold polar air flows over a warmer sea-ice surface.**

What about Arctic Stratus clouds similarities and differences to warm clouds (Dong and Mace 2003, Dong et al. 2010)

➔**Once Arctic stratus clouds form, they persist. This is the significant difference between the Arctic and midlatitude stratus Clouds because the dissipative mechanisms found in the midlatitudes such as precipitation, convective heating from the surface, absorption of solar radiation, and destruction by synoptic activity are either nonexistent or relatively weak.**

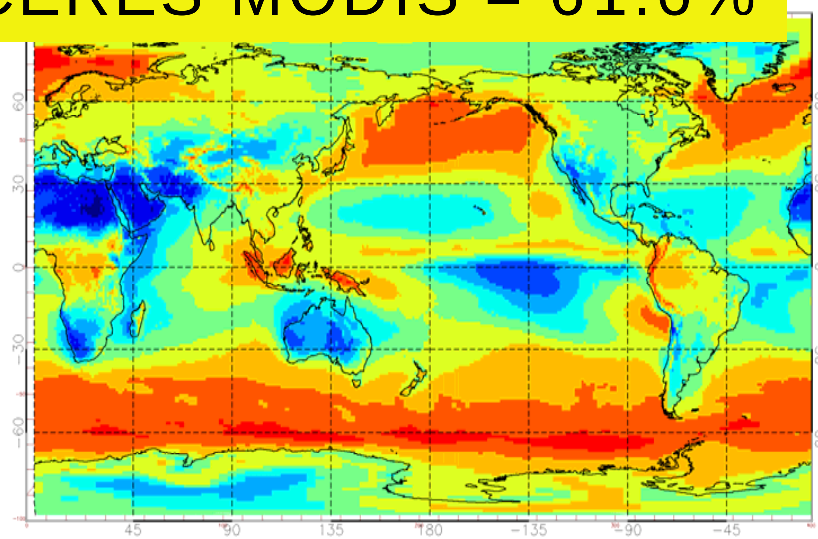
➔**The persistence of the cloud field occurs in a steady-state situation where dissipative processes are balanced by advection of air masses into a region where the synoptic regimes are suitable for cloud formation and maintenance.**

Challenge and Difficult for modelers to simulate low-level clouds

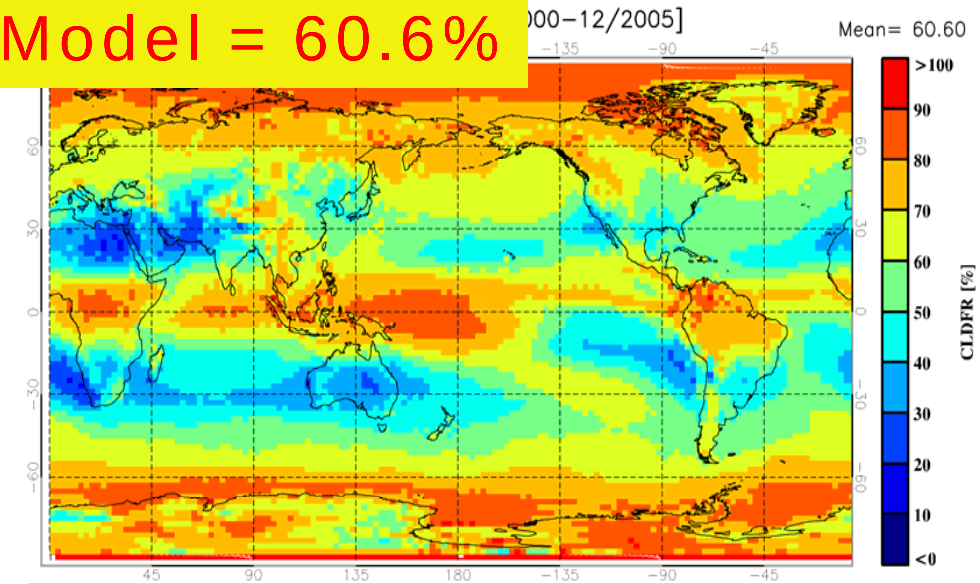
- Recent climate modeling results have revealed that the largest disagreement between coupled climate model simulations of present-day climate is found in the Arctic region (Gates et al. 1992; Tao et al. 1996). These results reflect the weakness of our current understanding of the sensitivity of the simulated Arctic climate to different formulations of various physical processes in global models (Randall et al. 1998).
- Because various climate models have different representations of cloud microphysical and radiative properties, an intercomparison of 19 GCMs produced a variety of cloud feedback results, ranging from modest negative to strong positive (Cess et al., 1990).
- An updated comparison by Cess et al. (1996) showed a more narrow difference with most models producing modest cloud feedback because they changed their cloud optical properties in the models, <u>such as an improper cloud droplet radius.</u>

CF comparison between CERES and GISS AR5

CERES-MODIS = 61.6%



Model = 60.6%

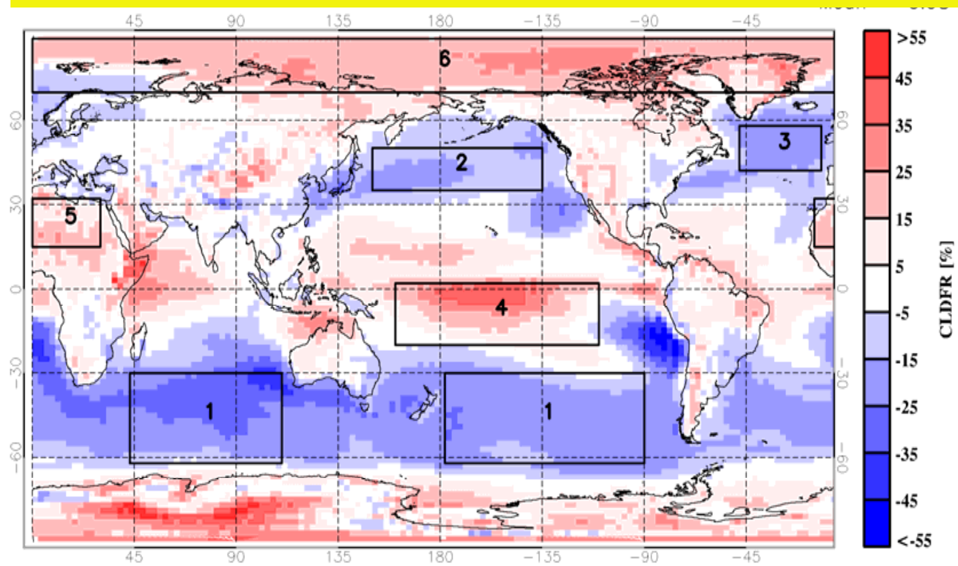


Although their global CF mean difference is 1%, there are significant differences over some regions.

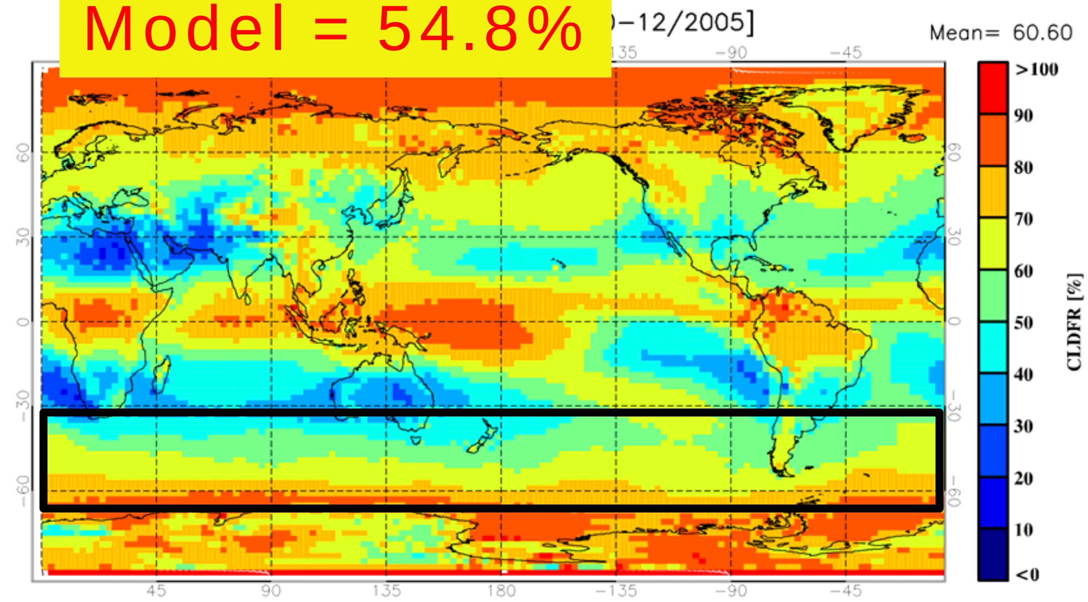
For example, GCM underestimates CFs in the South and North Mid-lat regions (1, 2, 3), mainly MBL clouds.

We will investigate the causes leading to these CF discrepancies. Is caused by cloud parameterization issues, or model dynamics, or a combination of the two.

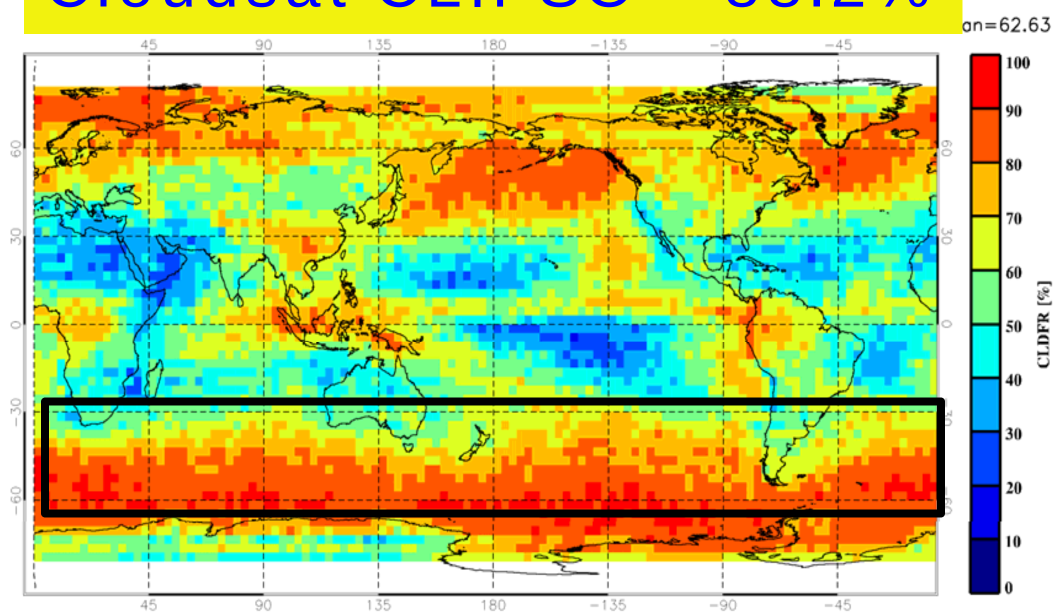
Model – CERES= -1.0%



Model = 54.8%



Cloudsat-CLIPSO = 88.2%



CF

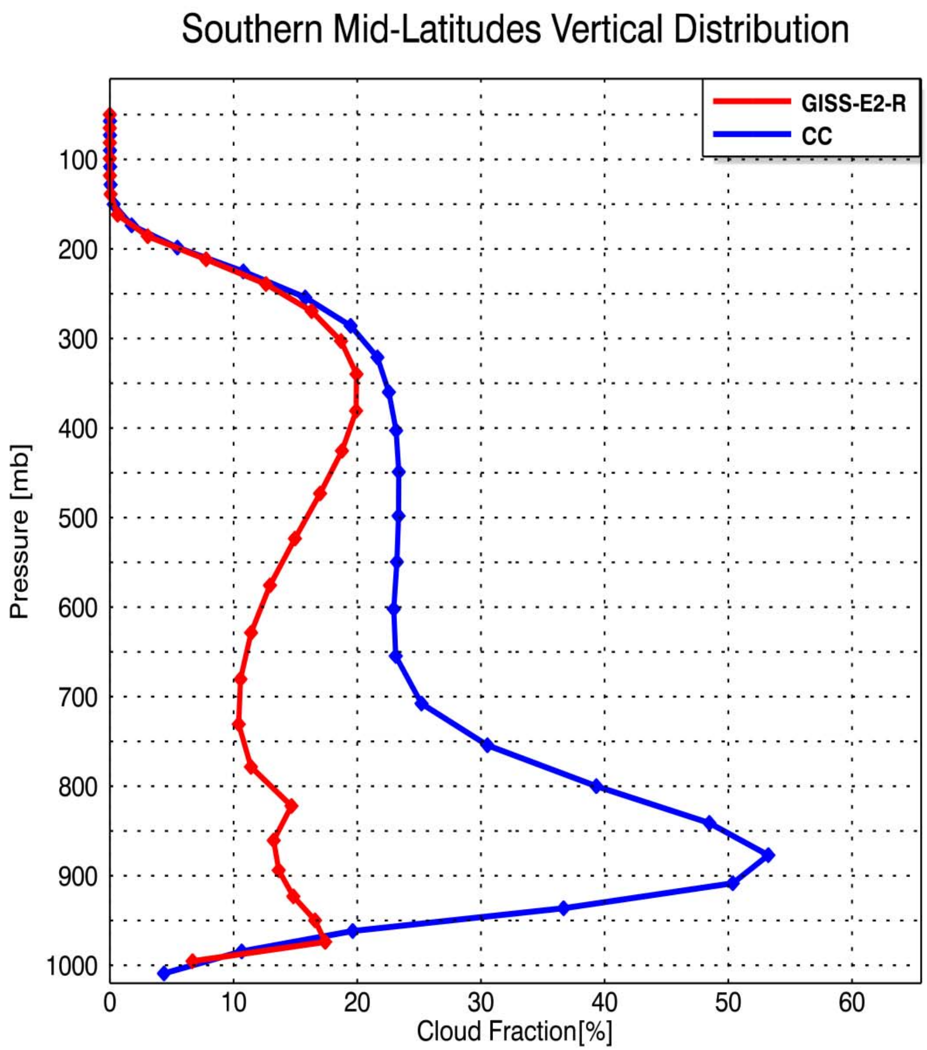
Global CF:
MODEL=60.6%
CC =62.6% (for tau>0.3)

Global CFs from MODEL and CC are nearly the Same, but

Over the southern mid-lat.
MODEL=54.8%
CC =88.2%

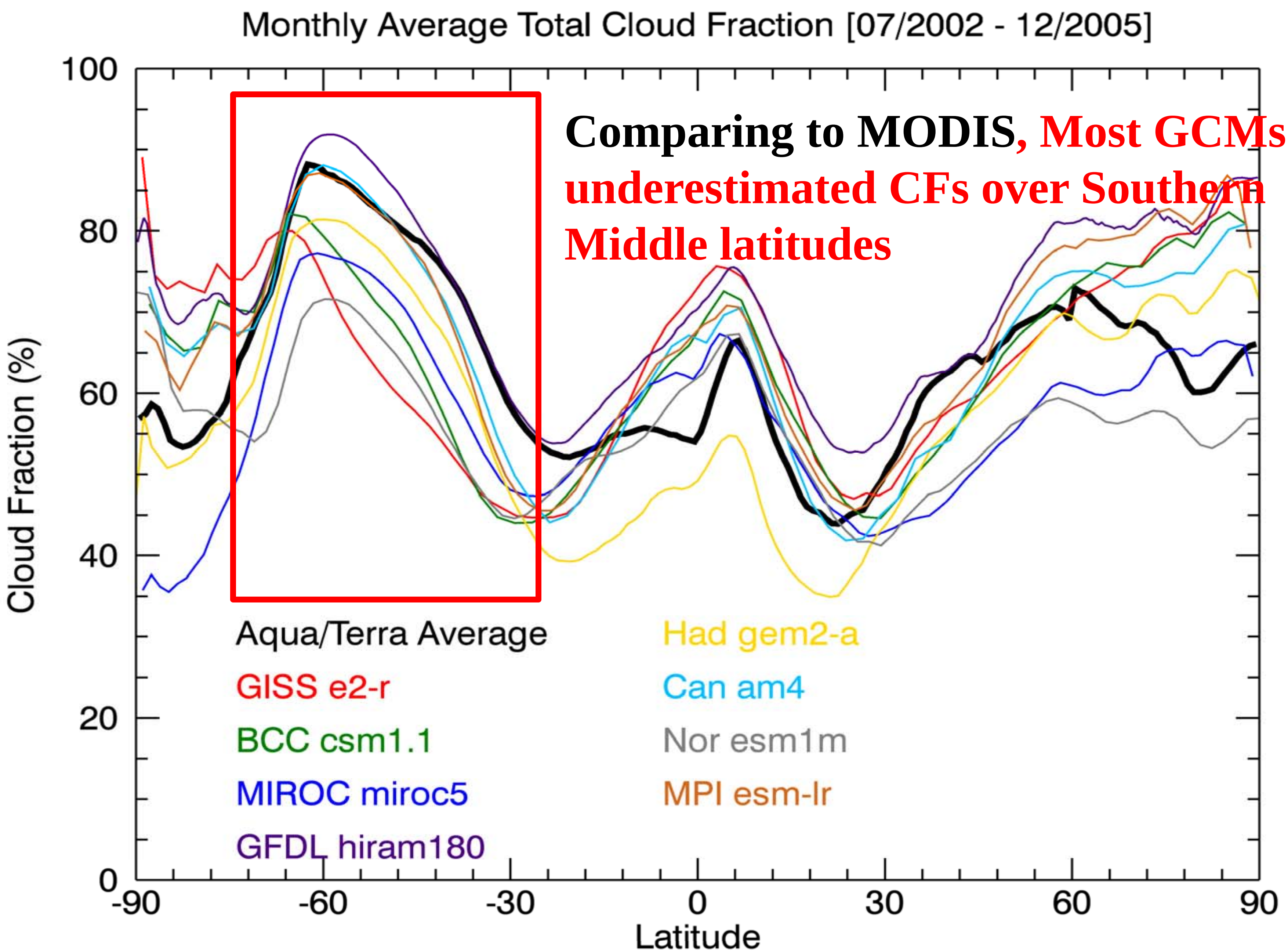
Model largely underestimates cloud fraction by 33.4% when compared to CC.

CF comparison between CC and AR5 over Southern Mid-lat. (Region 1)



CC vertical distributions are grouped into Model levels using maximum overlap within a model layer.

Compared to CC, Model underestimates low-level clouds, which may result in
1) lower SWup due to highly reflective low cloud
2) OLR differences should be small because cloud-top temperature is close to sea surface temperature.


Monthly Average Total Cloud Fraction [07/2002 - 12/2005]
Comparing to MODIS, Most GCMs underestimated CFs over Southern Middle latitudes
Cloud Fraction (%)
Latitude
100
80
60
40
20
0
-90
-60
-30
0
30
60
90
Aqua/Terra Average
GISS e2-r
BCC csm1.1
MIROC miroc5
GFDL hiram180
Had gem2-a
Can am4
Nor esm1m
MPI esm-lr

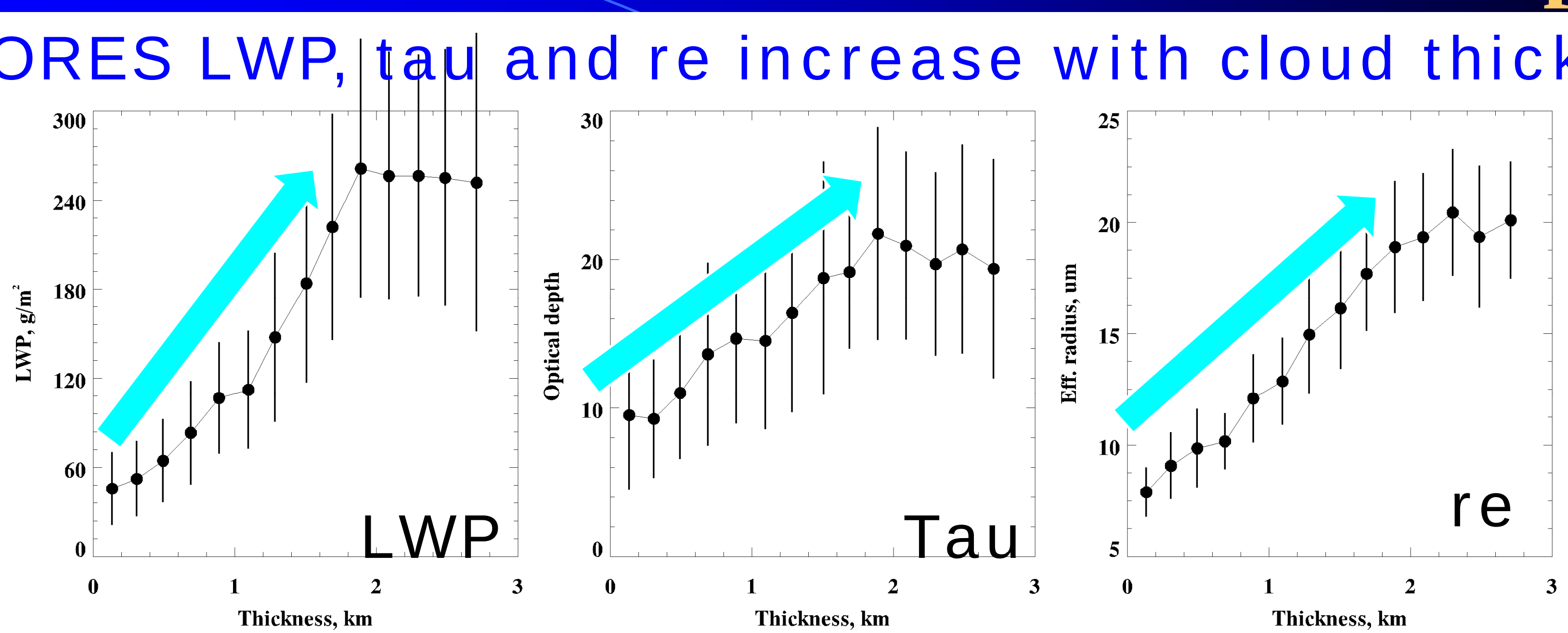
How do ARM/ASR data/results can help

Most GCMs require bulk cloud microphysical/optical parameterizations that can be directly used in GCM simulations. The cloud LWC/LWP can be provided by either diagnostic (Cess et al. 1990) or prognostic (Del Genio et al. 1996) schemes. However, even in modern sophisticated climate models the treatment of clouds is overly simplistic (Del Genio et al. 1996). This is partially due to the wide degree of variability in relevant cloud properties at both large and small scales.

Processes leading to cloud formation and which determine their interaction with atmospheric radiation cannot be fully resolved in large-scale climate/forecast models. Thus the treatment of clouds must rely on parameterizations that relate the small-scale cloud properties of importance to the large-scale variables those can be handled by the models.

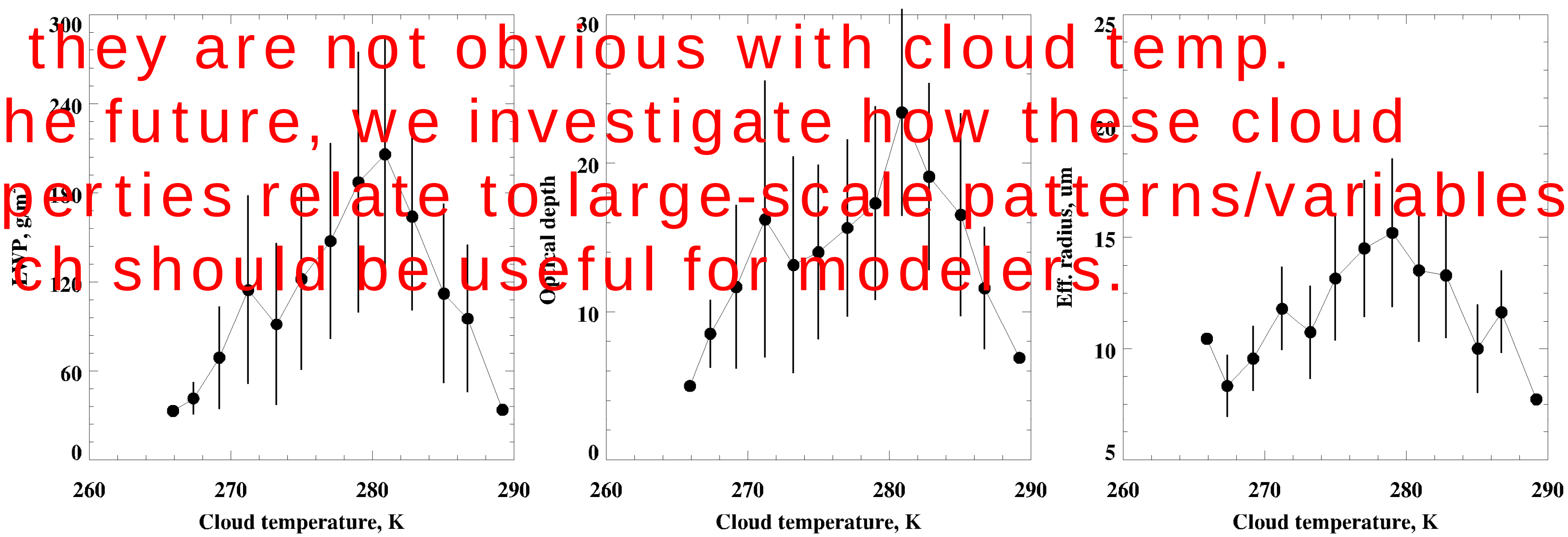
How do ARM/ASR data/results can help

AZORES LWP, tau and re increase with cloud thickness



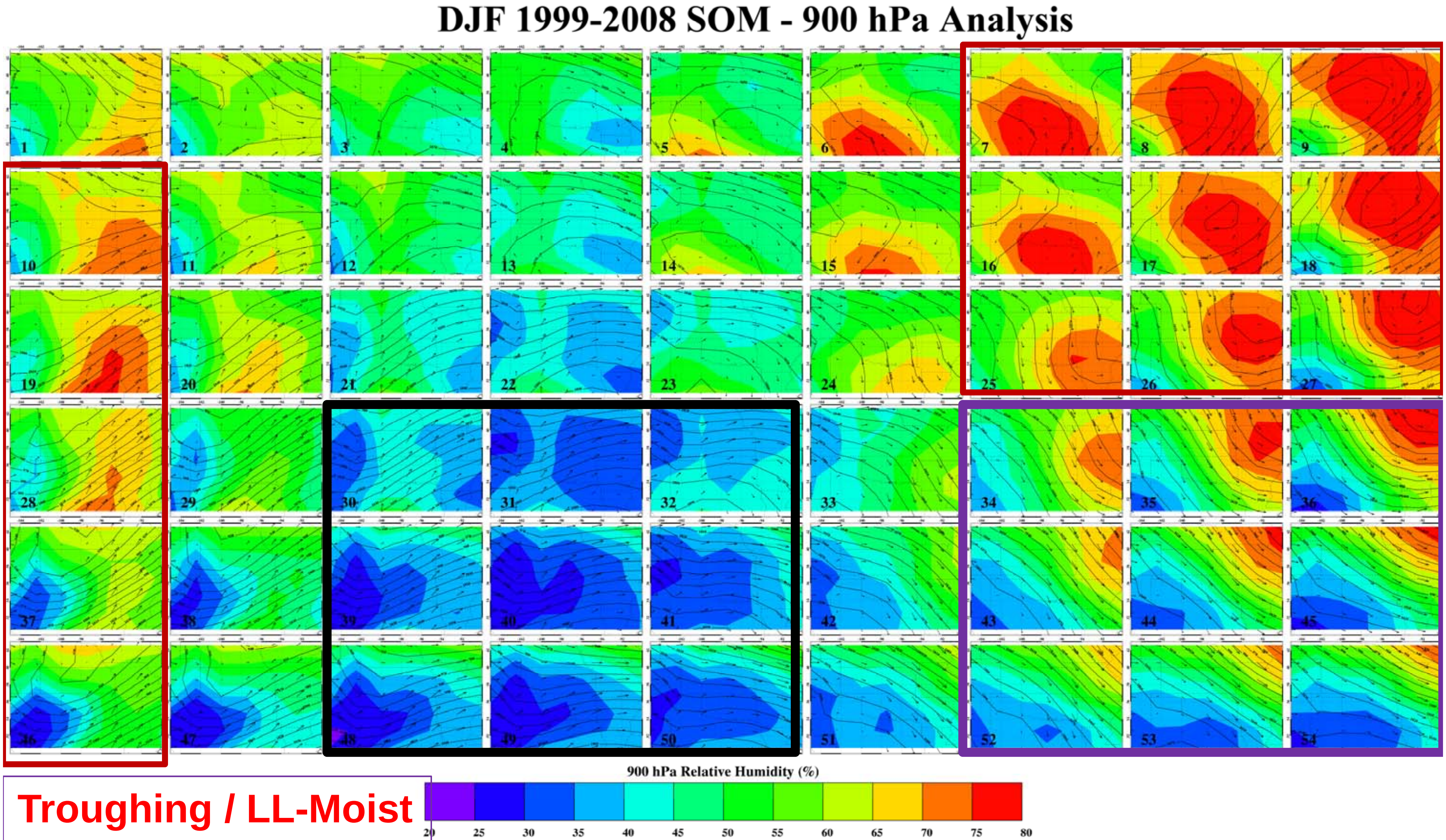
But they are not obvious with cloud temp.

In the future, we investigate how these cloud properties relate to large-scale patterns/variables, which should be useful for modelers.



Backup slide

SGP Synoptic Patterns



Troughing / LL-Moist
Post-Frontal
Quiescent/LL-Dry

Kennedy et al. 2012

We Keep Enhancing the ARM Cloud Retrieval Ensemble Dataset (ACRED)

11 ARM Ground-Based Cloud Retrievals

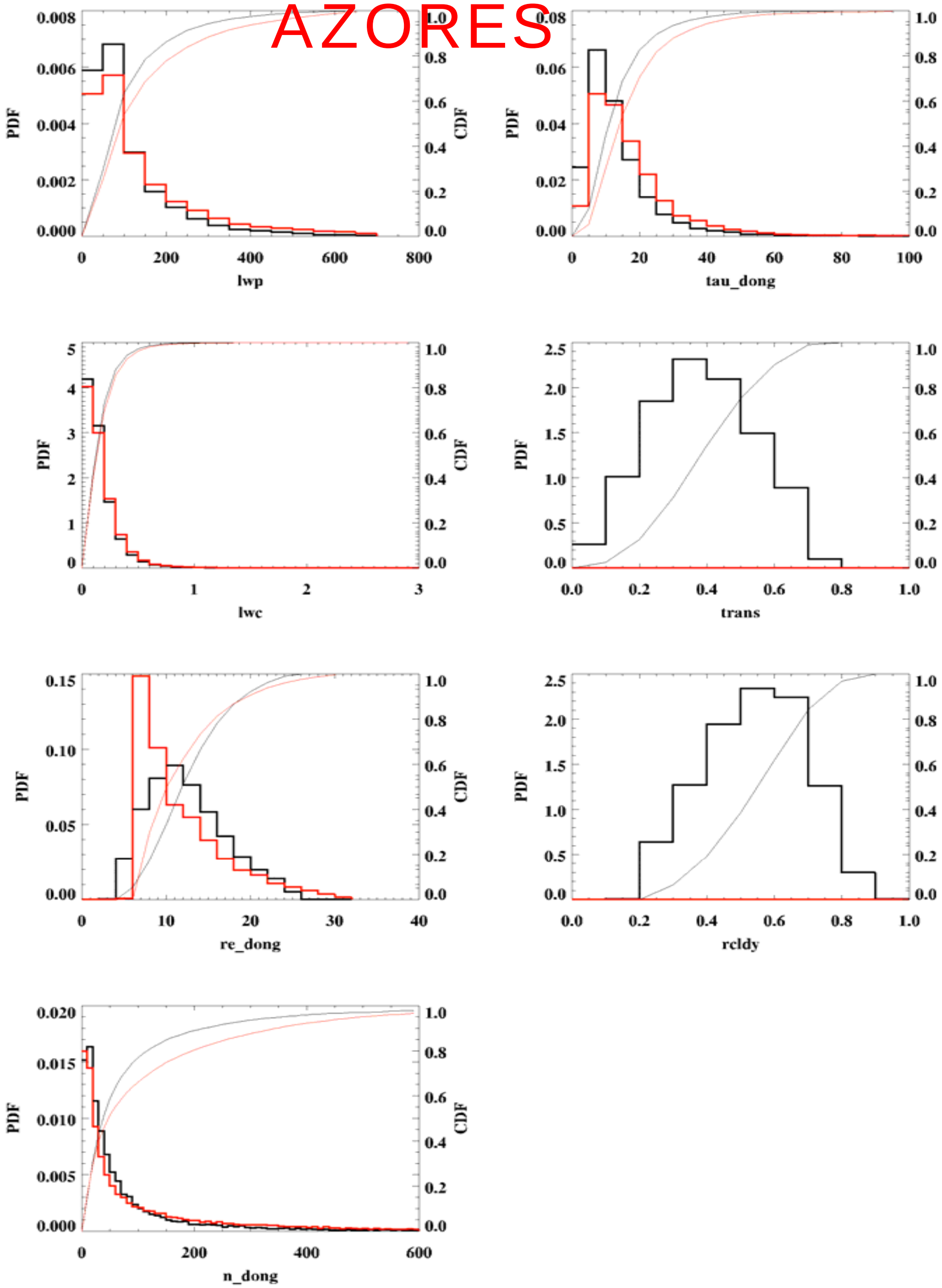
- **ACRED has been updated and the number of retrievals has been increased from 9 to 11 since its initial release (i.e., *MIN and DONG's data were added*)**

Thanks to all relevant PIs!!!

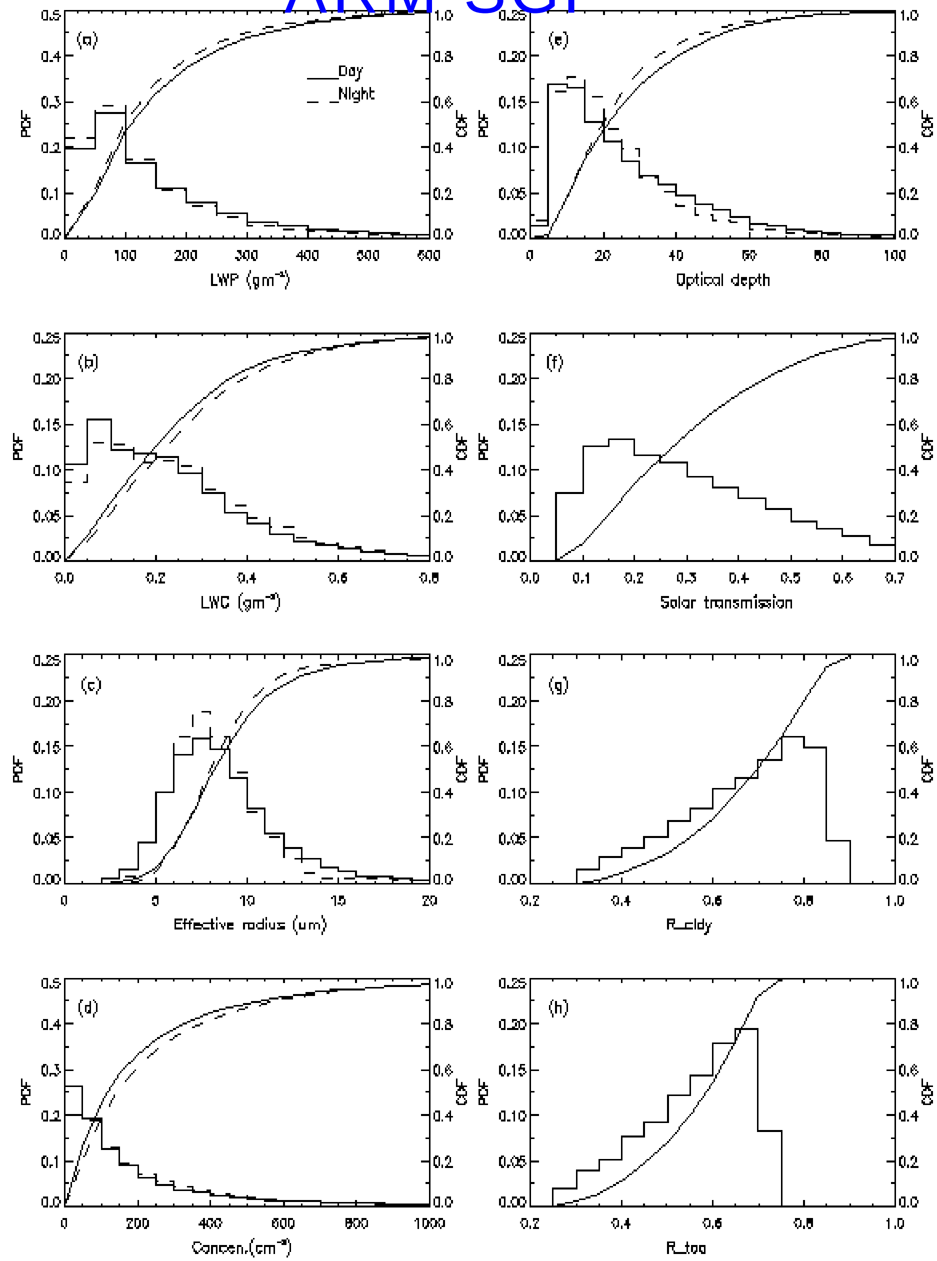
Location of DOE ARM sites

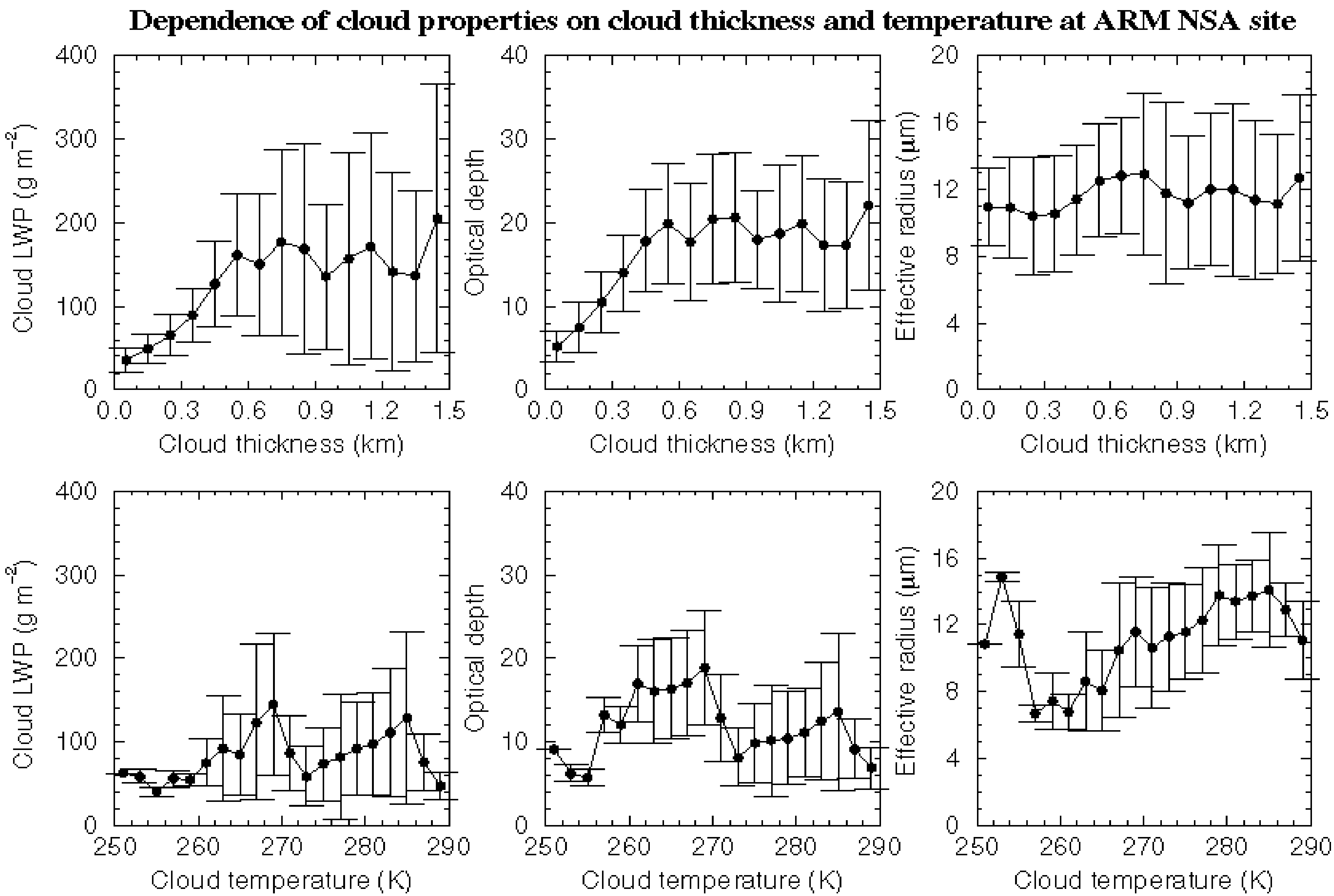
PDFs of LWP/re/N/tau

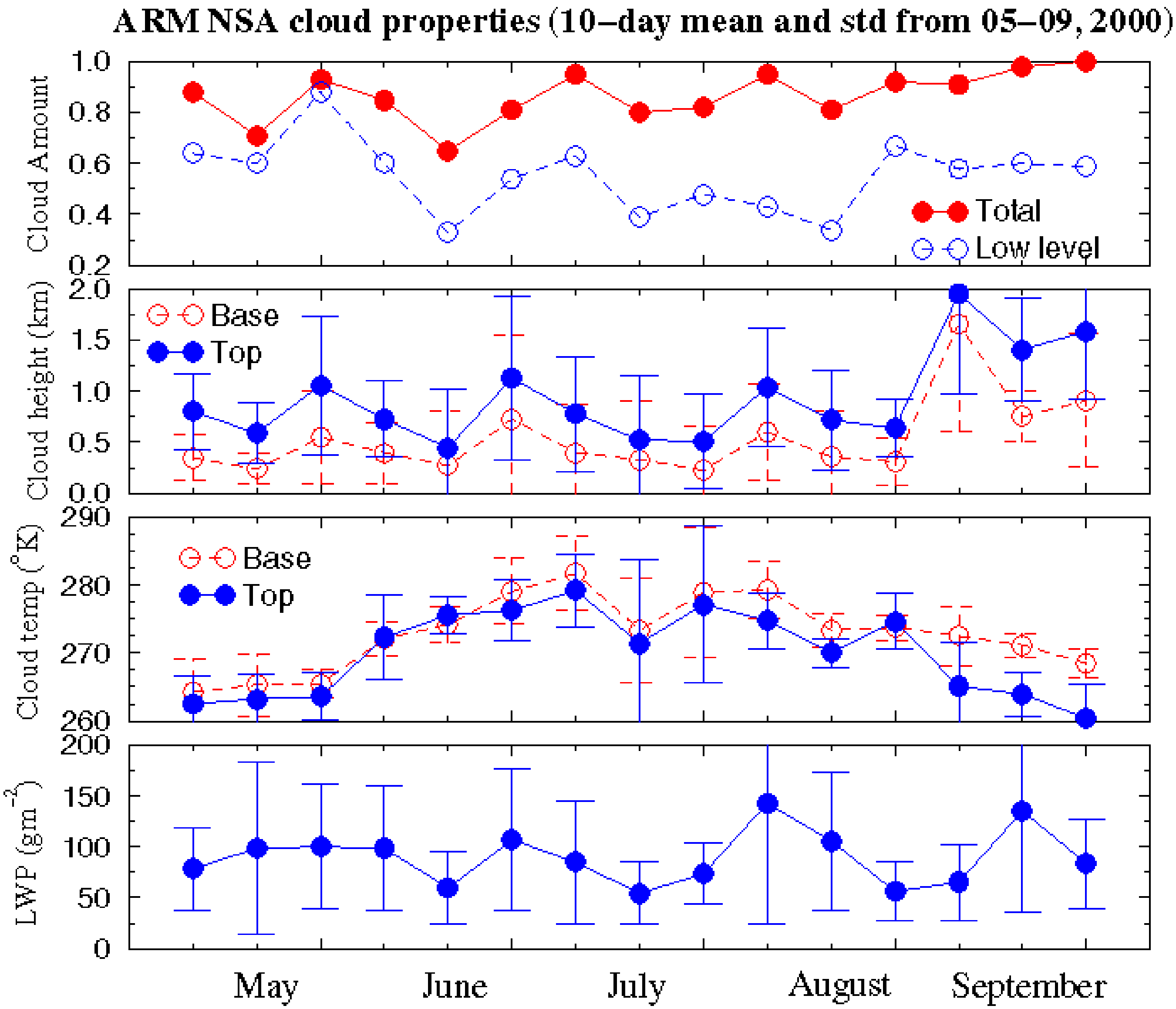
AZORES



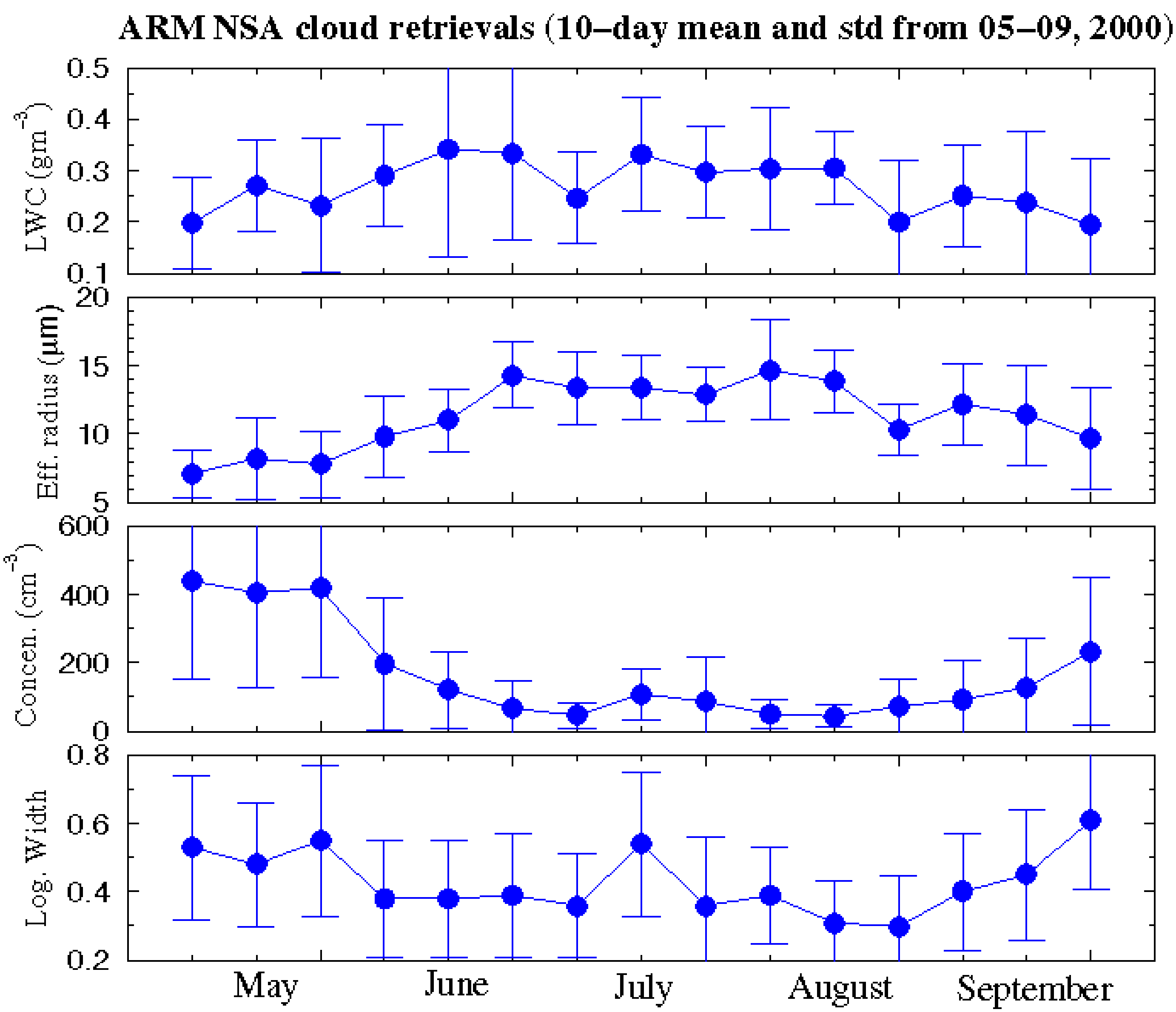
ARM SGP




Dependence of cloud properties on cloud thickness and temperature at ARM NSA site
Cloud LWP (g m-2)
Optical depth
Effective radius (μm)
Cloud thickness (km)
Cloud temperature (K)



Dong and Mace 2003



Dong and Mace 2003