

# Characterization of Polar Mixed-phase Clouds and Tropical Convective Clouds with **Multi-sensor Data fusion**

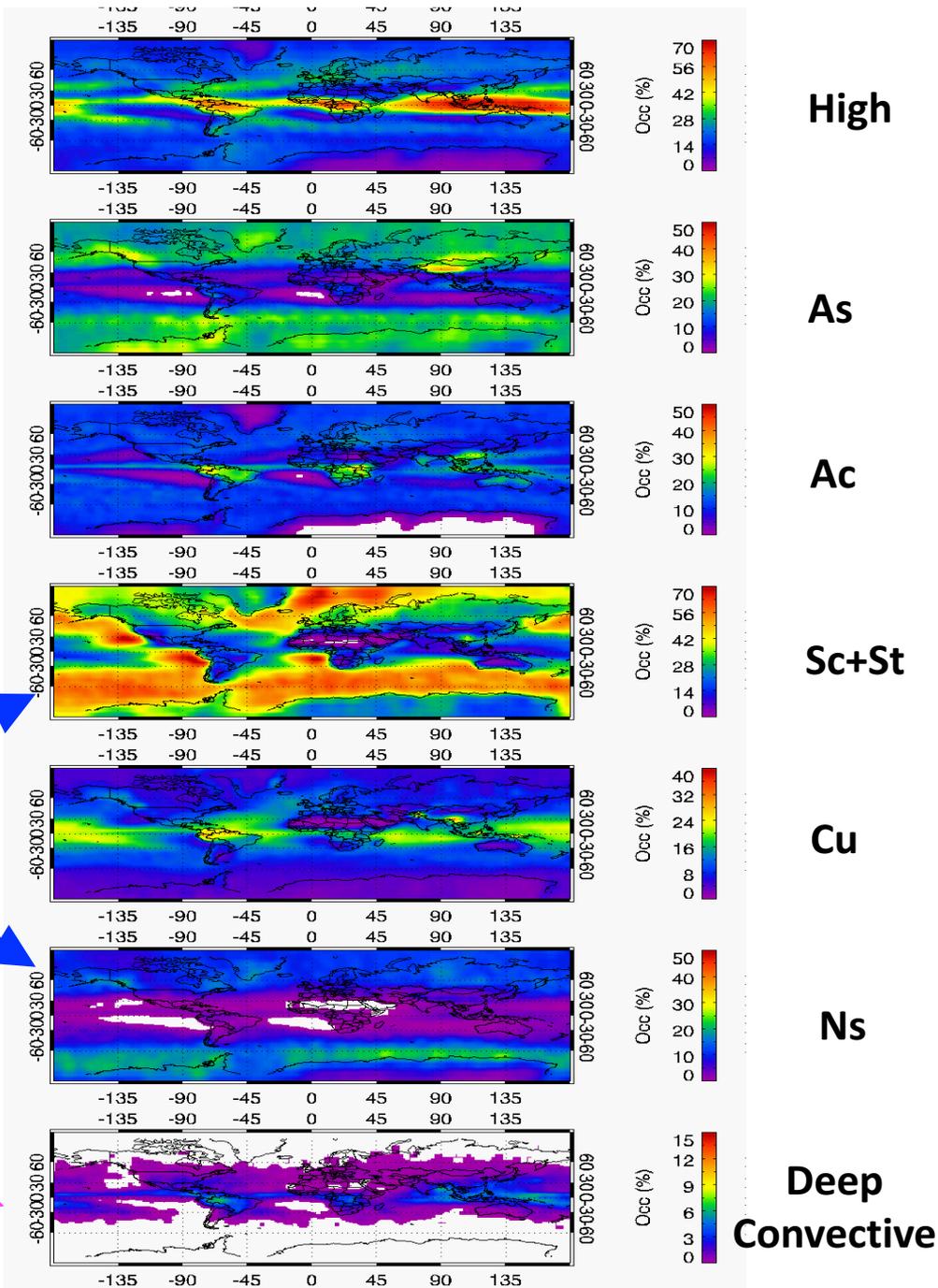
Zhien Wang, Sujana Khanal, and Min Deng

**Supported by NASA**

# Multi-sensor data (**MODIS**, **CloudSat** **radar** and **CALIPSO** **Lidar**, ...) fusion to better Characterize:

► Stratiform mixed-phase clouds

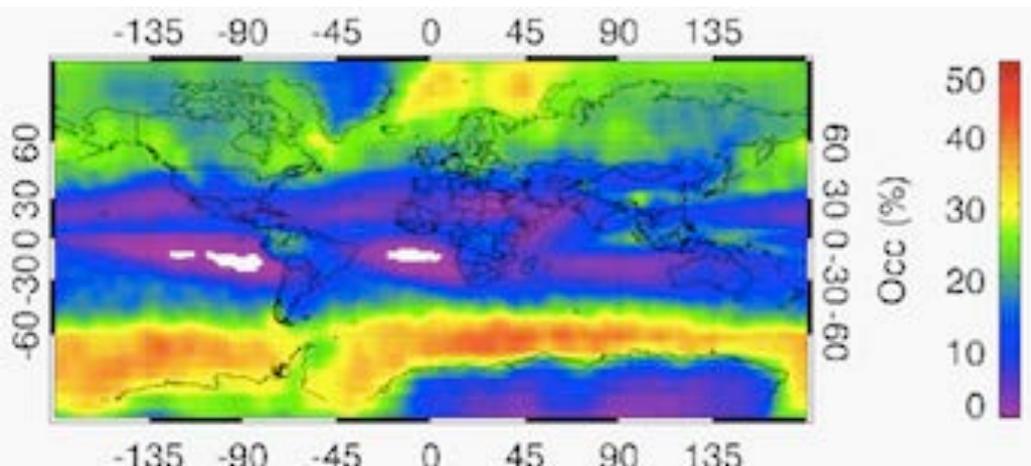
► Tropical convective clouds



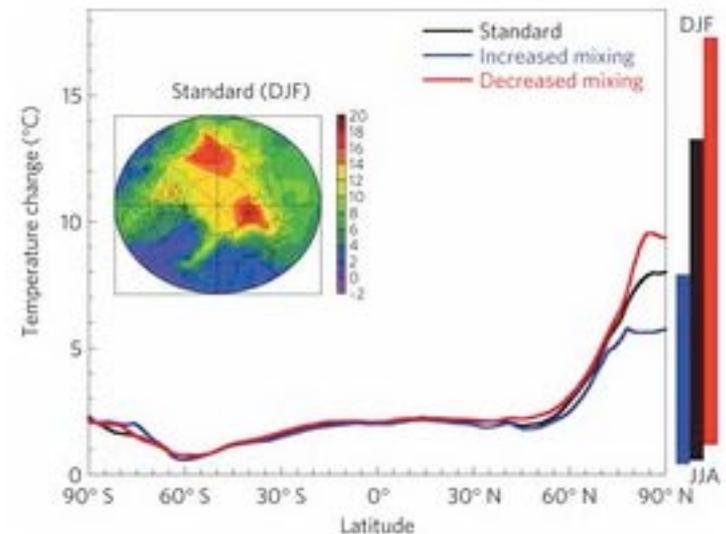
# Motivations

*Why these Stratiform mixed-phase clouds*

- Wide spreading of stratiform mixed-phase clouds in Polar Regions.
- Fast temperature increases in Polar Regions.



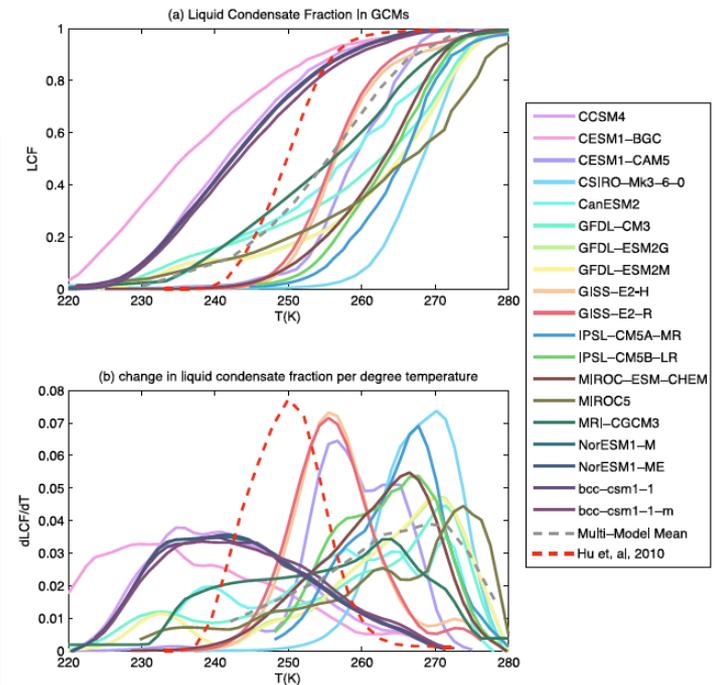
**Annual mean mixed-phase  
cloud distribution from 5-year  
2B-CLDCLASS-lidar**



Bintanja, et al., *Nature Geoscience* **4**,  
758–761 (2011)  
doi:10.1038/ngeo1285

# Cloud Phase Changes Contribute to Large Cloud Radiative Forcing Changes and Inter-model Differences In CAMIP5

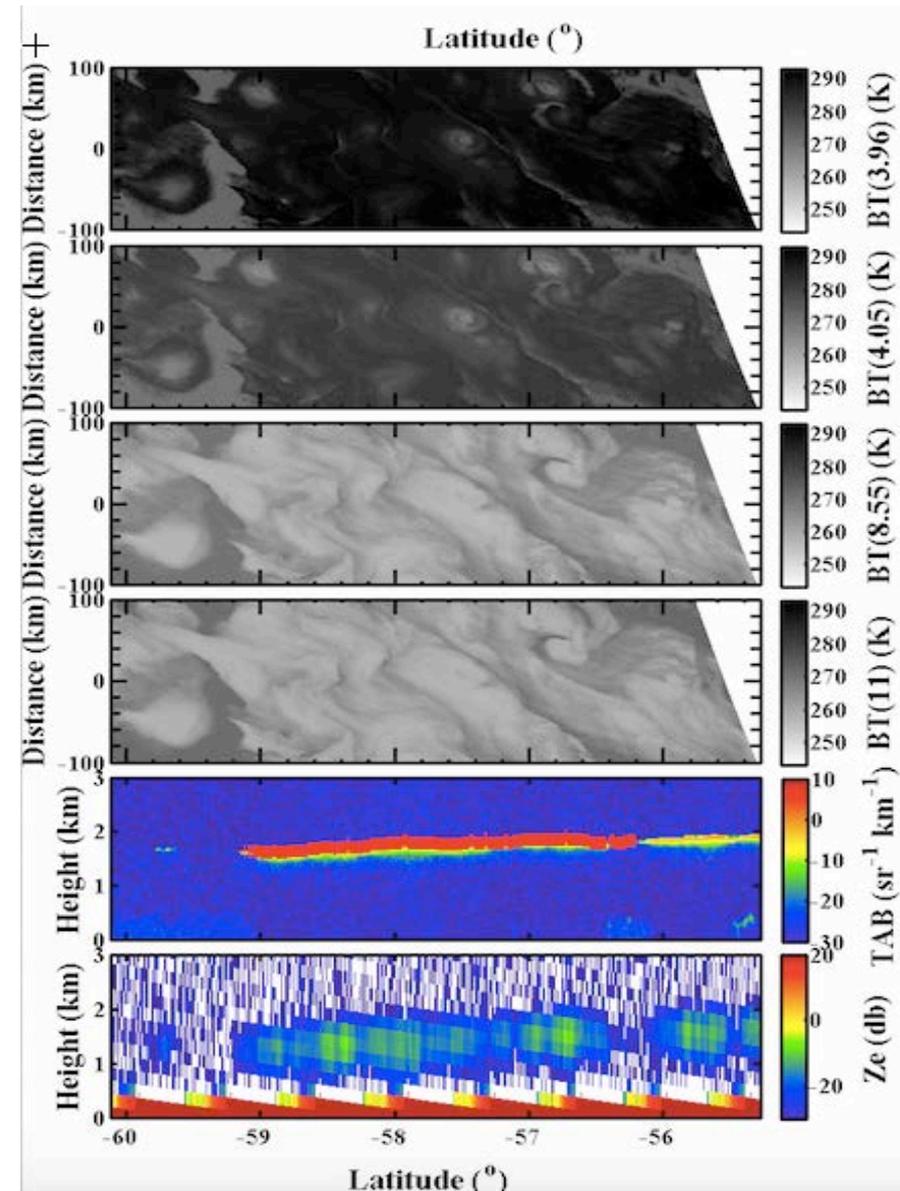
- There are large differences among models in simulated liquid mass fractions as a function of temperature.
- Observed **liquid cloud occurrence fraction** is not enough to constrain **model liquid mass fractions**.



**Figure 1.** (a) The diagnosed mixed-phase partitioning from the historical experiment for the years 1850–1900 in the 30°S–80°S latitude band. Observations from *Hu et al.* [2010] are shown as a dashed red line. The multimodel mean is shown as a dashed grey line. (b) The slope of the LCF curve at each temperature.

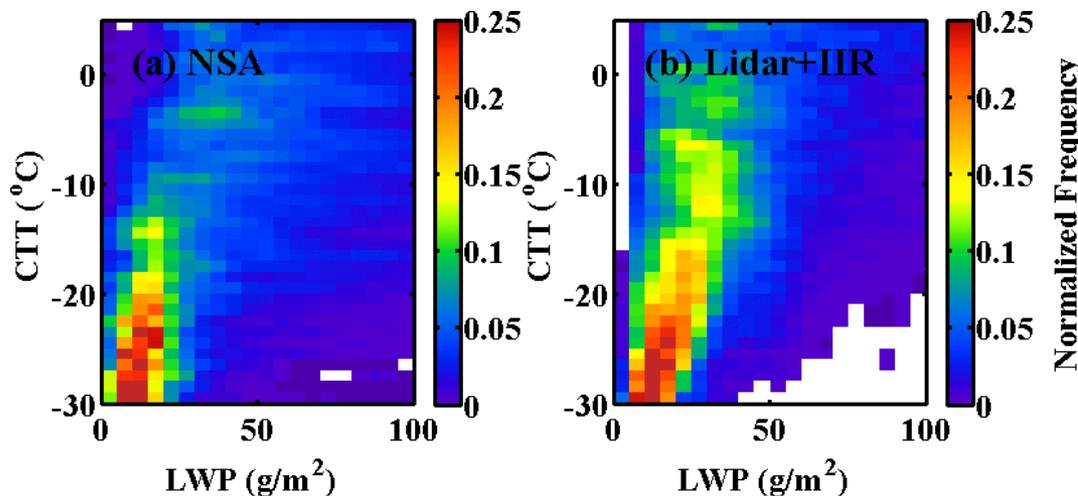
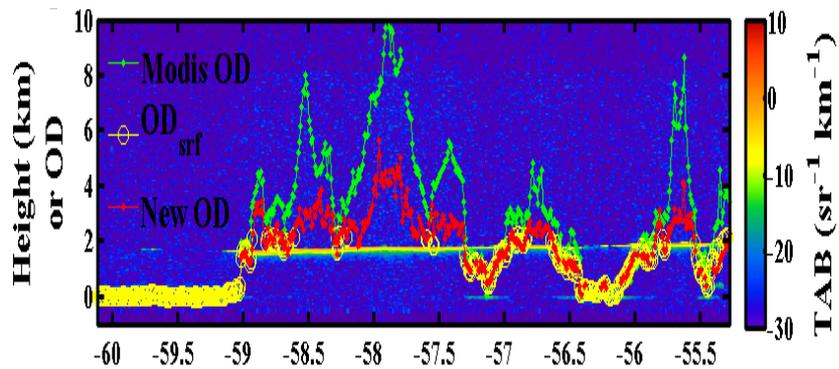
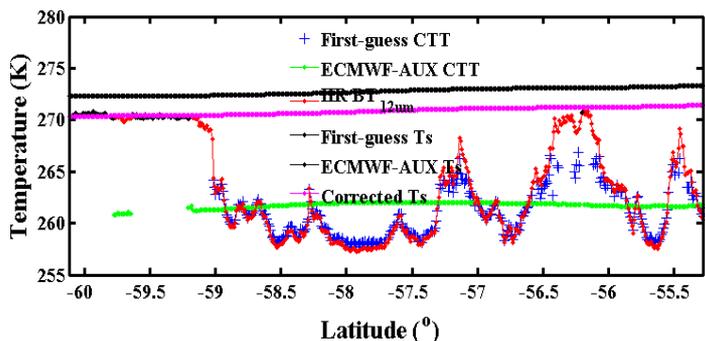
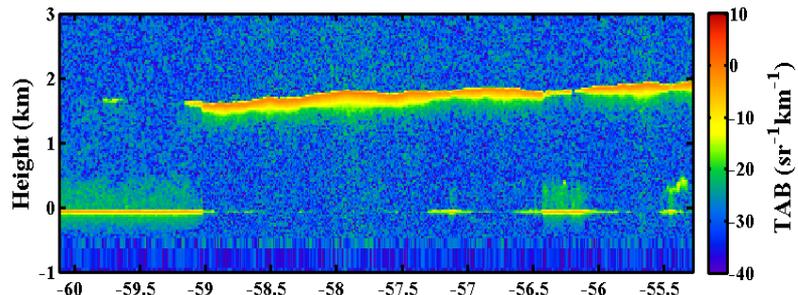
# Our Multi-Sensor Approaches for LWPs

- Available Observations:
  - Day and night: **CALIOP** + **MODIS** IR or CALIPSO IIR + **CPR** Ze and brightness temperature
  - Day: **CALIOP** + **MODIS** visible and near IR + **CPR** Ze
- Different combinations under different conditions



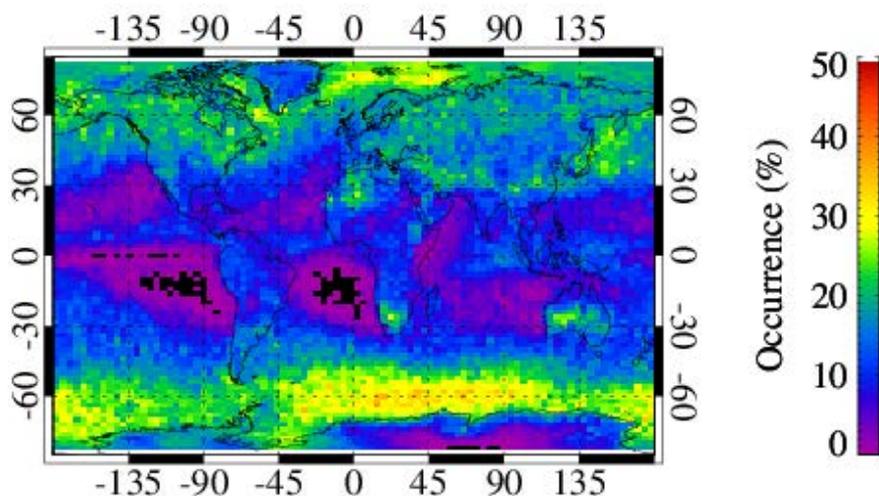
# A CALIOP+ IR Retrieval Example and Evaluation

2008-01-07 13:27:8 to 13:28:31

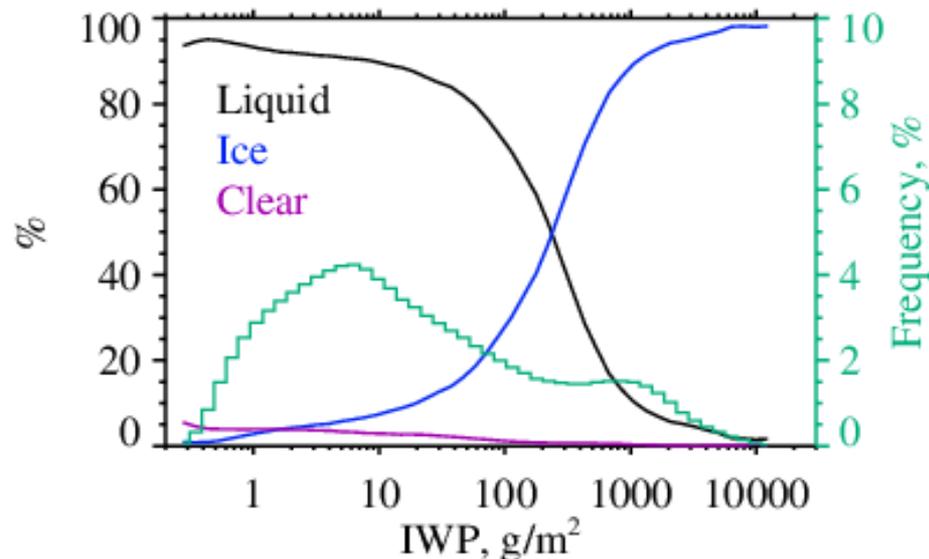


**CALIOP+ IR LWP retrievals can capture ground-base MWR observed temperature dependency of LWP well.**

# Potential MODIS LWP Biases in the Polar Region

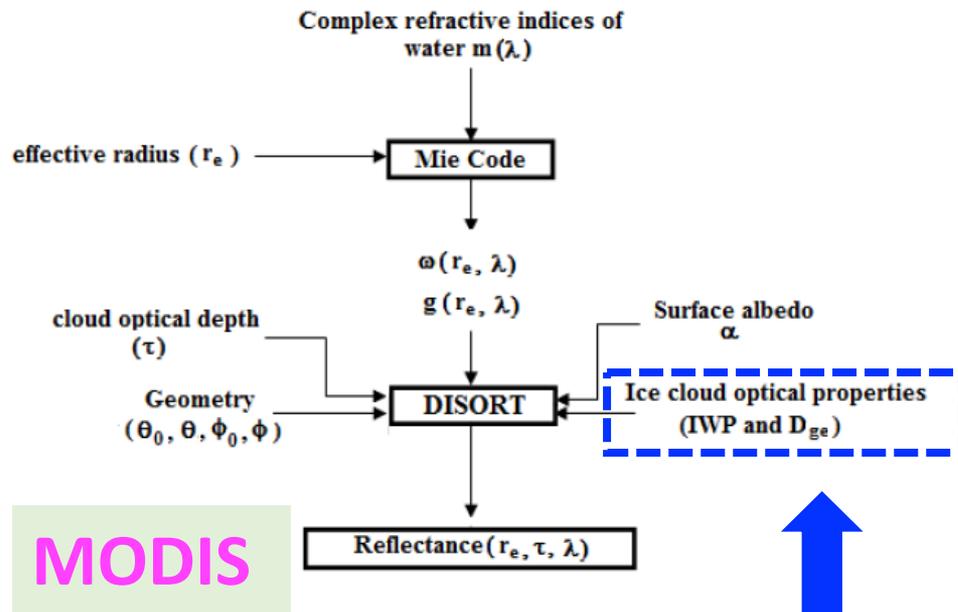


Annual mean mixed phase  
clouds occurrence from 2007  
CloudSat and CALIPSO  
measurements

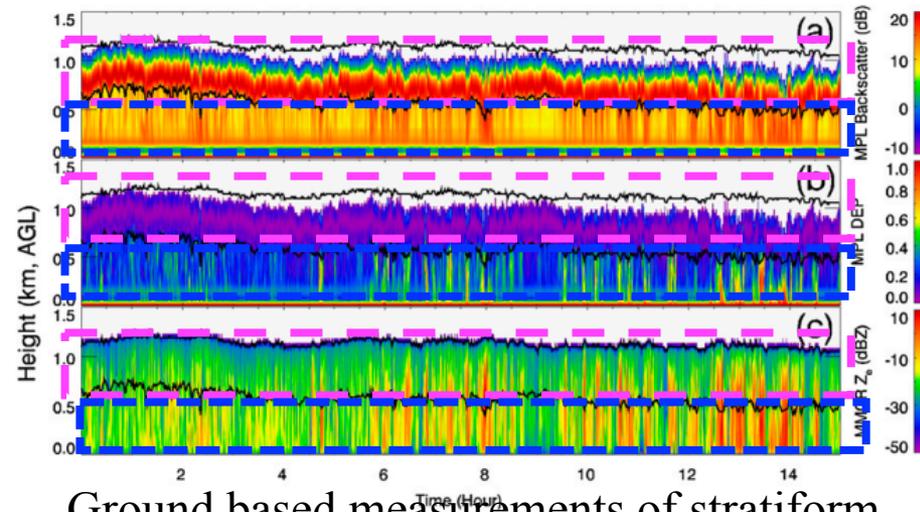
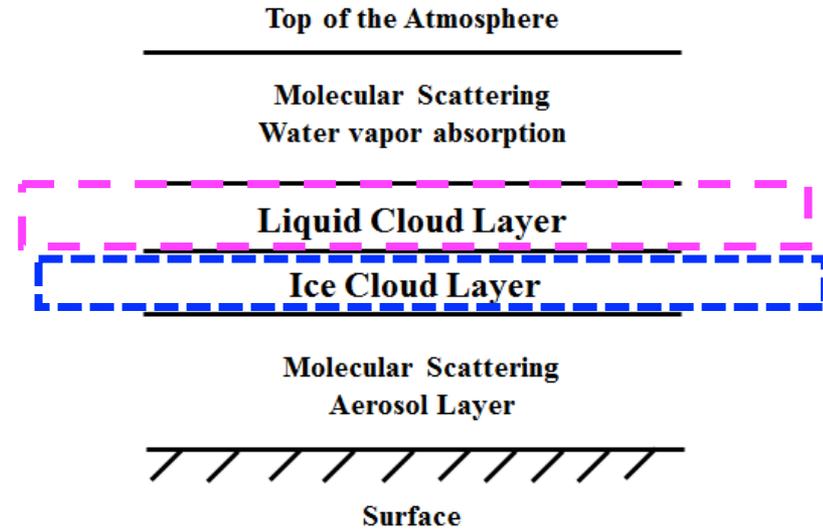


MODIS cloud phase  
classification for  
non-precipitating single  
layer mixed phase clouds

# Stratiform Mixed Phase Cloud Retrieval Setup with CALIOP + MODIS + CPR



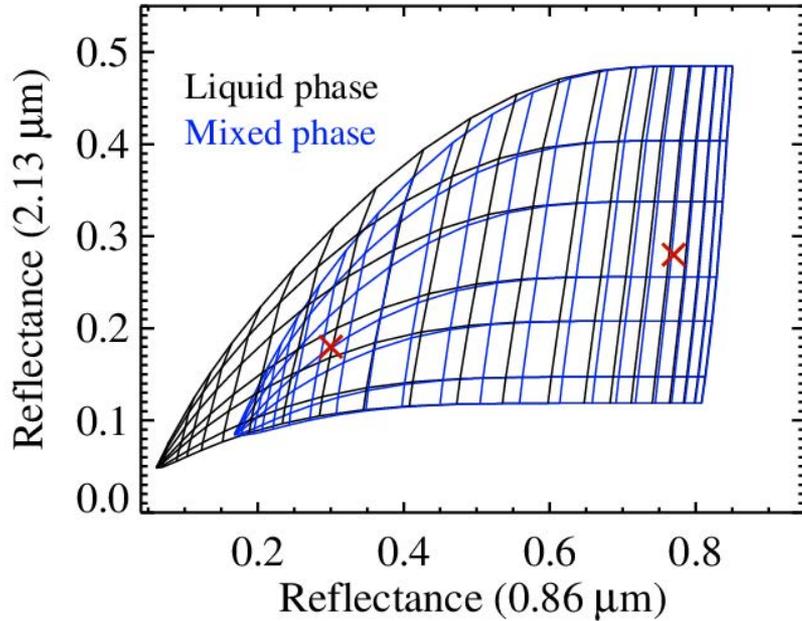
CALIOP + CPR  
2C-ICE



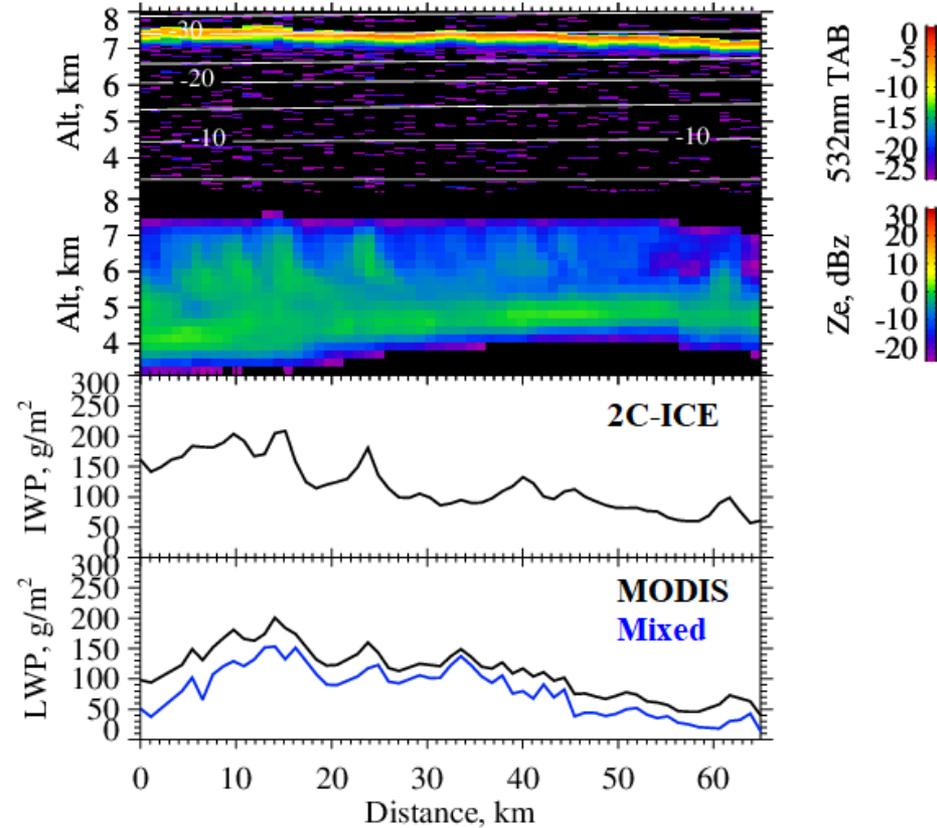
Ground based measurements of stratiform mixed-phase clouds over NSA

Adhikari and Wang, 2013  
Khanal and Wang 2018

# Multi-sensor Mixed Phase Cloud Retrieval Example

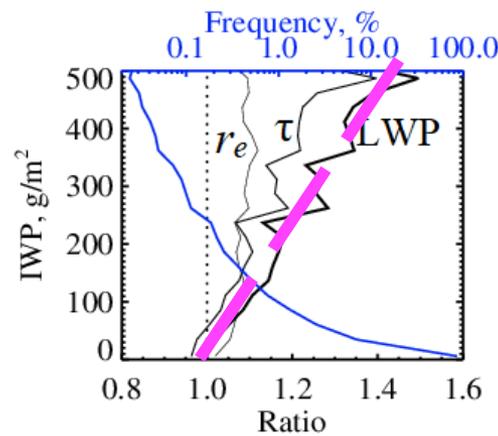
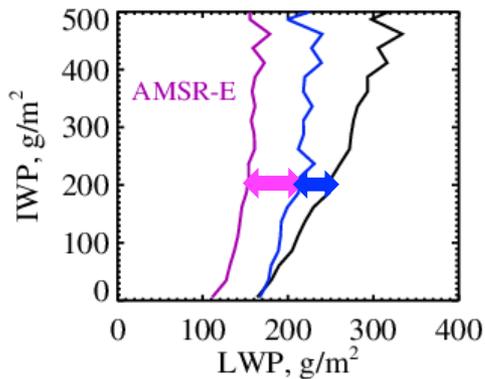
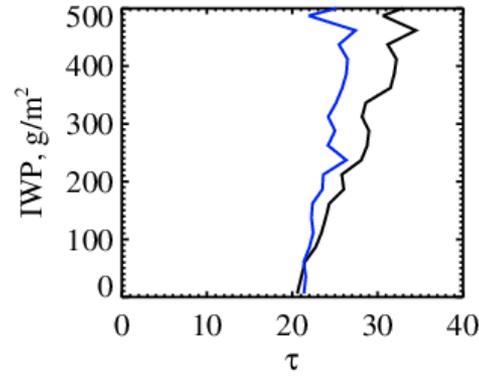
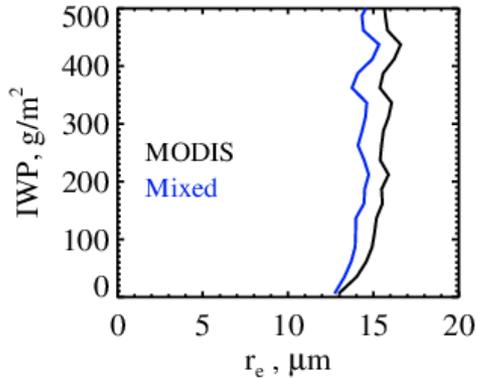


$\theta = 10^\circ$ ,  $\theta_0 = 60^\circ$  and  $\phi = 75^\circ$  and  $\alpha = 0.05$   
 $D_{ge} = 80 \mu\text{m}$ ,  $\text{IWP} = 50 \text{g/m}^2$



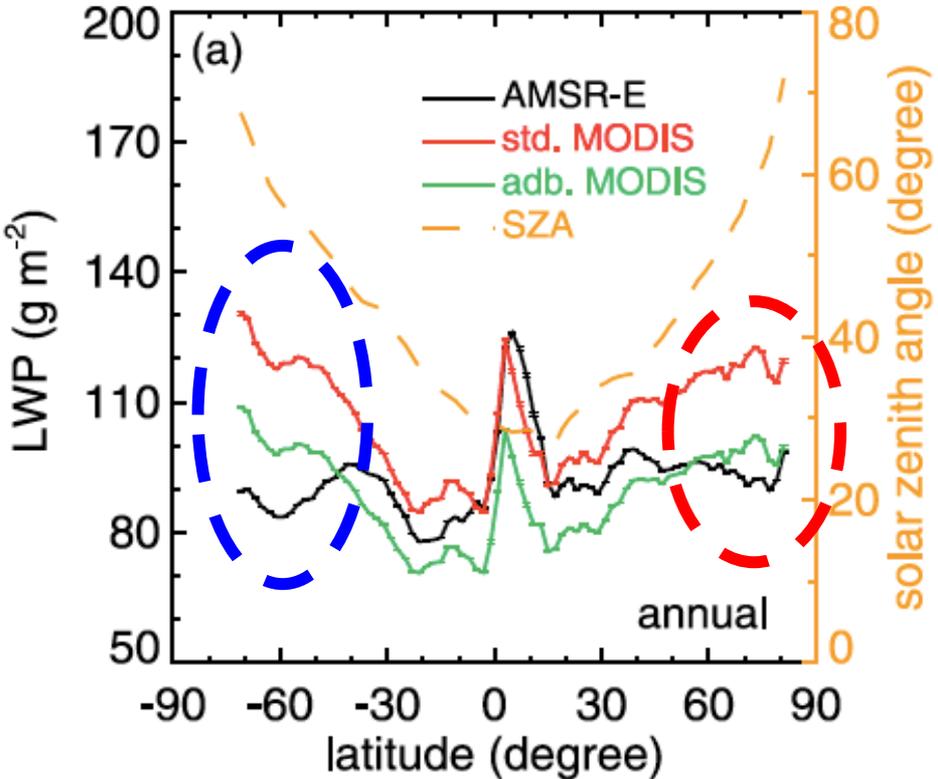
|             | $r_e (\mu\text{m})$ | $\tau$ | LWP ( $\text{g/m}^2$ ) | $r_e (\mu\text{m})$ | $\tau$ | LWP ( $\text{g/m}^2$ ) |
|-------------|---------------------|--------|------------------------|---------------------|--------|------------------------|
| Liquid      | 14.4                | 6.3    | 58.4                   | 10.8                | 68.5   | 471.0                  |
| Mixed-phase | 11.8                | 4.1    | 30.9                   | 10.8                | 66.3   | 455.9                  |

# Multi-sensor mixed phase cloud retrievals compared with standard liquid phase MODIS retrievals



- ❖ The difference depends on IWP.
- ❖ Mixed phase LWP bias  $> 20\%$  for  $\text{IWP} > 250 \text{ g/m}^2$
- ❖ Mean LWP in stratiform mixed phase clouds biased by  $\sim 5.7 \text{ g/m}^2$

# MODIS's zenith angle dependent biases in LWP over High Latitudes



Seethala and Horváth (2010)

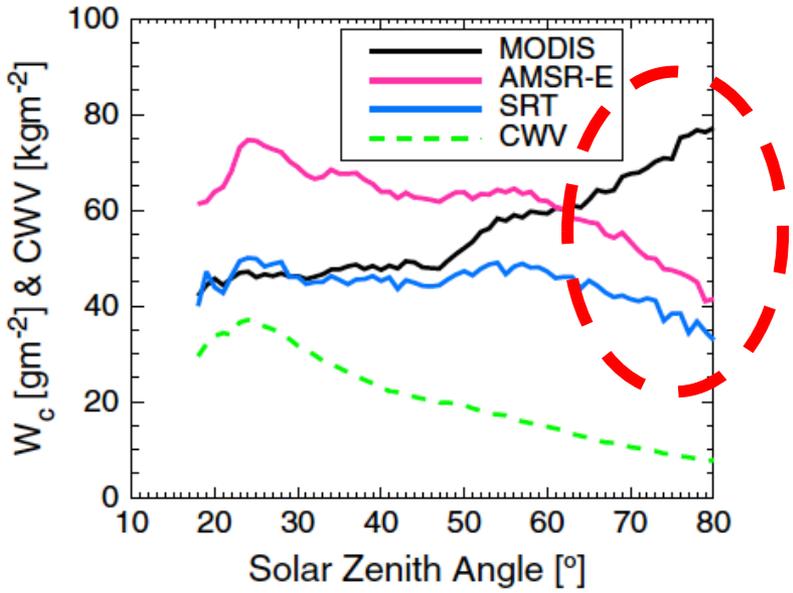
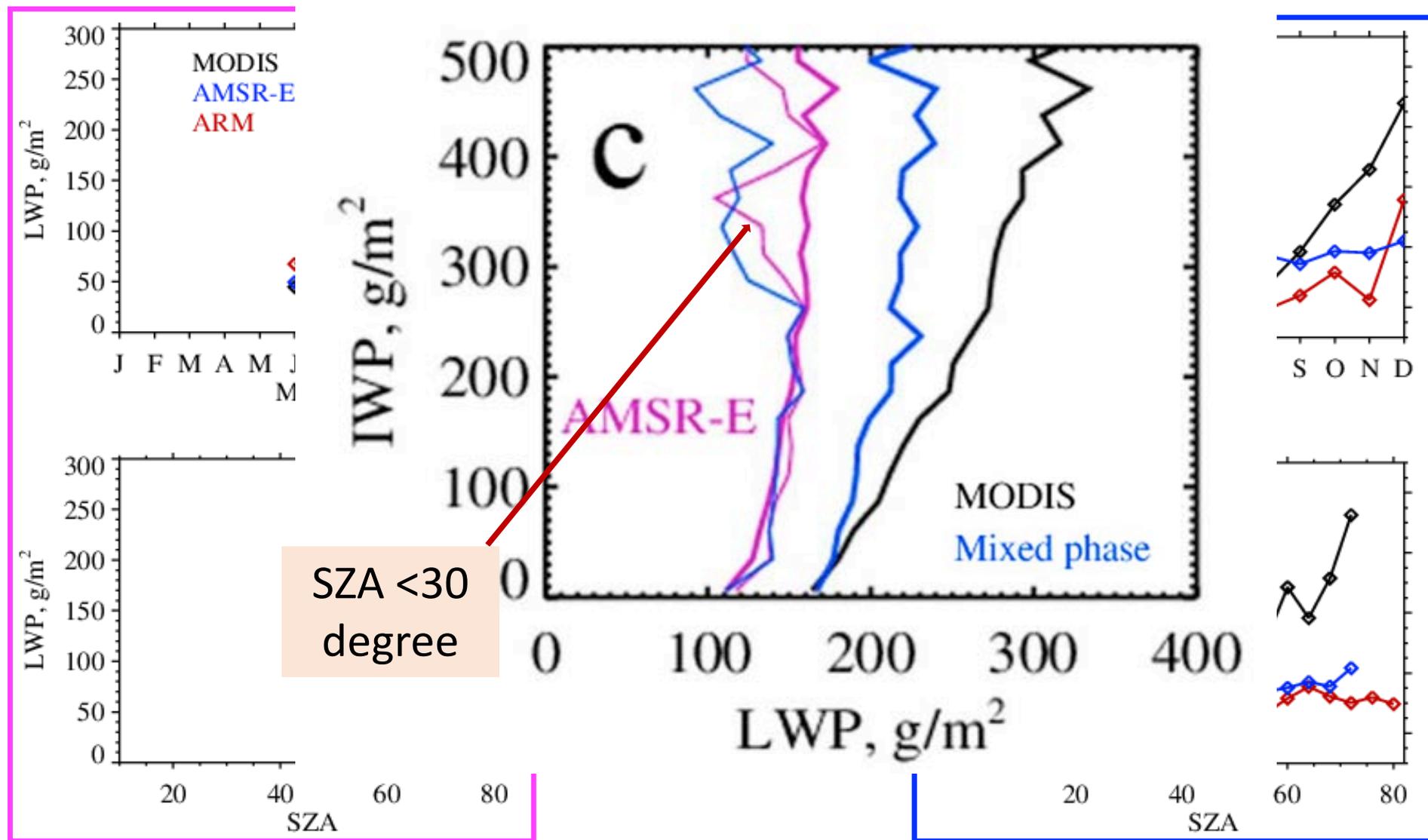


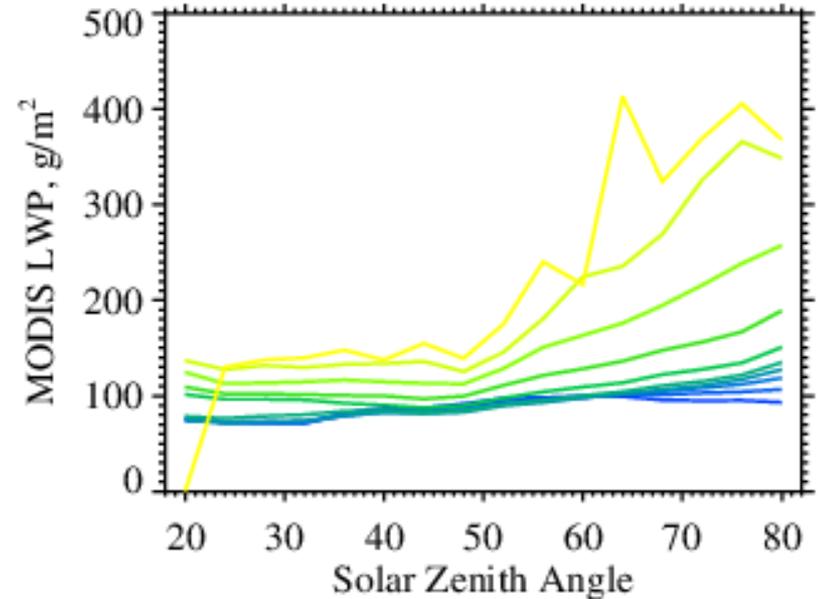
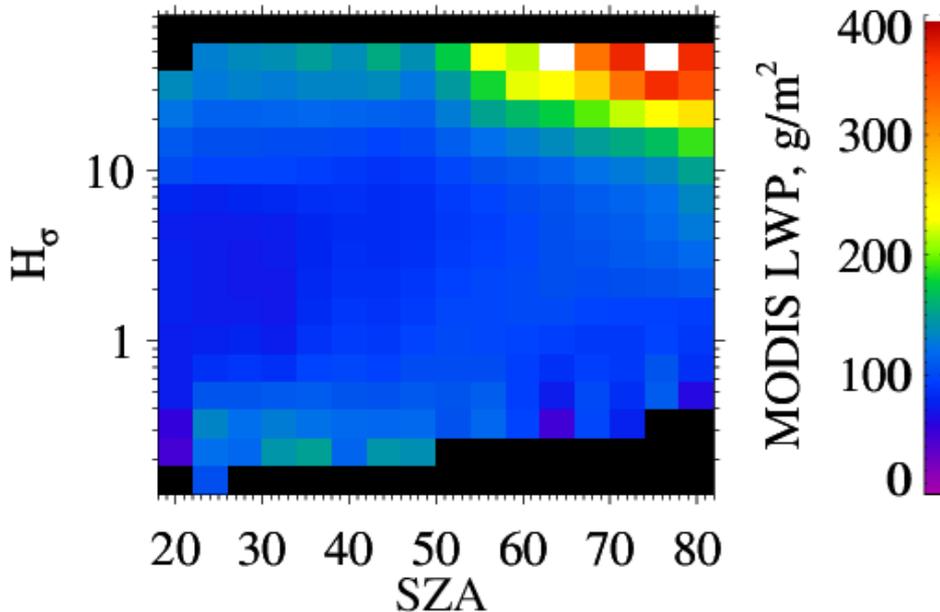
Figure 6. The MODIS, AMSR-E, and SRT cloud water paths ( $W_c$ ) as a function of solar zenith angle. Also shown is the column water vapor (CWV).

Lebsock and Su (2014)

# Can we trust well screened AMSR-E IWP?

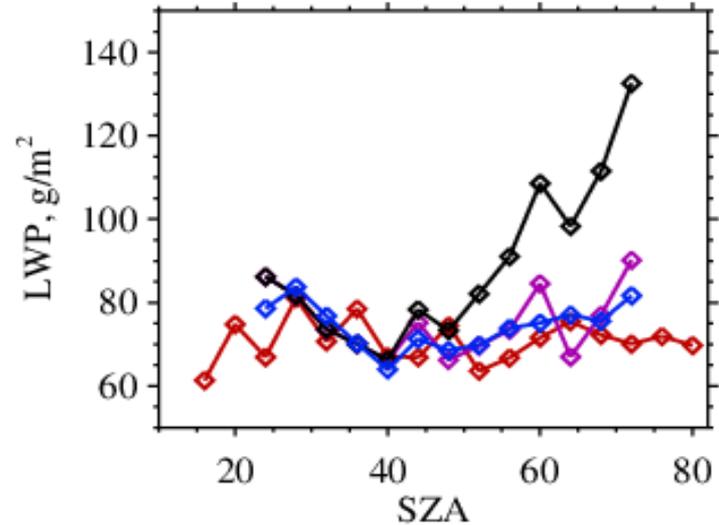
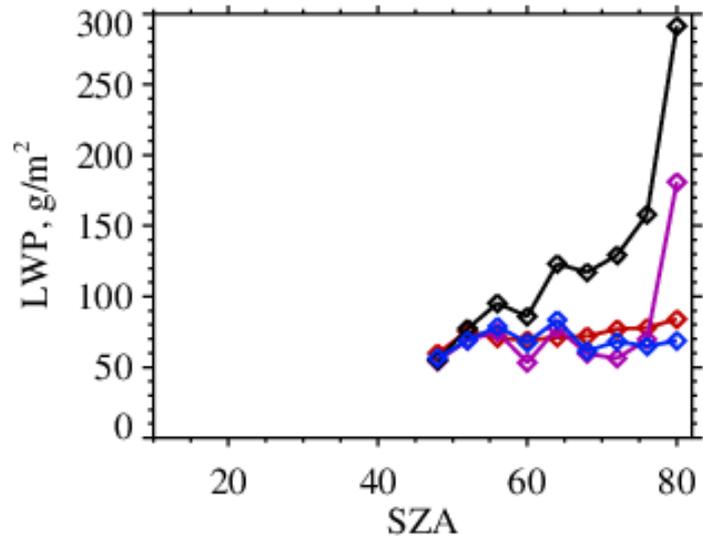
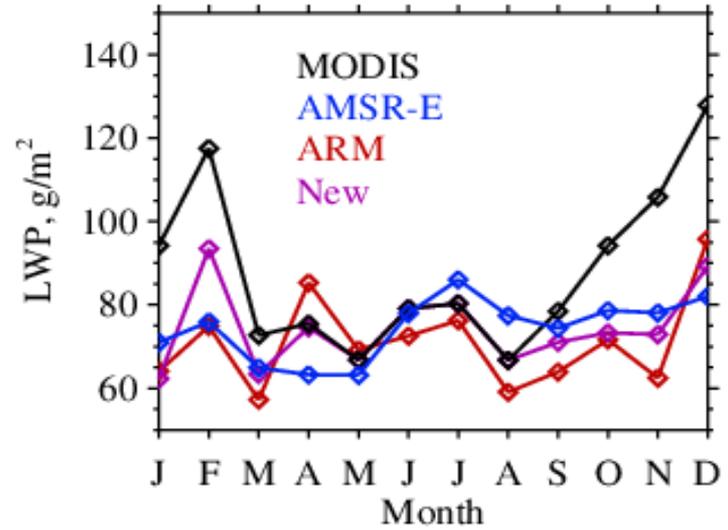
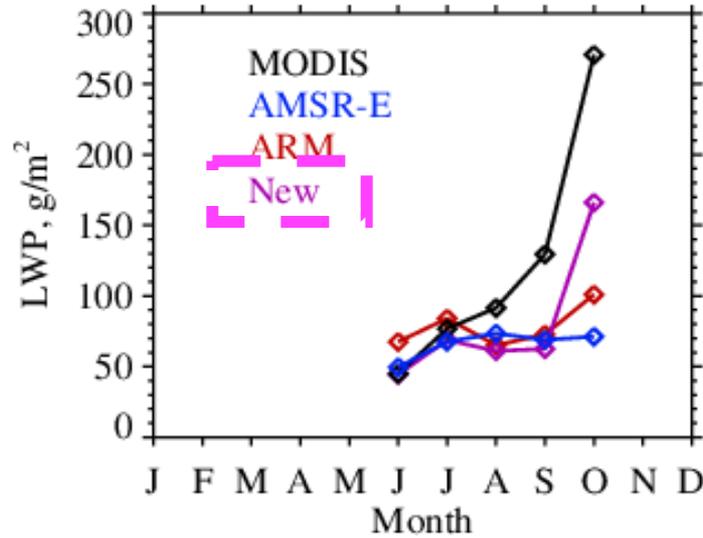


# Correcting 3D-effect in High Latitude MODIS Based LWP



- ( $H_\sigma$ ) is the standard deviation of 250m Reflectance values within each 1km MODIS pixel expressed as a %.
- Different color for different  $H_\sigma$  range: make it possible to develop a statistical correction for SZA dependent biases.

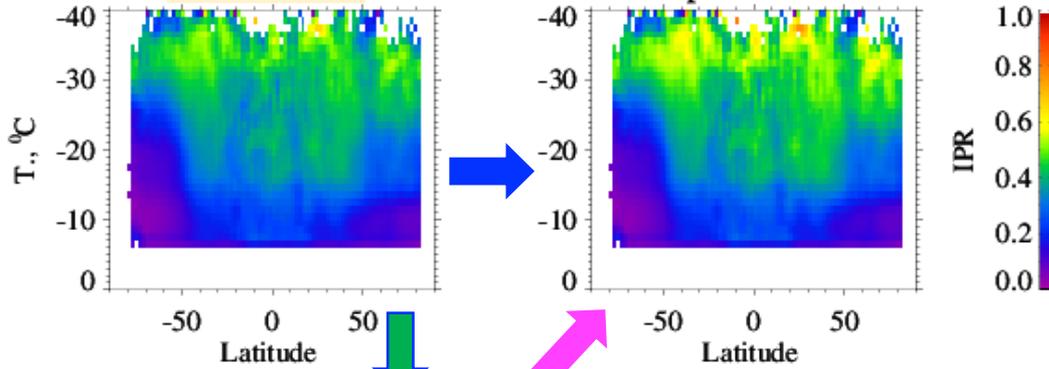
# Preliminary Results of Statistical Correction for SZA Dependent Biases



# Temperature Dependent Mass Partition for Stratiform Mixed-phase Clouds

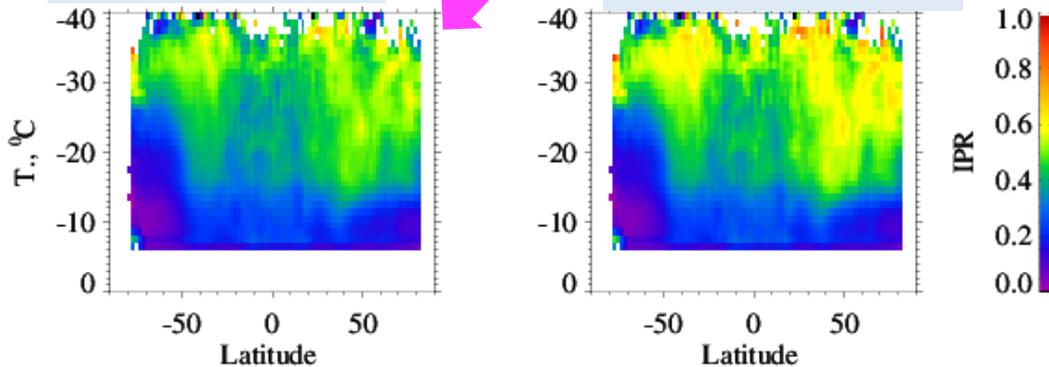
Original

Mixed-phase Cloud Correction



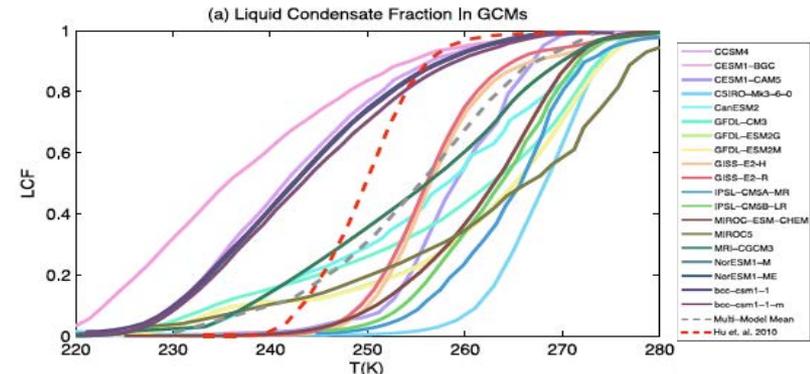
SZA Correction

Total Correction



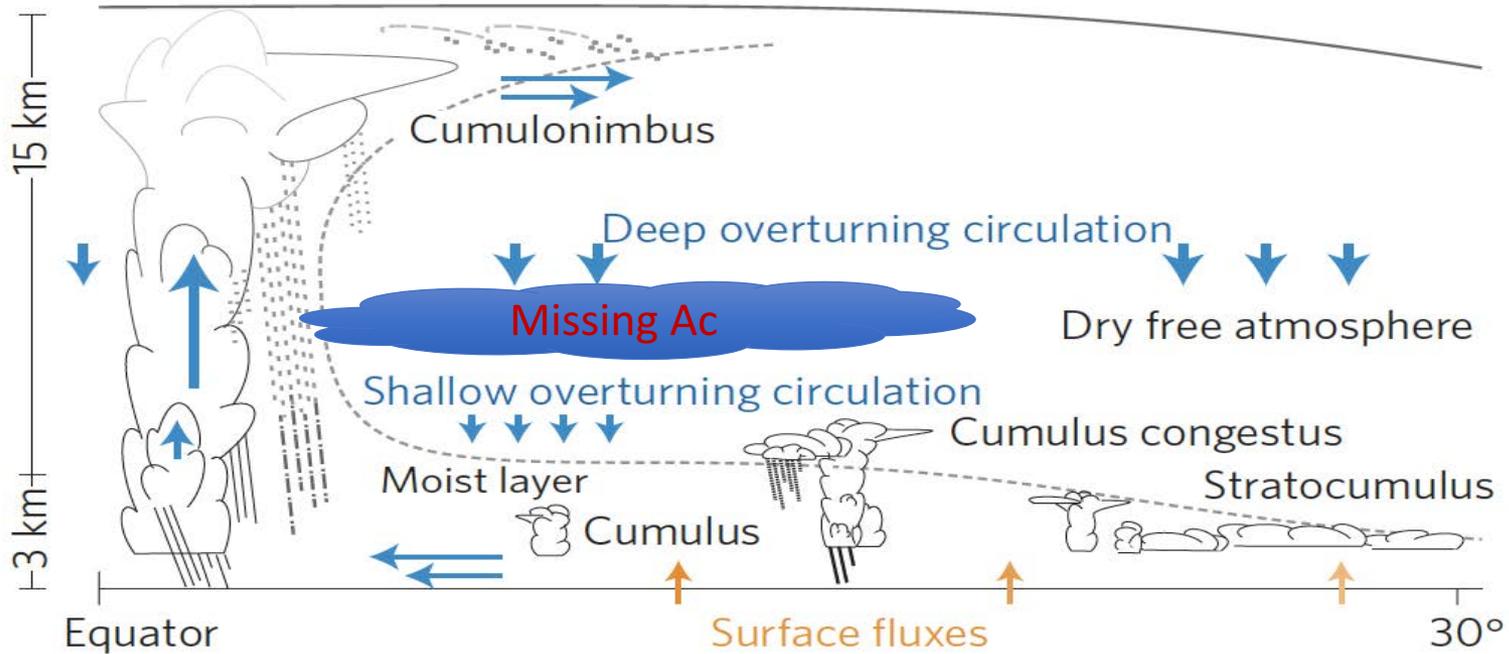
Ice Mass Fraction  
 $IPR = IWP / (IWP + LWP)$

Based on 2007 A-train measurements



# Tropical Convective Cloud Variations

Bony et al. 2015



**Convective clouds are the engine of the atmosphere!**

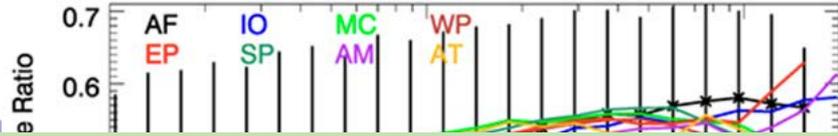
**But they are poorly simulated!**

# Tropical Convective Cloud Variations

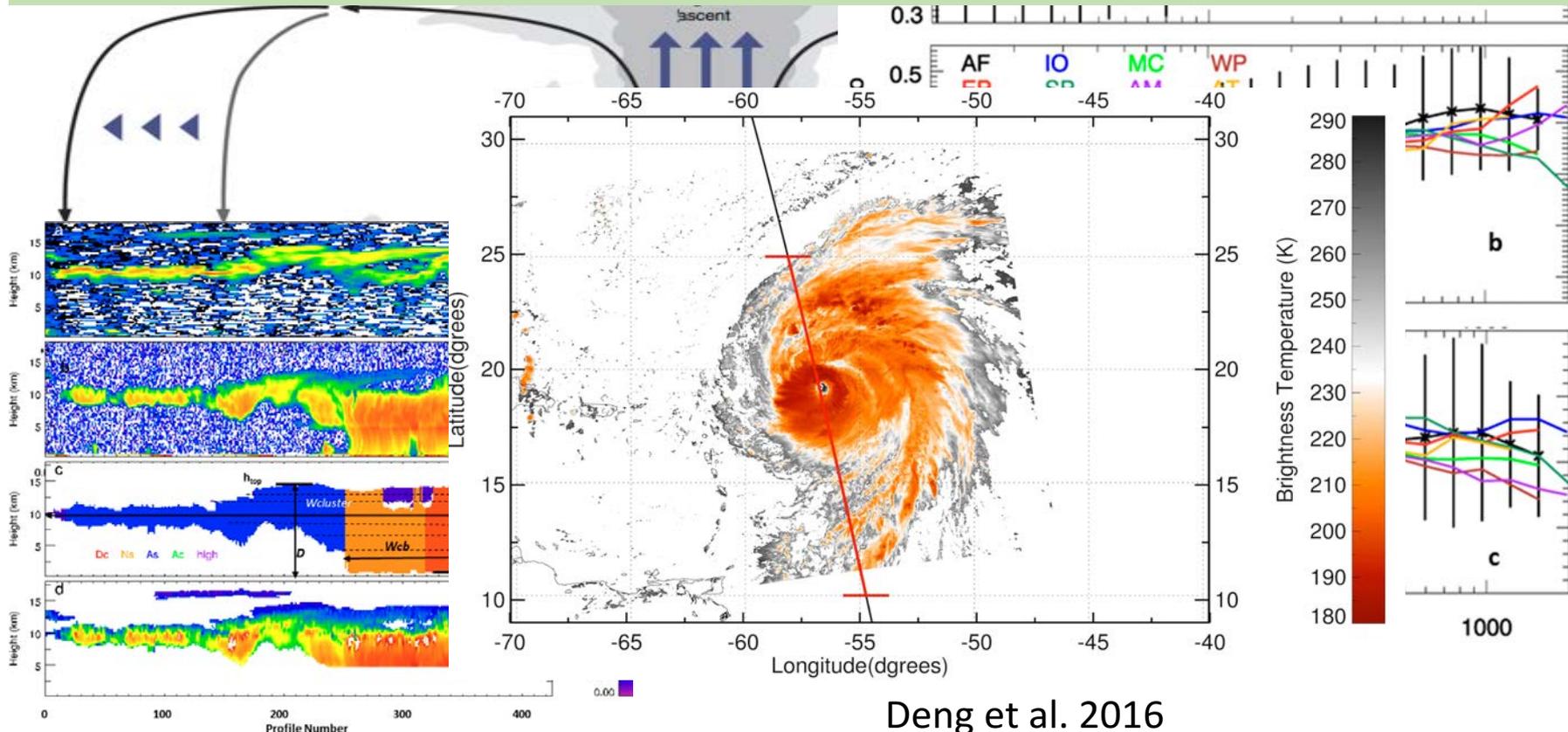
## Multi-sensor data fusion

Su et al.2017

Increased OLR      Decreased OLR

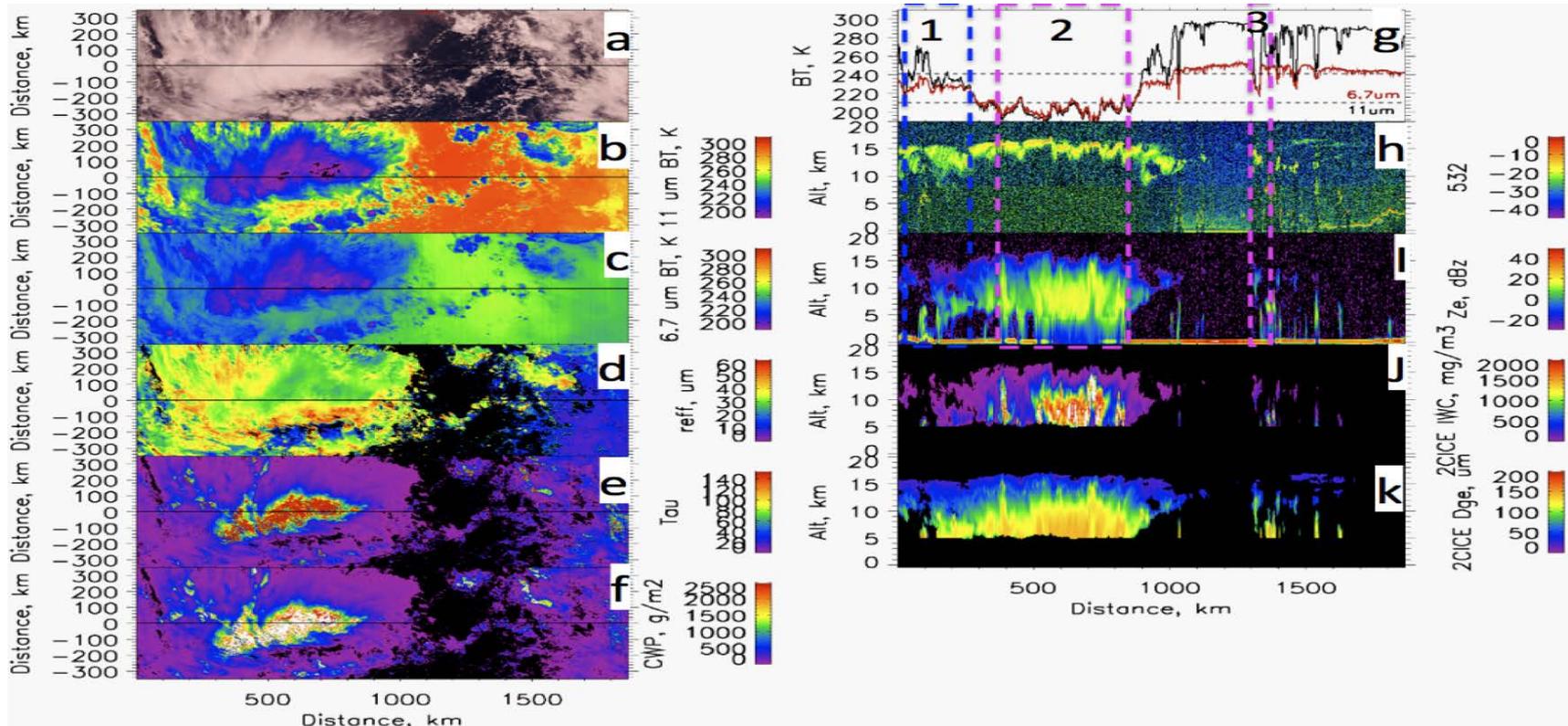


**Multi-sensor data fusion are needed !**



Deng et al. 2016

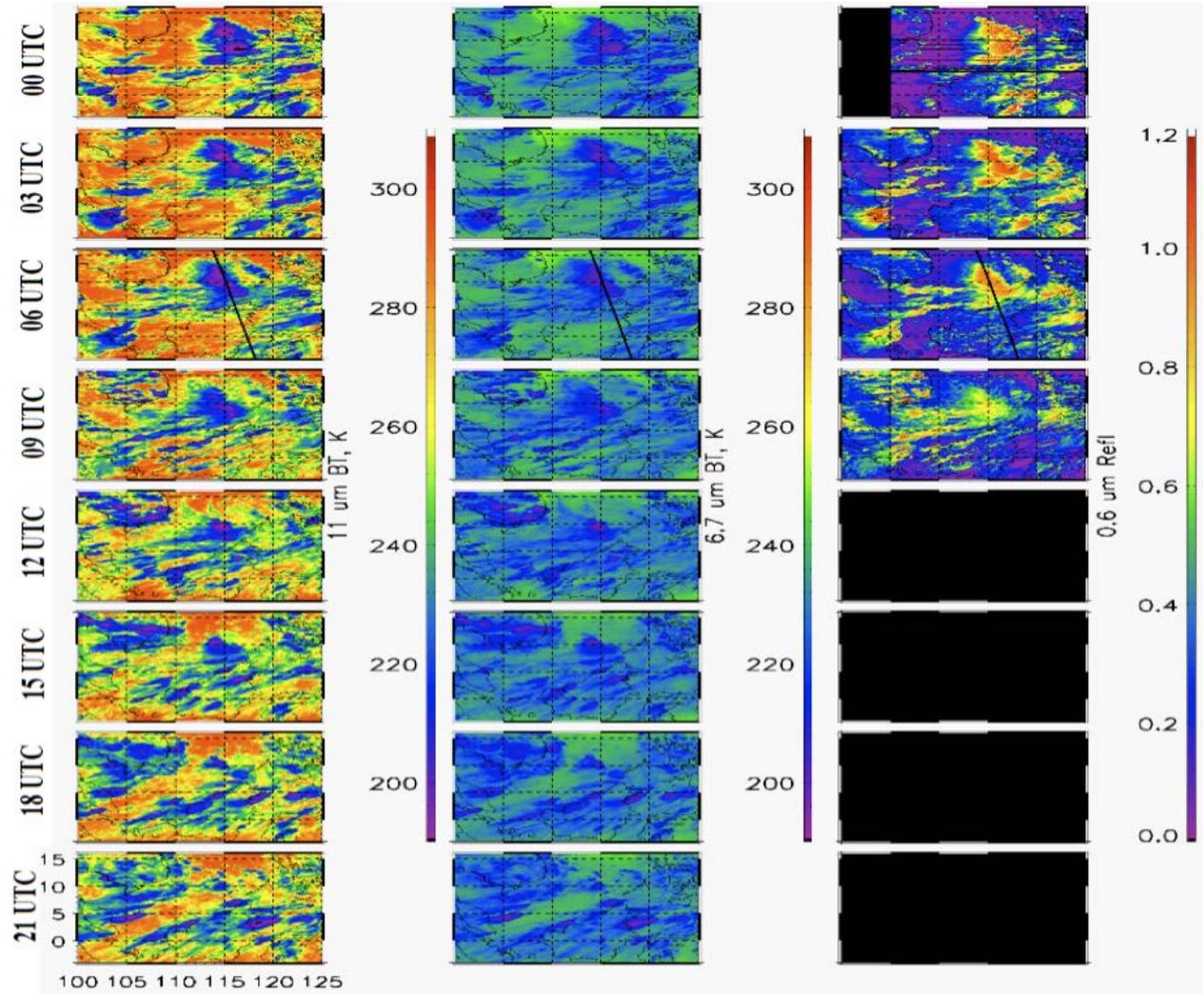
# Using **active sensors** to improve convective cloud characterizations with **passive sensors**



- Improve MODIS convective core and anvil separation with multi-wavelength measurements.
- Fuse MODIS, CloudSat, and CALIPSO measurements to characterize convective cloud system.

# Transferring MODIS-Based Capability to Other Passive Measurements to Improve Temporal Coverage

**NOAA GridSat**  
radiance  
3-hourly  
1982 - present



# A Long-term Daily Tropical Convective Cloud Dataset

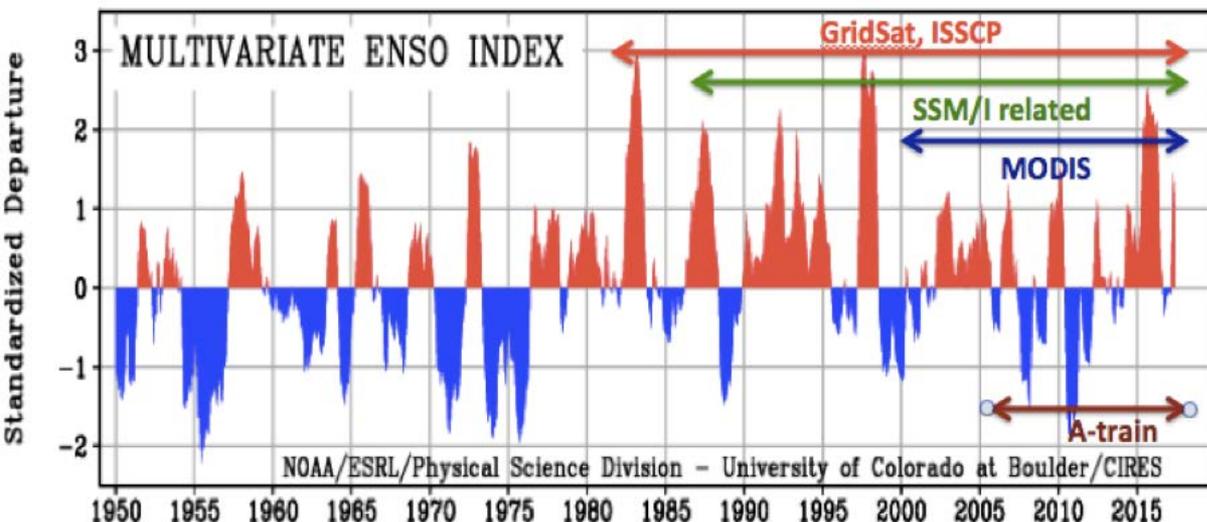


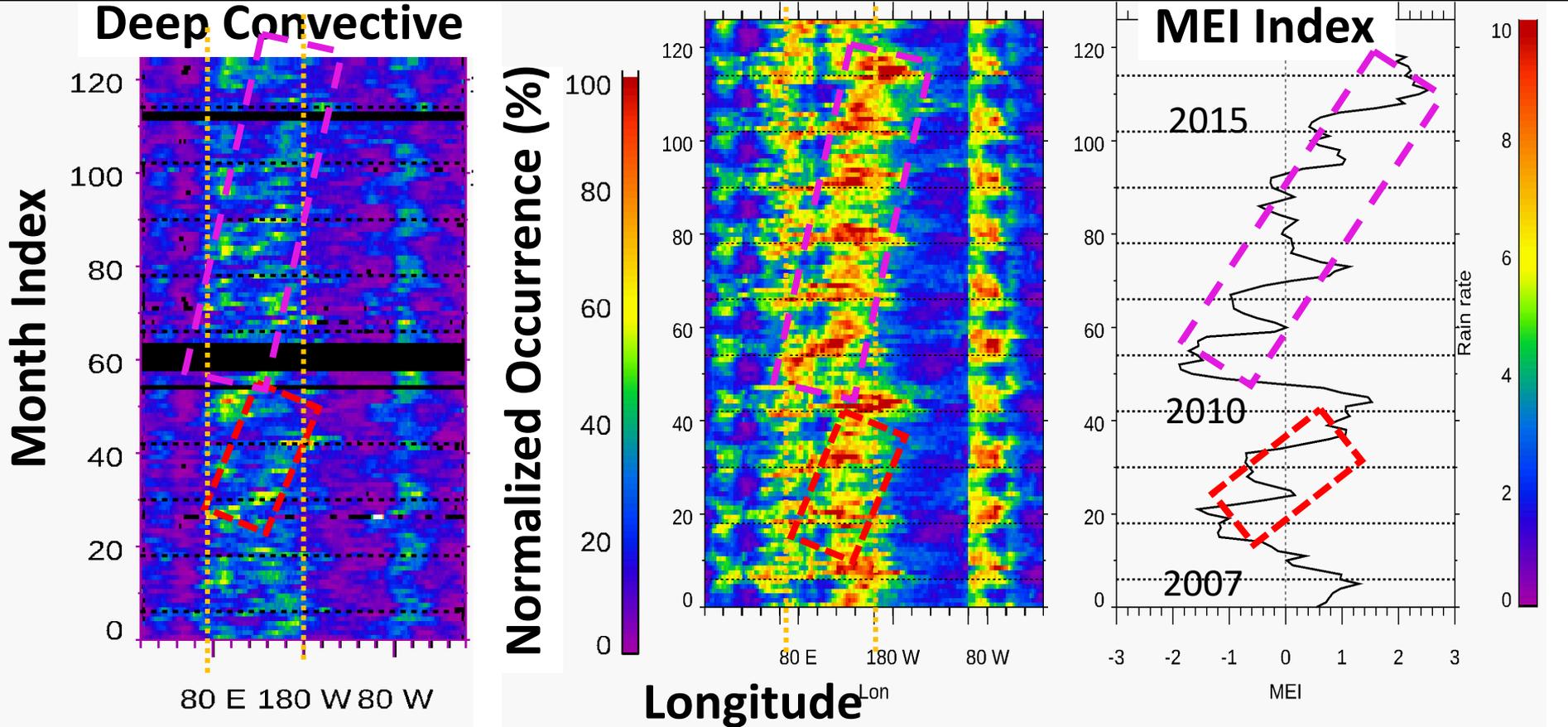
Table 1. Summary satellites, sensors, and products used in the study

| Satellite/Sensors/products | Properties   | Period                   |
|----------------------------|--|--------------------------|
| Terra and Aqua             | Radiance; cloud optical depth, water path, and particle size | 3/2000 - present (Terra) |
| MODIS                      |  | 7/2002 - present (Aqua)  |
| CloudSat and CALIPSO       | Vertical cloud and precipitation structure and properties    | 6/2006 - present         |
| AIRS                       | Temperature and water vapor profiles                         | 8/2002 - present         |
| GridSat and ISSCP          | Radiance and retrieved cloud properties                      | 1982 - present           |
| AMSR-E                     | LWP and precipitation  | 7/2002- 9/ 2011          |
| CERES                      | TOA LW and SW fluxes   | 3/2000 - present         |
| SSM/I                      | LWP, PWV, SST  | 7/1987 - present         |
| OAFlux                     | Ocean surface sensible and latent heat fluxes                | 7/1987 - present         |
| NOAA OISST                 | SST  | 9/1981 - present         |
| NASA MUR                   | SST  | 6/2002 - present         |
| CCMP surface wind          | Gridded surface vector wind                                  | 7/1987 - present         |
| NAVP-M                     | PWV  | 1988 - 2009              |
| MERRA-2                    | Meteorological fields  | 1/1980 - present         |

- Convective Cloud Properties
- Atmospheric Environmental Conditions
- Ocean Conditions

# ➤ Understand the seasonal and interannual variations of tropical convective cloud systems.

- ❑ How oceanic and atmospheric states and different scales of wave activities control the interannual tropical convective cloud spatial distribution shifting?
- ❑ How convective detrainment varies regionally and seasonally?
- ❑ How do convective aggregations evolve in tropics and control regional deep convective cloud distribution and properties?



# Summary

- The synergy of MODIS, CloudSat, and CALIPSO measurements provide global retrievals of stratiform mixed-phase cloud properties to effectively constrain model simulations.
- Multi-sensor fusion offers a new potential to characterize tropical convective cloud variabilities.

**Improved atmospheric process understanding and property retrieval through multi-sensor data fusion.**

**The critical role of MODIS and the A-Train Satellites!**