Saharan dust layer suppress deep convection and precipitation

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Saharan dust and dry air effects:

On Hurricans and cloud systems:

- **The entrainment of dry air into tropical cyclones**
- **A surge in easterly winds, which can increase vertical shear**
- **Altered microphysical properties of convection**

Enhance Altantic hurricans [*Pennington 2003, Karyampudi and Pierce 2002*].

Suppress Atlantic hurricans [*Dunion and Velden, 2004*]

Saharan dust and dry air effects:

On clouds and precipitation:

- **The first indirect effect [*Towmey, 1976*]**
- **The second indirect effects [*Albrecht, 1989, Rosenfeld, 2001*]**
- **The semi-direct effect *[Ackerman et al, 2000; Huang et al, 2006*]**

As giant CCN, which may enhance the collision and coalescence of droplets and therefore increase warm precipitation formation and decrease the clouds' albedo [*Yin et al, 2000, van den Heever et al, 2005*].

Some observations show that dust suppress clouds and precipitation [Rosenfeld 2000, Rosenfeld et al. 2001]

Ayers [2005] disputed the conclusions of Rosenfeld [2000]

Aerosol Indirect Effect (AIE) and Semi-direct:

Inconsistent evidence of AIE:

➔dynamic and thermodynamic conditions

AQUA

- **AMSR-E: Cloud and ice water and precipitation**
- **MODIS: Aerosol and cloud optical properties**
- **CERES: Radiation and climate forcing**
- **AIRS/AMSU/HSB: Temperature and humidity**

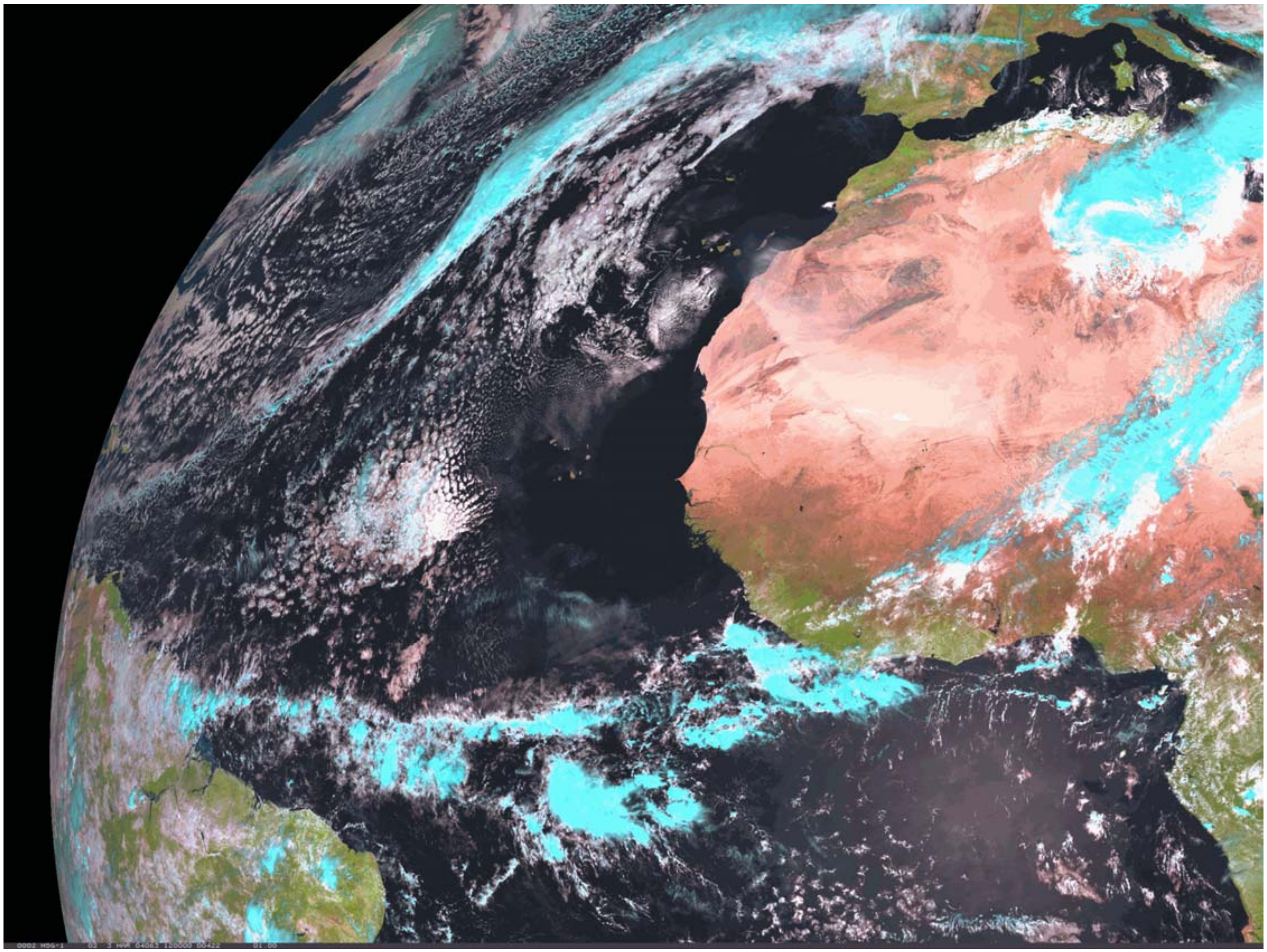
TRMM

- **TMI: Cloud water and precipitation**
- **PR: Precipitation**
- **VIRS: Aerosol and cloud optical properties**
- **CERES: Radiation**

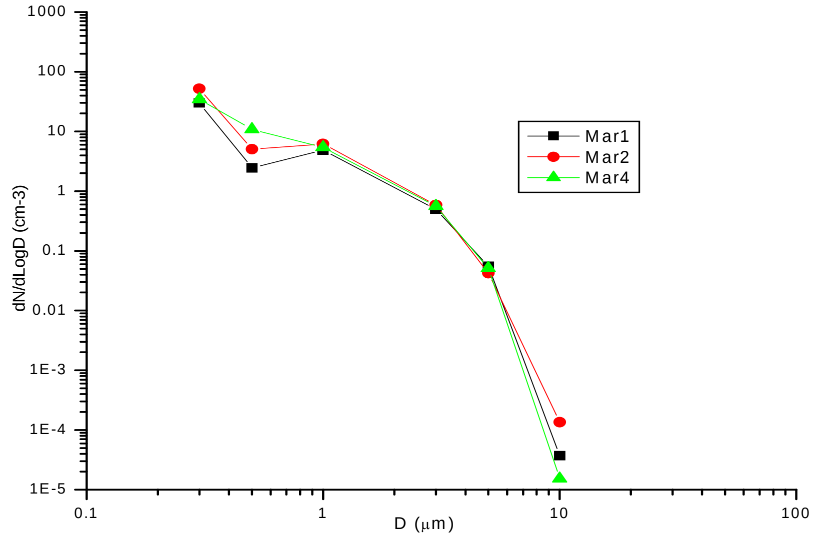
GOES and METSAT

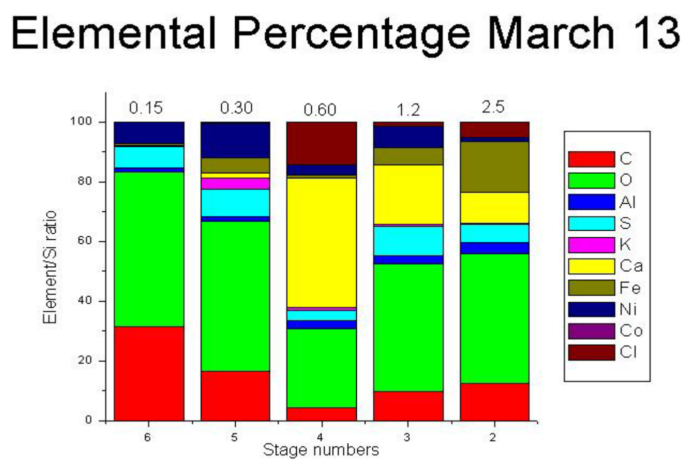
Surface network: AMMA and AERNET

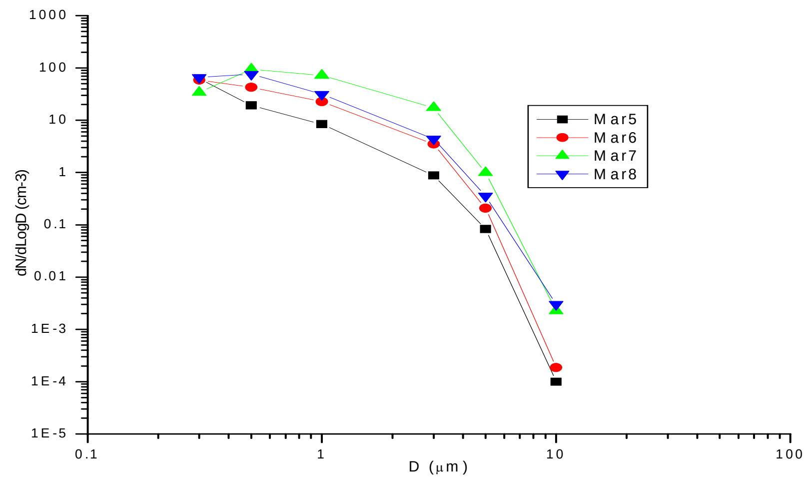
Observations from METSAT
Visible image (Mar 3~10, 1 frame / day)



Measured aerosol size distribution and composition on AROSE 2004

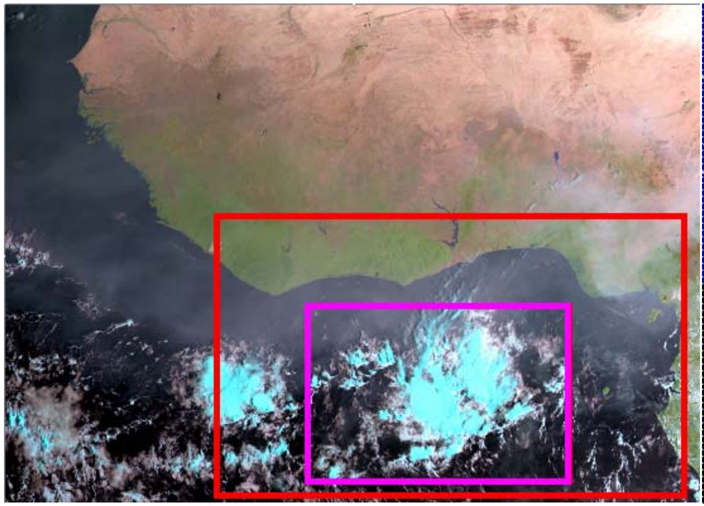


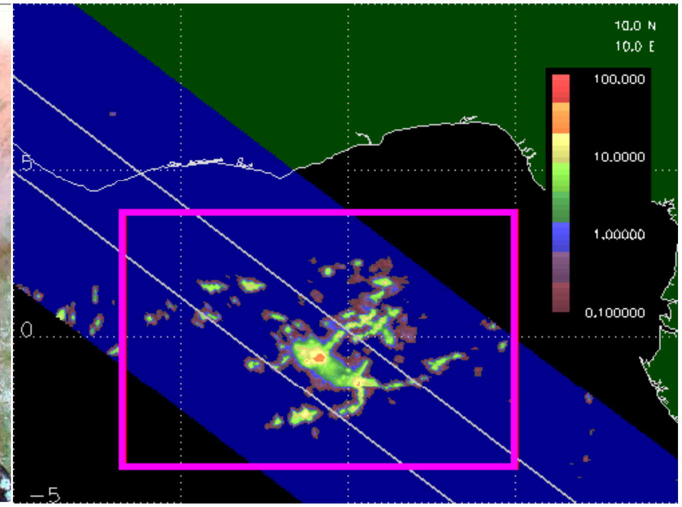


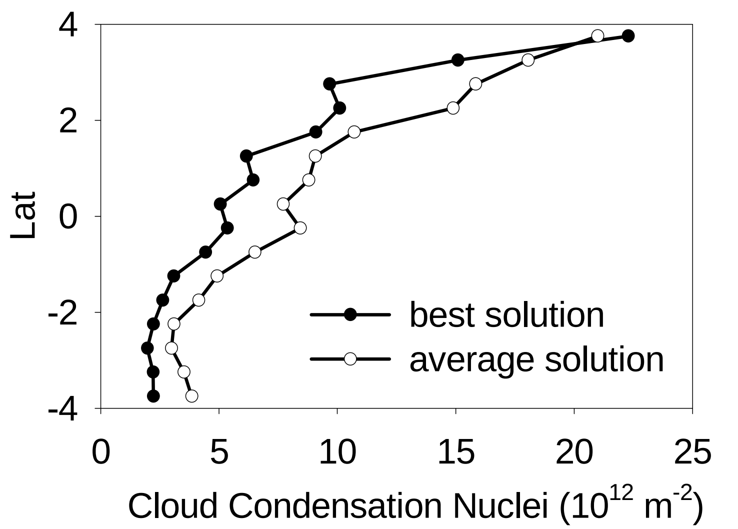


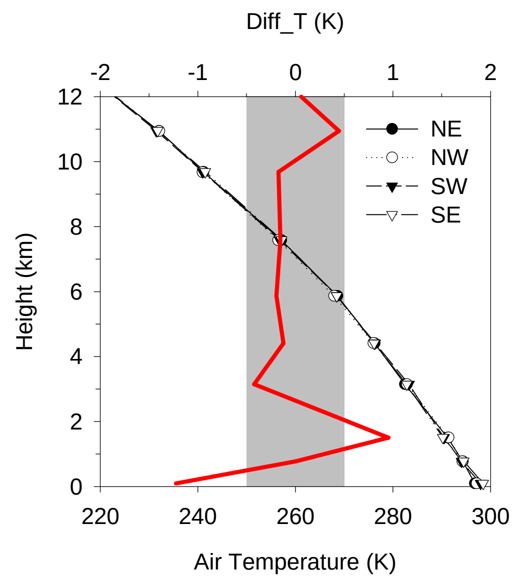
Dust aerosol on precipitation:

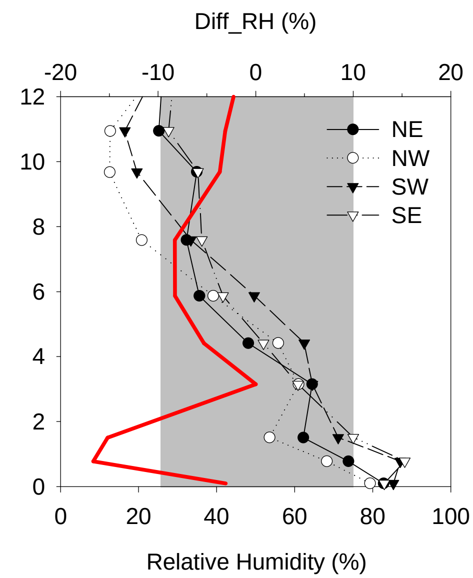
A partially dusty Case: UT 9:11, March 8, 2004



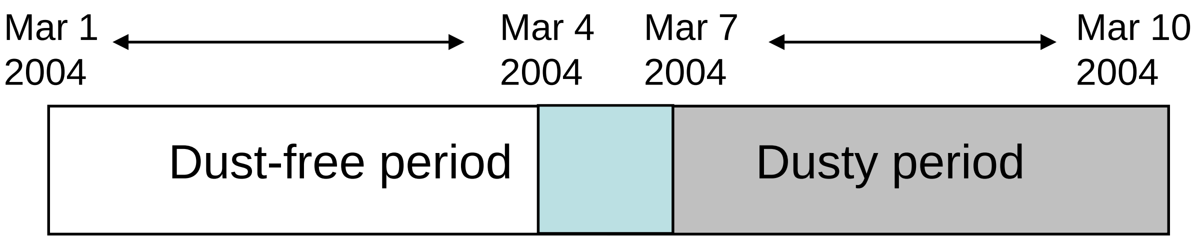


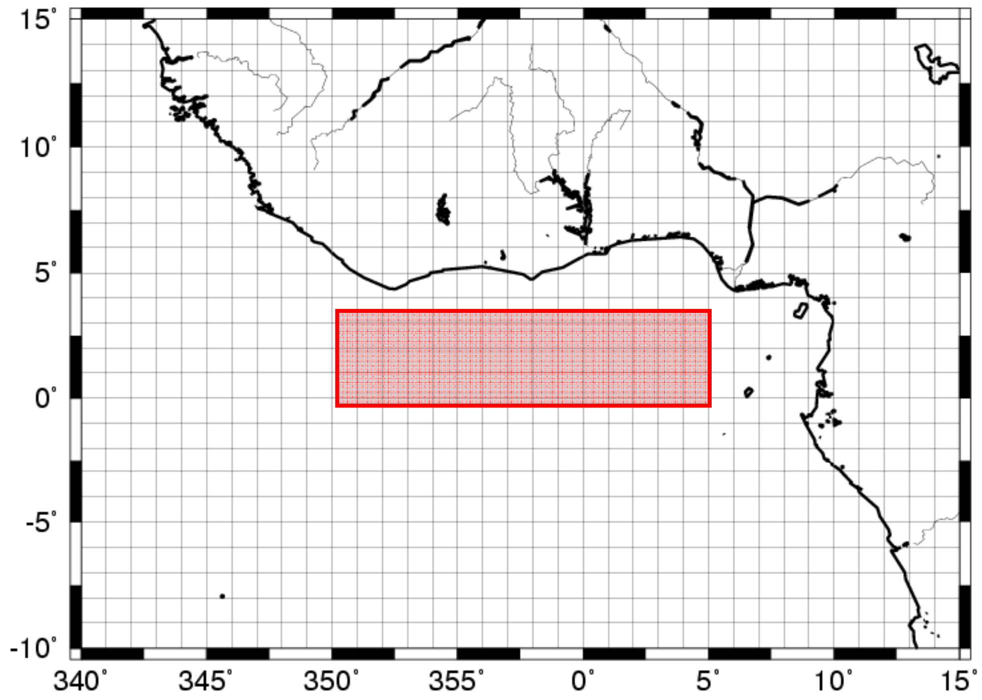






Statistic study

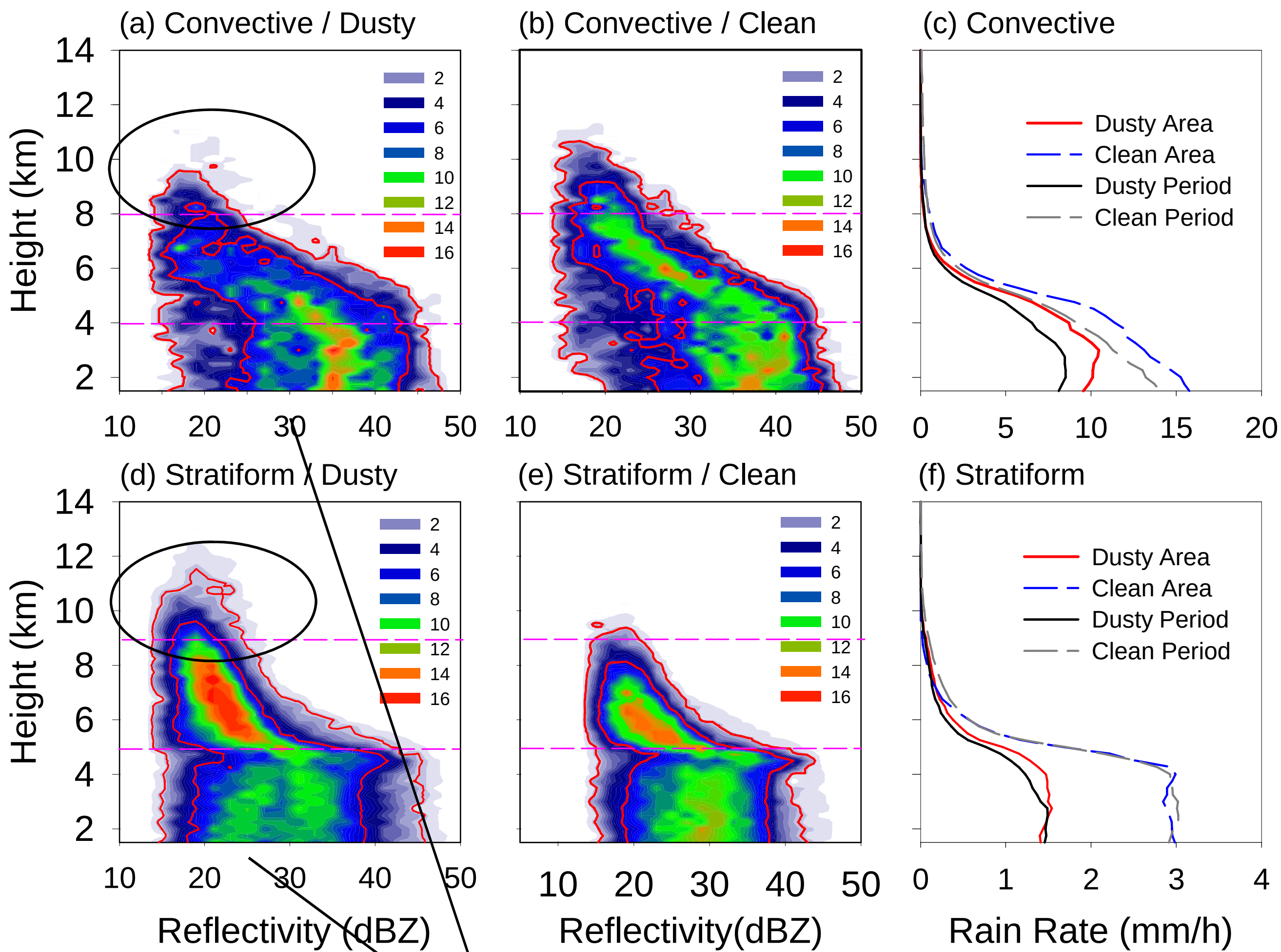




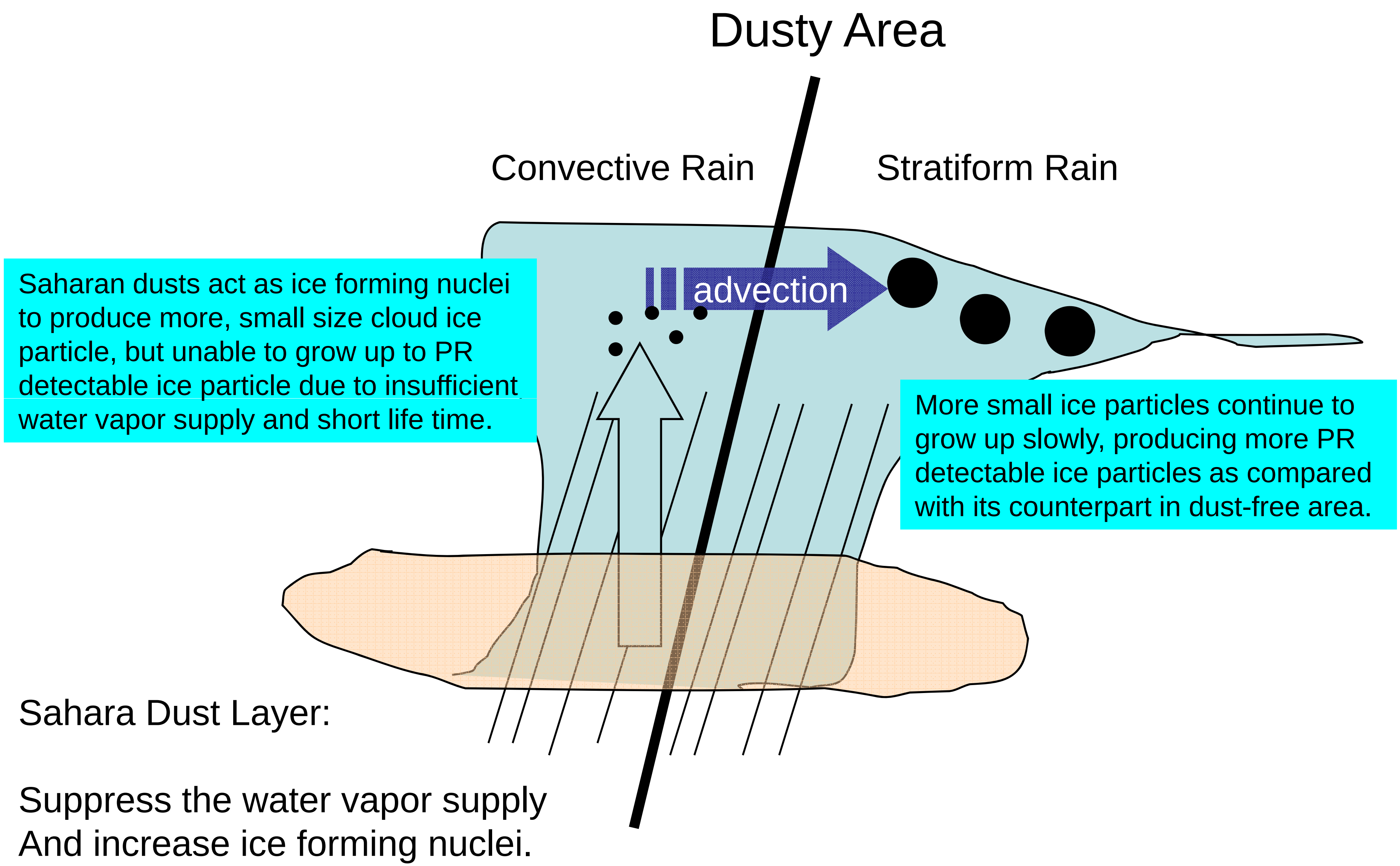
Precipitation size growth: CFADs of PR Reflectivity

Less precipitation-size ice here

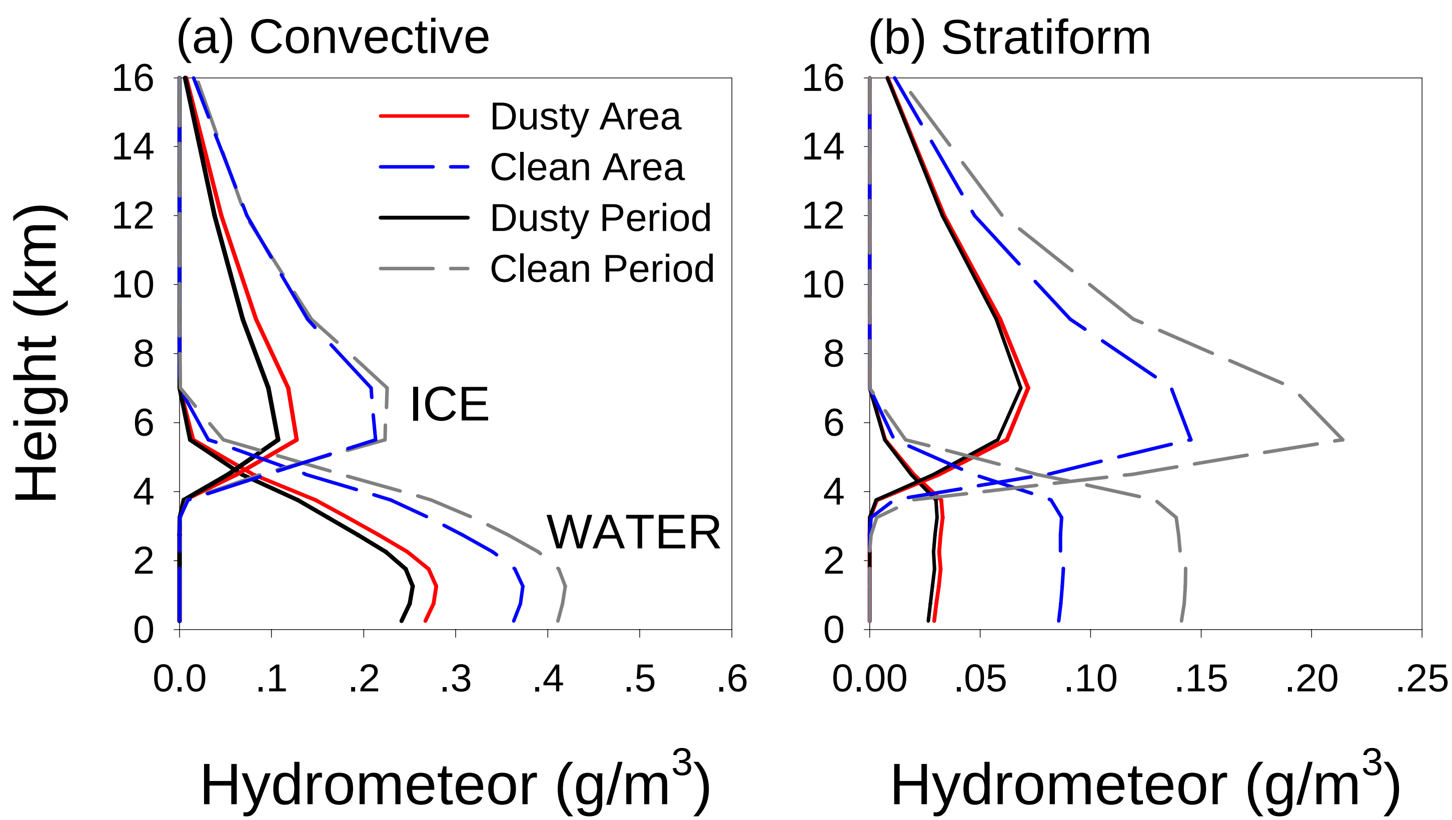
More precipitation-size ice here!



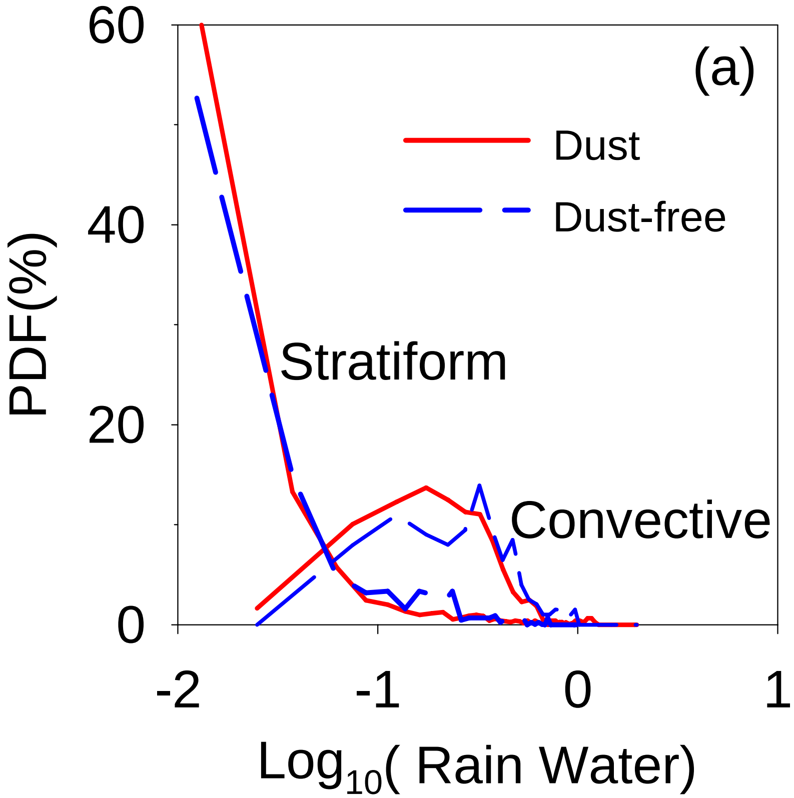
Weaker near surface radar reflectivity

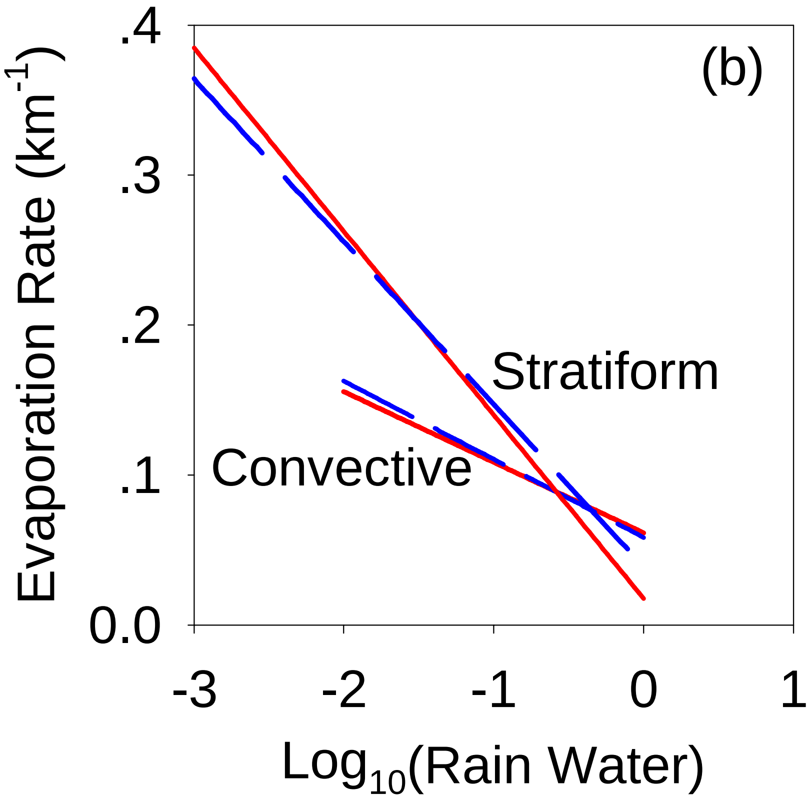

Dusty Area
Convective Rain
Stratiform Rain
Saharan dusts act as ice forming nuclei to produce more, small size cloud ice particle, but unable to grow up to PR detectable ice particle due to insufficient water vapor supply and short life time.
advection
More small ice particles continue to grow up slowly, producing more PR detectable ice particles as compared with its counterpart in dust-free area.
Sahara Dust Layer:
Suppress the water vapor supply
And increase ice forming nuclei.

TMI Precipitation Water



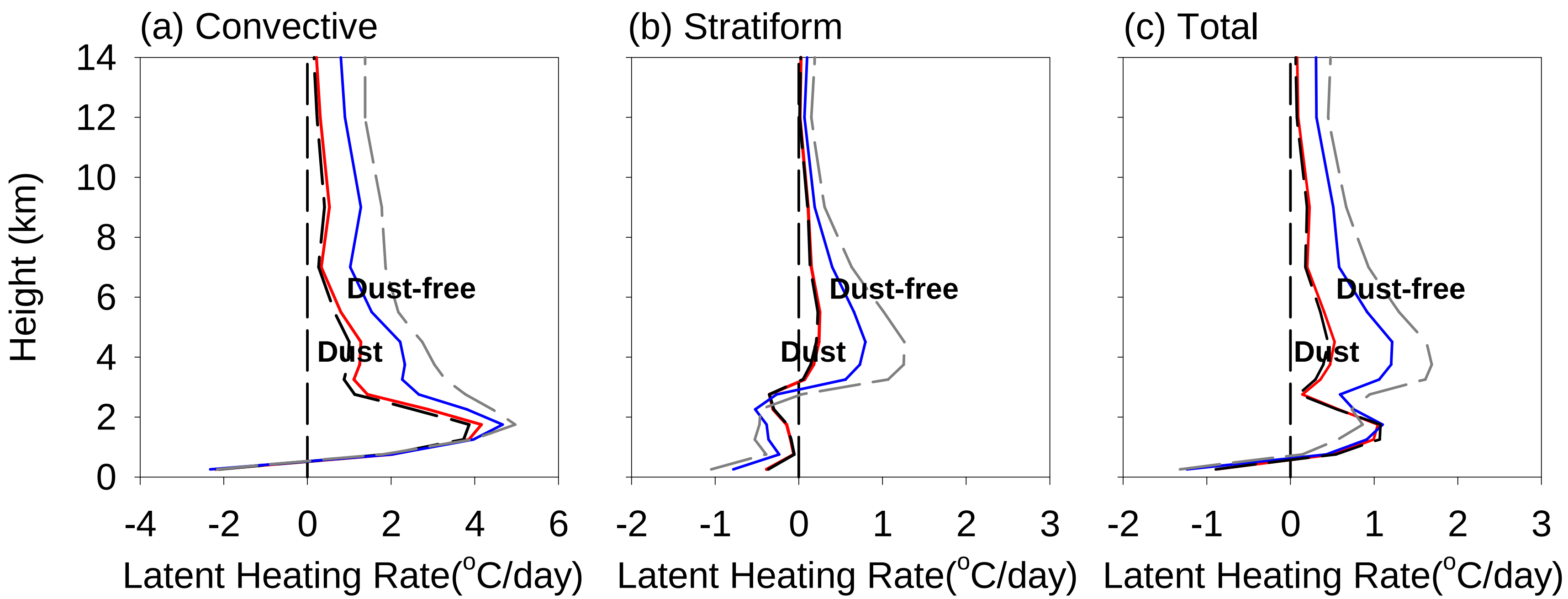
Evaporation below the freezing level





•Shifting to light precipitation
•Enhancing evaporation

Mean Latent Heating Rate profiles



- **Reducing latent heating rate**
- **altered the vertical distribution of heating profiles**

Statistics of TRMM PR rainfall profiles

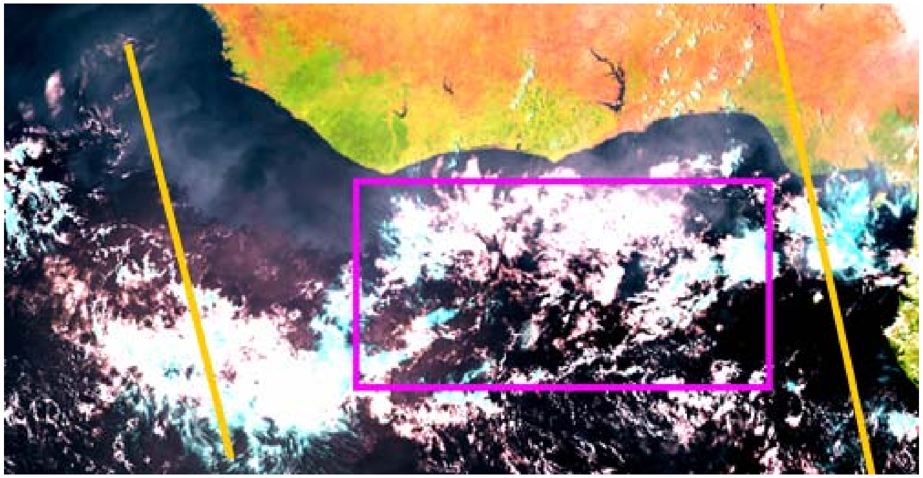
Rain Type / *Dust condition*	*Convective Rain*				*Stratiform Rain*			
	Pixel	*AF(%)*	*RF(%)*	*Rd(mm/h)*	*Pixel*	*AF(%)*	*RF(%)*	*Rd(mm/h)*
Dust	**312**[a]	**39.64**	**79.26**	**7.97**	**475**	**60.35**	**20.74**	**1.37**
	160[b]	*33.61*	*77.44*	*9.56*	*316*	*66.39*	*22.56*	*1.41*
Dust-free	**913**	**24.27**	**62.11**	**14.17**	**2849**	**75.73**	**37.89**	**2.77**
	156	*20.83*	*58.18*	*15.76*	*593*	*79.17*	*41.81*	*2.98*

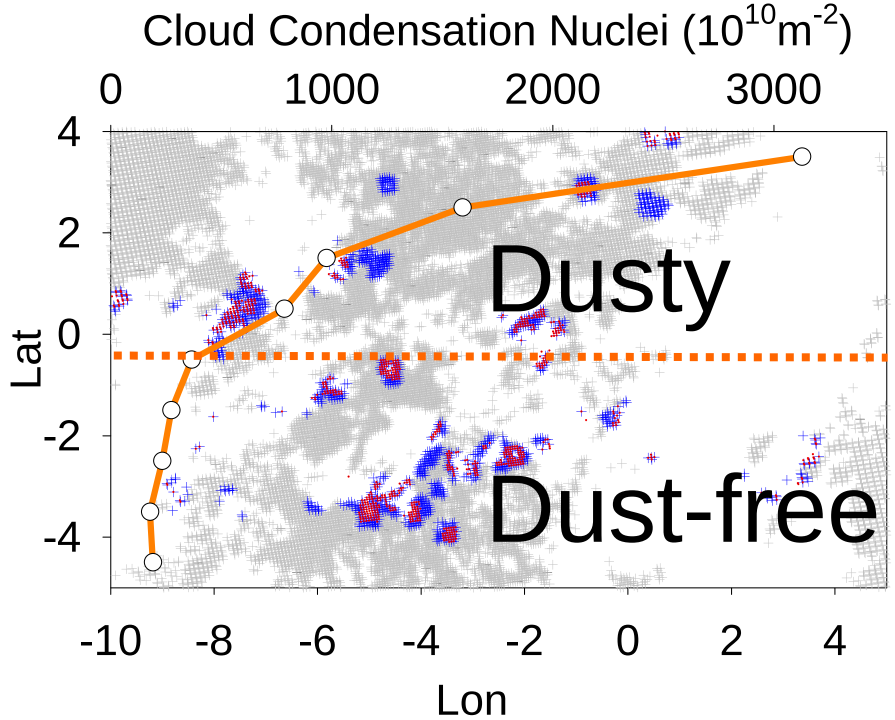
a: the fixed area statistics
b: the case statistics

Sahara Dust Aerosol Indirect Effect on Warm Clouds

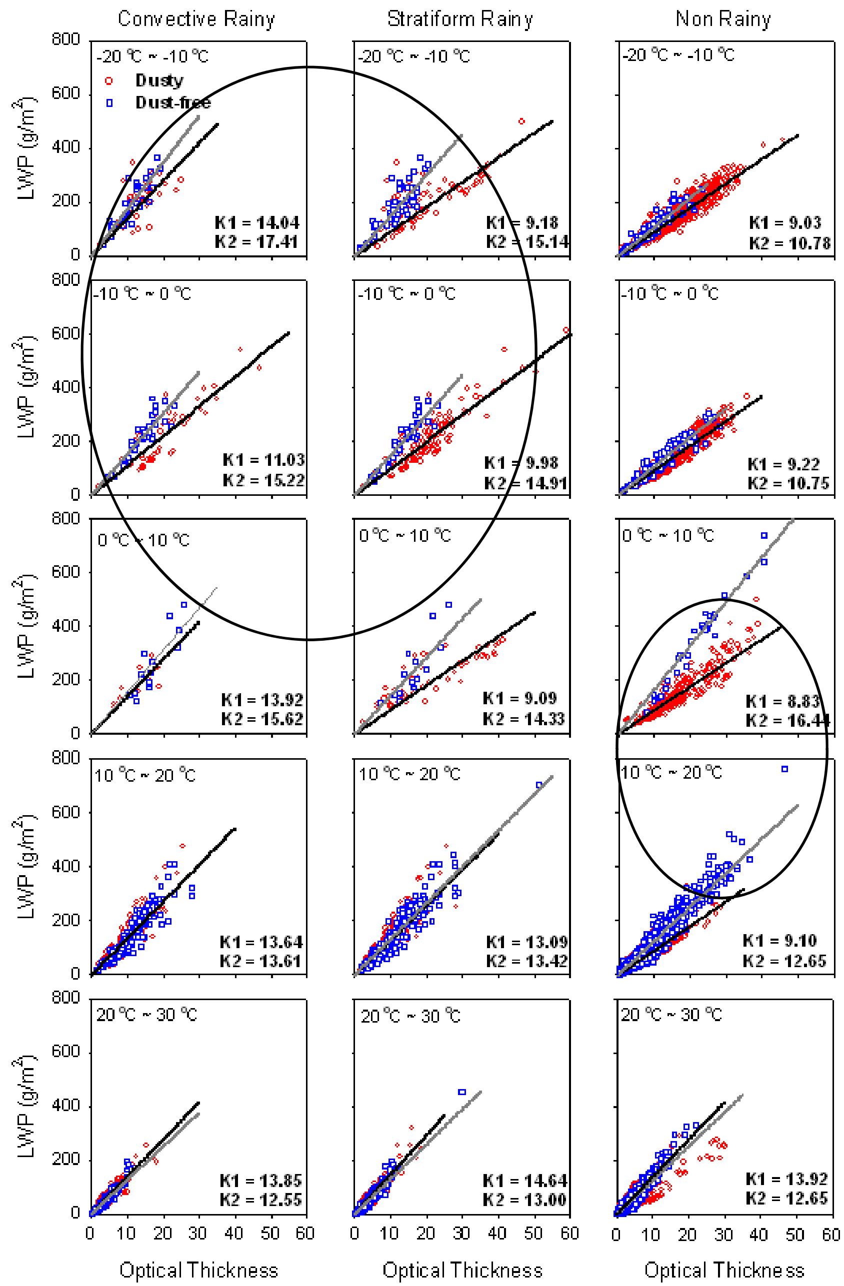
Dynamic effect

The case: March 7,2004





- Cloud precipitation regime
- Cloud top temperature (or height),
- Cloud liquid water path,
- Aerosol number concentration.



Quantitative Estimation

- To quantitatively estimate Sahara dust aerosol indirect effect, we define:

$$\mathrm{AIE} = \frac{\Delta \mathrm{Log}_{10}(\mathrm{Zregression\_slope}(\mathrm{LWP}/\tau))}{\Delta \mathrm{Log}_{10}(\mathrm{Zmean\_CN})} \qquad \text{(based on CCN)}$$

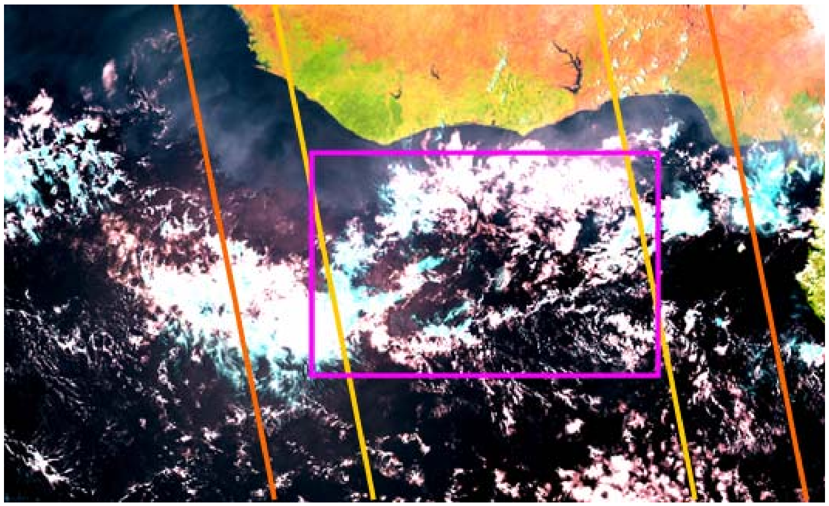
Calculated AIE based on CCN

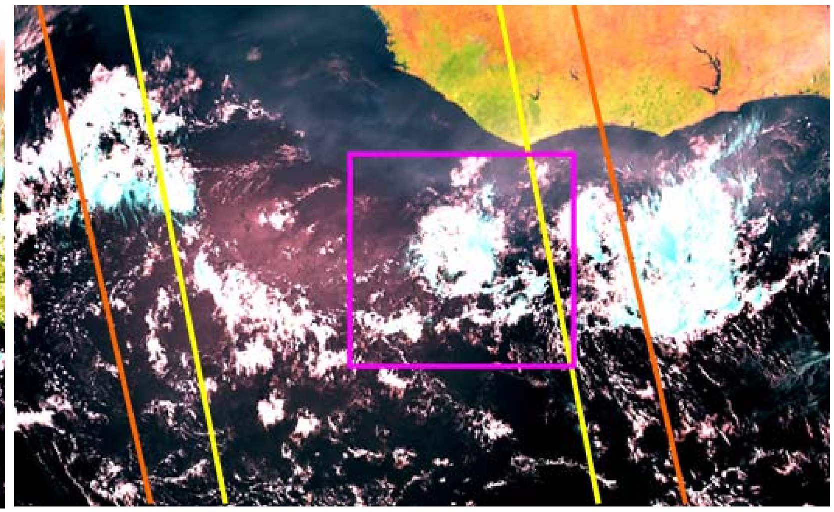
Layer	LWP (g m^{-2})	Cloud Type	AIE	R	|t|	P
Up Layer (T<0℃)	All in	**Rainy**	**-0.14 ± 0.05**	**0.75**	**2.80**	**0.03**
		Non-rain	-0.13 ± 0.08	0.59	1.57	0.17
Low Layer (T > 0℃)	All in	Rainy	-0.09 ± 0.06	0.50	1.53	0.17
		Non-rain	**-0.15 ± 0.03**	**0.89**	**4.83**	**<0.01**
	75~150	Non Rain	-0.15 ± 0.04	0.74	4.26	<0.01
	150~225		-0.21 ± 0.04	0.83	5.48	<0.01
	225~300		-0.18 ± 0.05	0.78	3.79	<0.01
	>300		-0.12 ± 0.02	0.96	7.44	<0.01

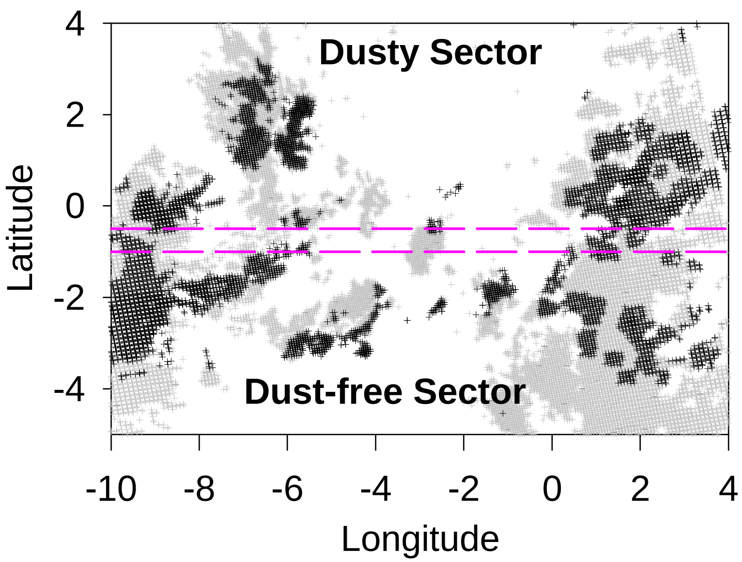
Sahara Dust Aerosol Indirect Effect on Ice Cloud

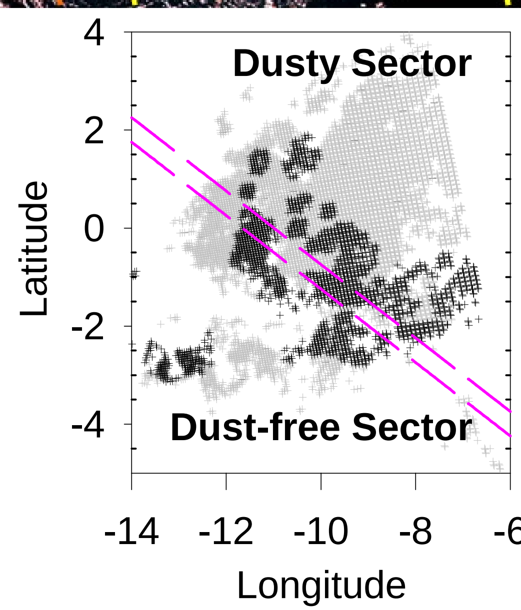
- Heterogeneous and homogeneous nucleation

The cases:

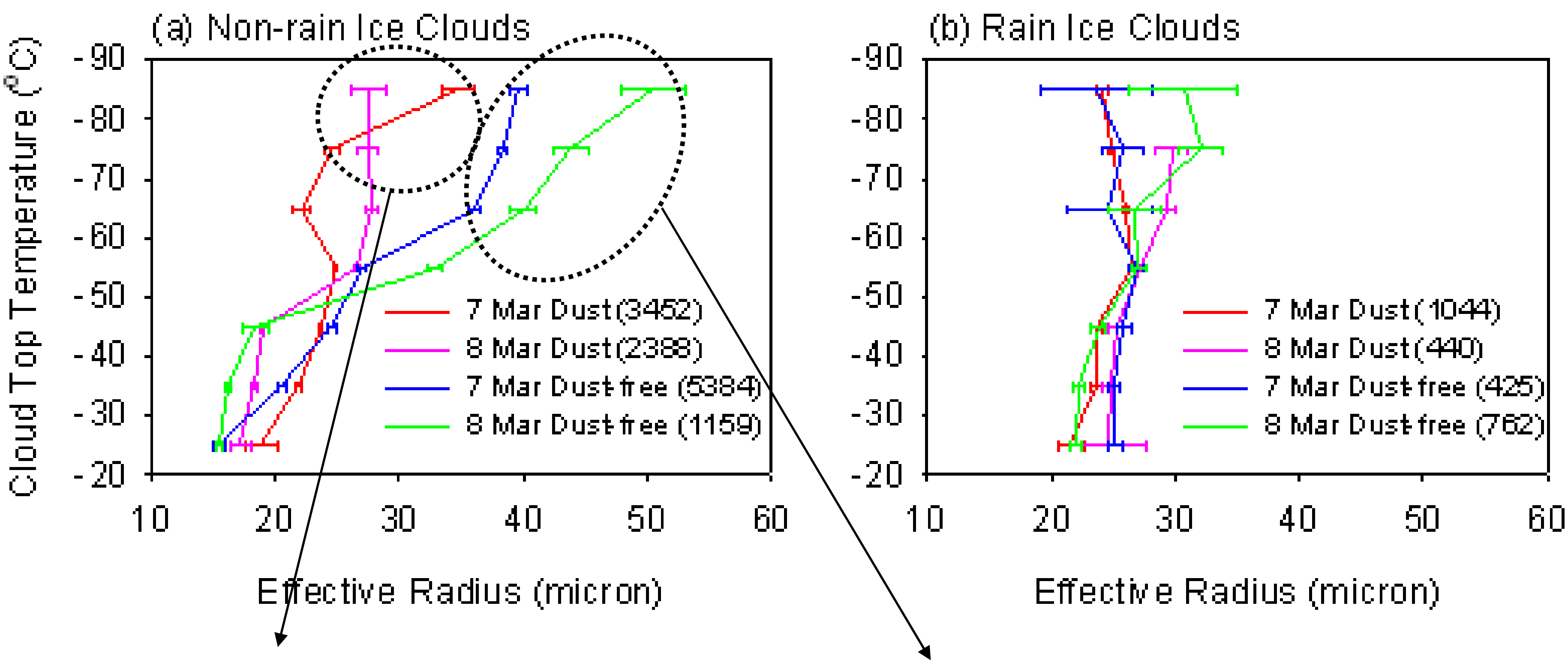





Dusty Sector
Dust-free Sector
Latitude
Longitude
4
2
0
-2
-4
-10
-8
-6
-4
-2
0
2
4


Dusty Sector
Dust-free Sector
Latitude
Longitude
4
2
0
-2
-4
-14
-12
-10
-8
-6

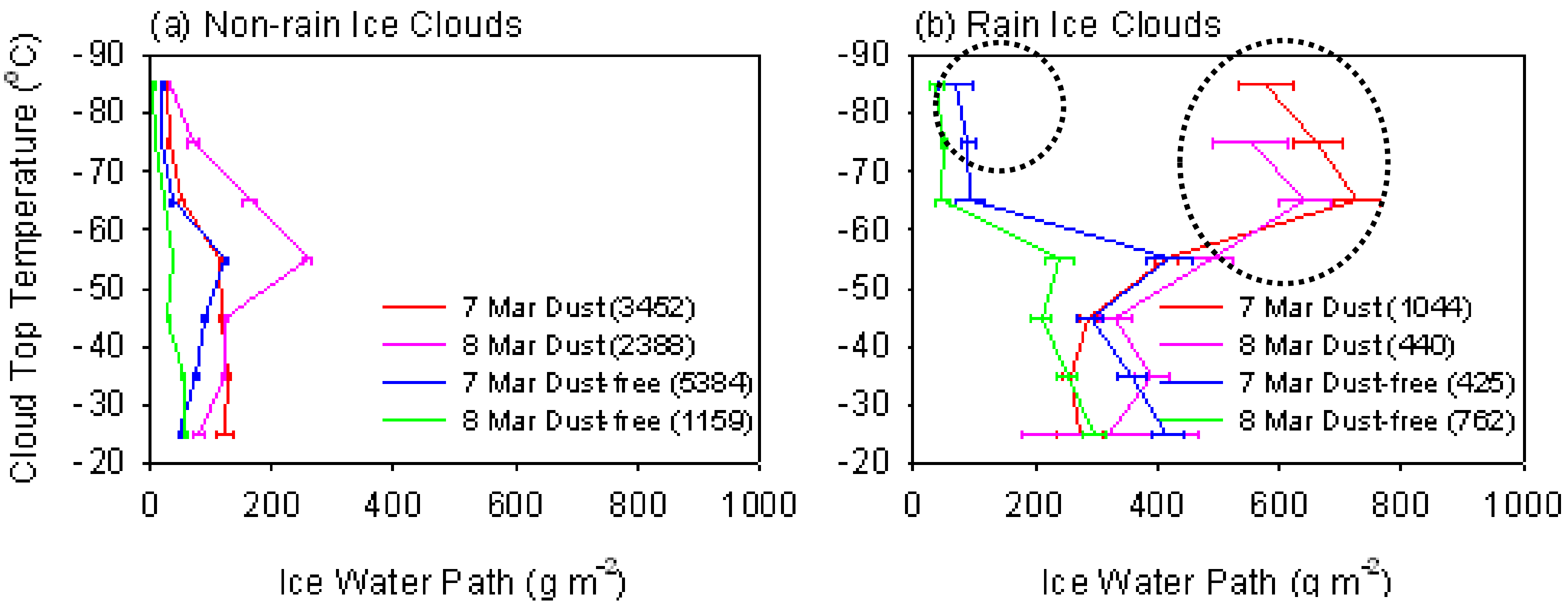
Mean profiles of Re
(with standard errors)

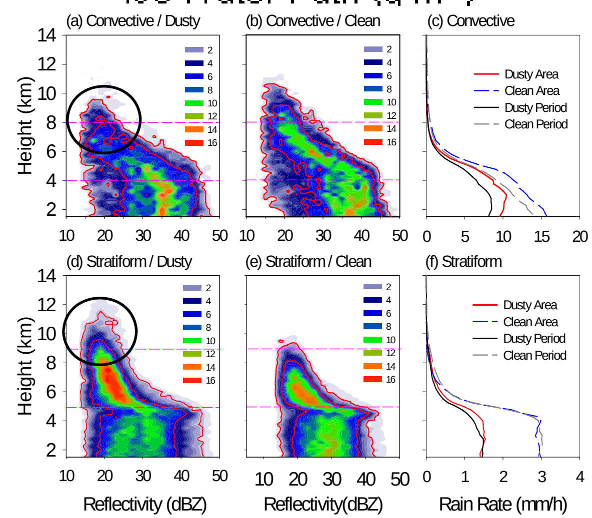


Dust sector: Heterogeneous Nucleation

Dust-free sector: Homogeneous Nucleation

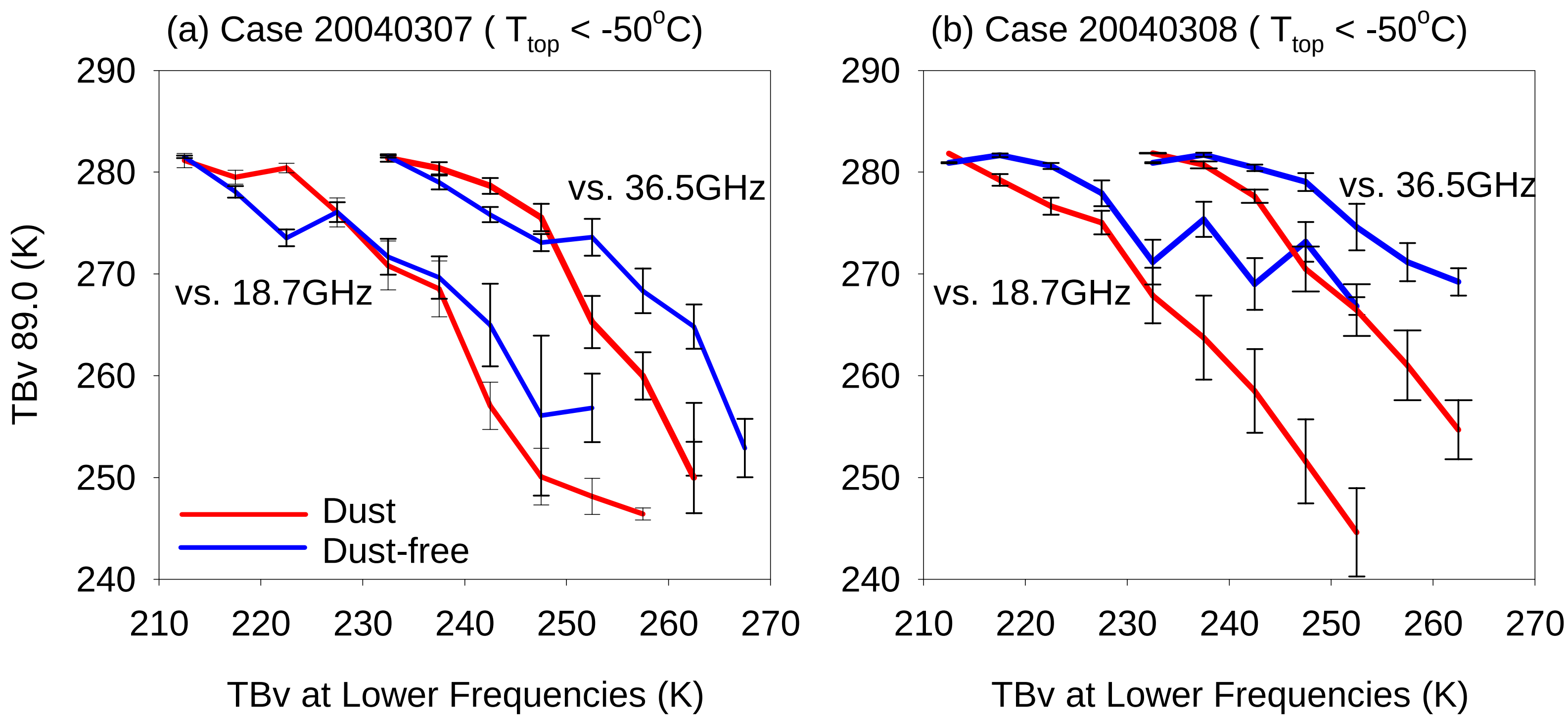
Mean profiles of IWP (with standard errors)



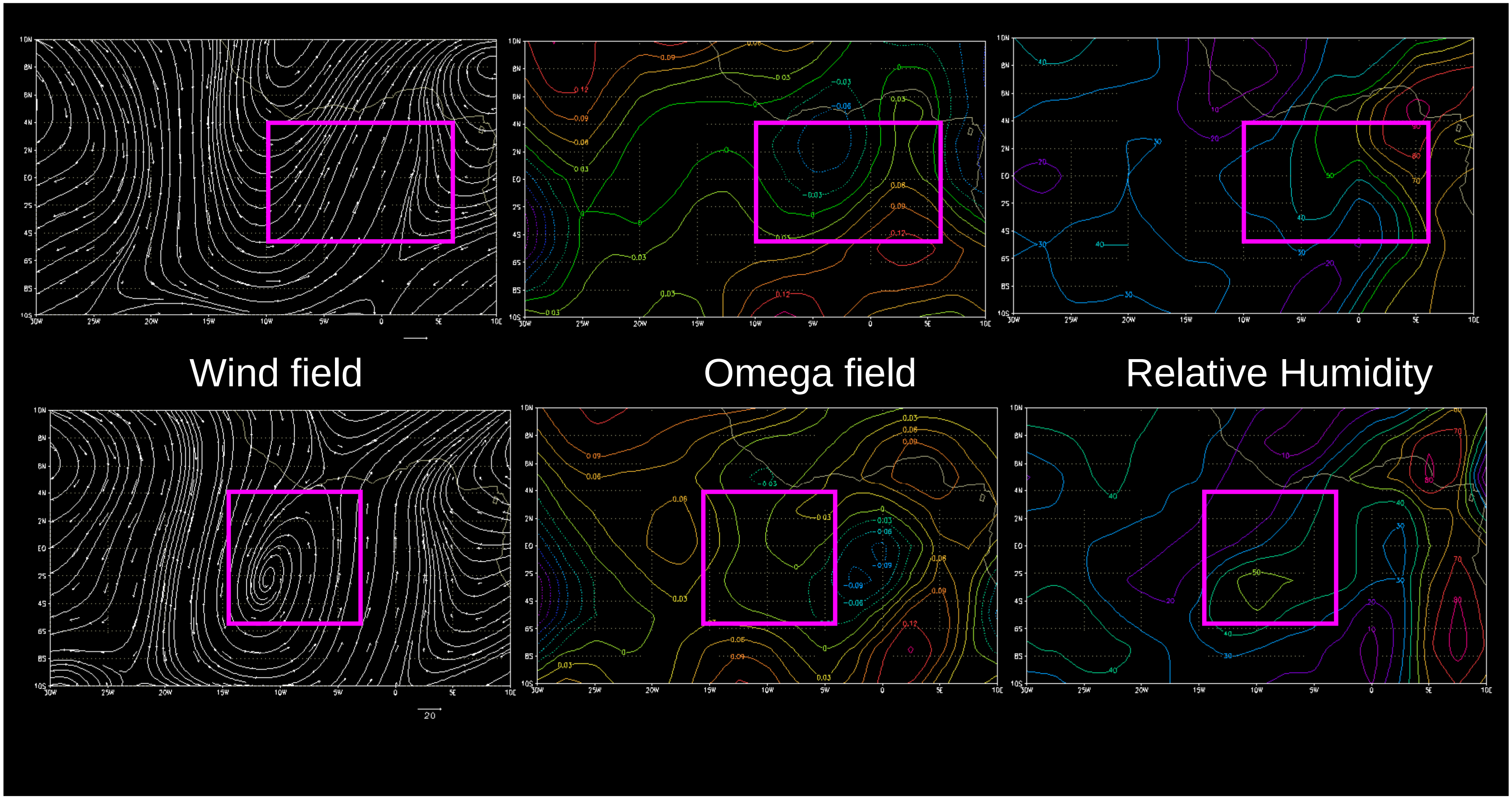


TRMM PR CFADs of radar reflectivities in dust / dust-free rain area (another paper)

Microwave brightness temperature over rain clouds



Meteorologic diagnostics:
NCEP reanalysis data at 300 mbar (~ -35^{o}C)



- Generally uniform wind field at 300 mbar for both cases.
- Both vertical velocity and relative humidity conditions in dust sectors are not more favorable to produce more ice at upper layer.

Summary and conclusion

- Saharan dusts are transported from lower layer to upper layer by strong convection in convective rain region and advected into stratiform rain region and non-rainy clouds
- Saharan dusts and associated dry air suppress precipitation
  - Suppress convection and reduce moisture supply
  - Increase Ice Nuclear concentration and result in smaller size (weaker) precipitation
  - Enhance evaporation below the freezing level
  - Reduce latent heat release in the upper troposphere and increase cloud lifetime

Summary and conclusion

- For rain water clouds, the first AIE is significant in the upper layer but much weaker in lower layer due to the relative stronger vertical transportation and scavenging of dust particle by rainfall.
- For non-rain water clouds, the first AIE is significant in the lower layer but weaker in upper layer due to the relative weaker vertical transportation.
- Dusts direct SW forcing is 48 w/m2/AOD;
- Dust indirect SW forcing
  - 34.21 $\pm$ 4.87 (14.25%) w/m2/AOD for LWP of 100 g/m2

Summary and conclusion

- Dusts reached upper layer through strong convection can act as ice nuclei
  - Heterogeneous nucleation can produce more ice particles under relative lower humidity as compared to homogeneous nucleation
  - Smaller ice effective radius.
- More ice clouds, which have larger ice water path and smaller ice effective radius, are found in the dusty sector than in the dust-free sector
  - Not due to dynamic and thermodynamic conditions
  - Due to microphysical process