
G S Bhat
TBA Soon



G S Bhat

Clouds: Some observed features

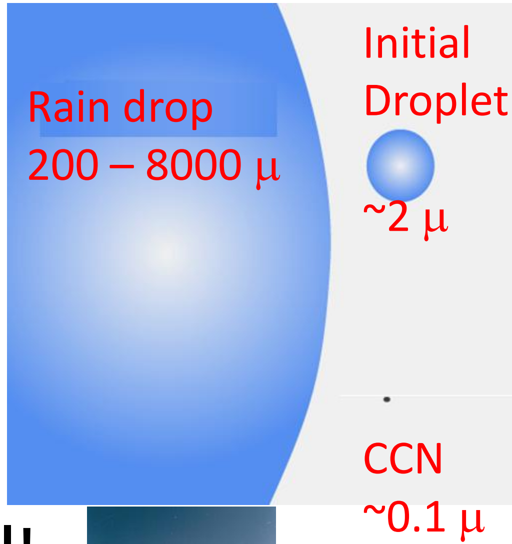


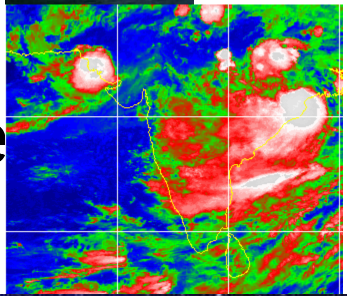


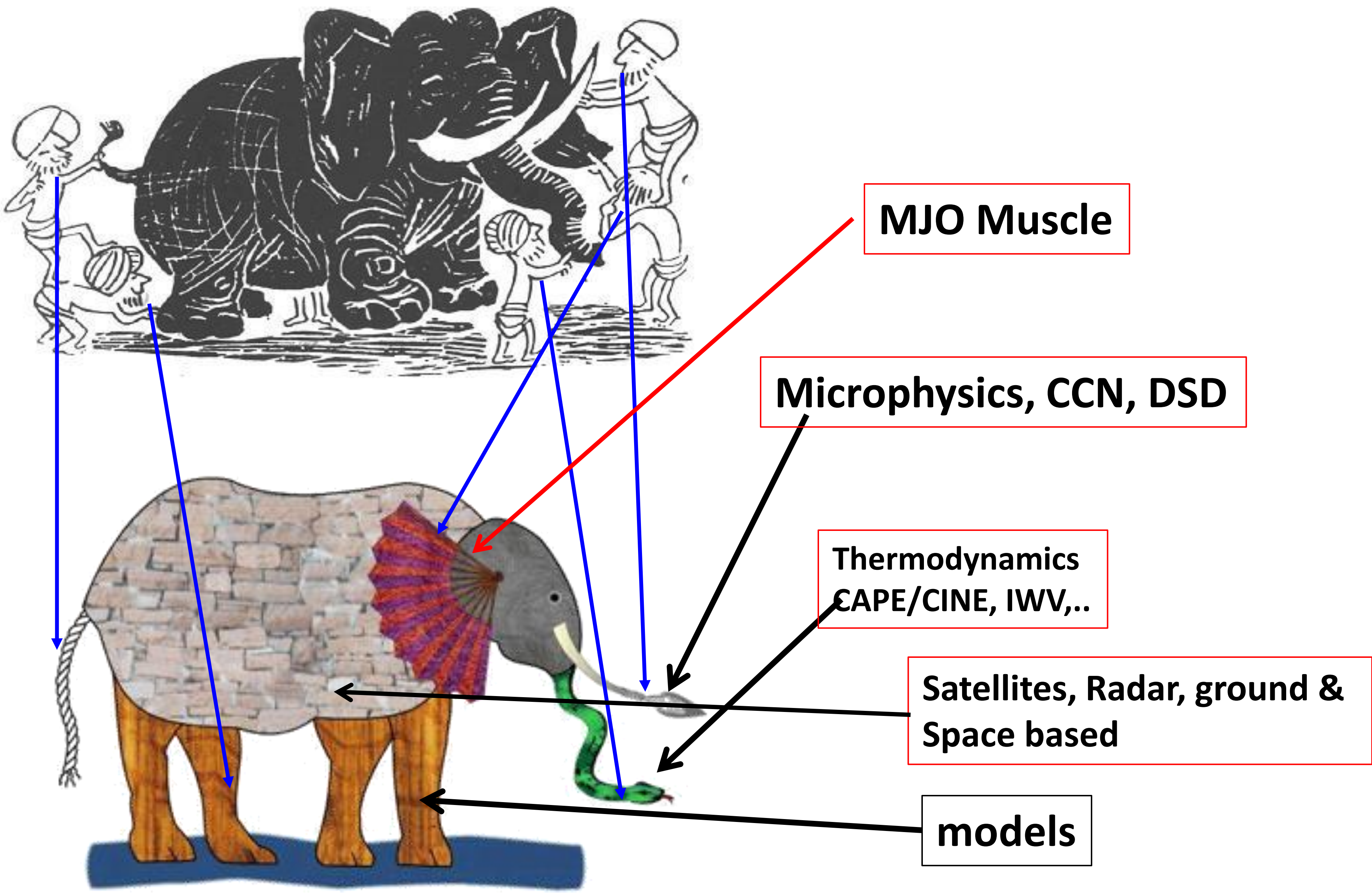

→ Multi-scale problem

1. Condensation : sub-micron sized CCN ~10^{-7} m
2. Moisture supply: ~1000 km, 10^{6}m
   Range ratio ~ 10^{13}, Astronomical!

3. In between : Cloud scale (~ 1 km)
   Mesoscale (~ 100 km)
4. Form, grow, decay, reborn - Propagate






MJO Muscle
Microphysics, CCN, DSD
Thermodynamics
CAPE/CINE, IWV,..
Satellites, Radar, ground &
Space based
models

Data Source:

Observations made during ICRP field phase

Satellite data (TRMM PR)

CAIPEEX Aircraft Observations

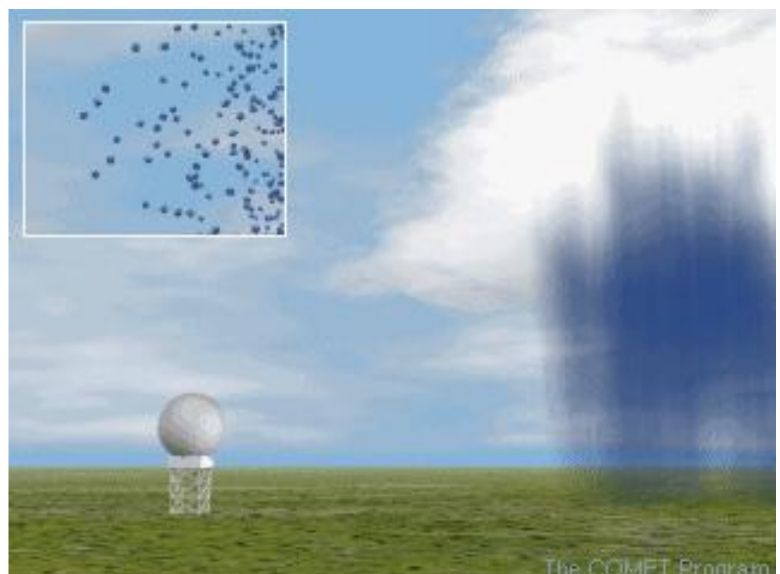



Disdrometer


MWR


CAIPEEX, IITM
N361JC


2D-video disdro


The COMET Program

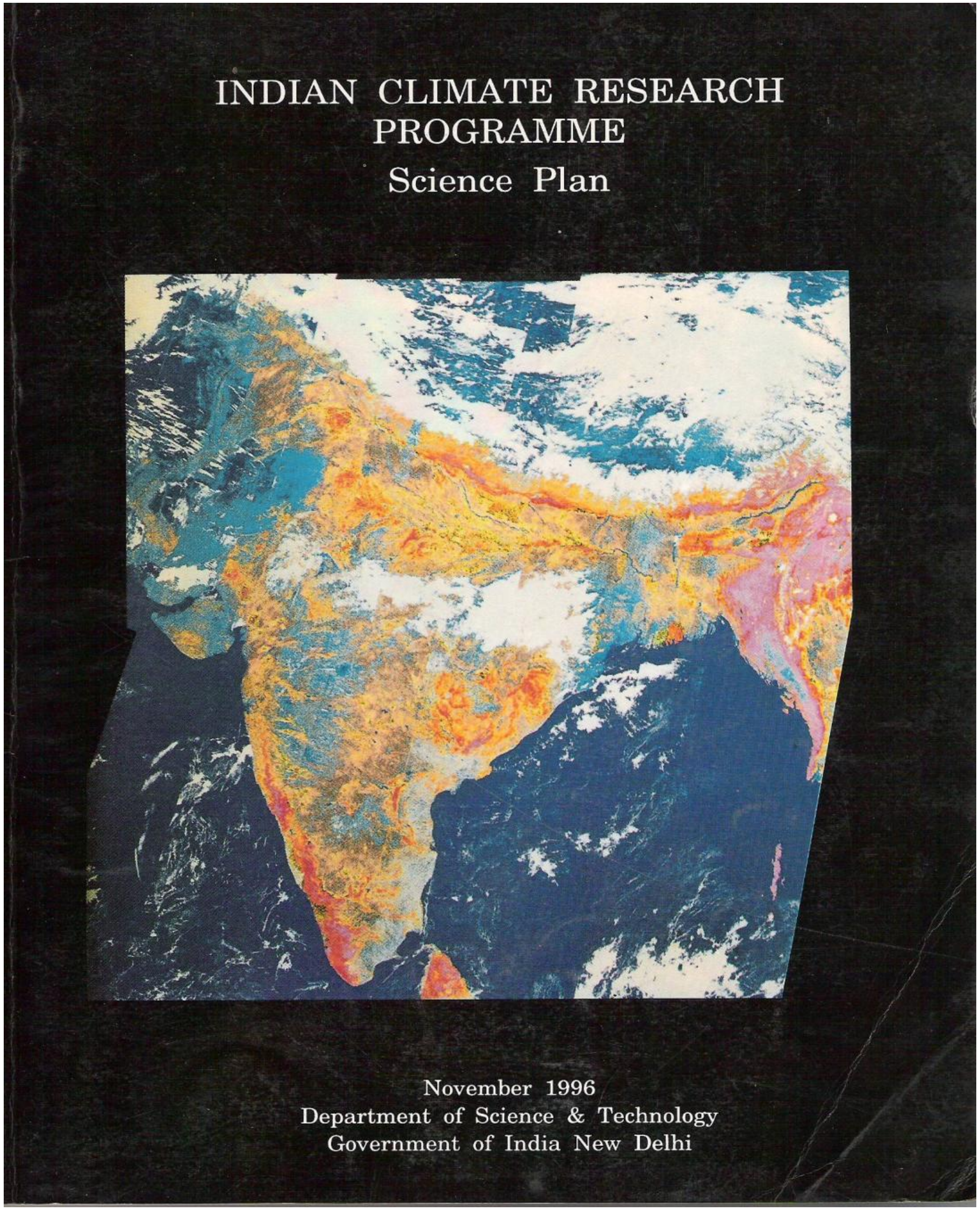
IMD DWR

Indian Climate Research Programme
1996: Sci. Plan; 1998: Impl. Plan

Main Focus: Understanding monsoon variability on timescales ranging from sub-seasonal to inter annual and decadal, and its impact on critical national resources

CAOS → Major role in conceiving & implementing

Wonderful cooperation from many, Govt, Defense, CSIR, UNIV, ….



DST +
DOD (MoES)+
DOS +
MoD +
CSIR +
IMD +
IISc,IITs +
Universities

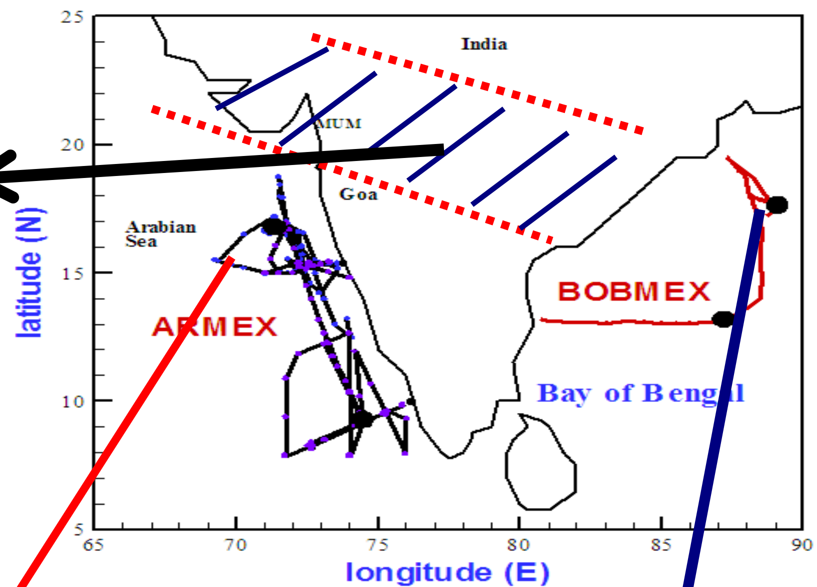
ICRP Field Experiments: 3 so far

Bay of Bengal Monsoon Experiment (BOBMEX): 1998-1999

Arabian Sea Monsoon Experiment (ARMEX): Jun-Aug 2002,
Mar - June 2003 , April-May 2005

CTCZ- understand the mechanisms leading to the space-time variation of rainfall and the embedded monsoon disturbances during the summer monsoon with focus on intra-seasonal variations

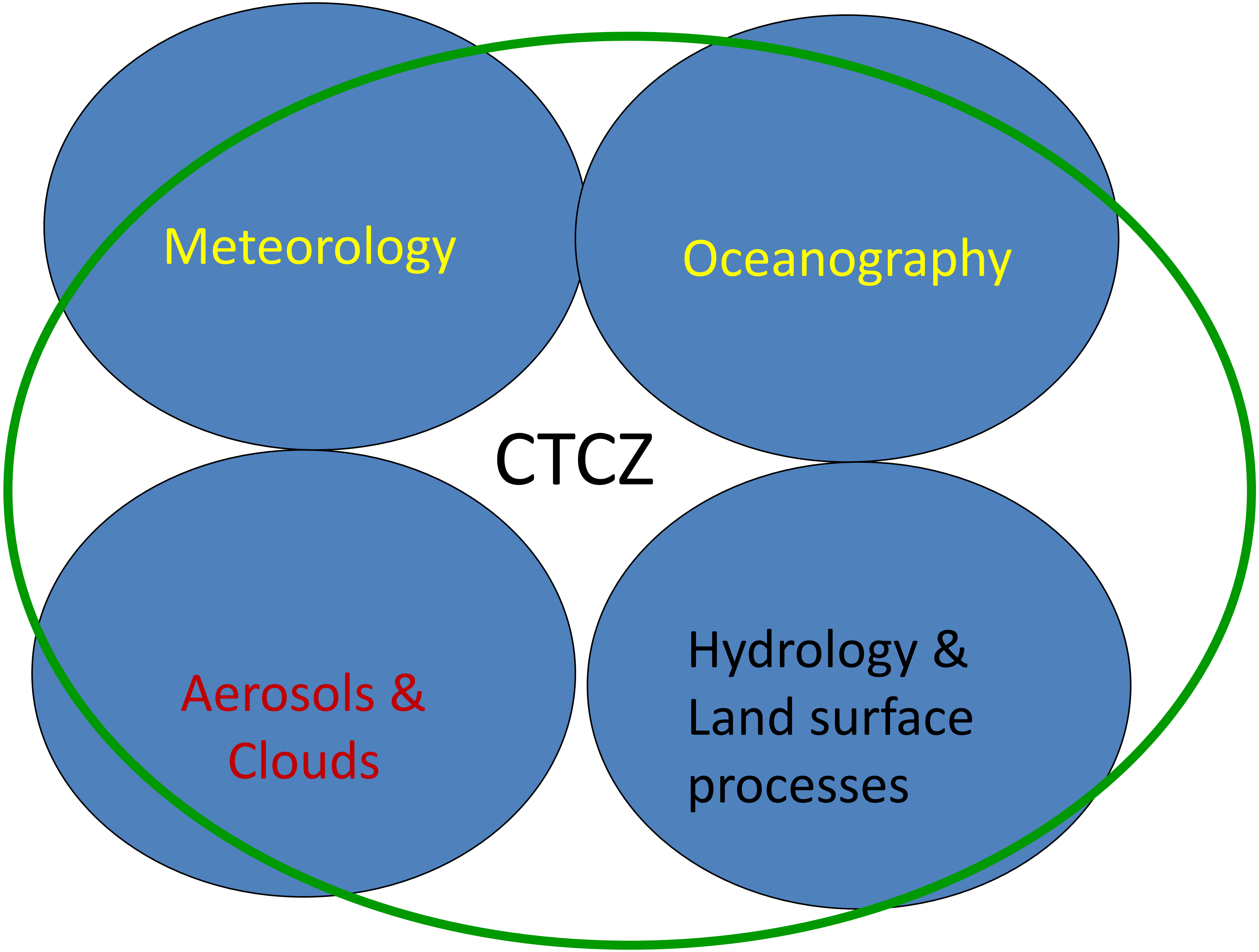
Large-scale, Land surface processes and hydrology, clouds & aerosols, ocean



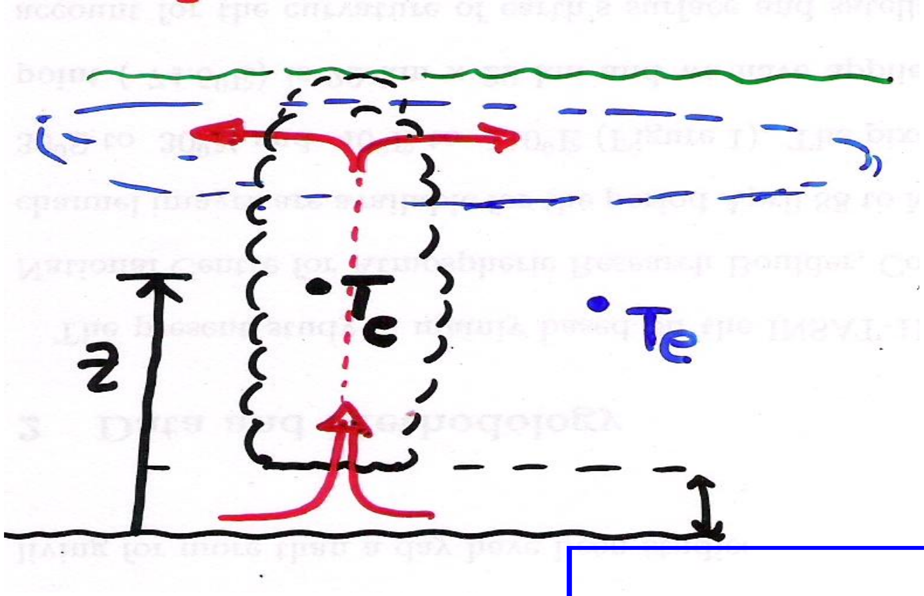
ARMEX – 2002-2003, 2005
1. Intense Rainfall Events on WC
2. Warm pool build up & Collapse
3. Monsoon Onset over Kerala

Mausam Jan. 2005 (Special Issue)

BOBMEX – 1998-99
Air-sea Coupling
Rapid SST Recovery
Northward Propagation
North-South gradients
(Bhat et al, *BAMS*, 2001)



Land-hydrosphere-atmosphere-vegetation interact



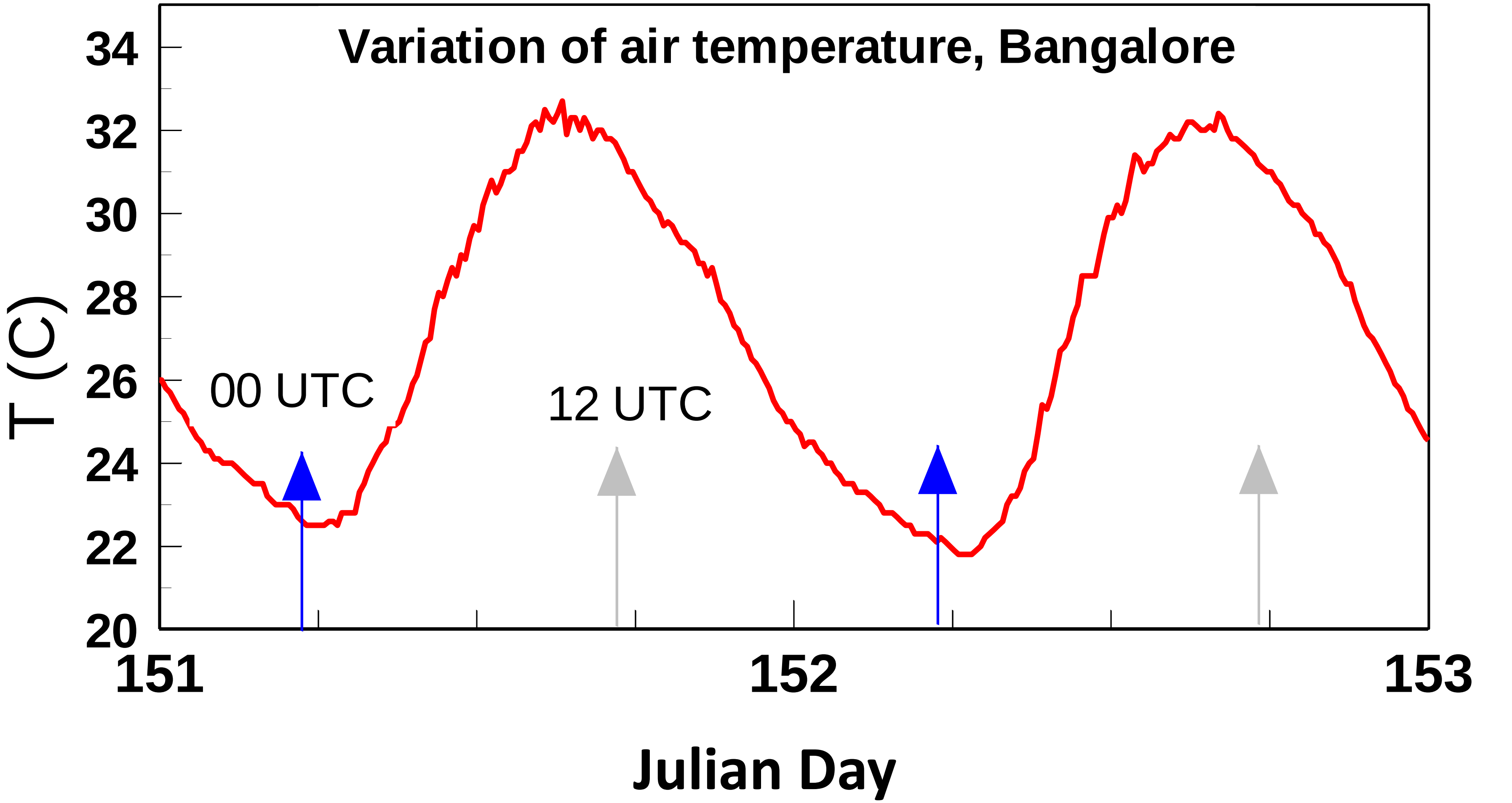
$$B = g\frac{T_c - T_e}{T_e}$$

Deep cloud formation

Manifestation of moist instability

CAPE – Convective Available Potential Energy
CINE – Convection inhibition energy

What happens to CAPE & CINE as clouds develop?



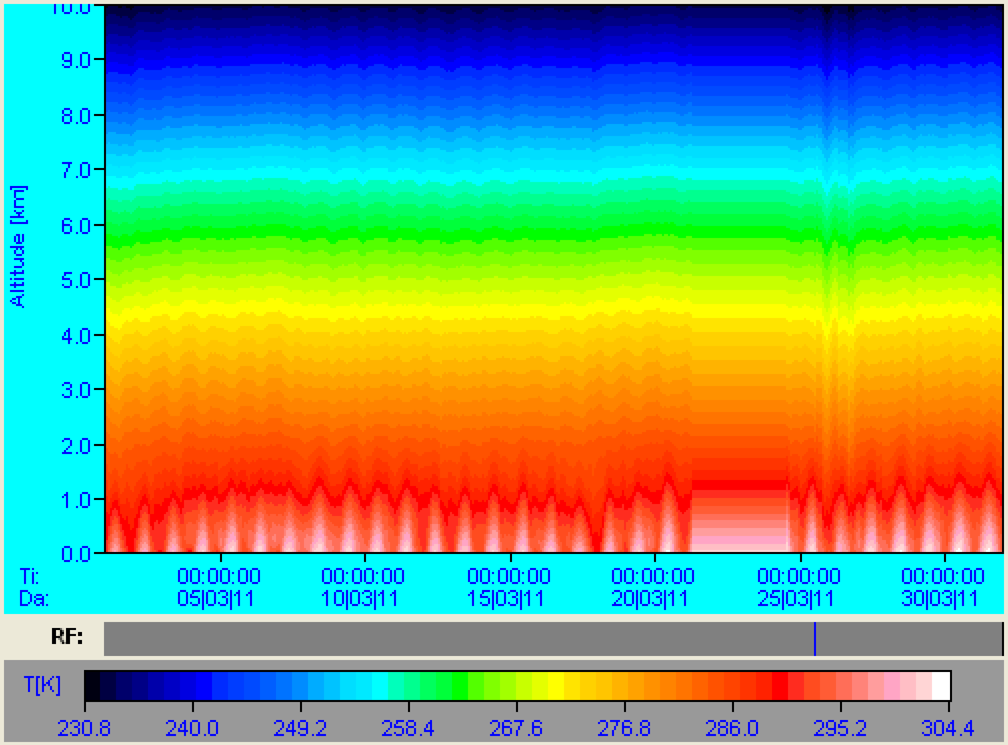
Variation of air temperature, Bangalore
T (C)
34
32
30
28
26
24
22
20
00 UTC
12 UTC
151
152
153
Julian Day

(CTCZ Project, DST, Govt India)

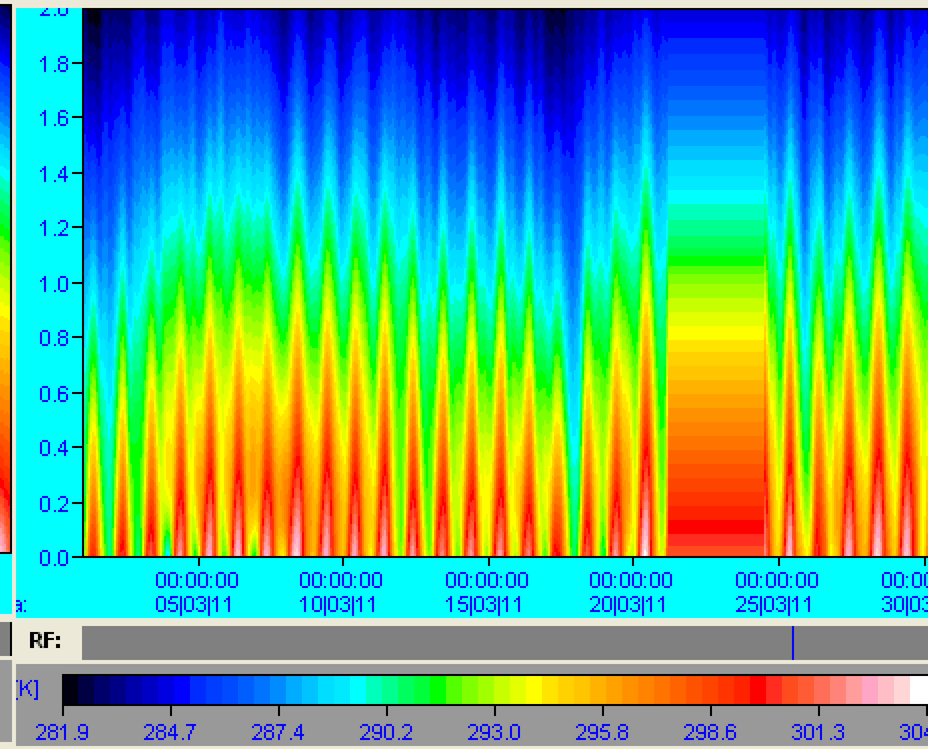
Microwave Radiometer

Measures T & humidity profiles up to 10 km height

Data ~ continuous, every minute

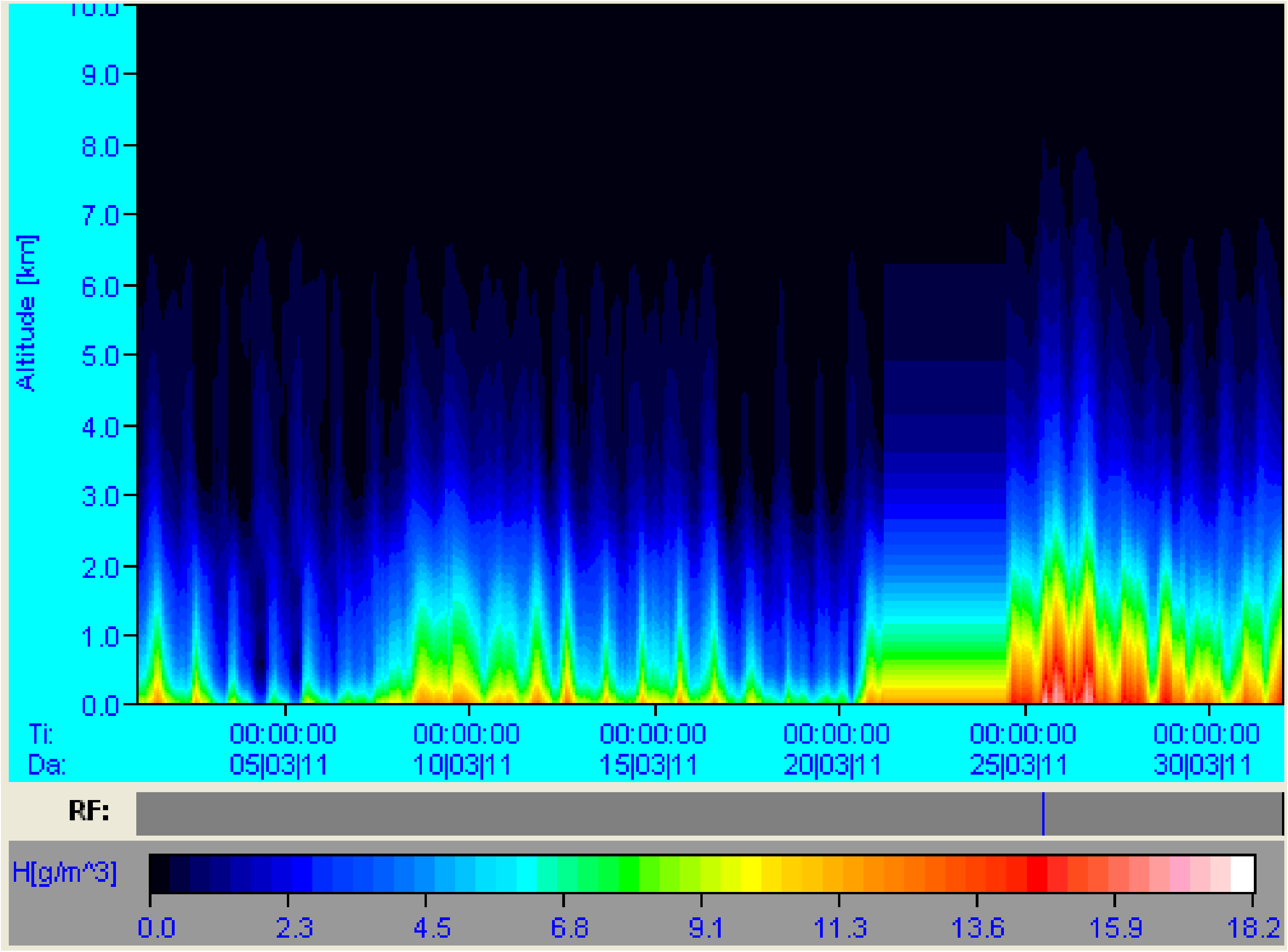


Temperature, up to 10 km height



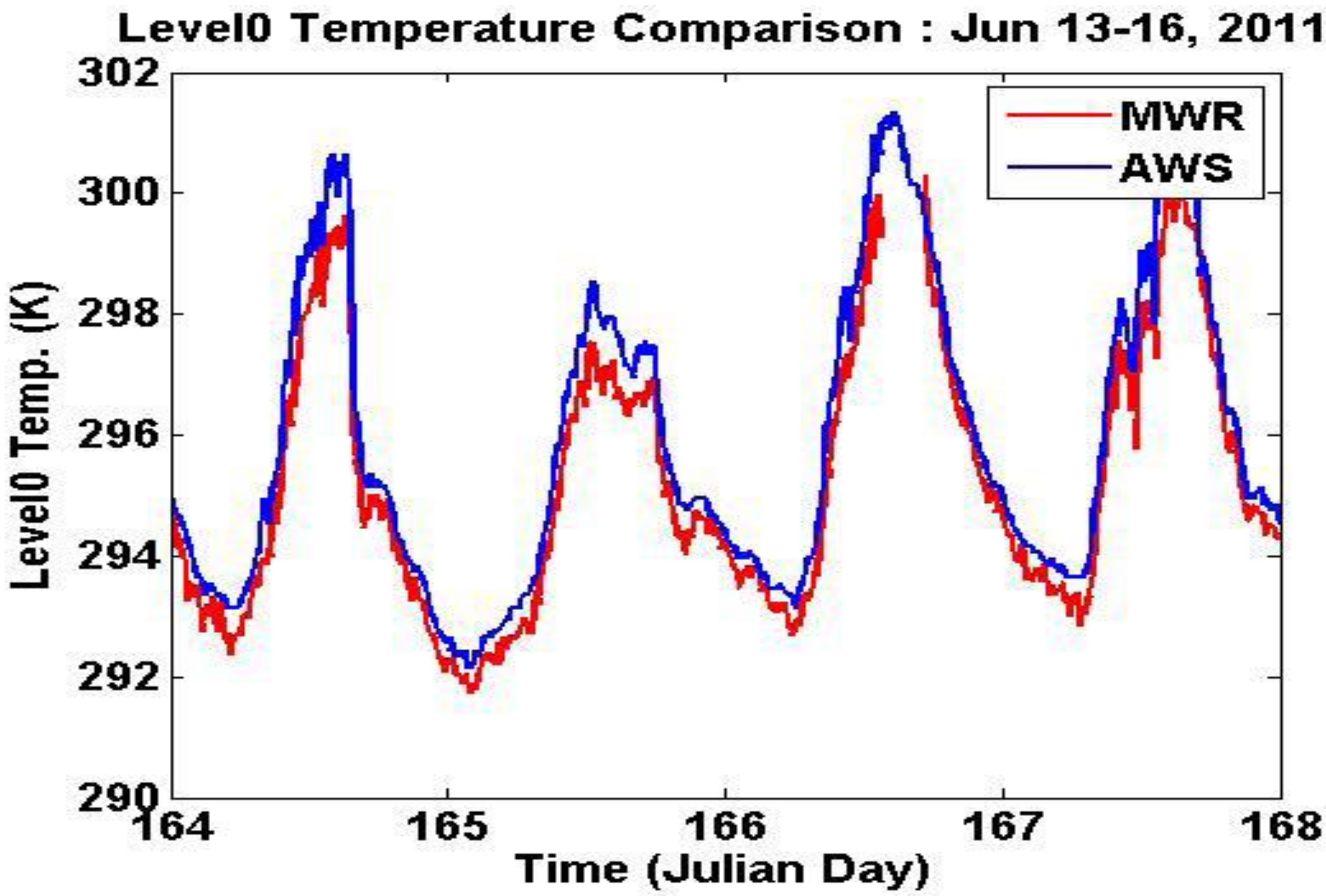
Temperature, lowest 2 km

March 2011

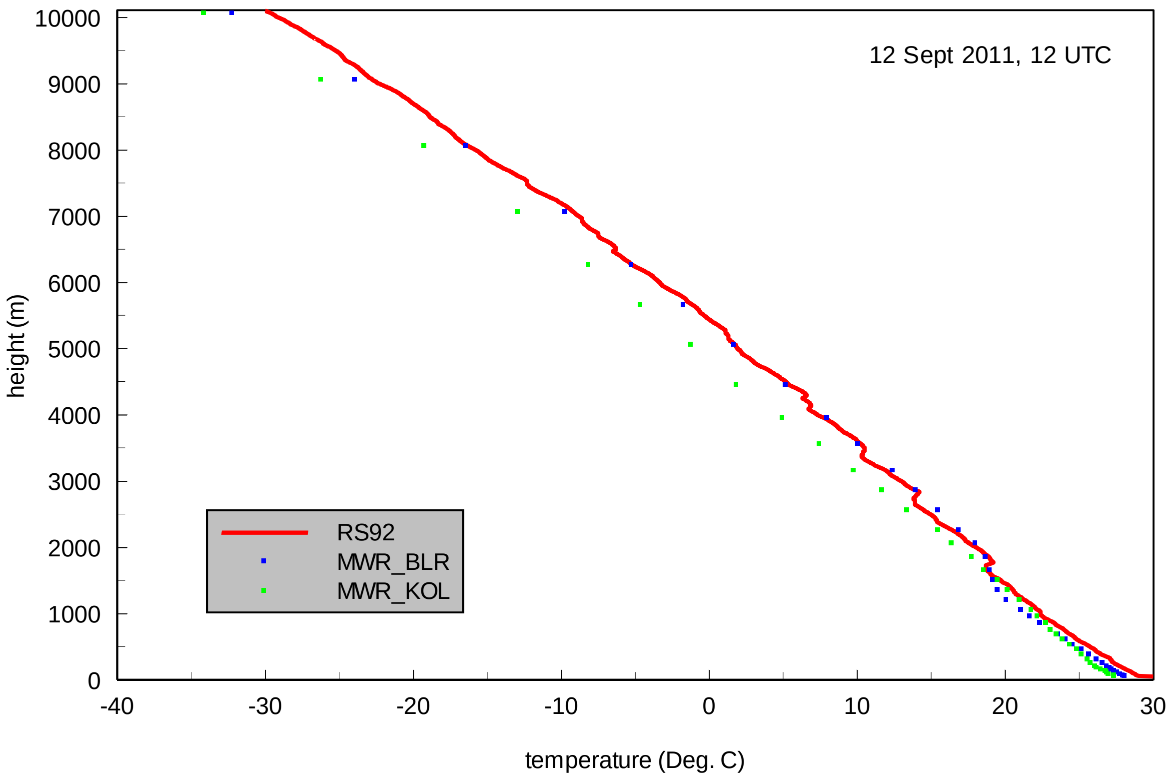


Water vapor concentration (g/m^^3)

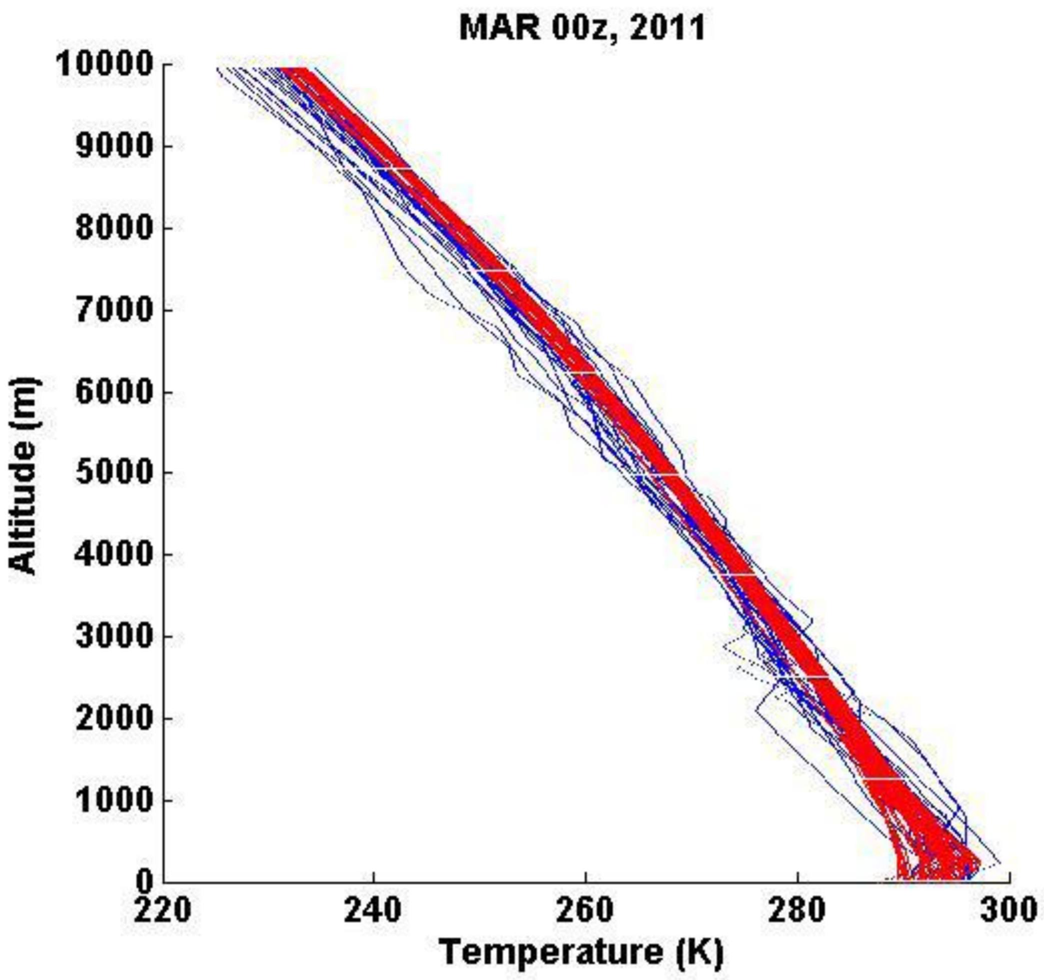
How reliable is the data?



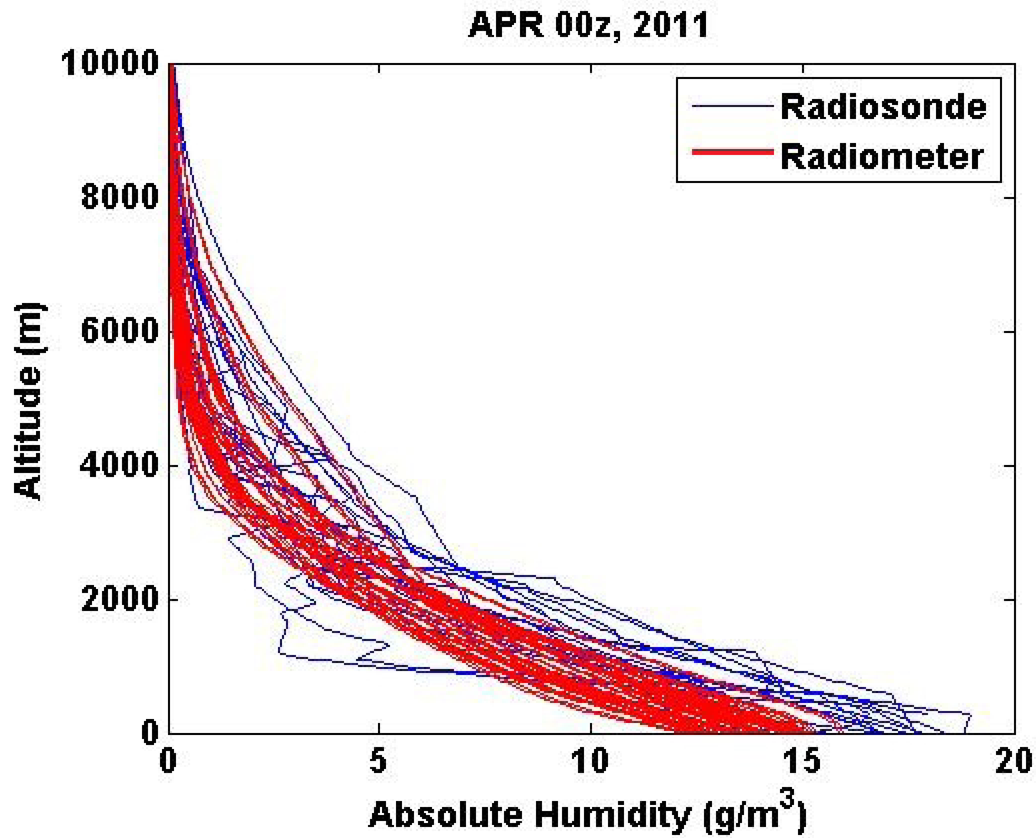
~0.5 to 1 K temperature bias, corrected



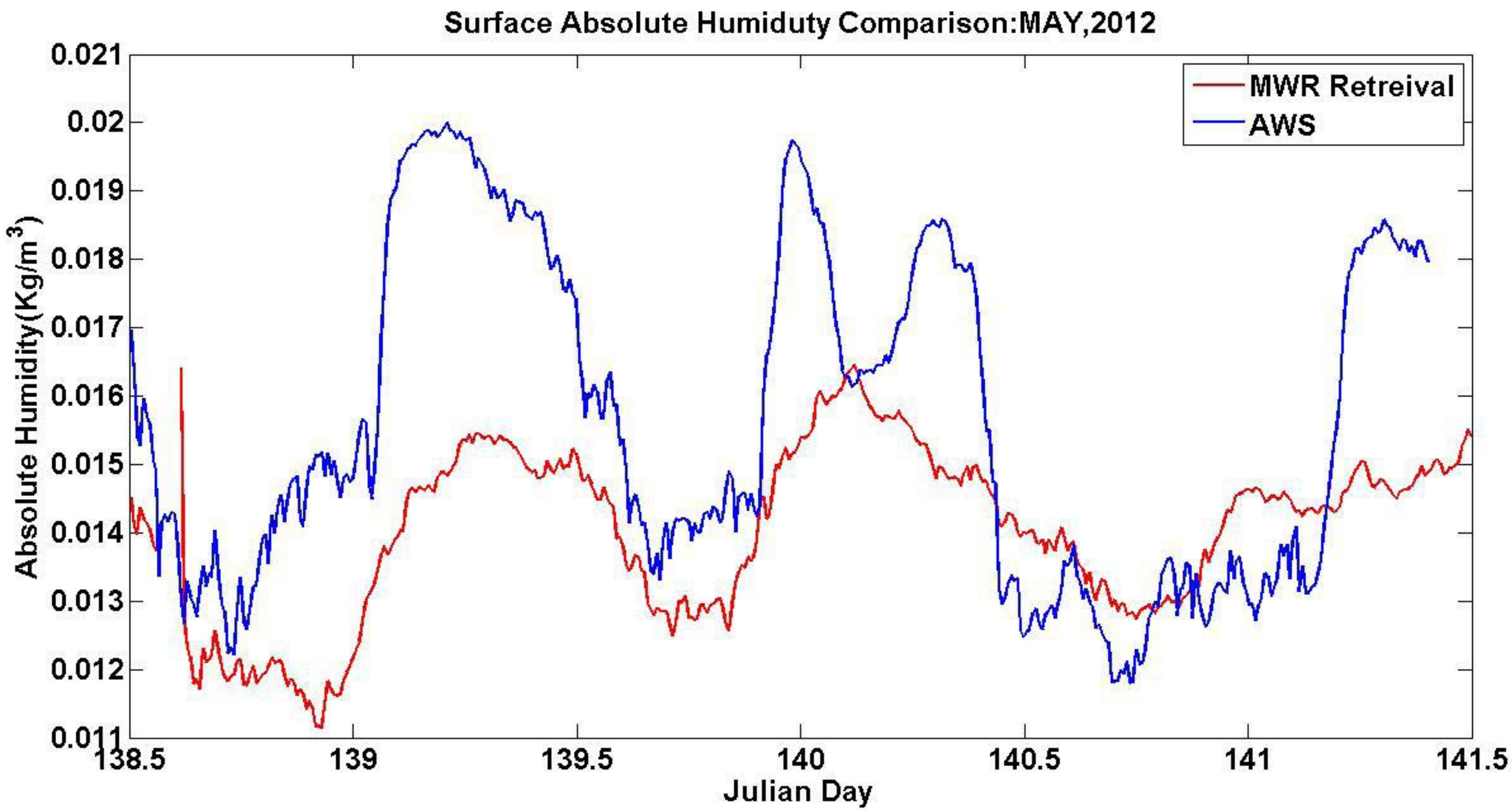
12 Sept 2011, 12 UTC
RS92
MWR_BLR
MWR_KOL
height (m)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-40
-30
-20
-10
0
10
20
30
temperature (Deg. C)



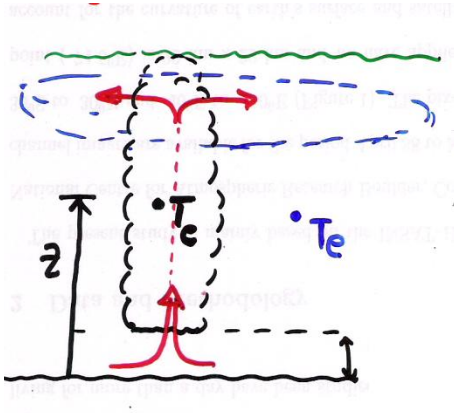
Validation of the Microwave Radiometer Temperature profiles against the Bangalore IMD radiosondes. The MWR profiles are indicated by Red and the radiosonde profiles by blue.



MWR – captures the structure of water vapor profile well



MWR - Mean ~ reasonable but misses diurnal amplitude

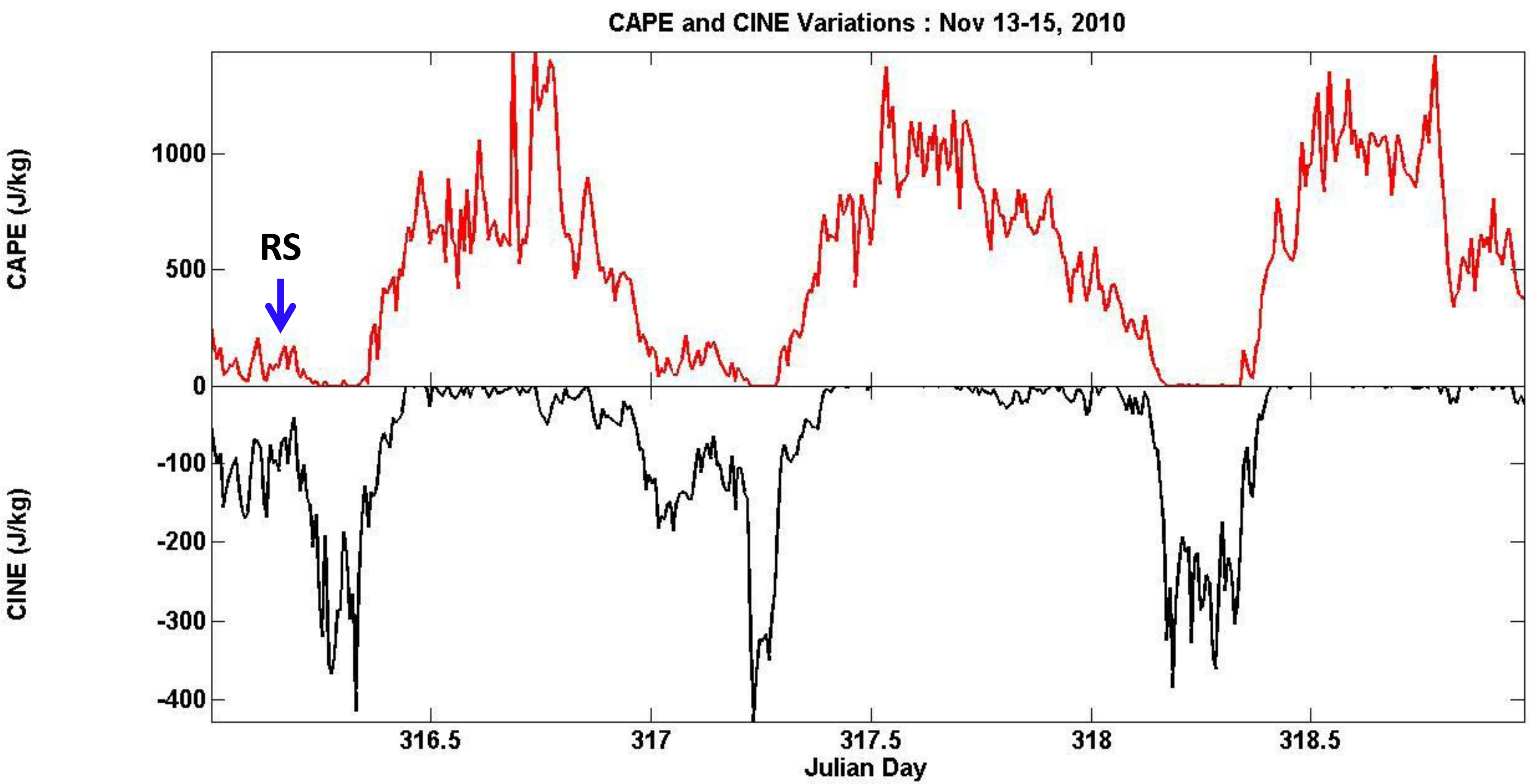


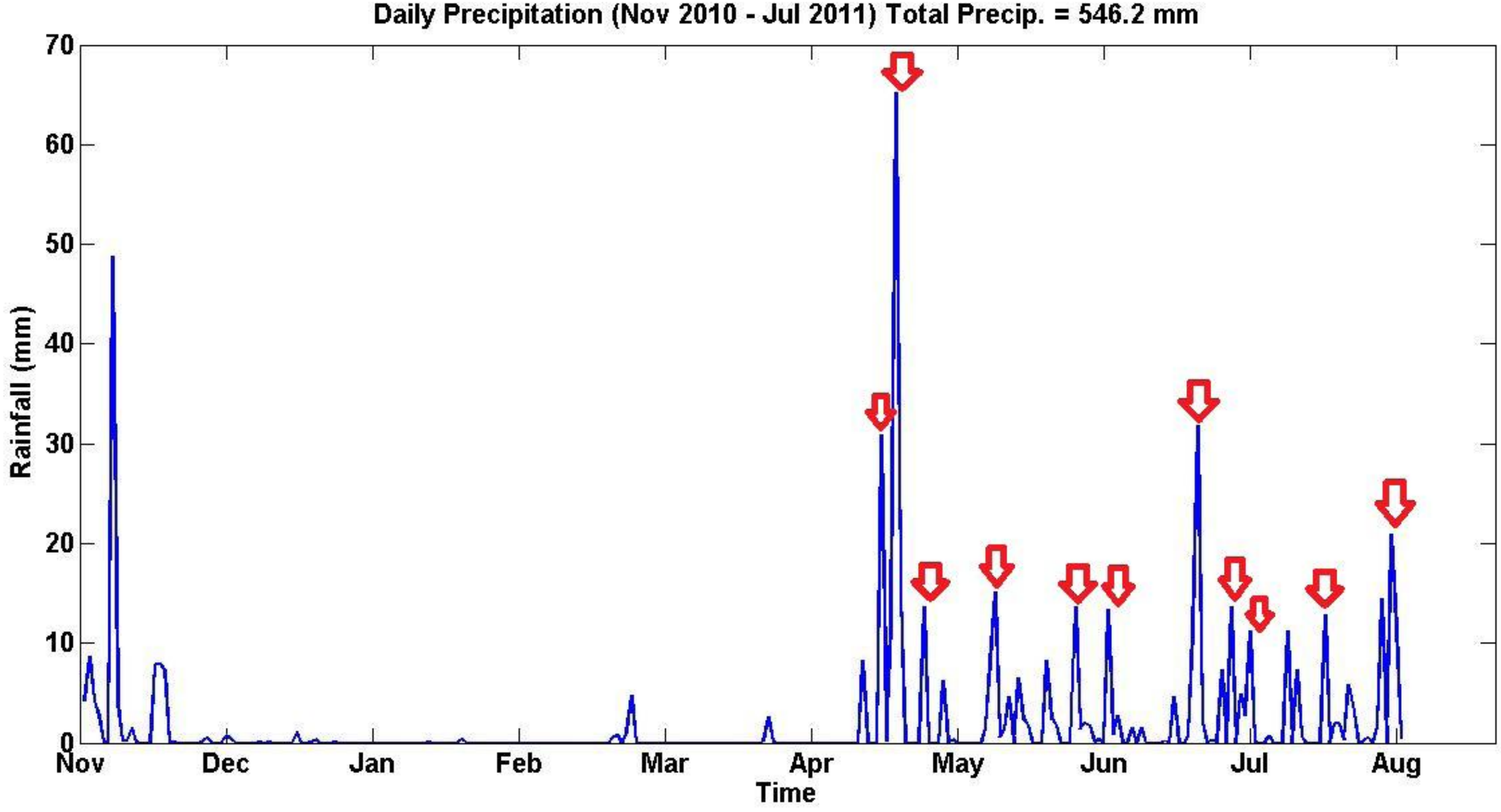
Computation of CAPE & CINE

Parcel: T_c → To from MWR, RH – from AWS

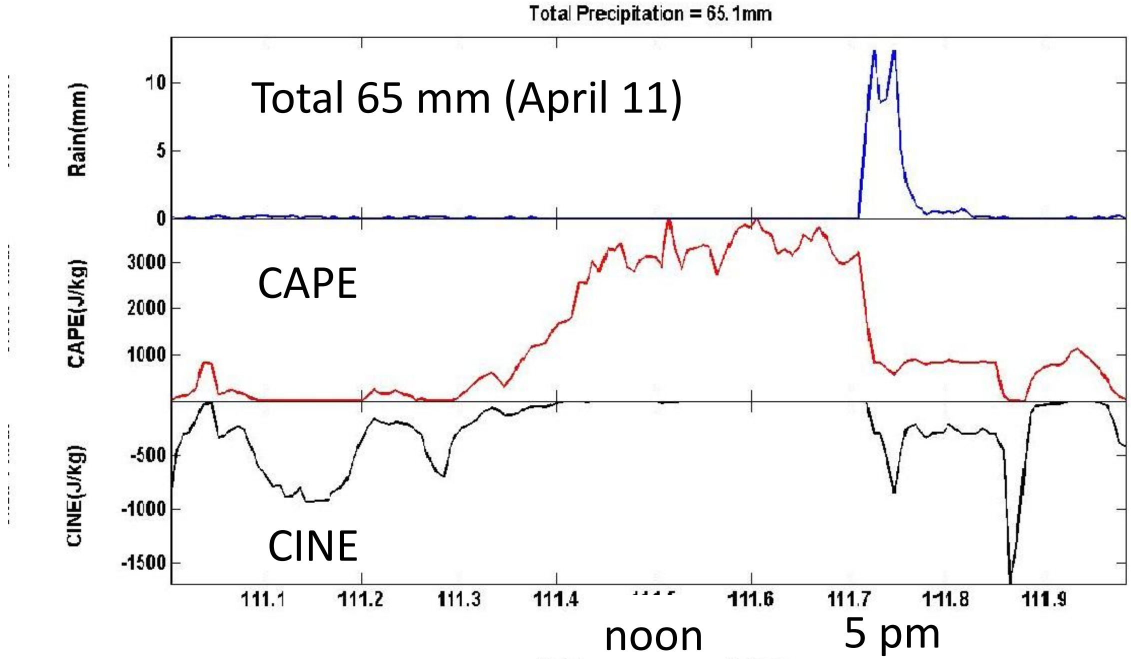
Te - MWR temperature (corrected)& humidity profile

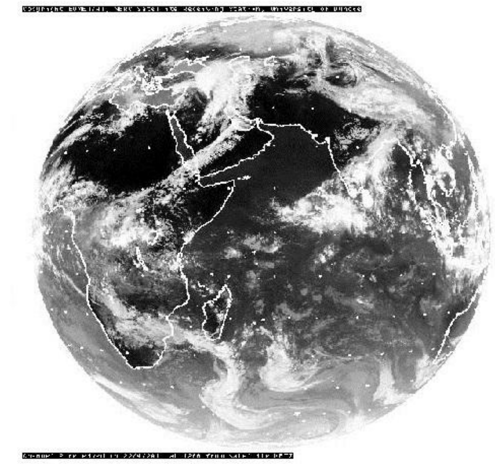
Calculate CAPE up to 10 km height

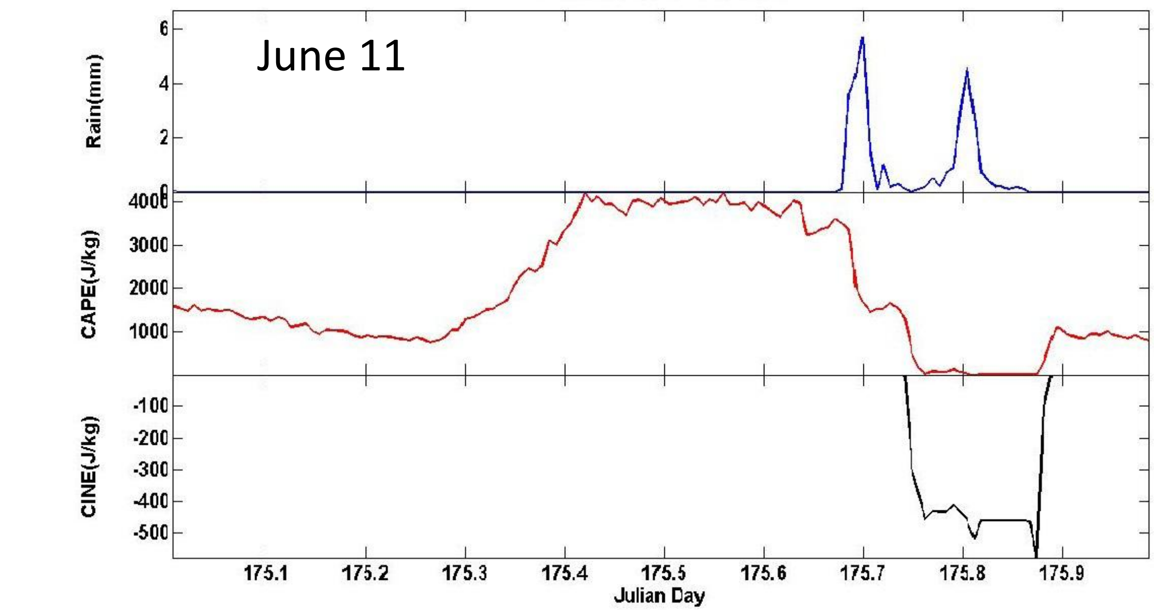


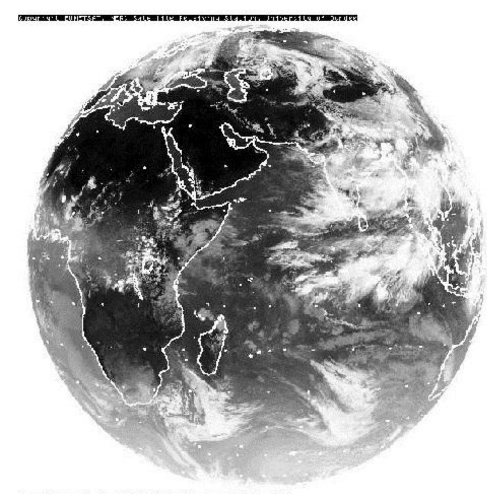


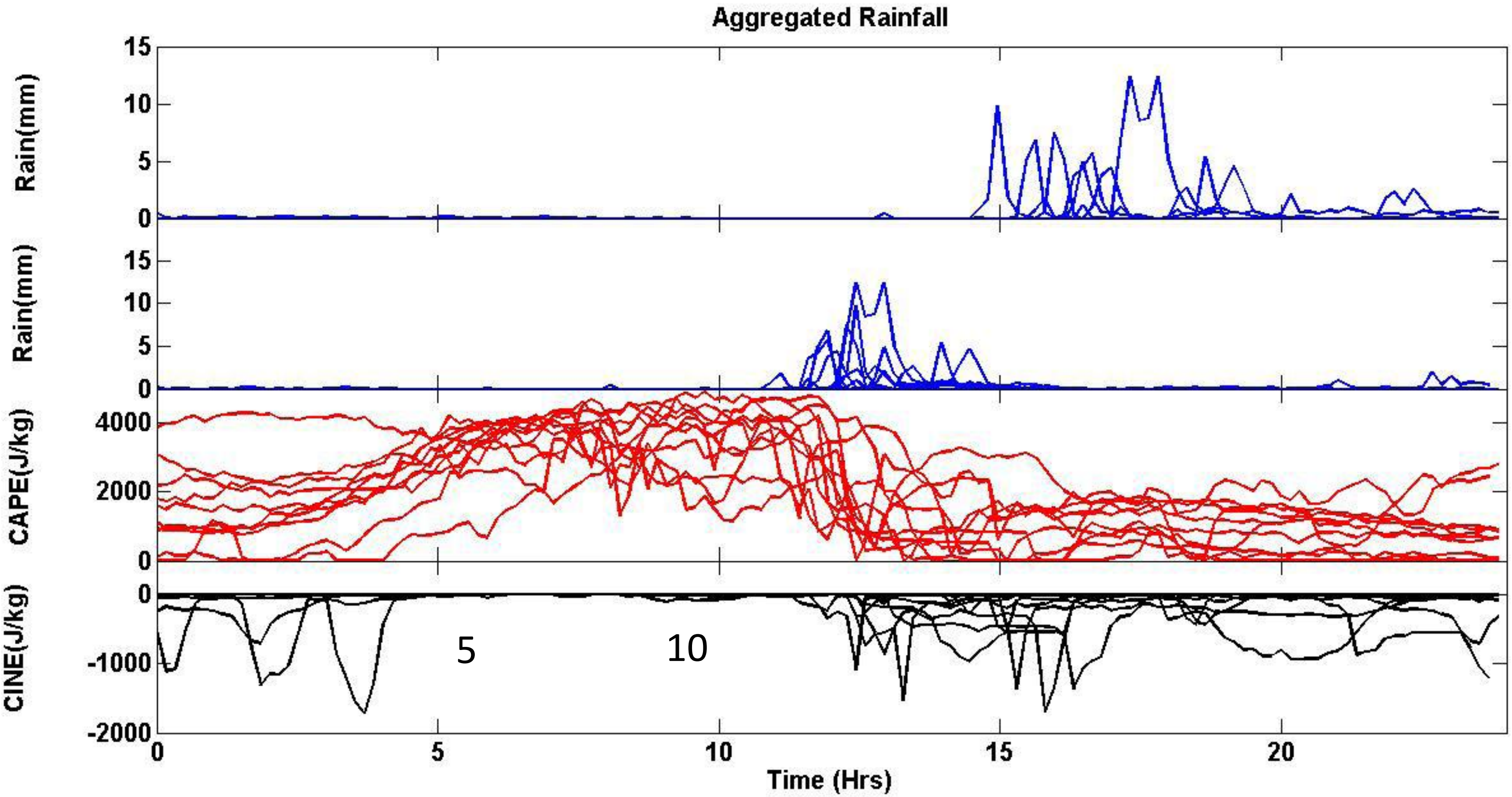
Daily rainfall measured in IISc, Bangalore


Total Precipitation = 65.1mm
Total 65 mm (April 11)
CAPE
CINE
Rain(mm)
CAPE(J/kg)
CINE(J/kg)
10
5
0
3000
2000
1000
-500
-1000
-1500
111.1
111.2
111.3
111.4
111.6
111.7
111.8
111.9
noon
5 pm

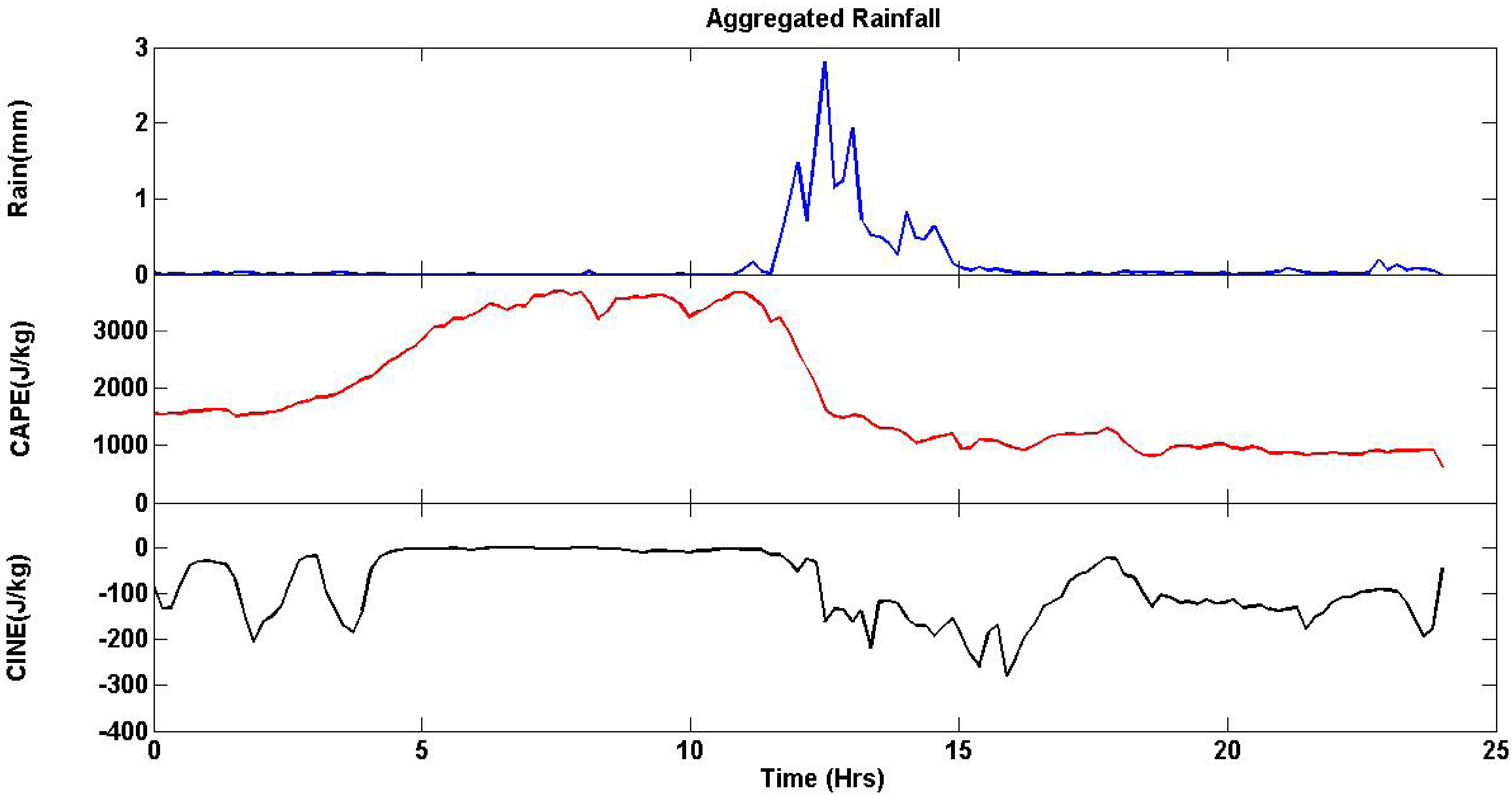



June 11
Rain(mm)
CAPE(J/kg)
CINE(J/kg)
6
4
2
0
4000
3000
2000
1000
-100
-200
-300
-400
-500
175.1
175.2
175.3
175.4
175.5
175.6
175.7
175.8
175.9
Julian Day





Major Precipitation Events.

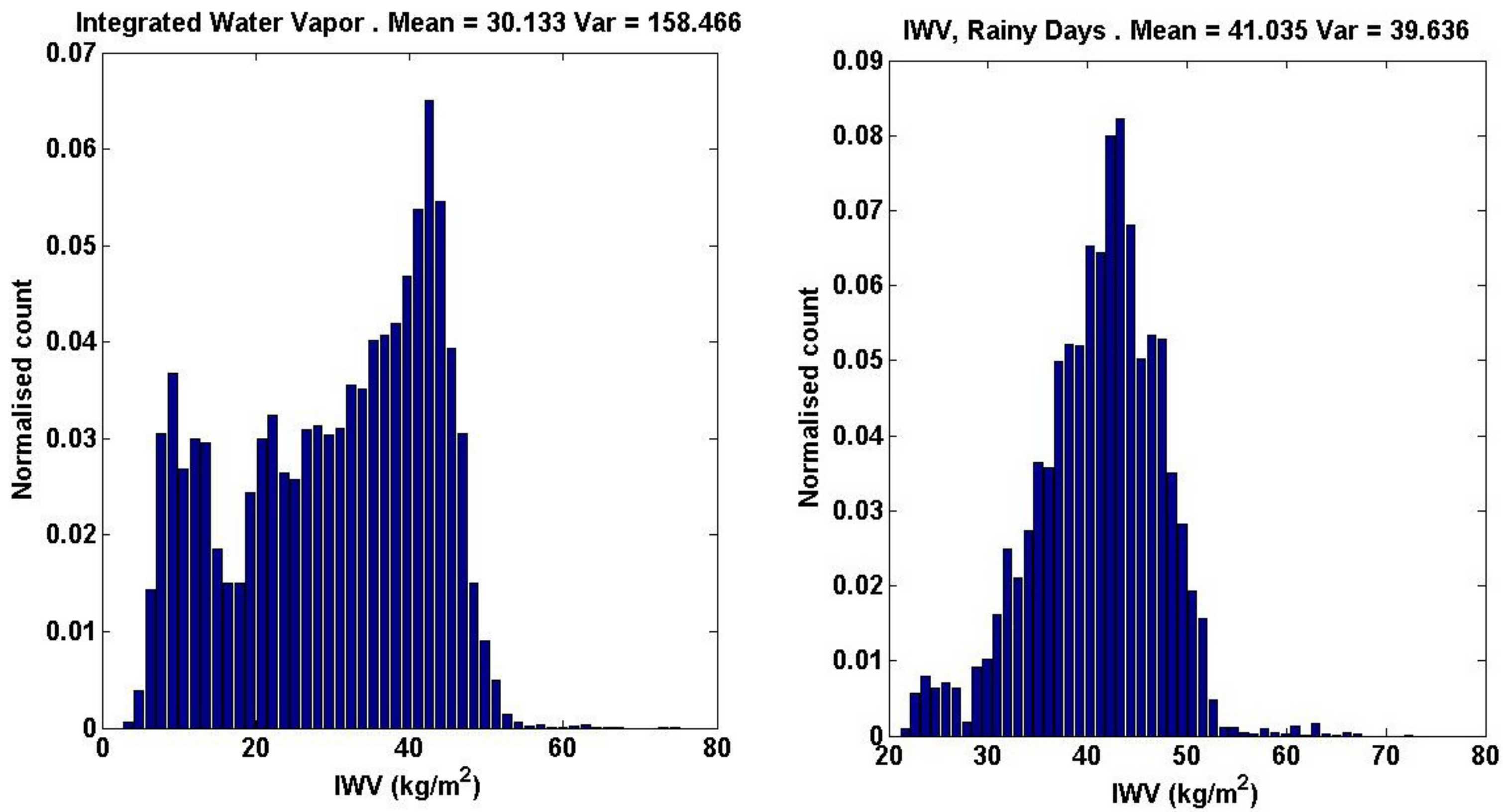


CAPE – starts building up ~ 8 hours before

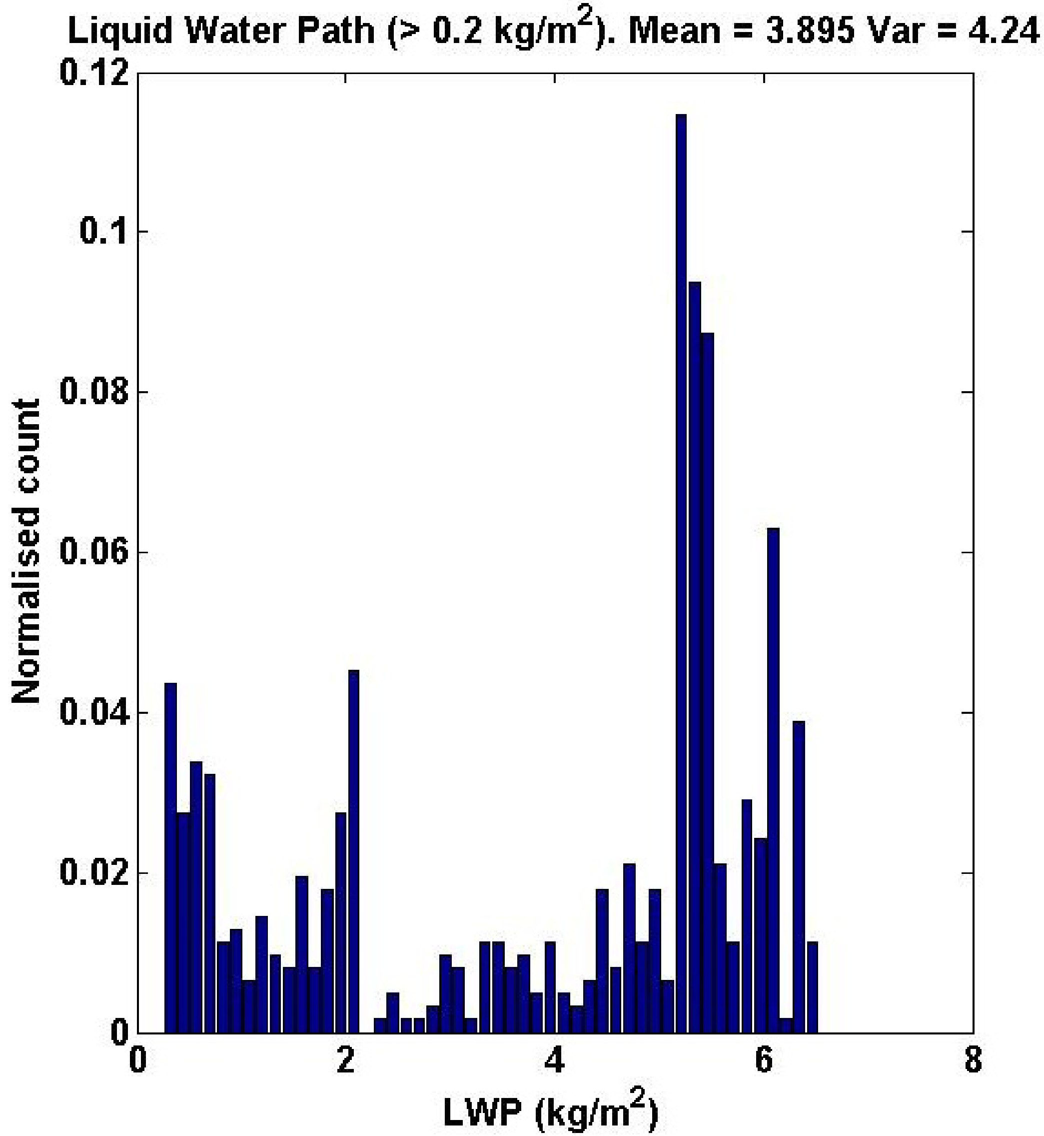
remains nearly steady ~5 hrs prior to rain

decreases below 1000 J/kg after rain

CINE – becomes negligible few hours earlier to rain



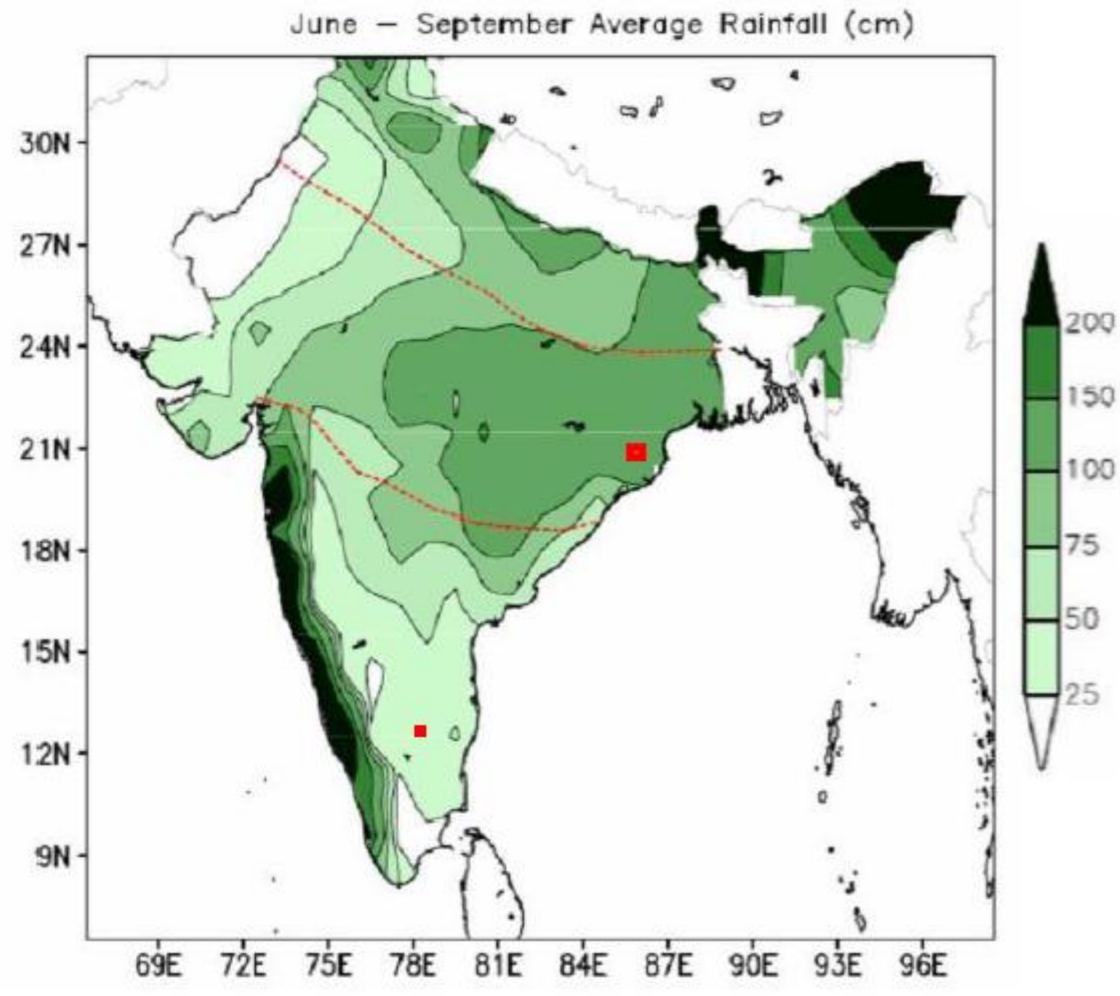
Comparison of distribution for IWV.
Left: Entire Observation period
Right: Rainy Days



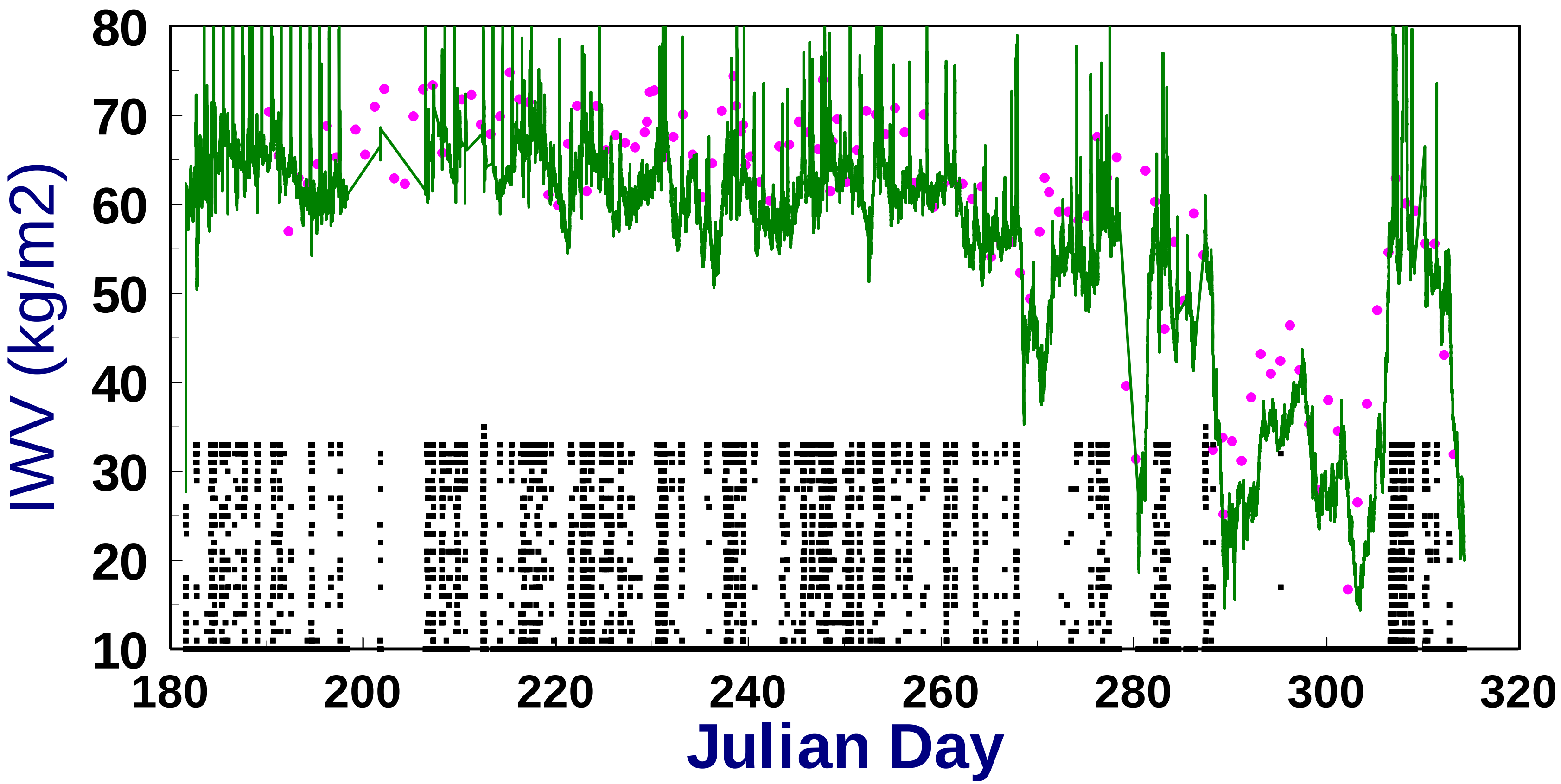
The distribution of LWP during rainy days

CTCZ Field Phase: 2011, 2012→ shifted to Bhubaneswar

2011: Sep – Nov; 2012: July - Nov

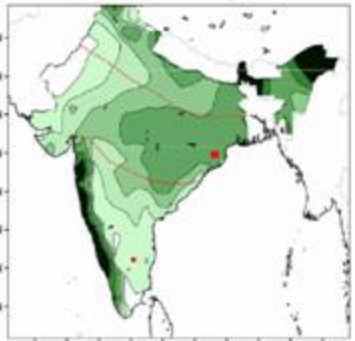


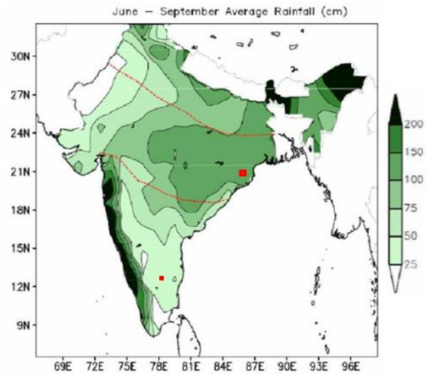
(IMD)

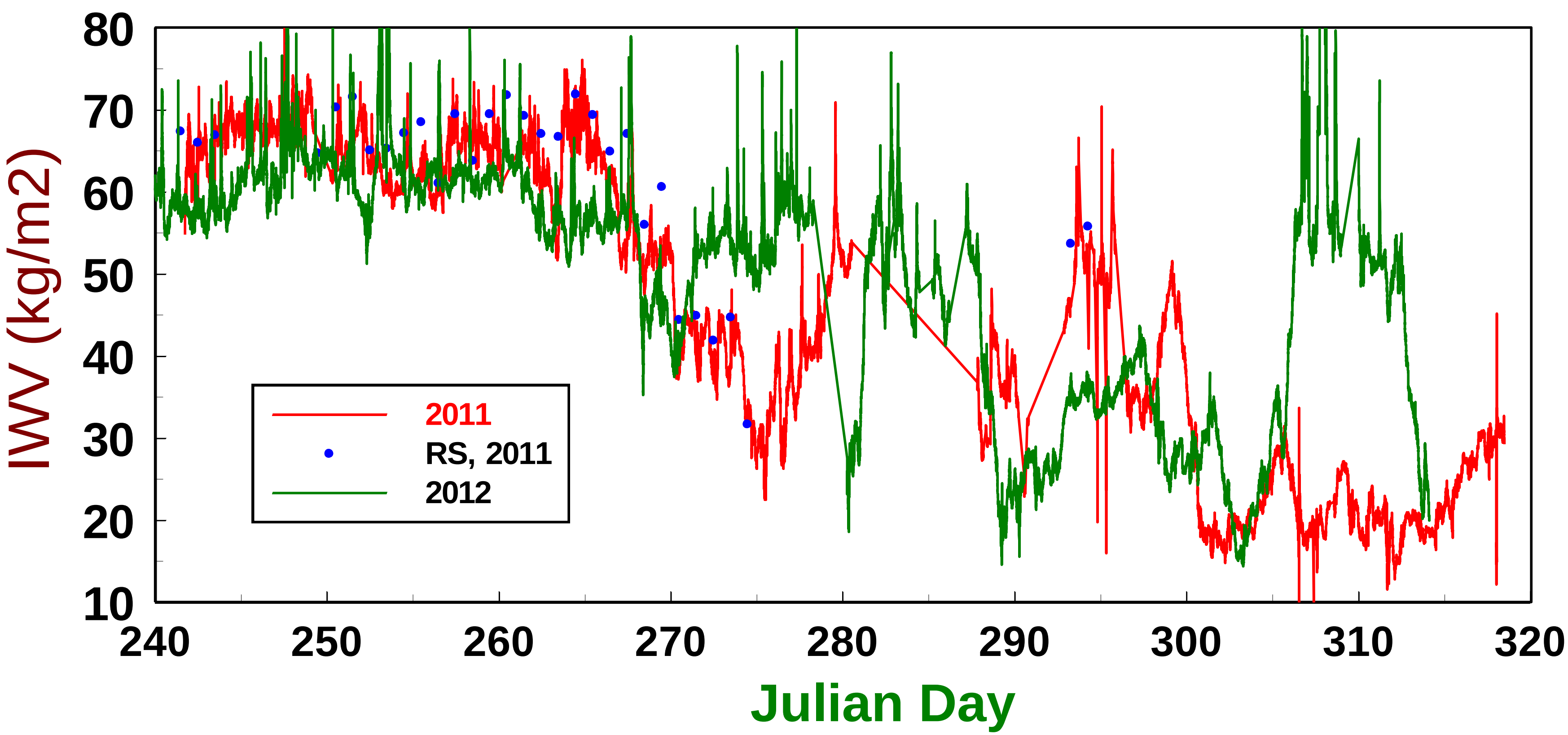


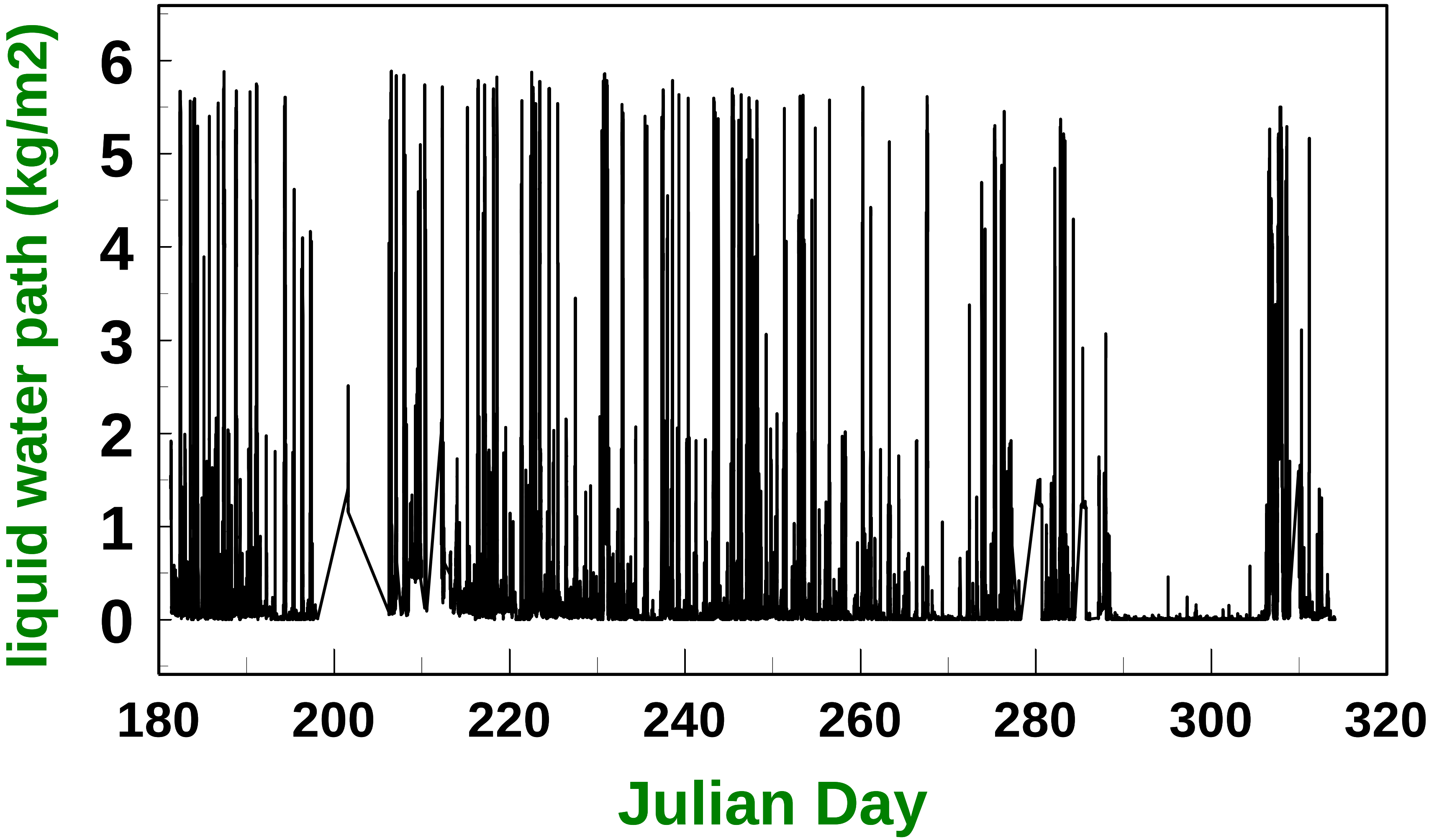
Variation of IWV from July – Nov 2012

Line – MWR, symbol: radiosonde

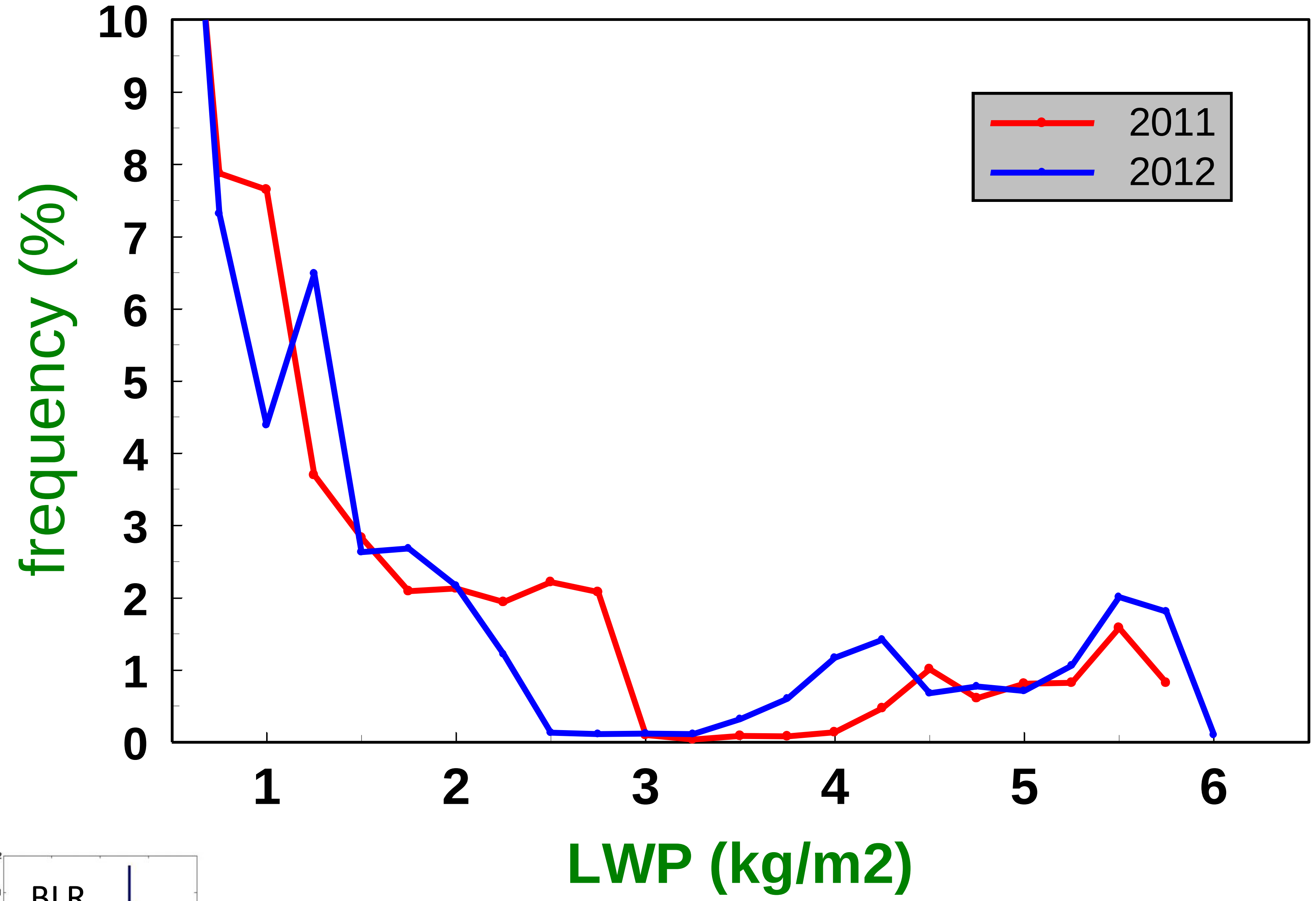



June – September Average Rainfall (cm)
30N
27N
24N
21N
18N
15N
12N
9N
69E 72E 75E 78E 81E 84E 87E 90E 93E 96E
200
150
100
75
50
25

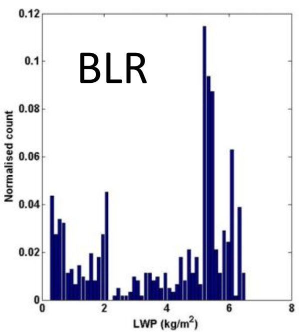

IWV (kg/m2)
80
70
60
50
40
30
20
10
240 250 260 270 280 290 300 310 320
Julian Day
2011
RS, 2011
2012



liquid water path (kg/m2)
0
1
2
3
4
5
6
180
200
220
240
260
280
300
320
Julian Day



frequency (%)
LWP (kg/m2)
2011
2012
0
1
2
3
4
5
6
7
8
9
10
1
2
3
4
5
6



BLR

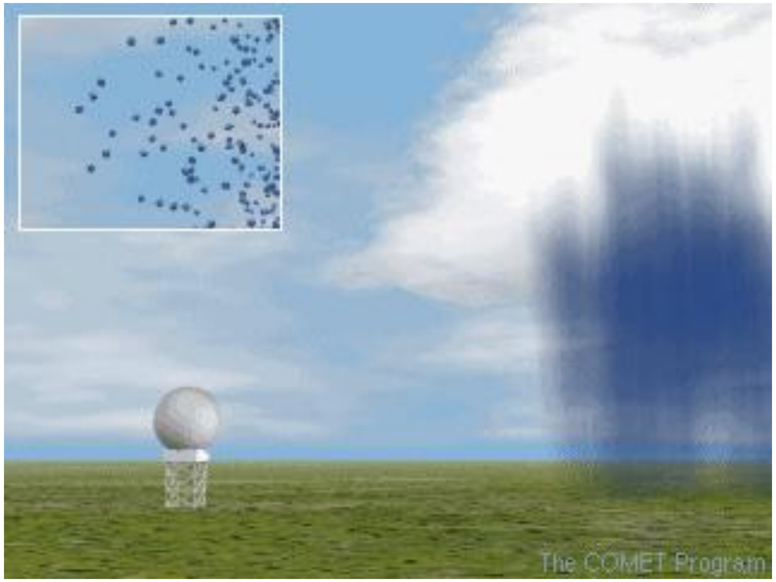
1. CAPE & CINE change significantly during day time

2. CAPE builds up ~ hours prior to onset of rain

3. Bimodal distribution in CLW path

4. IWV > 60 kg/m^^2 during monsoon over Bhubaneswar

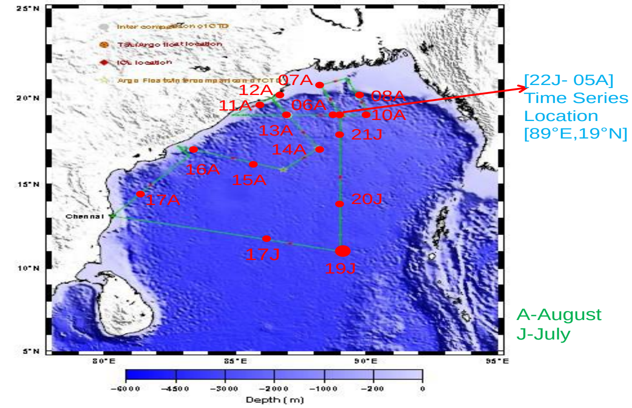
Cloud microphysics
Conv. Instability
Conv. Cloud structure



IMD DWR

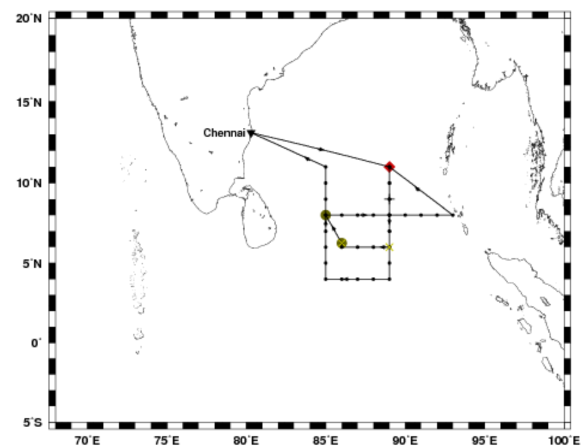
CTCZ-Pilot:2009, 2011; Main:2012

ORVSagar Kanya (NCAOR, MOES)

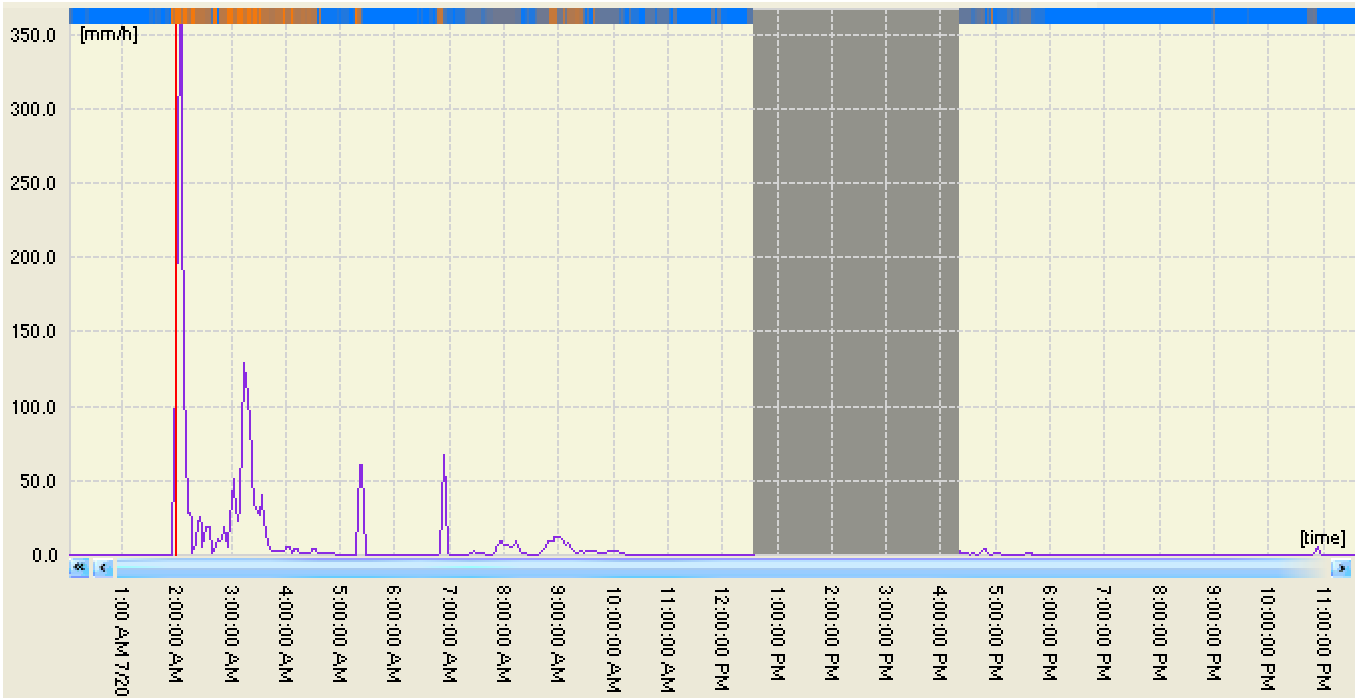


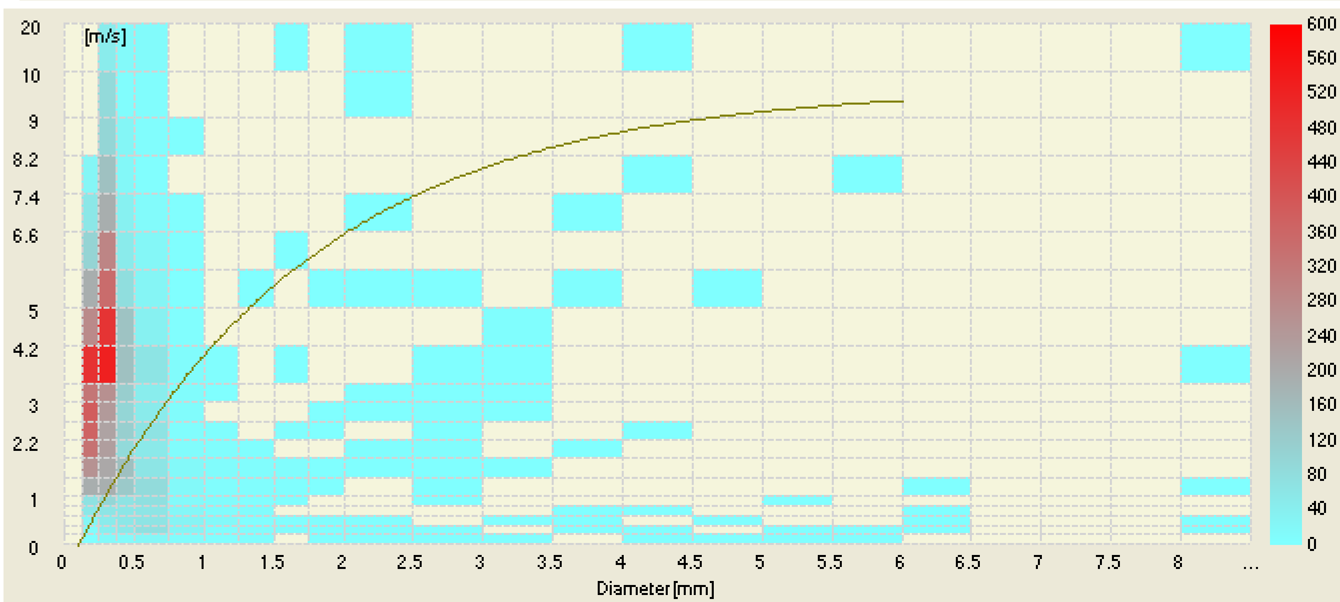
BOB CRUISE –SK261 [17JULY'09-17 AUGUST'09]

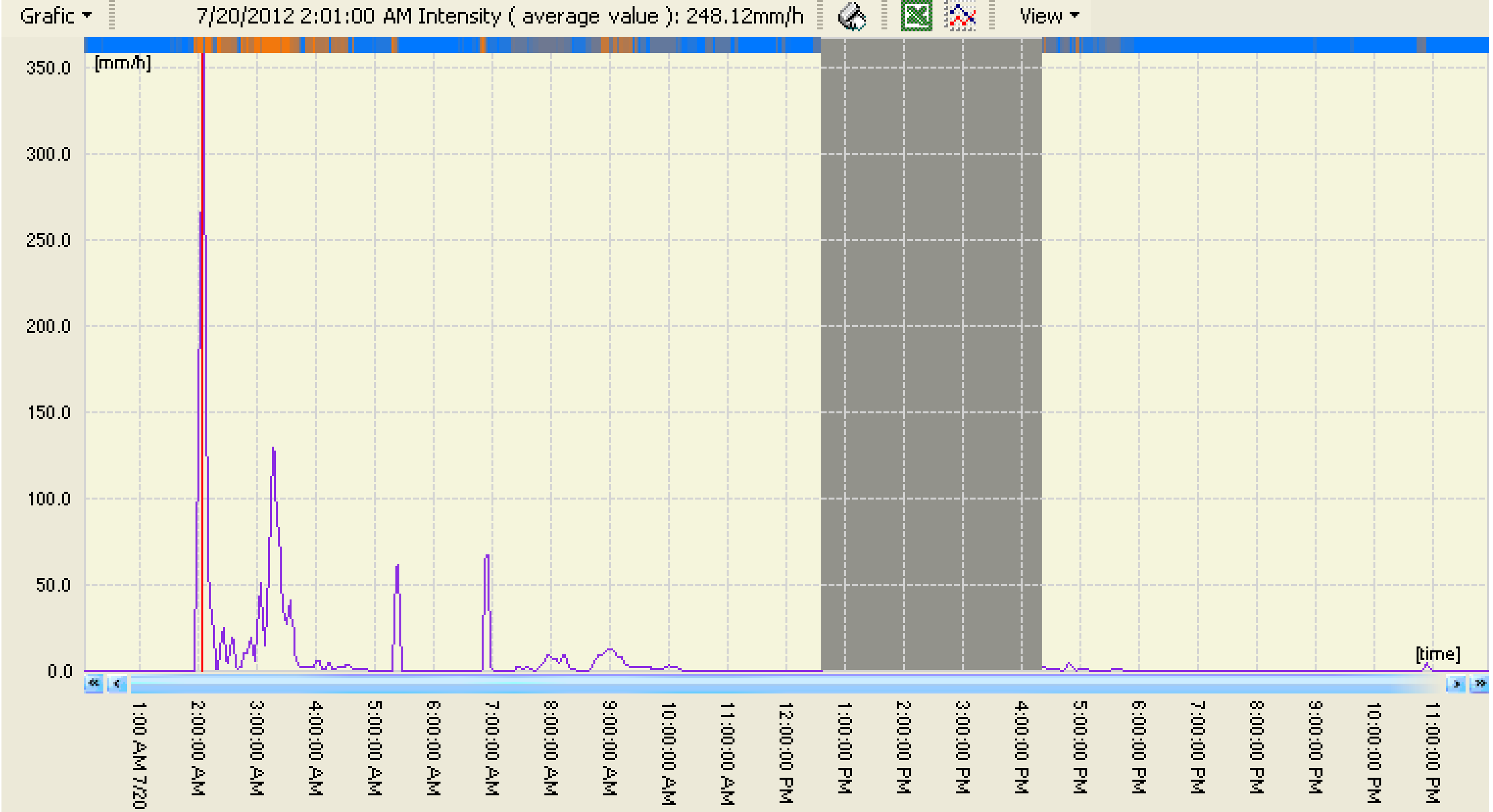
Sagar Nidhi (NIOT, MOES)

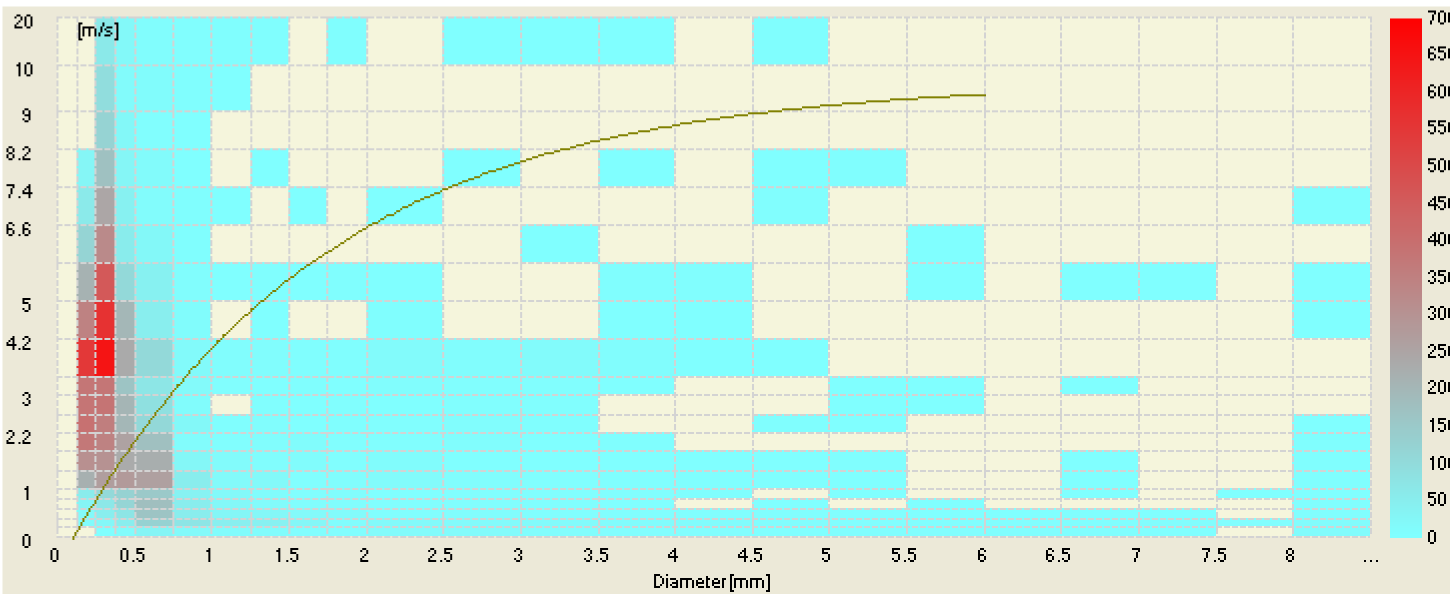


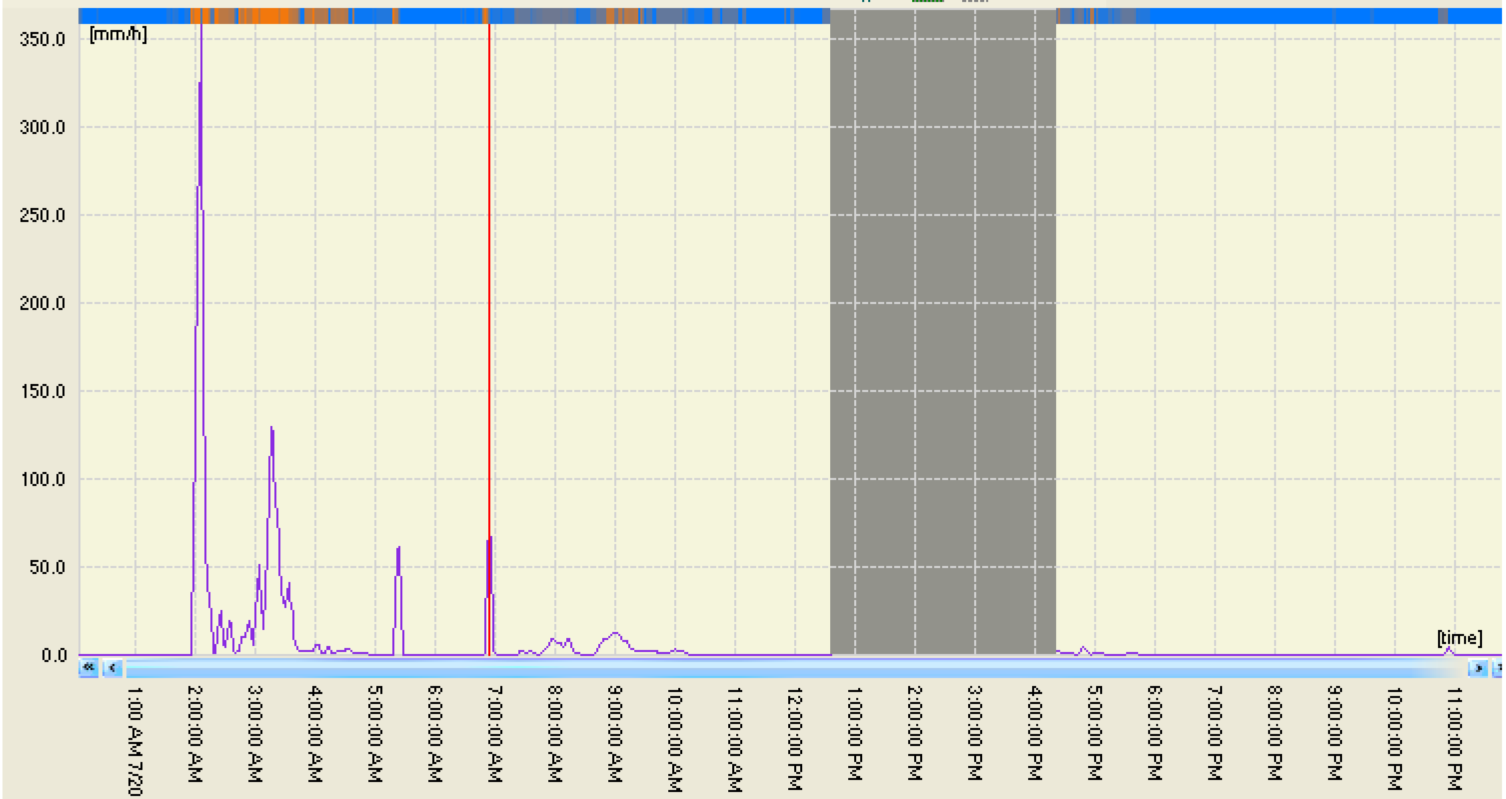
20 July 2012, BoB

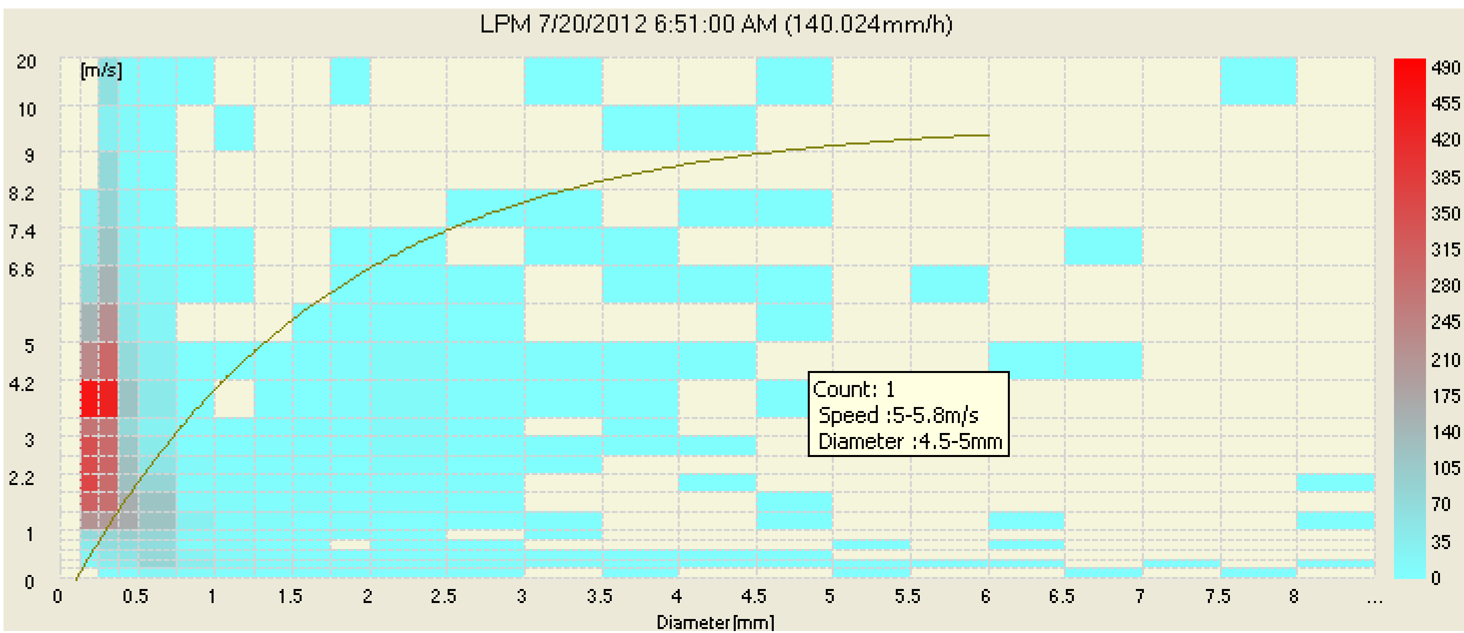


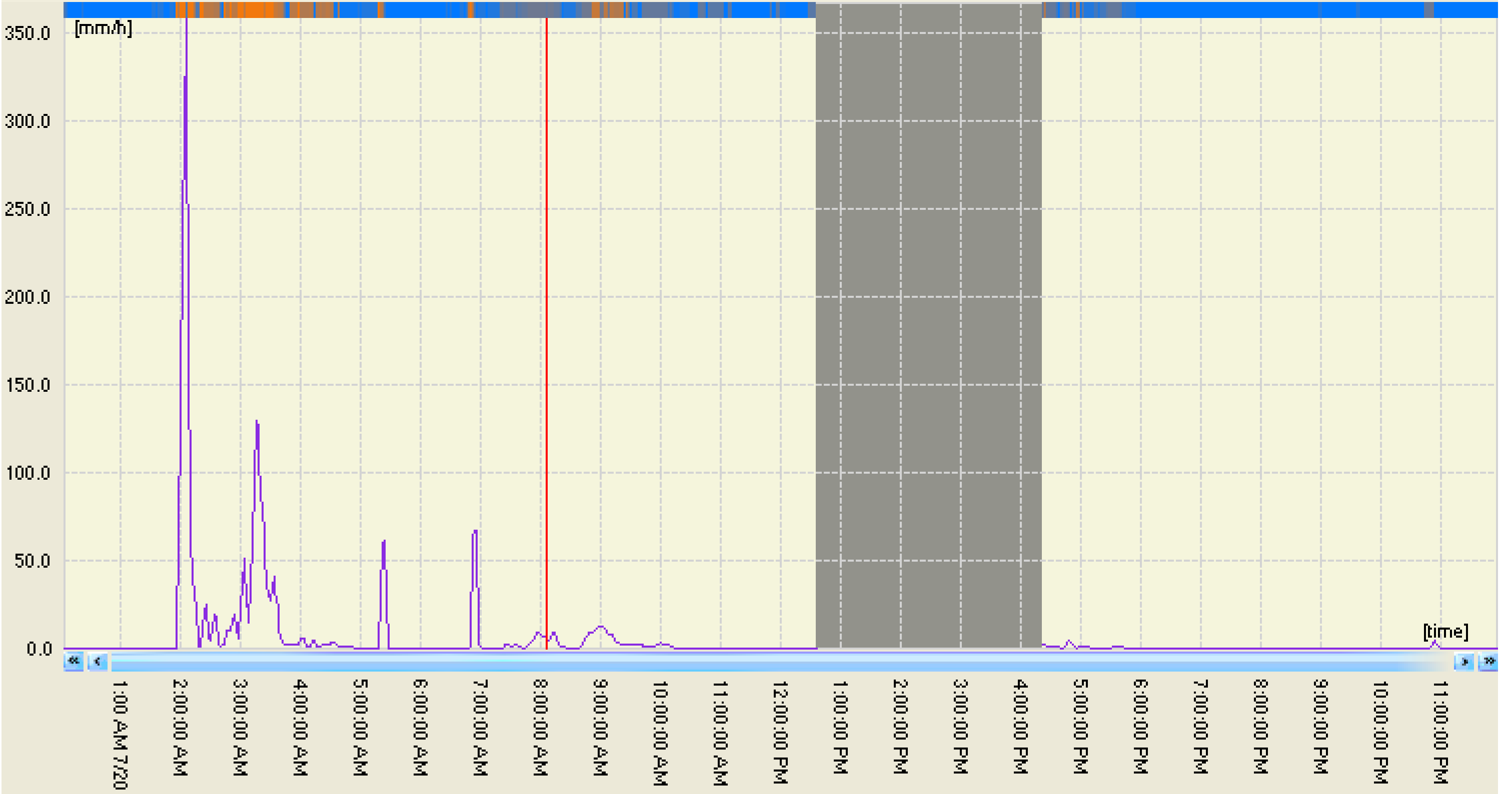


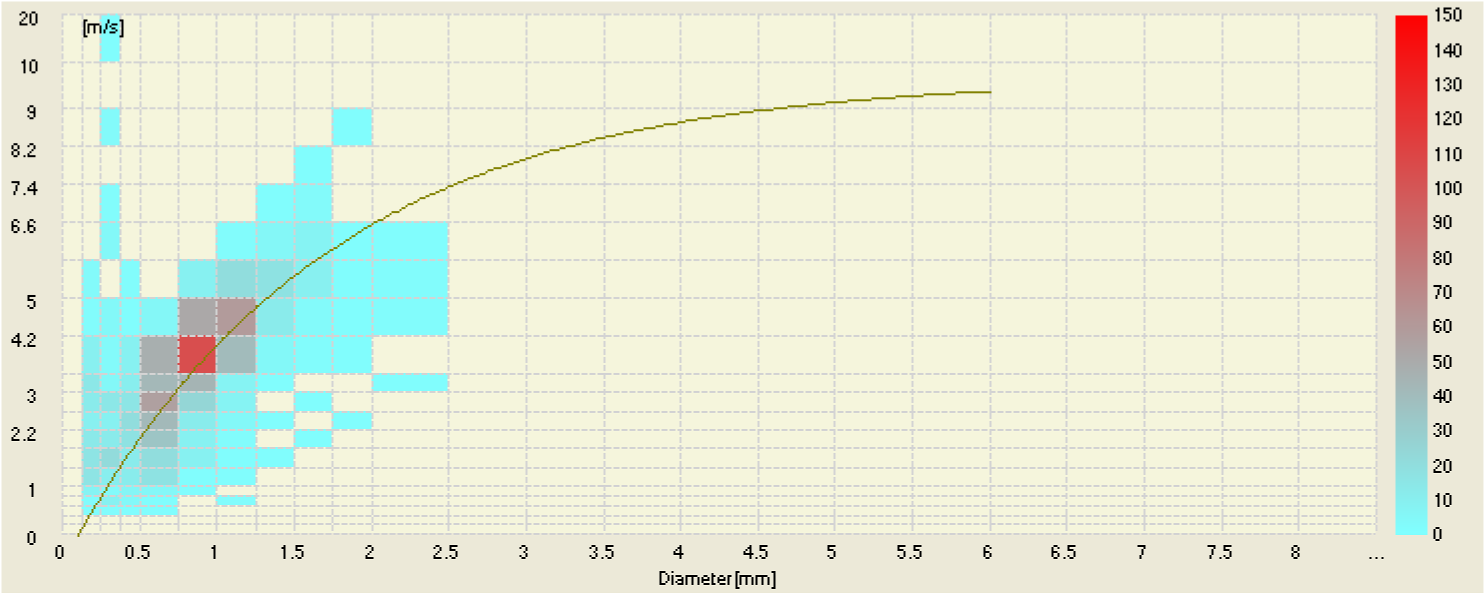

Grafic
7/20/2012 2:01:00 AM Intensity (average value): 248.12mm/h
View
[mm/h]
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
[time]
1:00 AM 7/20
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
8:00:00 AM
9:00:00 AM
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM

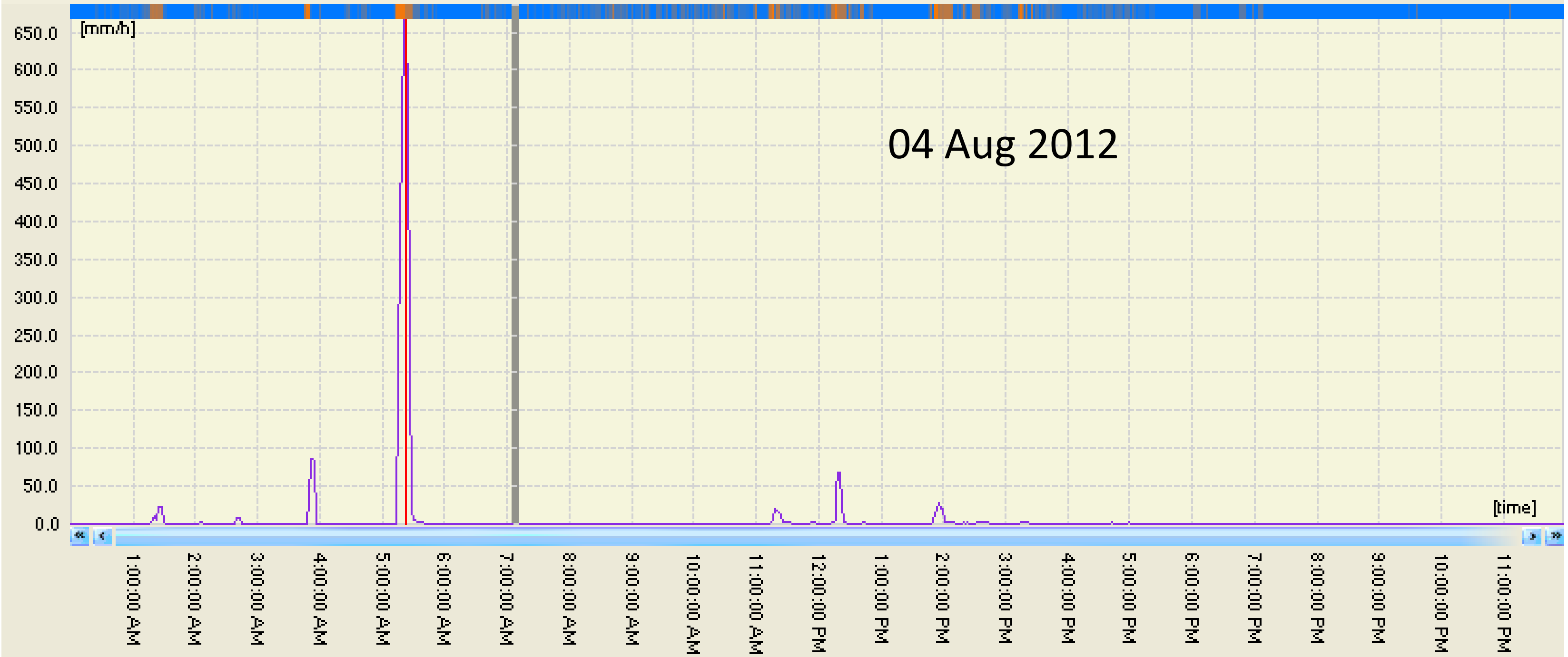

[m/s]
20
10
9
8.2
7.4
6.6
5
4.2
3
2.2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
...
Diameter [mm]
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0


[mm/h]
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
[time]
1:00 AM 7/20
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
8:00:00 AM
9:00:00 AM
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM

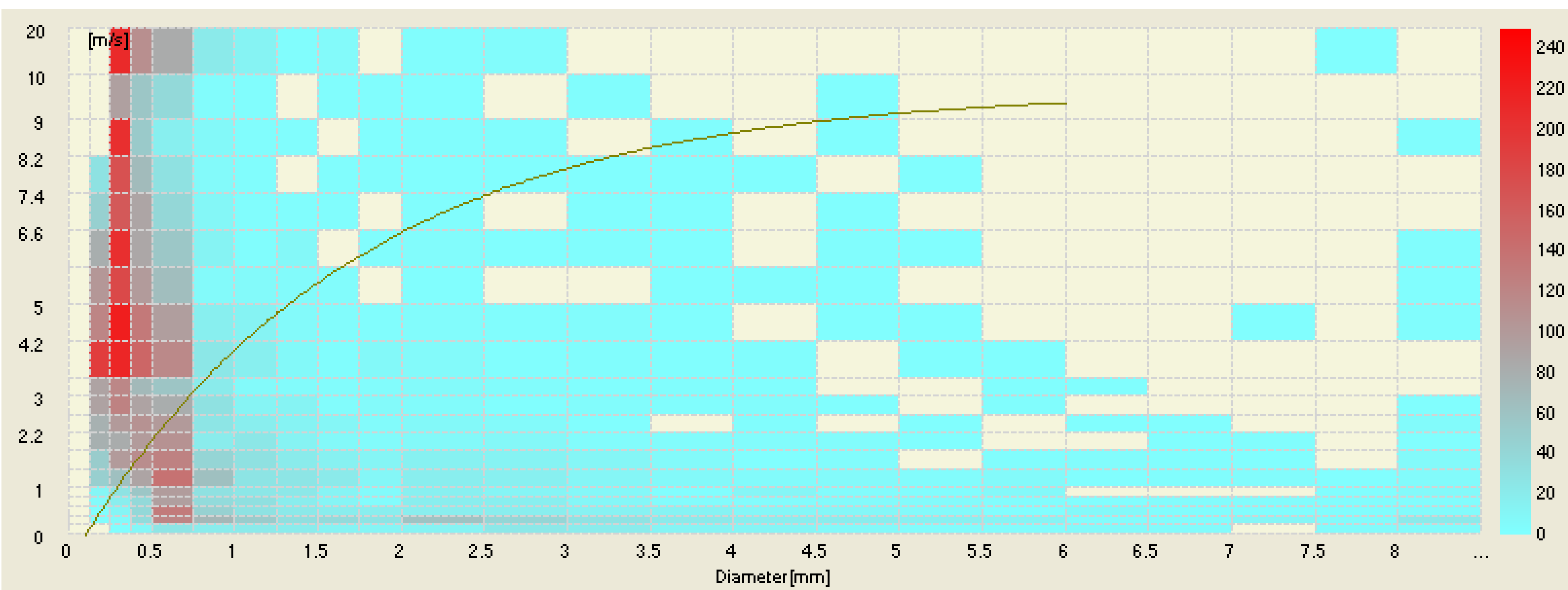

LPM 7/20/2012 6:51:00 AM (140.024mm/h)
[m/s]
20
10
9
8.2
7.4
6.6
5
4.2
3
2.2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
...
Diameter [mm]
Count: 1
Speed :5-5.8m/s
Diameter :4.5-5mm
490
455
420
385
350
315
280
245
210
175
140
105
70
35
0


[mm/h]
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
[time]
1:00 AM 7/20
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
8:00:00 AM
9:00:00 AM
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM

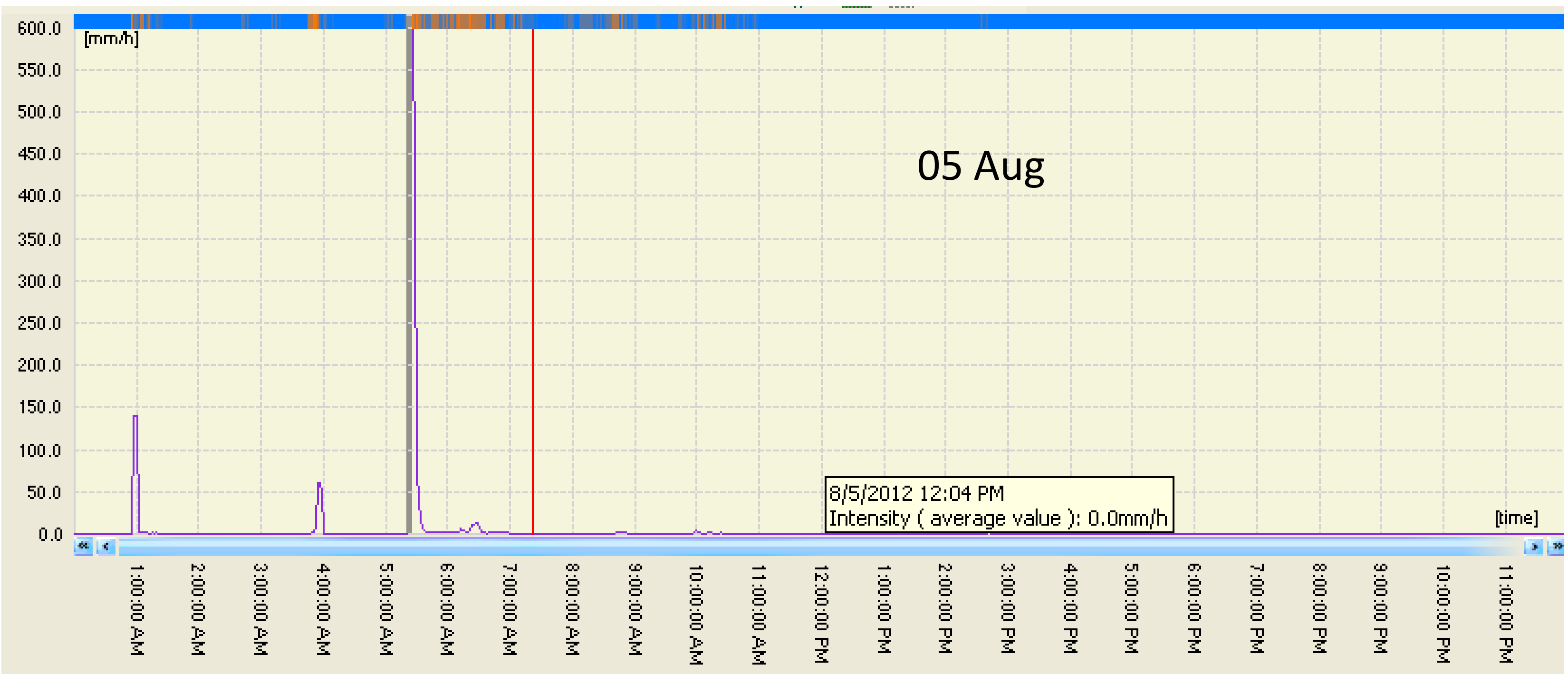

[m/s]
20
10
9
8.2
7.4
6.6
5
4.2
3
2.2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
...
Diameter [mm]
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0



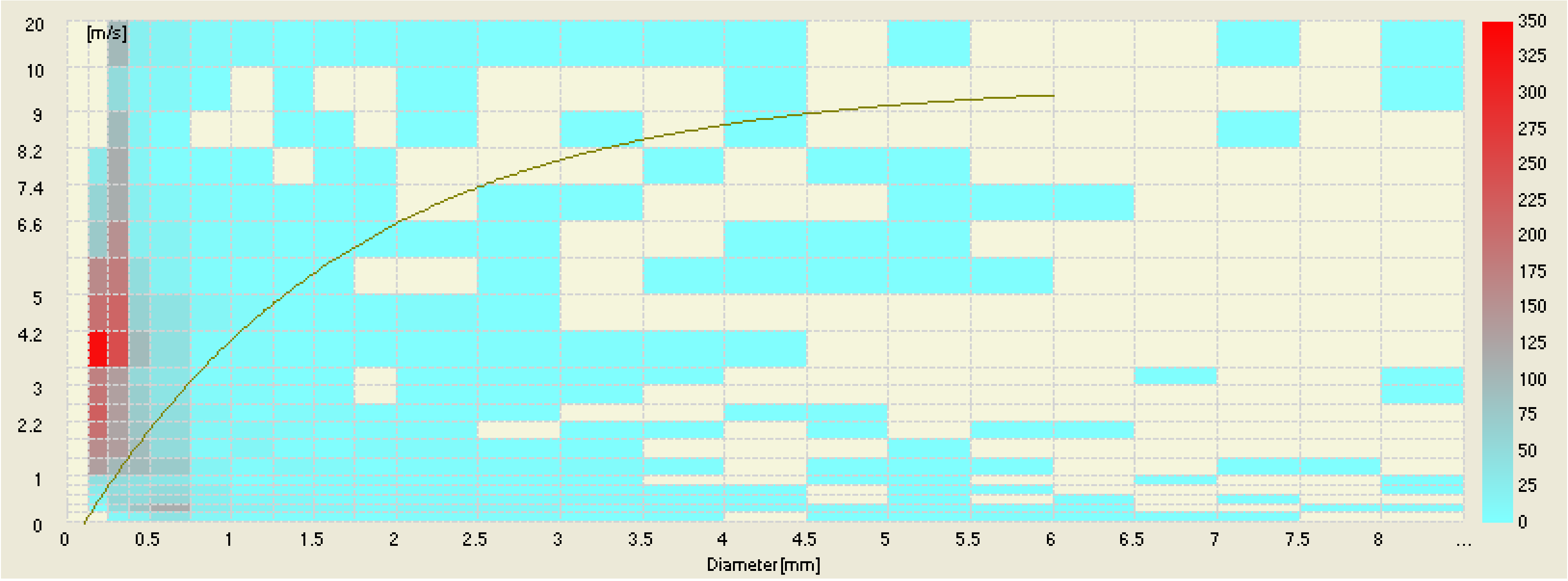
04 Aug 2012
[mm/h]
650.0
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
[time]
1:00:00 AM
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
8:00:00 AM
9:00:00 AM
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM



[m/s]
20
10
9
8.2
7.4
6.6
5
4.2
3
2.2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
...
Diameter [mm]
240
220
200
180
160
140
120
100
80
60
40
20
0



05 Aug
[mm/h]
600.0
550.0
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
8/5/2012 12:04 PM
Intensity (average value): 0.0mm/h
[time]
1:00:00 AM
2:00:00 AM
3:00:00 AM
4:00:00 AM
5:00:00 AM
6:00:00 AM
7:00:00 AM
8:00:00 AM
9:00:00 AM
10:00:00 AM
11:00:00 AM
12:00:00 PM
1:00:00 PM
2:00:00 PM
3:00:00 PM
4:00:00 PM
5:00:00 PM
6:00:00 PM
7:00:00 PM
8:00:00 PM
9:00:00 PM
10:00:00 PM
11:00:00 PM



[m/s]
20
10
9
8.2
7.4
6.6
5
4.2
3
2.2
1
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
...
Diameter [mm]
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0

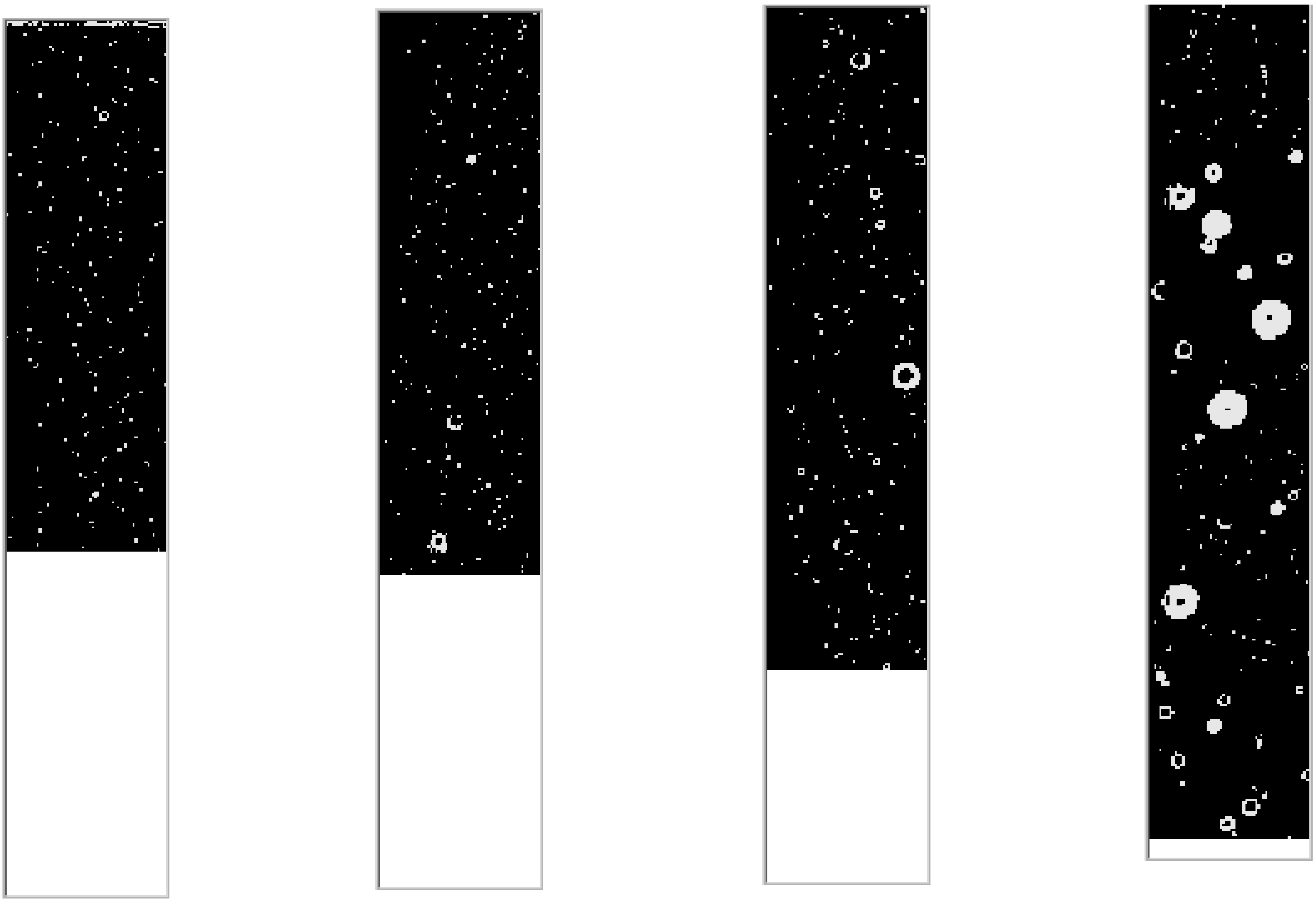
How is life inside a monsoon cloud?

IITM Pune
Cloud Aerosol Interactions and Precipitation Enhancement Expt.
(CAIPEEX)


Rosemount temp
AIMMS winds temp, RH
King hotwire LWC
PCASP SPP-200 (0.1 to 3µm)
FSSP SPP-100 (3 to 47µm)
CAPS
CAS (0.5 to 50µm)
CIP (25 to 1550µm)
Hotwire LWC
CDP (2 to 50µm)
2D-S (10 to 1280µm)
PIP (100 to 6200µm)

Rain Type

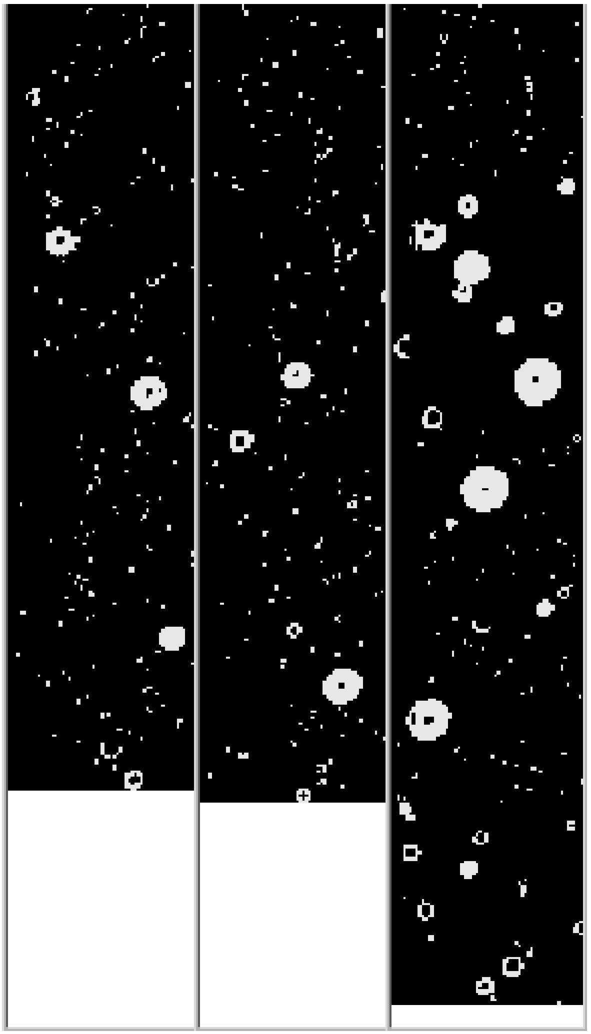
0 – No rain　　1 – Isolated drops　　2 – Drizzle　　3 – Rain



(J R Kulkarni, IITM)

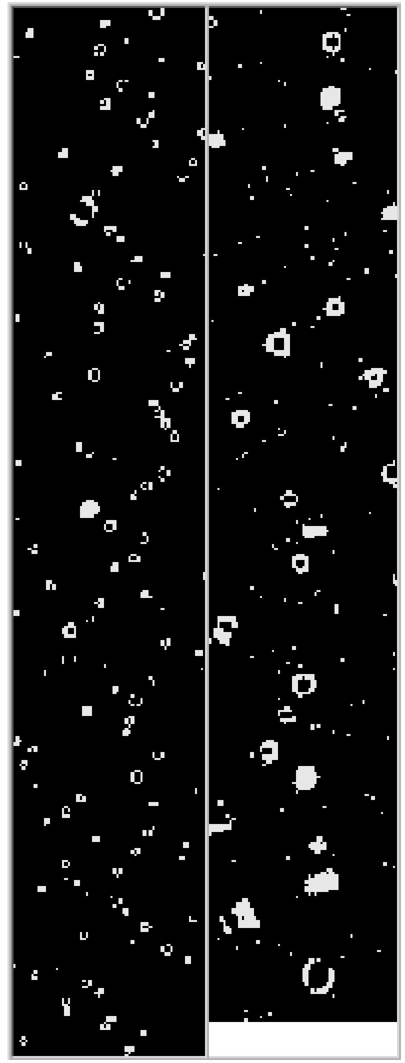
Hydrometeor Phase

Liquid



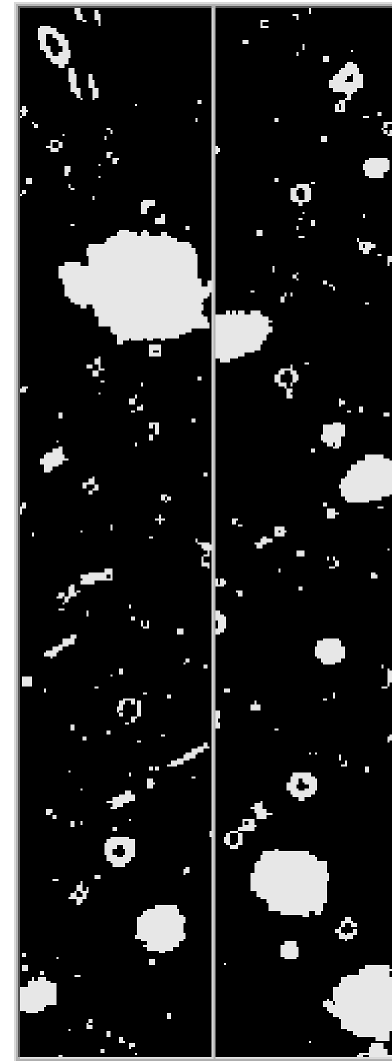
H= 2.5 km
T=11.0 ˚C
Re=11.0 µm

Mixed Phase



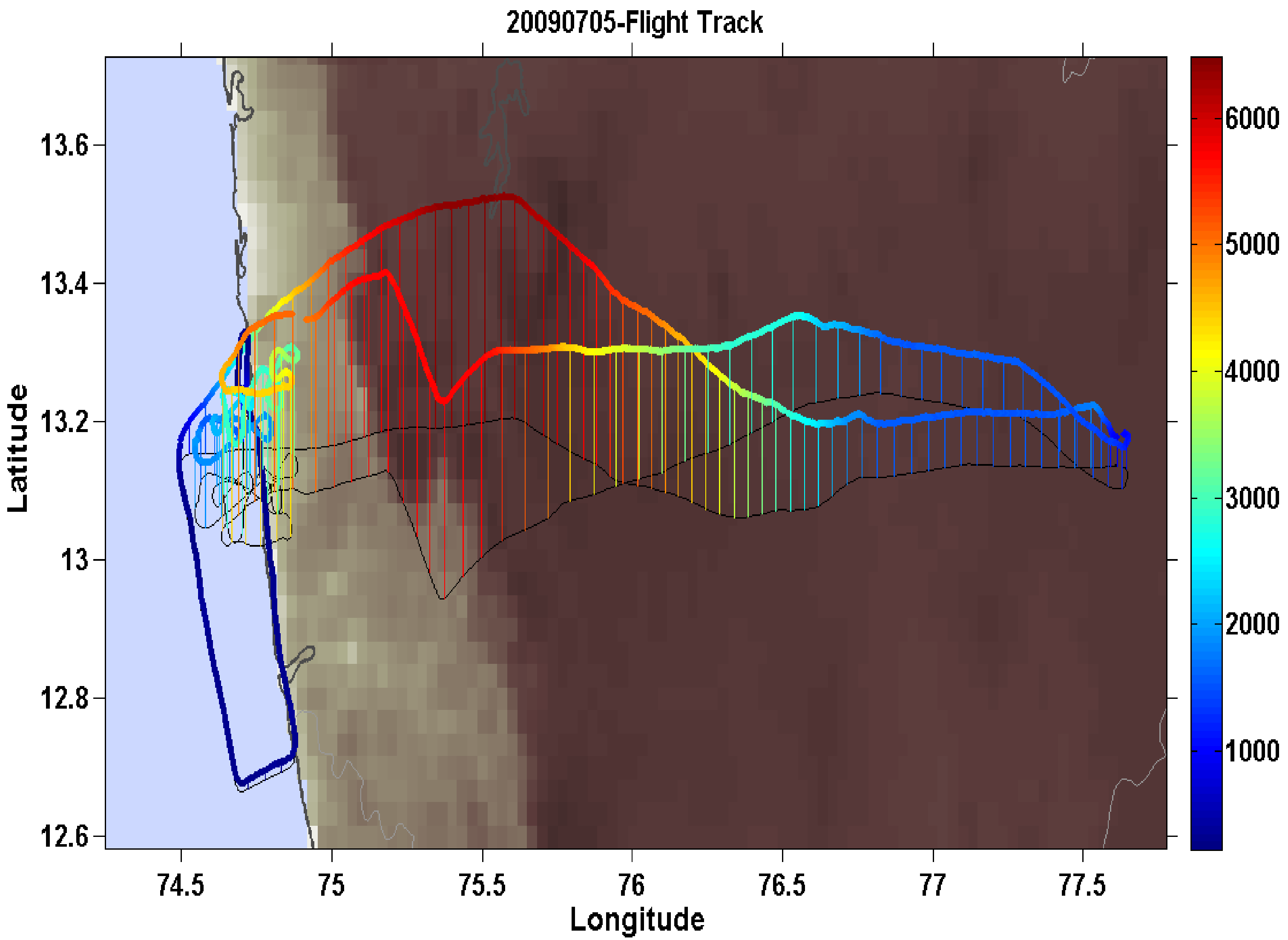
H= 5.5 km
T= - 4.5 ˚C
Re= 12 µm

Ice Hydrometeors



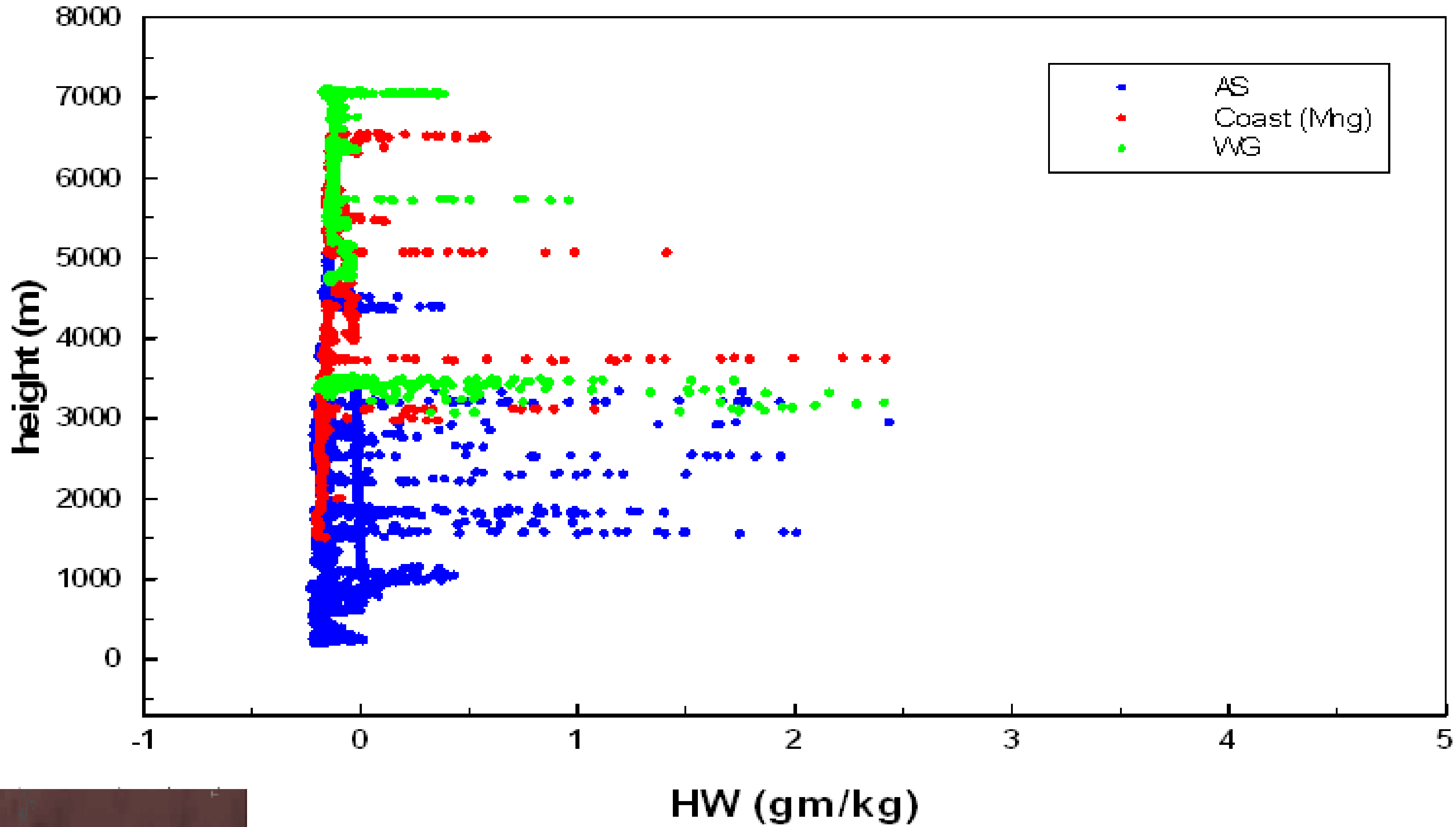
H= 6.3 km
T= - 10 ˚C
Re= 11 µm

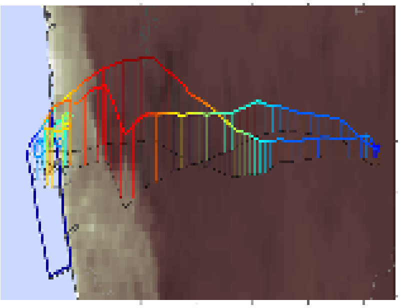
(J R Kulkarni, IITM)



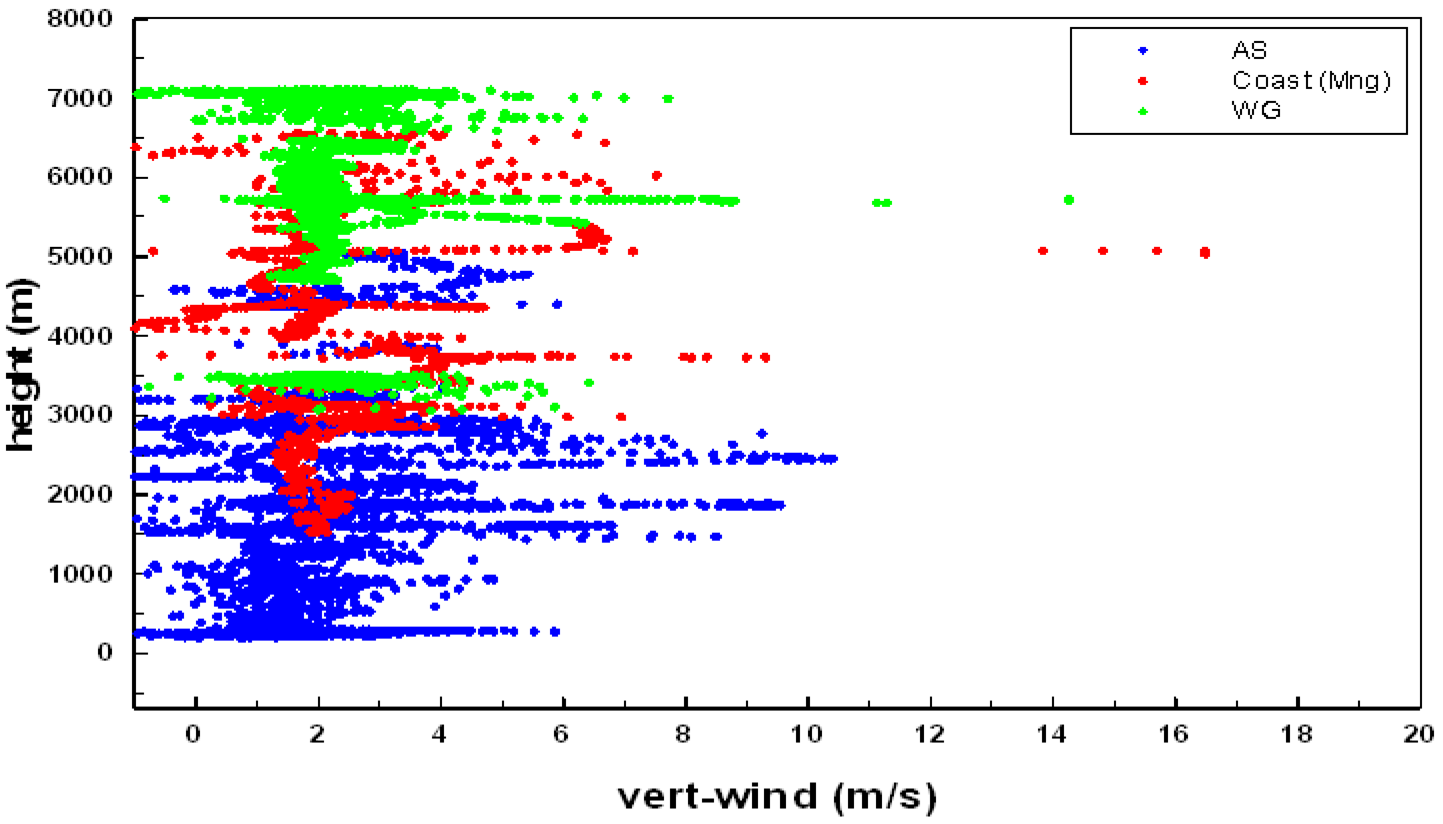
Bangalore leg flight path on 5th July 2009

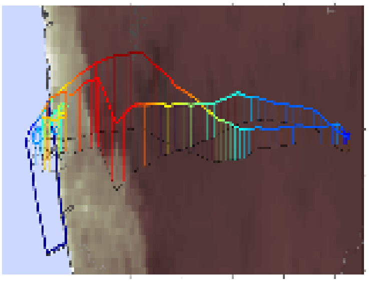
Amount of condensed water inside clouds over Karnataka (based on one day sampling, 13 July)





(based on one day sampling)



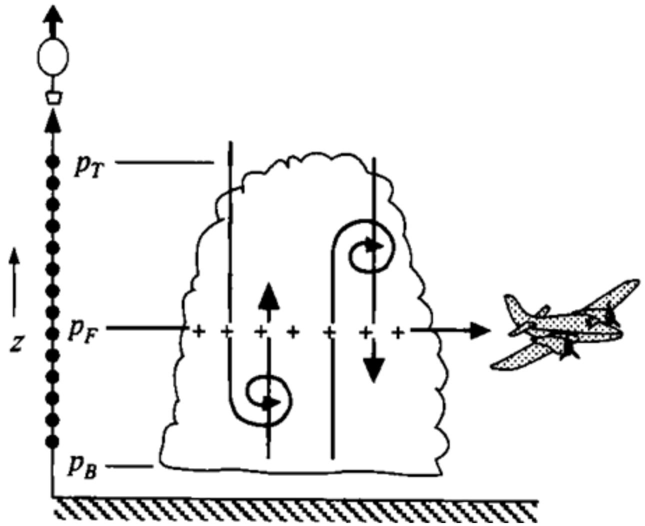


Entrainment

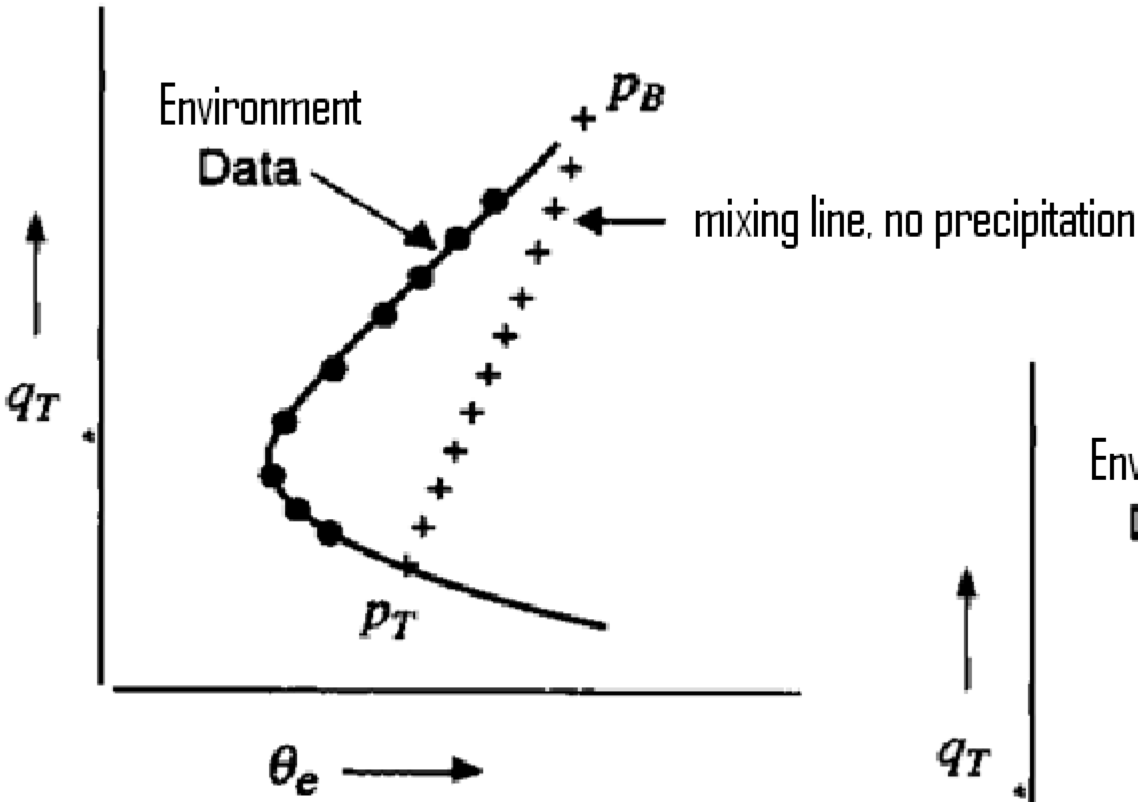
1. Construct conserved variable plots using θe and qt

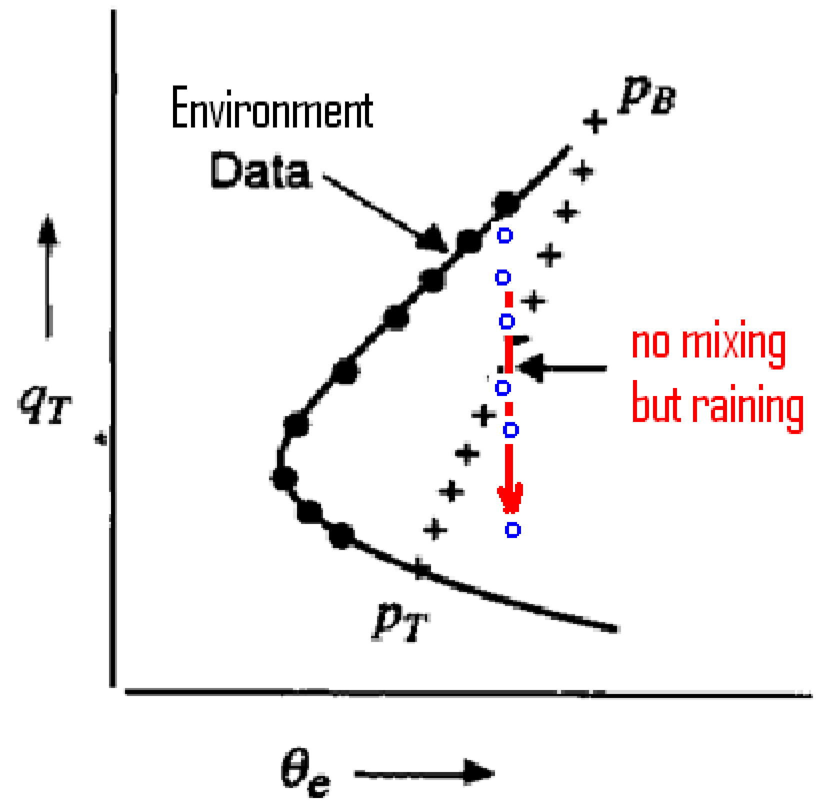
θe – obtained by (reversible) moist adiabatic process
qt = qv + LWC → total amount of water

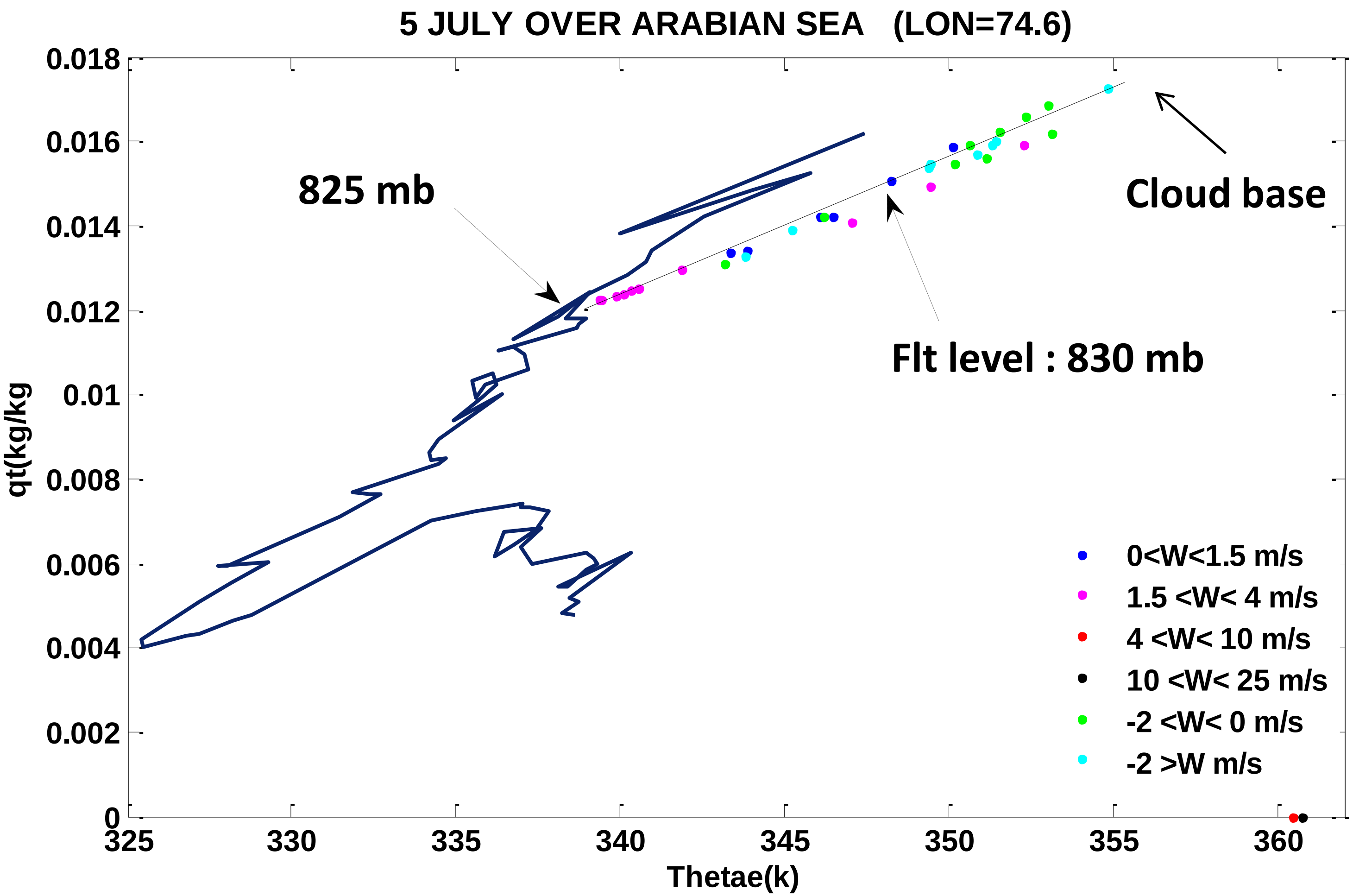
2. At a given instant, when air craft passes through a cloud, it may encounter rising or falling drops. So, colour code is used to distinguish vertical velocity in plots.

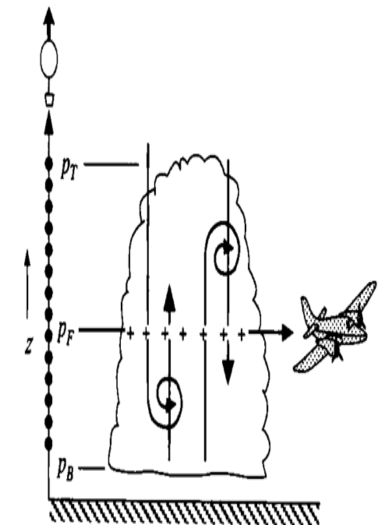


Paluch Diagram – Conserved variables



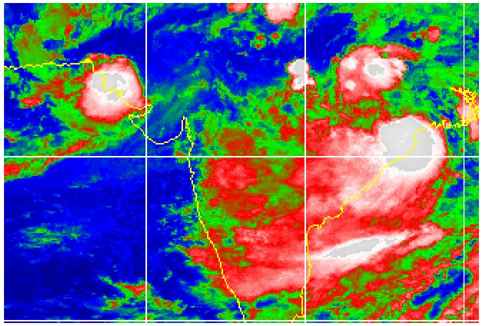


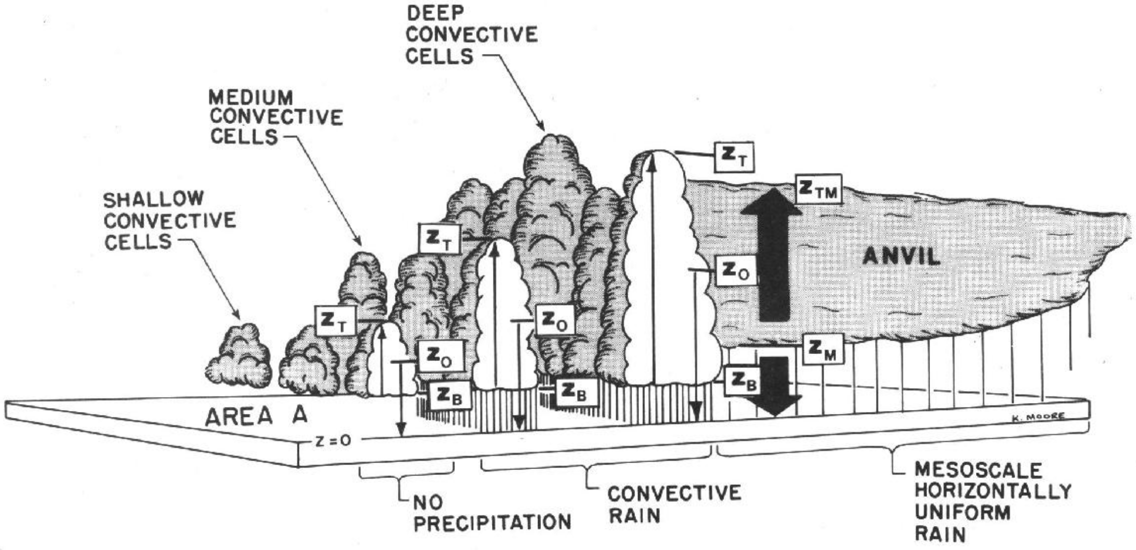




Clouds were precipitating type

Air entrained from above, but within 100 m





(Houze)

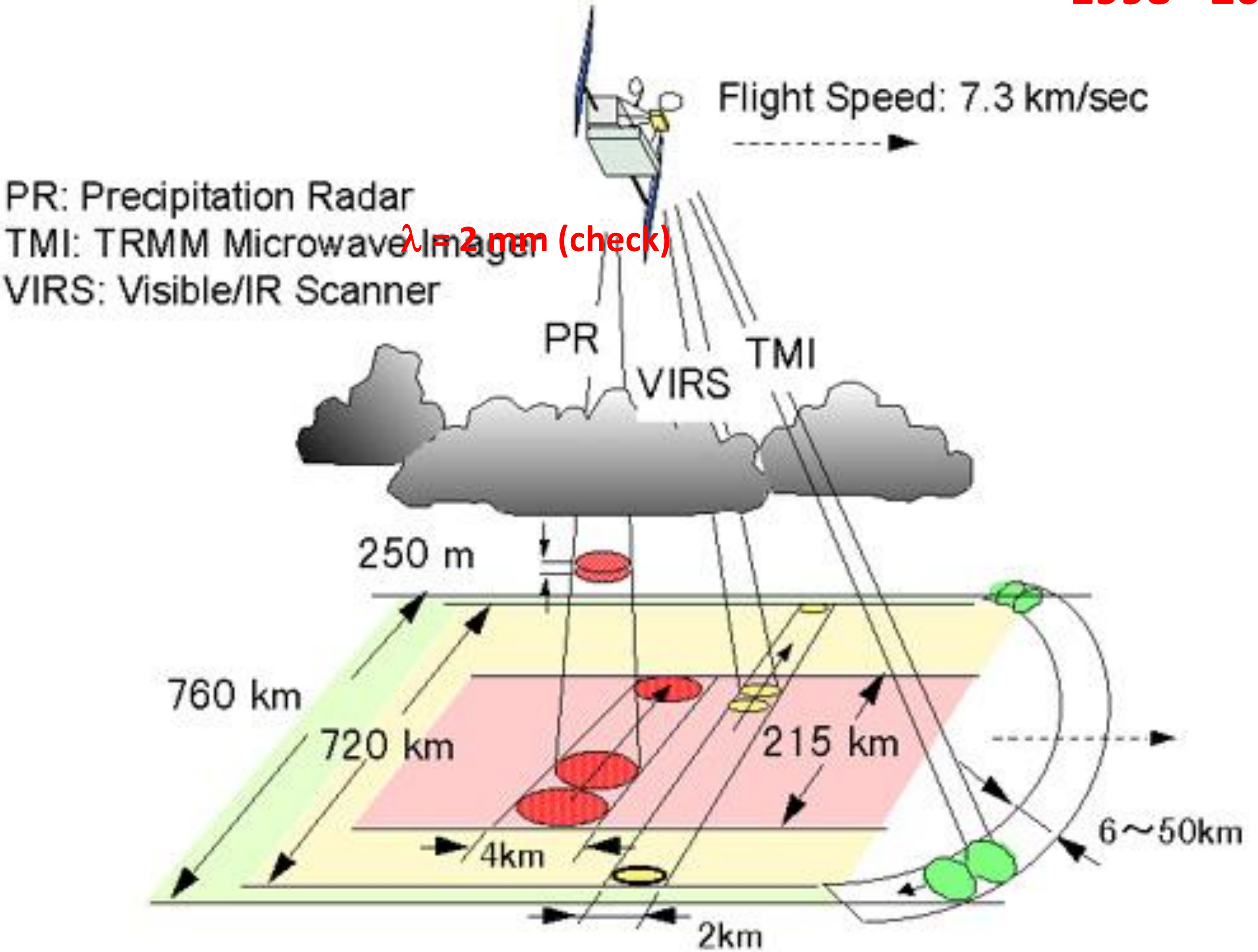
3D structure of monsoon clouds

1. TRMM Precipitation Radar

2. IMD’s S-band radar

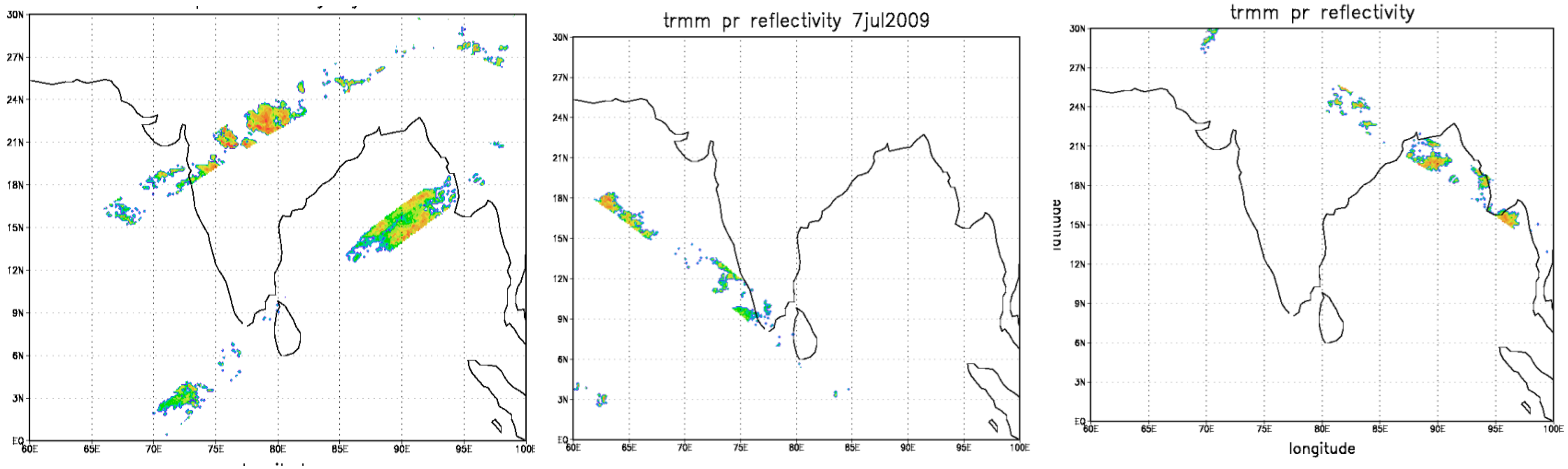
(Shailendra Kumar, Kapil Dev Sindhu)

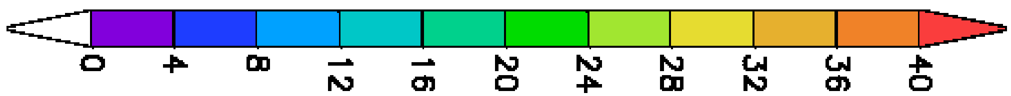
(US-Japan) TRMM Satellite Instrumentation 1998 - 2012



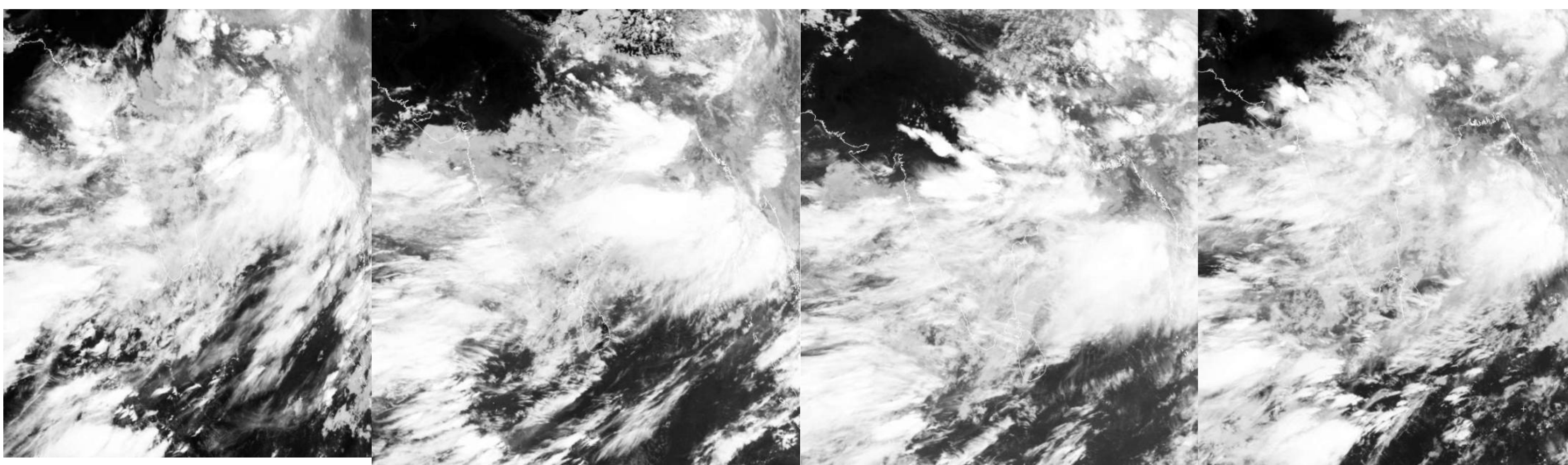
Kummerow et al, 1998

TRMM PR coverage on July 7, 2009



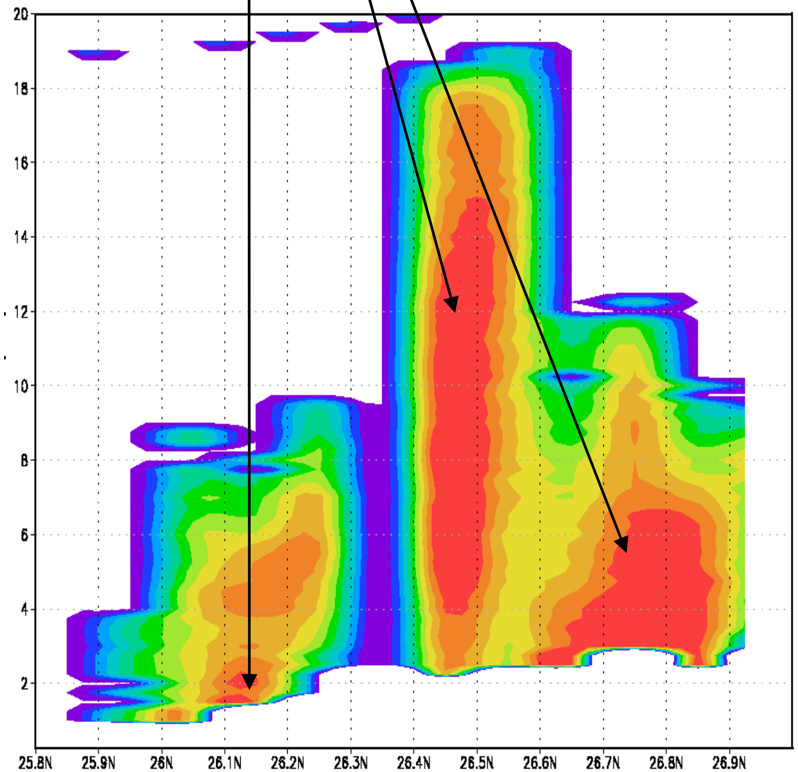


Satellite Image



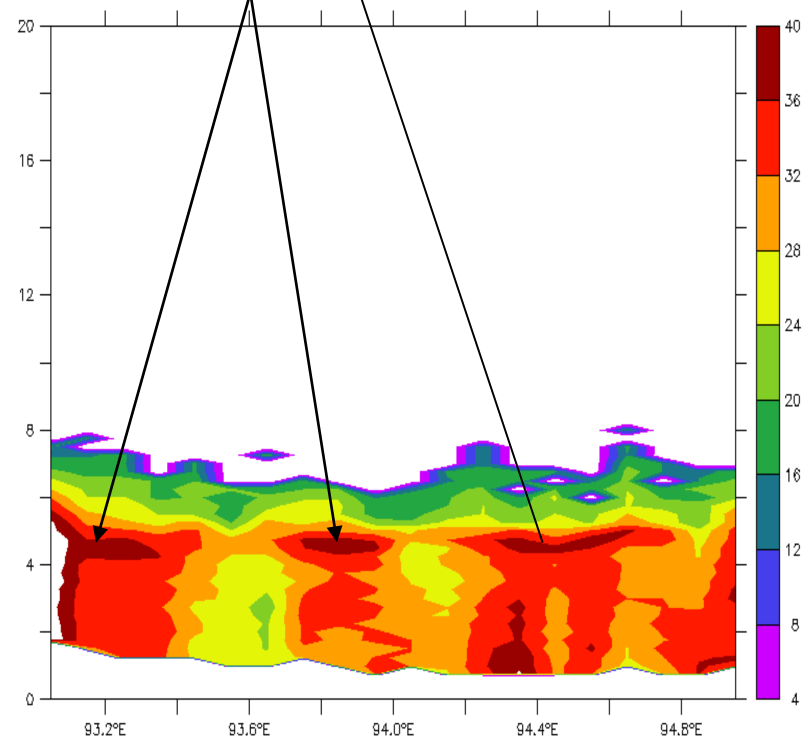
Study of Clouds system ?

Convective core



mean height of the clouds   Hight of convective core

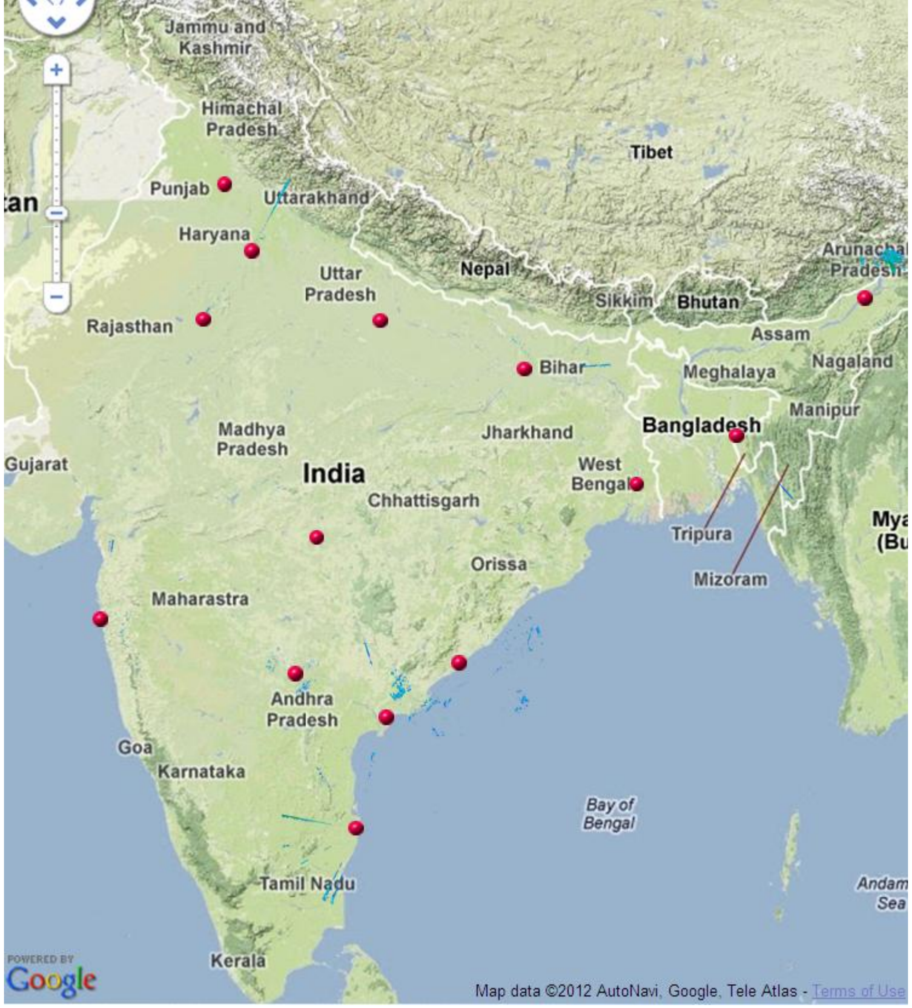
Melting Band



Effect of Melting Band(bright band) on the Height of clouds structure.

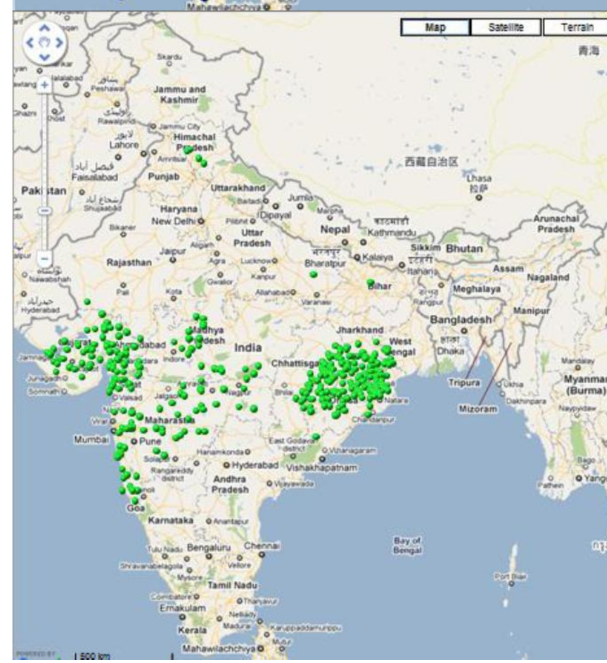
AWS

Map
Satellite
Terrain



Jammu and Kashmir
Himachal Pradesh
Tibet
Punjab
Uttarakhand
Haryana
Uttar Pradesh
Nepal
Sikkim
Bhutan
Arunachal Pradesh
Rajasthan
Assam
Bihar
Meghalaya
Nagaland
Manipur
Madhya Pradesh
Jharkhand
Bangladesh
Gujarat
India
West Bengal
Chhattisgarh
Tripura
Orissa
Mizoram
Maharastra
Andhra Pradesh
Goa
Karnataka
Bay of Bengal
Tamil Nadu
Andam Sea
Kerala
POWERED BY Google
Map data ©2012 AutoNavi, Google, Tele Atlas - Terms of Use

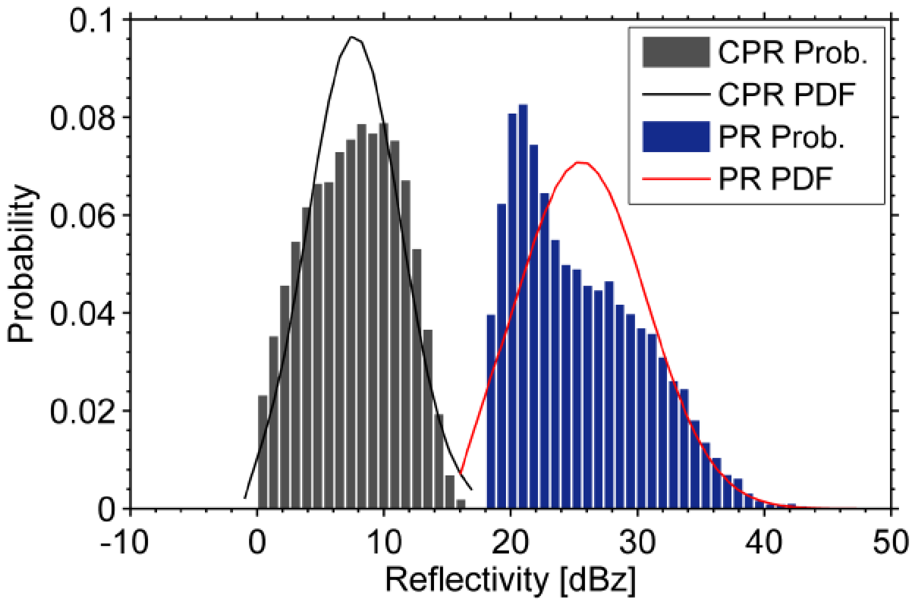
DWR

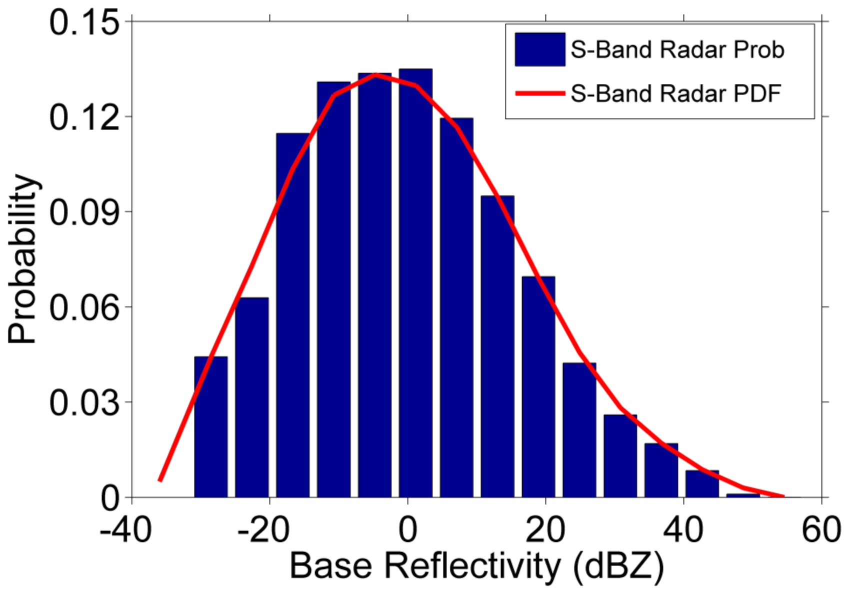


Map
Satellite
Terrain

ARG

Comparison Radar Reflectivities

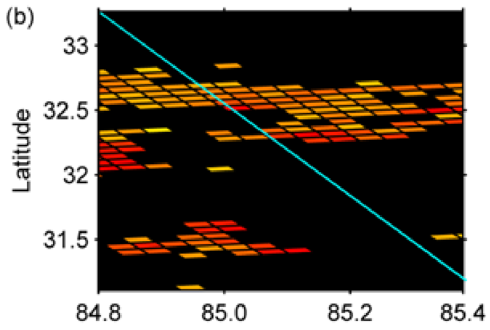




CLOUDSAT & TRMM radar

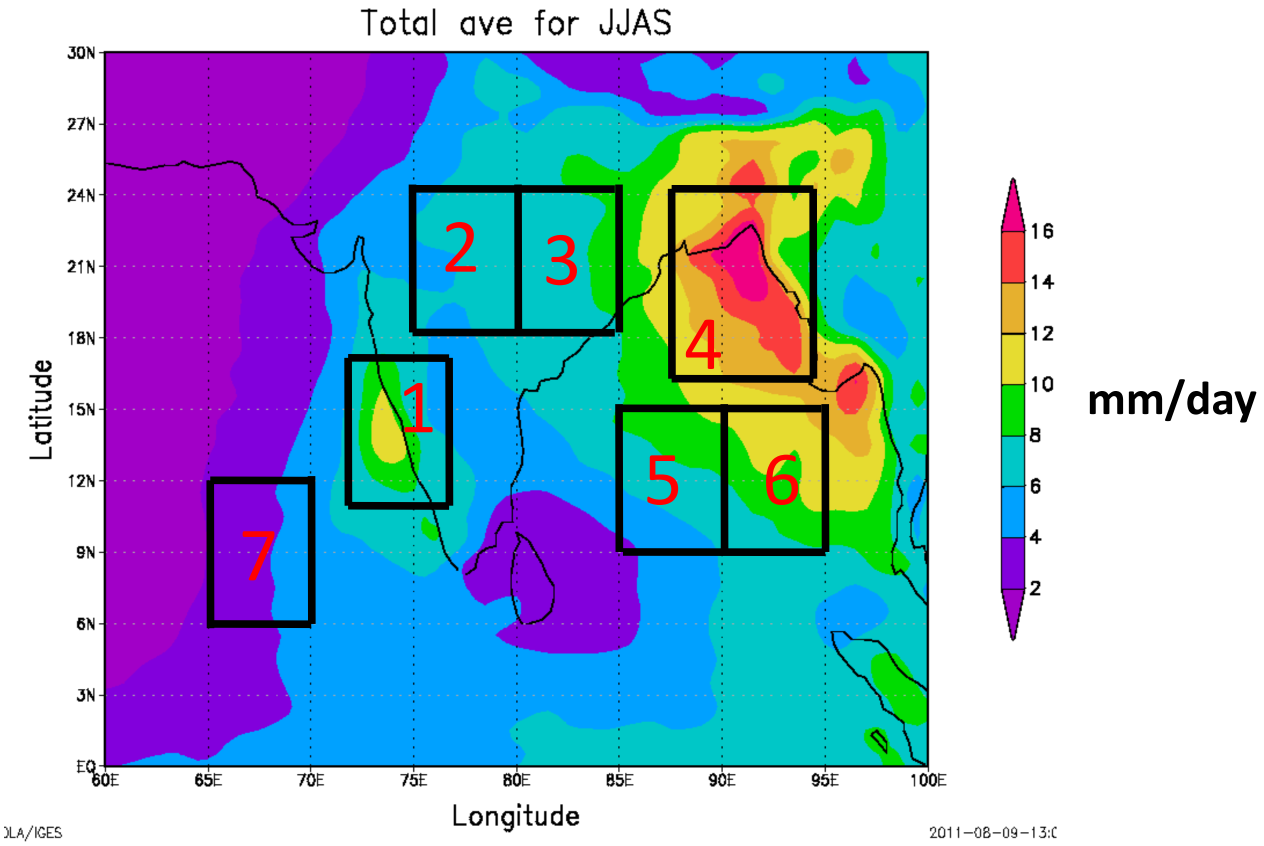
S-band DWR

Coincident, raining cloud systems

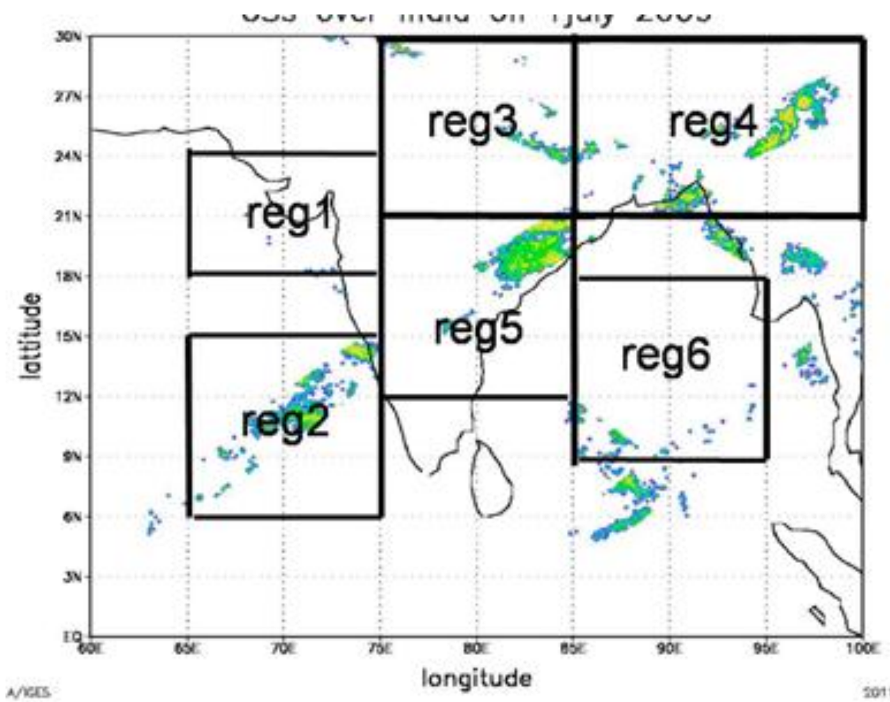


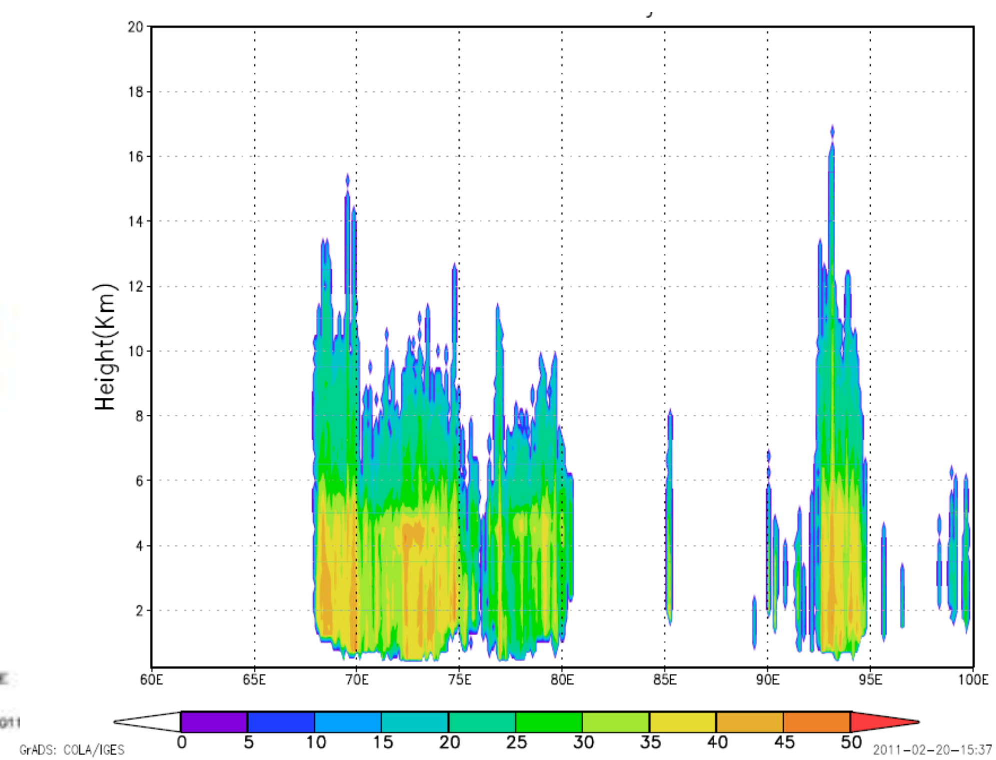
(Kapil Dev Sindhu)

Regions chosen for the study of convective core GPCP data



Surface & environmental conditions differ





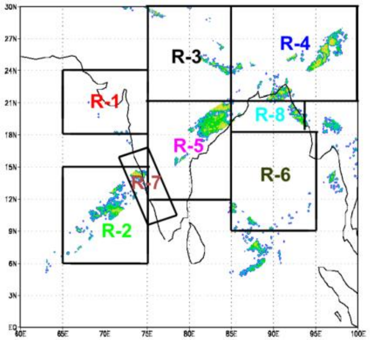
Actively growing clouds <0.1% area

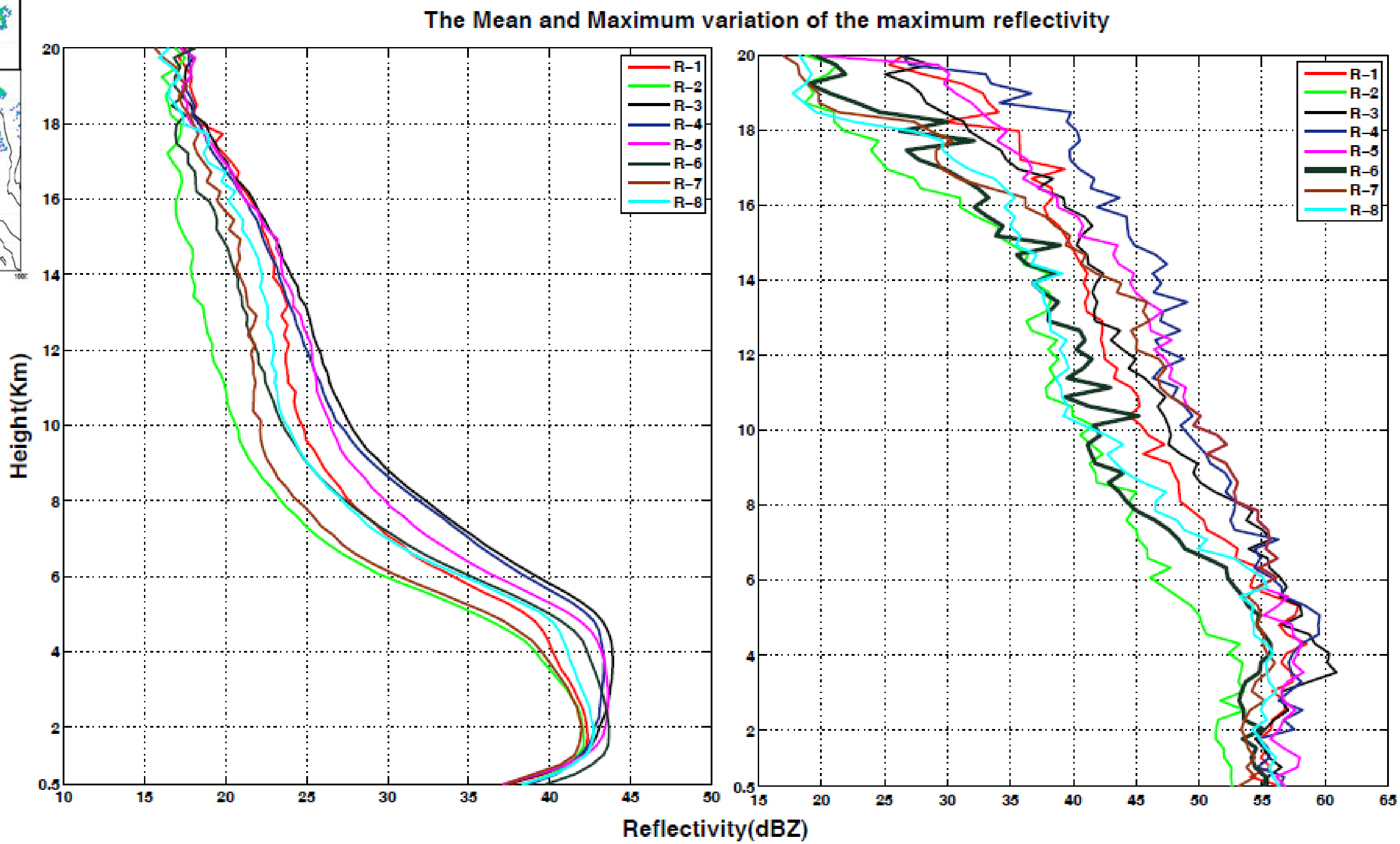
Matured clouds ~1-2 %

When averaged – decaying & weak precipitating clouds dominate

Pick the strongest from each frame, subject to at least
One profile with Z > 40 dBZ

Send the best athlete to the Olympics!

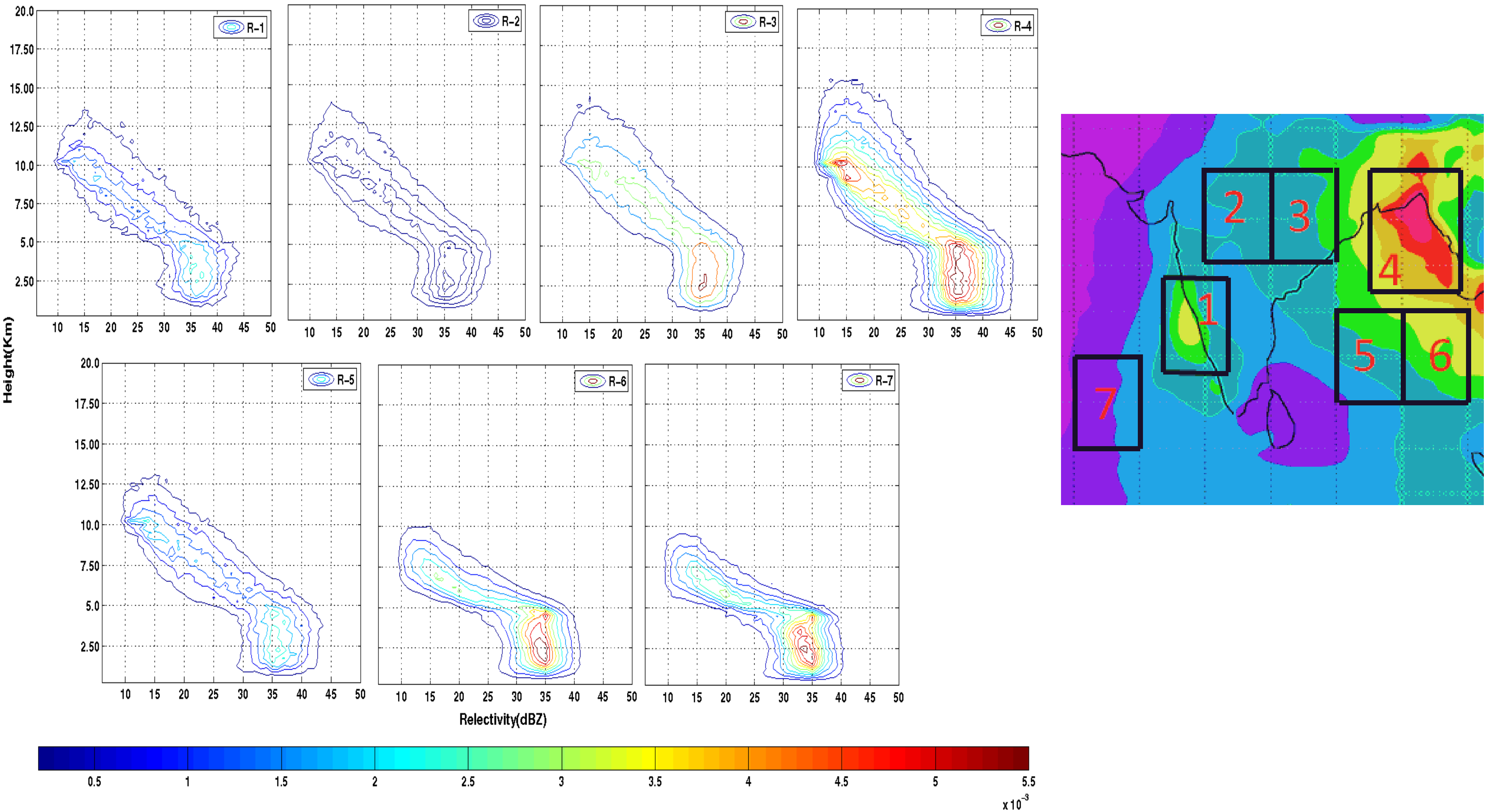




(Shailendra Kumar)

1. Max Z < the freezing level (~ 5 km)
2. Z decreases rapidly with height in 5 to 10 km range
3. Indo Gangetic plane & North East – CLW
4. Regional differences – surface forcing or microphysics?

Vertical extension of clouds



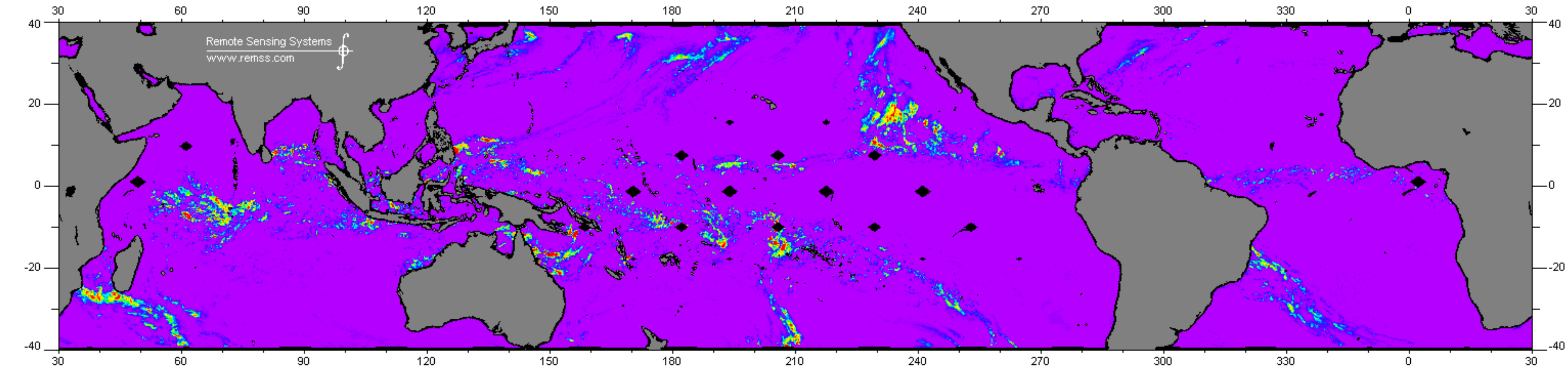
1.Condensed water lies below melting level in all the chosen regions.

2. Regional differences are indicated here.

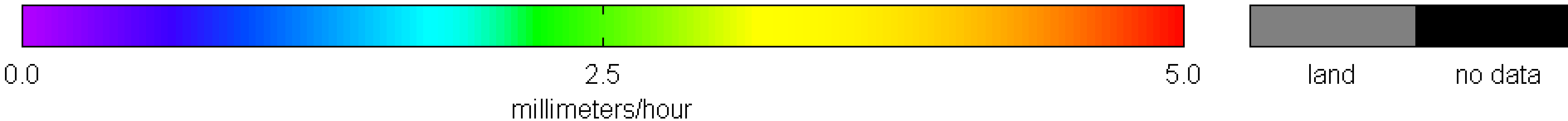
(Shailendra Kumar)

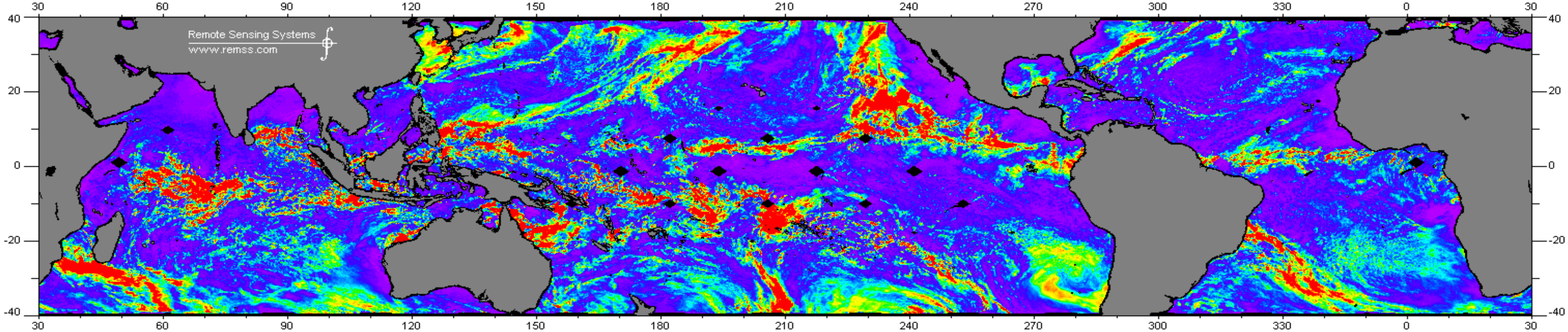
Large scale

Fractional area covered by deep clouds

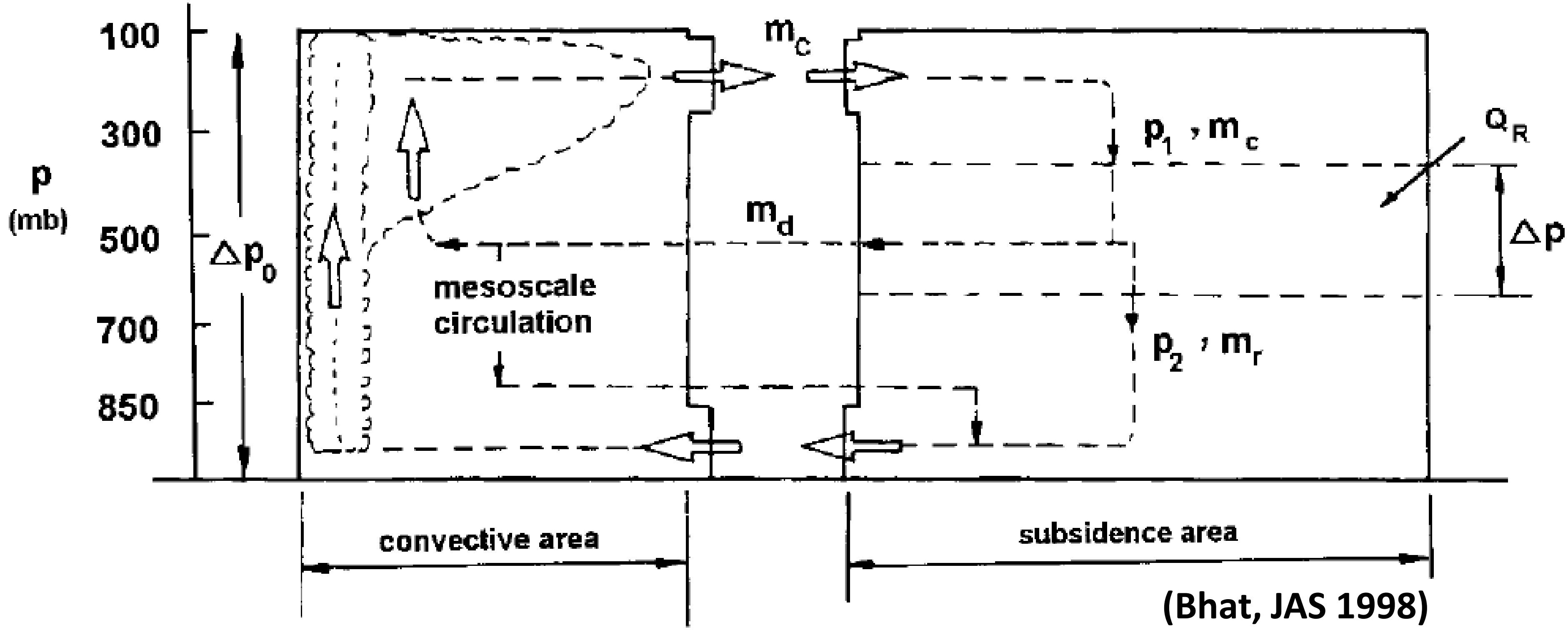


TMI Precipitation Rate, 3-days ending: January 23, 2013





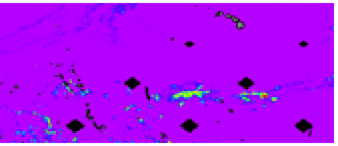
TMI Cloud Liquid Water, 3-days ending: January 23, 2013



(Bhat, JAS 1998)

Ascent → Deep convective clouds, time scale ~ 1 hr
Subsidence → clear regions → radiative cooling

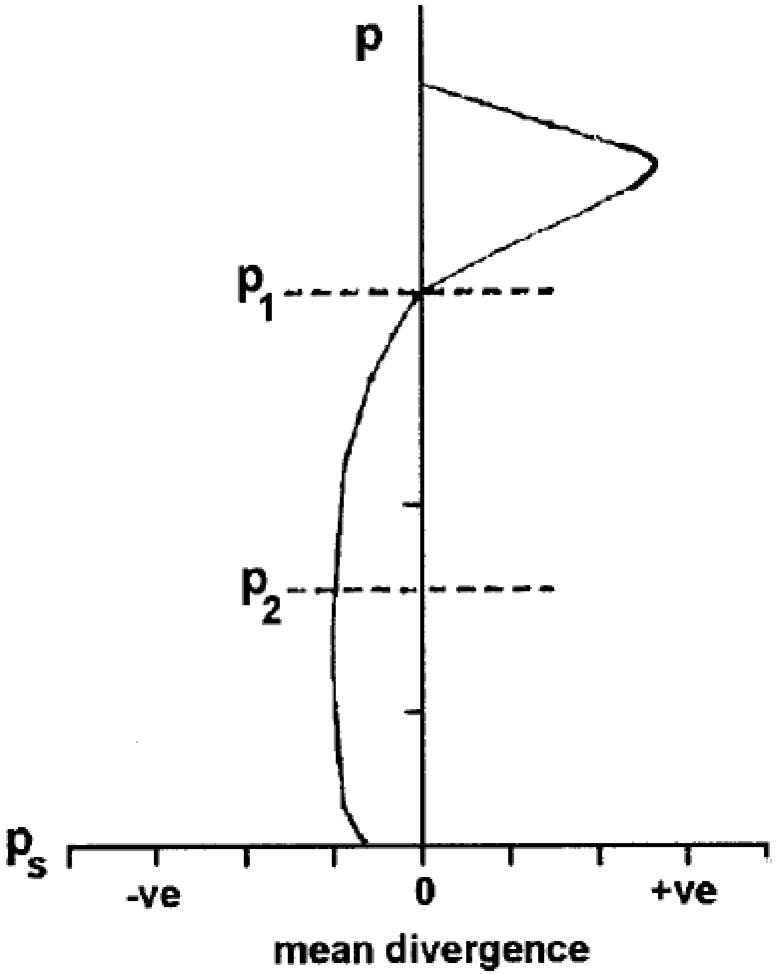
$$A_c/A_0 = [C_p \, (dT_R/dt)]/[\Delta p_0(ds/dp)(1 - \alpha\beta)]$$



Rad. cooling

stratification

Mesoscale circulation



$$\alpha = (p_2 - p_d)/(p_2 - p_1),$$

$$p_d = \int_{p_2}^{p_1} (\nabla \cdot \mathbf{V})p \, dp \Big/ \int_{p_2}^{p_1} (\nabla \cdot \mathbf{V}) \, dp,$$

$$\beta = m_d/m_c = \int_{p_2}^{p_1} (\nabla \cdot \mathbf{V}) \, dp \Big/ \int_{p_s}^{p_1} (\nabla \cdot \mathbf{V}) \, dp,$$

where $\mathbf{V}$ is the horizontal wind.

p_d being the mean detrainment level, related to thermal structure

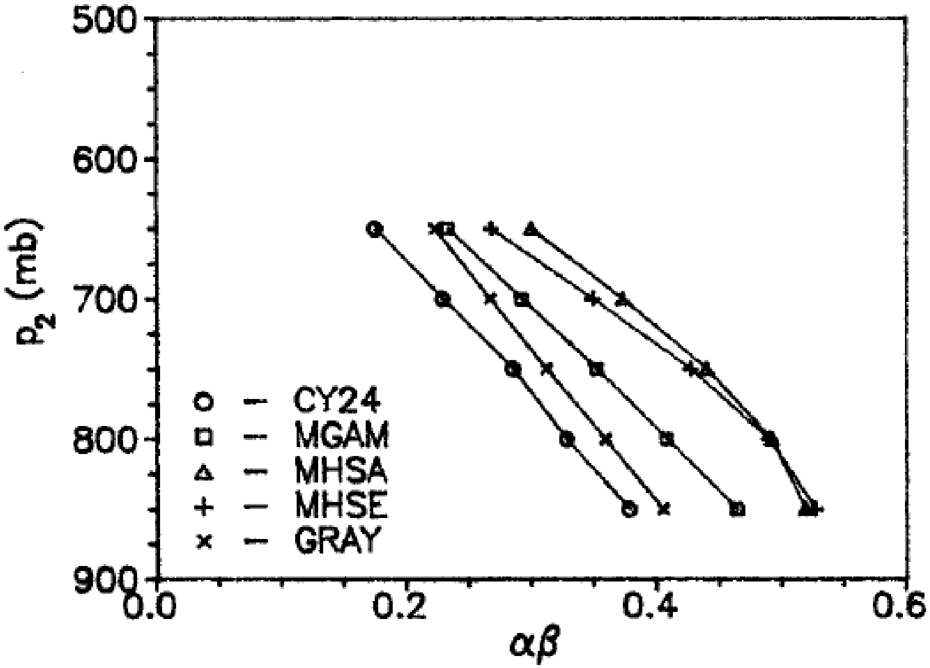
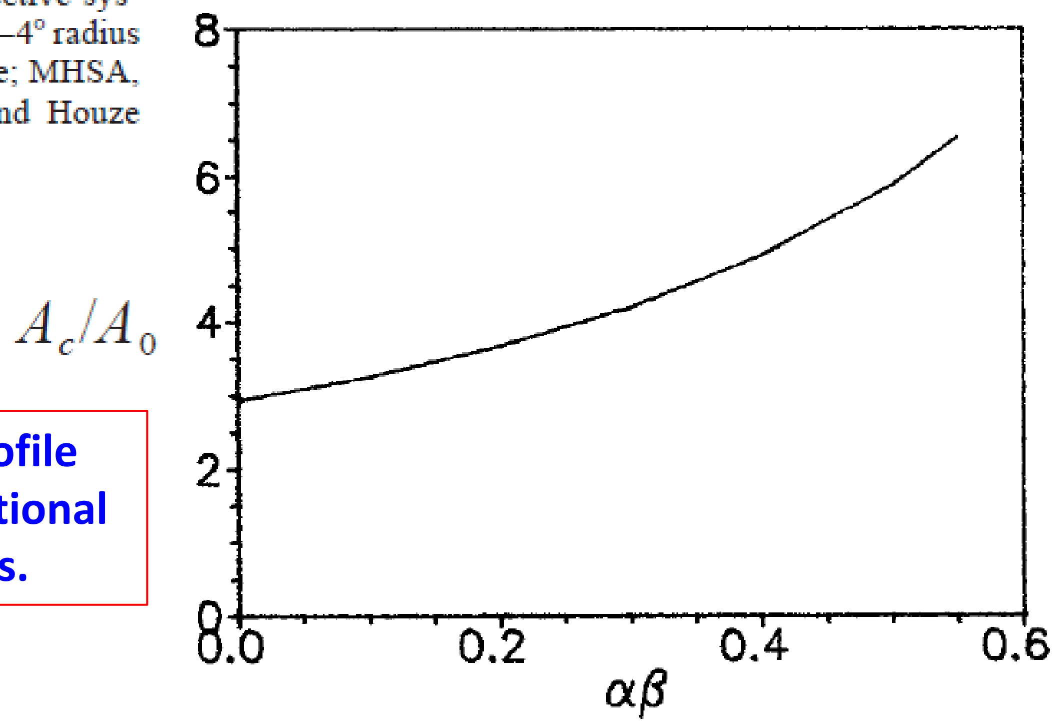


FIG. 6. Variation of $\alpha\beta$ with p_2 for some tropical convective systems. The divergence profiles are CY24, tropical cyclone 2°–4° radius (Frank 1977); MGAM, McBride and Gray (1980b) daytime; MHSA, Mapes and Houze (1995) active area; MHSE, Mapes and Houze (1995) extended area; and GRAY, Gray (1973).

Cyclone – least αβ

MCS (West Pacific) – largest αβ



Nature of organized convection→ div profile & downdraft structure → influence fractional area cover of convective clouds.

(Bhat, JAS 1998)

Thank you