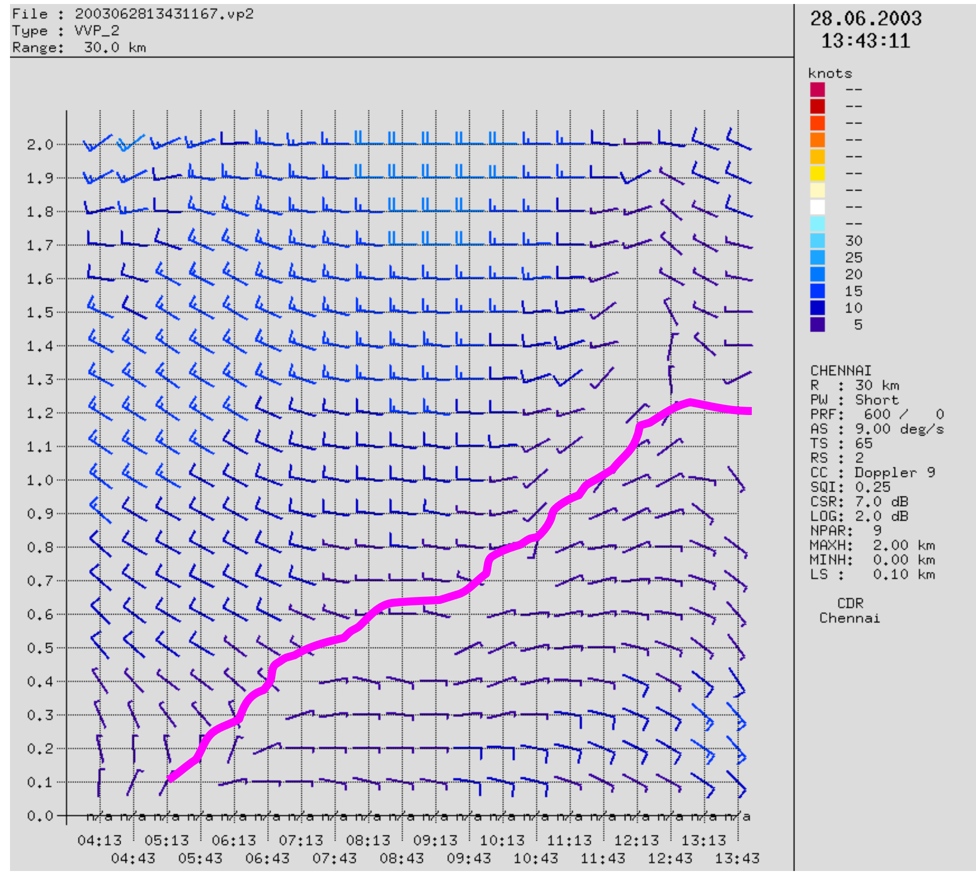
Doppler Weather Radar –
Observations, Utility & Limitations



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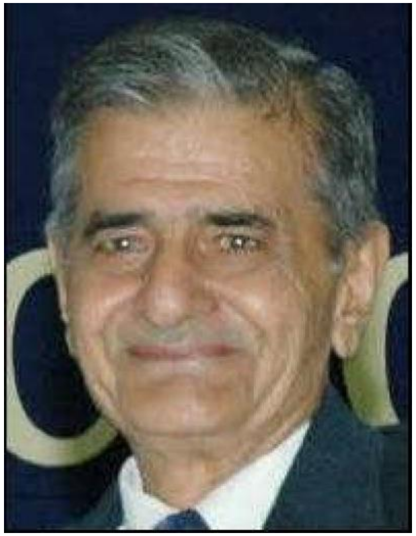
Radar observations –
merits, applications & limitations .....



Dedicated to Prof. D.R. Sikka- an advocate of quality observation and research; This lecture is on a few of my papers which attracted him.

Also, a tribute to Prof T.N. Krishnamurti, FSU who admired my Radar meteorology work & used the Radar rainrate data by way of physical initialization of a numerical model for Thane cyclone.

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Topics to be discussed

- Radar observations (& necessity of interpretation of products).
- Variety of applications (Public weather service/ severe weather warnings, Hail stone detection and warning (for Agriculture ?), Aviation, Hydrology, …..).
- We confine our discussions here to Hydrological application (Rain rate estimation and accumulation over a period of time), as it is relevant to agriculture.
- Physical initialization of NWP model - nudging of the latest Radar rain rate using reverse algorithms (reverse Similarity theory, Reverse Cumulus Parametrization) to improve FCST accuracy.
- Limitations and necessity of correct interpretation of Radar products.

Rainfall & Agriculture

- Plant and Animal life depend on rainfall.
- Rainfall is a spatio-temporal variable parameter.
- In about 40 km radius circle, variability of rainfall from 5 to 150mm is not at all uncommon.
- Unlike SW monsoon, ***NE monsoon rain is pulsatory and variability is quite high***.
- Dense network (2 X 2 km) may be needed for planning purposes ➔ practically infeasible ➔ ***an optimum network of rain gauges has been suggested (say 4km X 4km)***.
- But this network is also practically impossible in view of

1. High variability of rainfall in a dimension lesser than this grid.
2. Problem in locating sites (topographical / terrain constraints).
3. Cost constraints.
4. Maintenance related problems.

- Radar based rainrate estimation over a fine resolution is a probable solution to address the rainfall variability.

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Radar Hydrology

- **Radar's ability to see larger areas nearly simultaneously *is one of the major advantages of radar technology.***
- ***The problem of inadequate rain gauges can be addressed by Radar hydrology* .**
- **Radar reflectivity (*z*) – Rain rate (*R*) relationship [Marshall – Palmer relationship], viz., $z = A R^b$ where '*A*' and '*b*' are the parameters to be estimated.**
- **The parameters '*A*' and '*b*' can *vary spatially, temporally besides types of precipitation* (convective / stratiform etc).**
- **1000s of 'A' and 'b' are available in literature (Battan, 1973; Atlas, 1990; Rinehart, 1999; Raghavan, 2003 to name a few).**

- **Sample area of radar pulse (approx. 8 * 10^5 m^2 at 57 km) is million times larger than that of the rain gauges (3 to 5 *10^{-3} m^2).**

Radar Hydrology ... contd...

✓ Rain attenuation in S-band is less ➔ useful for rain rate estimation.

✓ The X-band radars *__are unsuitable for rain rate estimation in view of very high rain attenuation.__*

➔ Desirable to have a number of low powered radars capable of measuring hydrometeors upto 100 km without much rain attenuation (especially over mountainous region).

➔ Such radars commensurate with the cost-effectiveness of millions of rain gauges.

➔ Precipitation accumulation over a period of time can be estimated using the $z - R$ relationship.

- Limitations : Issues related to calibration of Radar, DSD, rain attenuation, beam filling, Clutters and Anomalous propagation etc to be understood and addressed before using the products.

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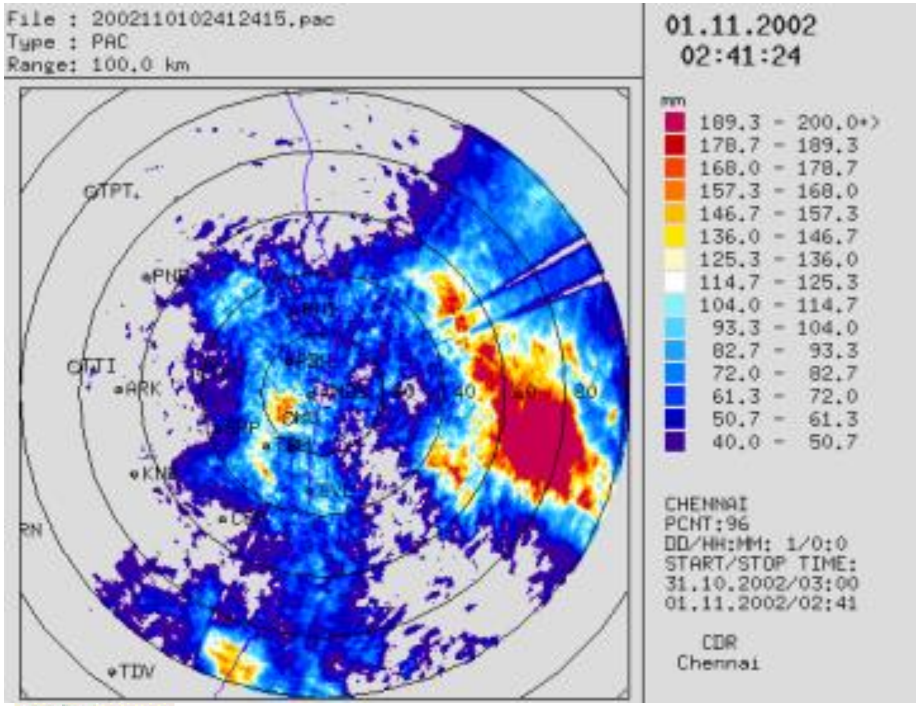
Validation of *z – R* relationship …. DWR, Chennai

- Developed z – R relation **z=267R$^{1.345}$** and used in operational set up since 2003 ***(Suresh et al, 2005, Mausam, p433-446).***
- Time integrated (1 to 24 hours) rainrate compared with ground truth (ORG / SRRG / ARG) *as a matter of routine* till date.
- 80 to 95% accurate in real world scenario.



R/G location	R/G (cm)	Radar (cm)
MO, Chennai	20	18.7 – 20.0
ACWC, Chennai	16	11.5 – 14.7
Tambaram	14	9.3 – 13.3
Cholavaram	13	12.0 – 13.3
RedHills	12.0	8.0 – 9.3
Poondi	4	2.7 – 4.0
Thamaraipakkam	8	6.7 – 8.1

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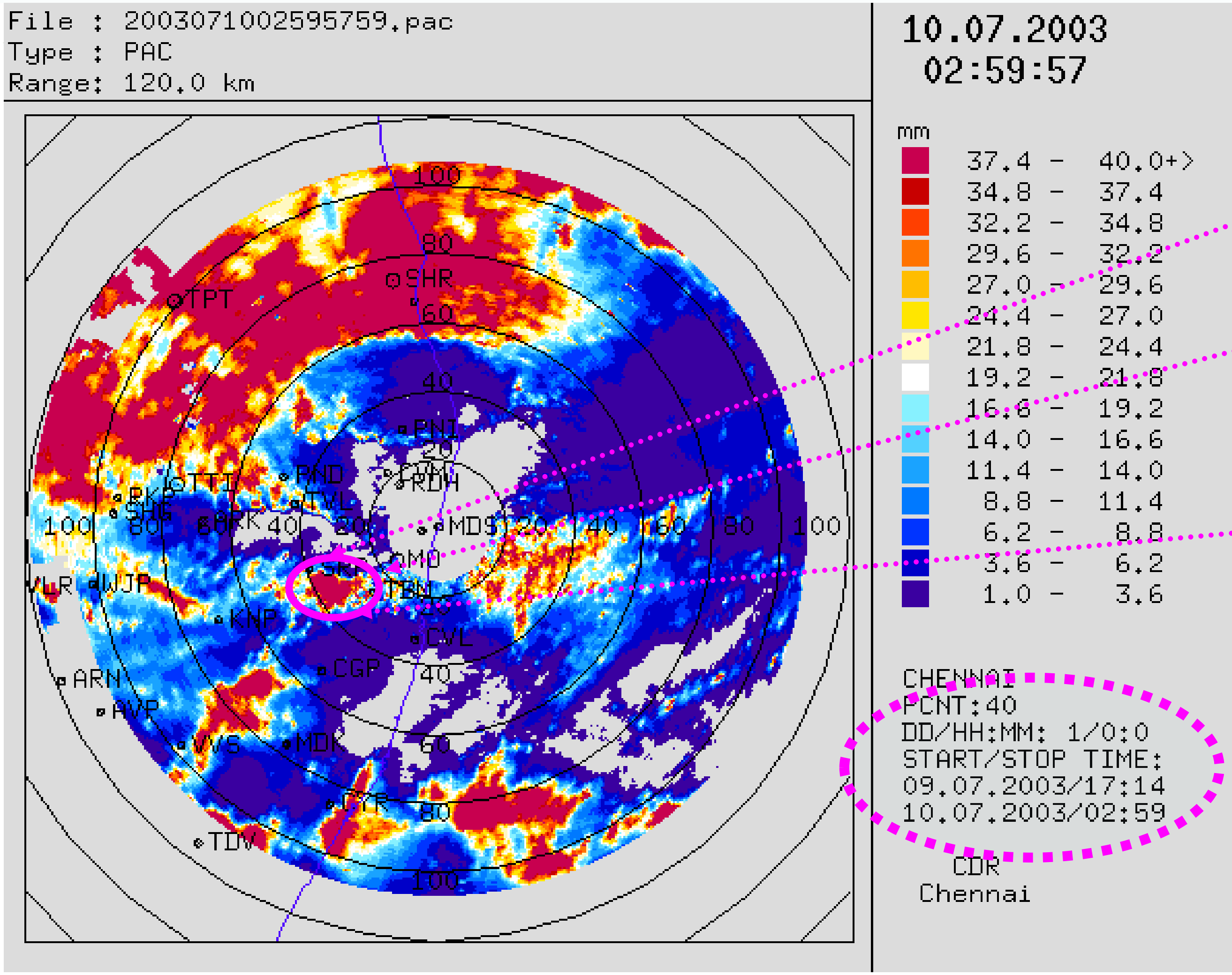
Inadequacy of rain gauges



Heavy rain event … (South of Sriperum-pudur Meenam-bakkam Tambaram) over no rain gauge area.

Rain eludes Raingauges.

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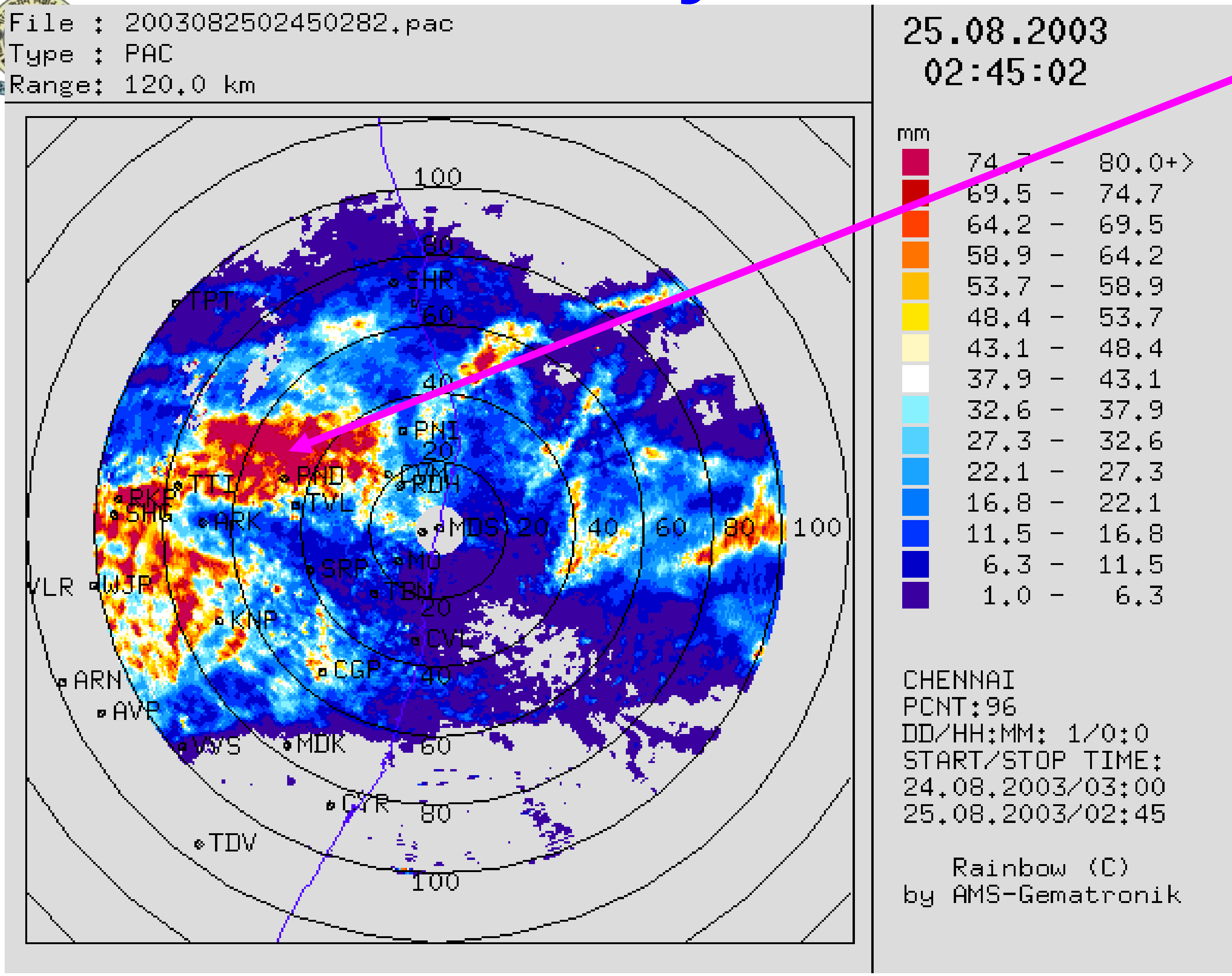
Variability of rainfall



- Rain accumulation in Poondi (PND) catchments in excess of 80 mm has been detected only by the radar in the absence of rain gauge network.
- **Irrigation/ water management depends on rain data over catchments.**

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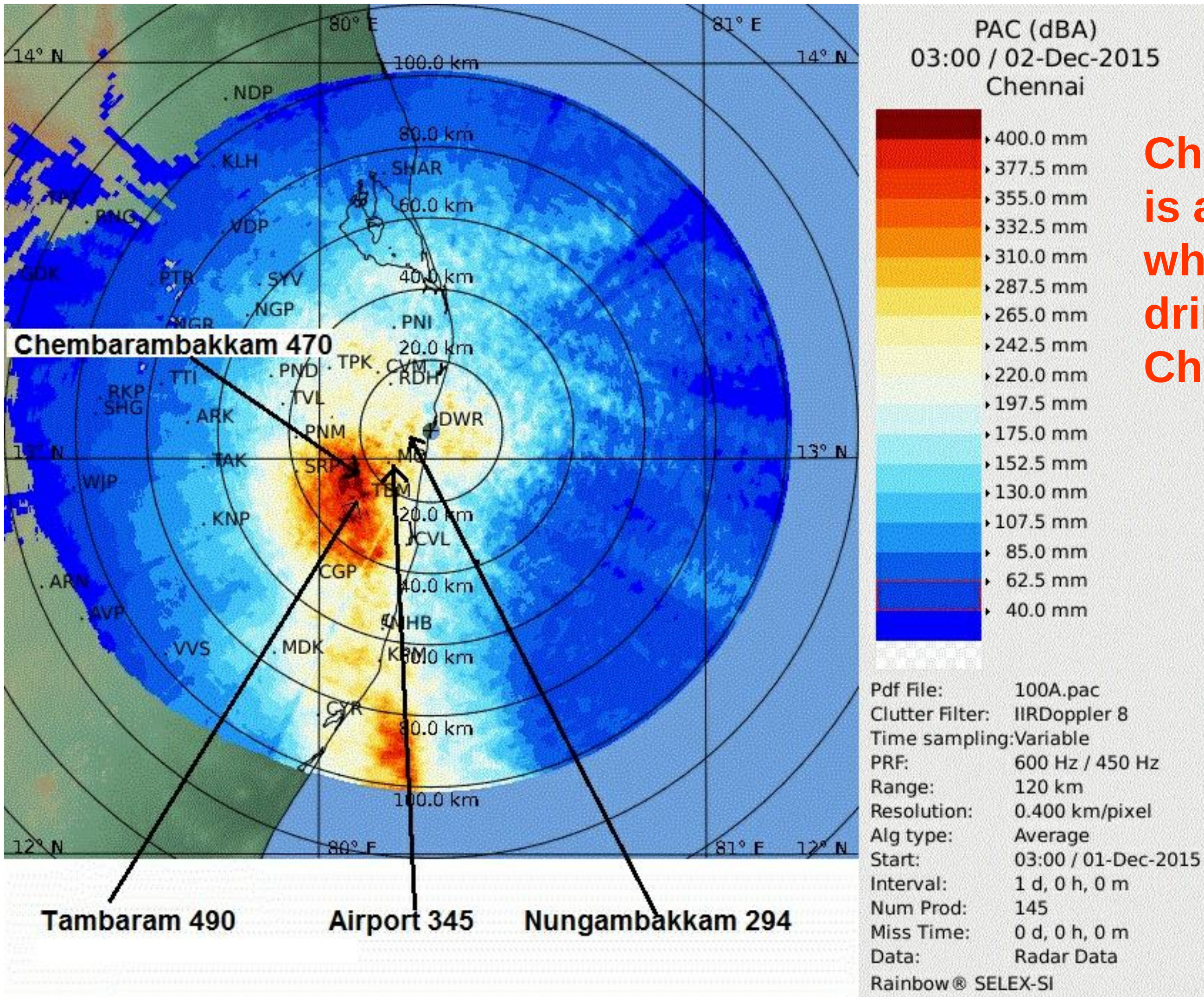
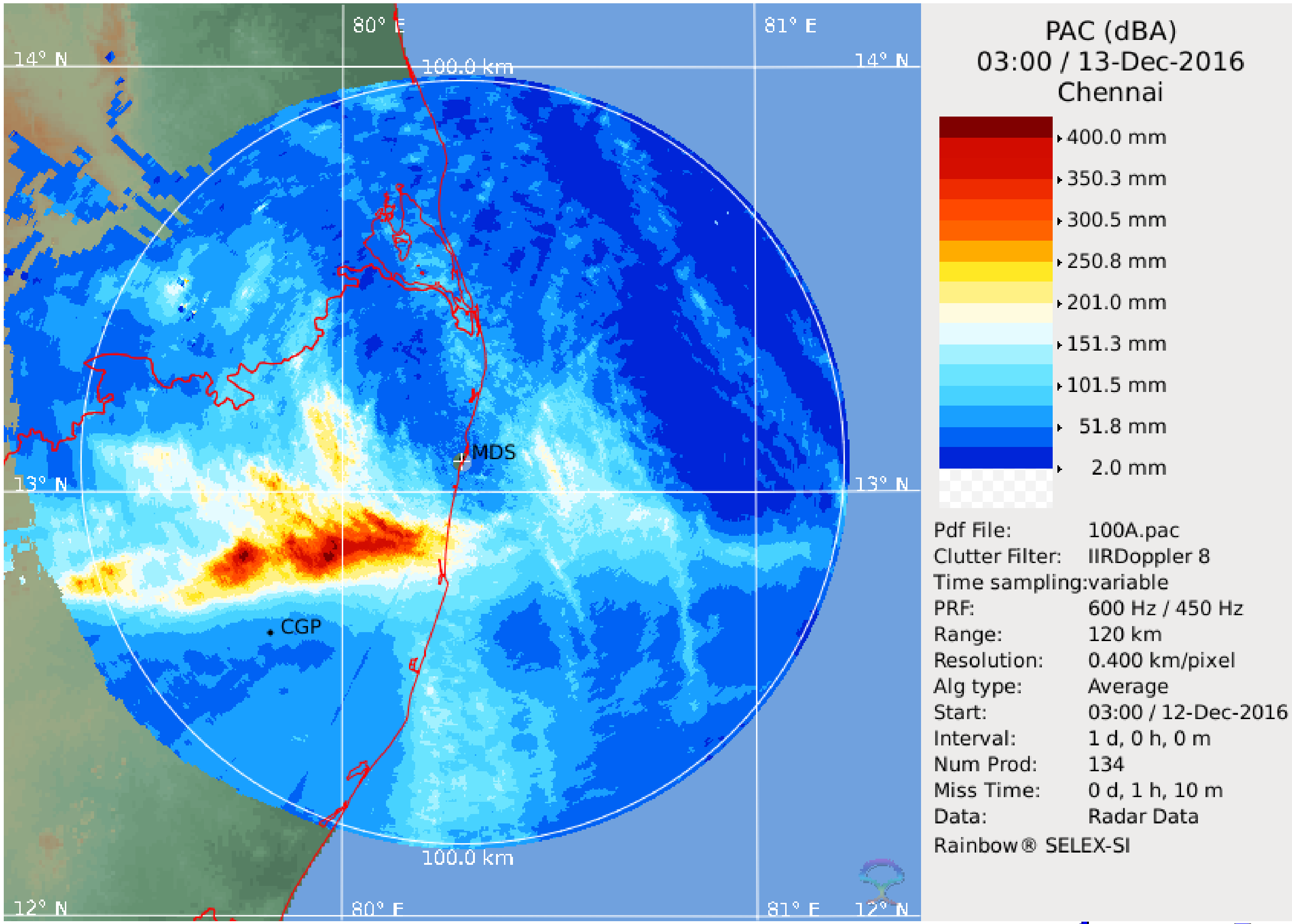
1-2Dec2015 Rain rate estimation $z=267R^{1.345}$



Chemparambakkam is a fresh water lake which provides drinking water to Chennai.

12-13Dec2016 Vardah cyclone Rain rate estimation $z=267R^{1.345}$



24hrs ending 0300Z/13 Rainfall (cm)

Satyabama Univ 38
Kancheepuram 28
Poonamallee 22
Chembarabakkam 21
Meenambakkam 20
Sriperumbudur 17
Tambaram 14
Nungambakam 12
Vellore 11
Poondi 9
Mahabalipuram 7
Maduranthagam 7
Vandavasi 7.

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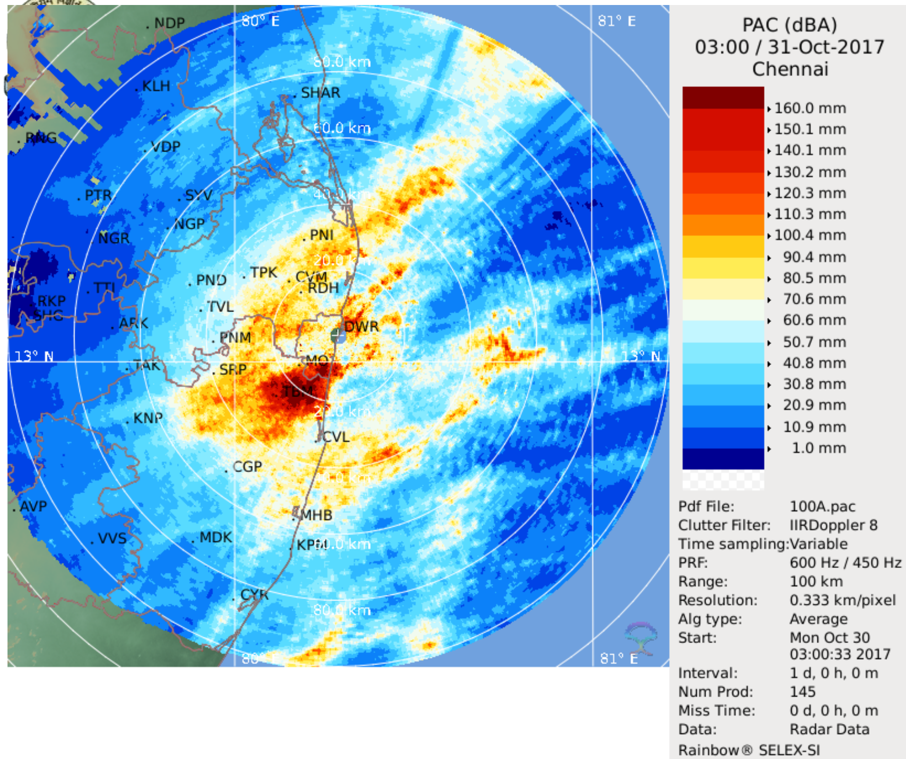
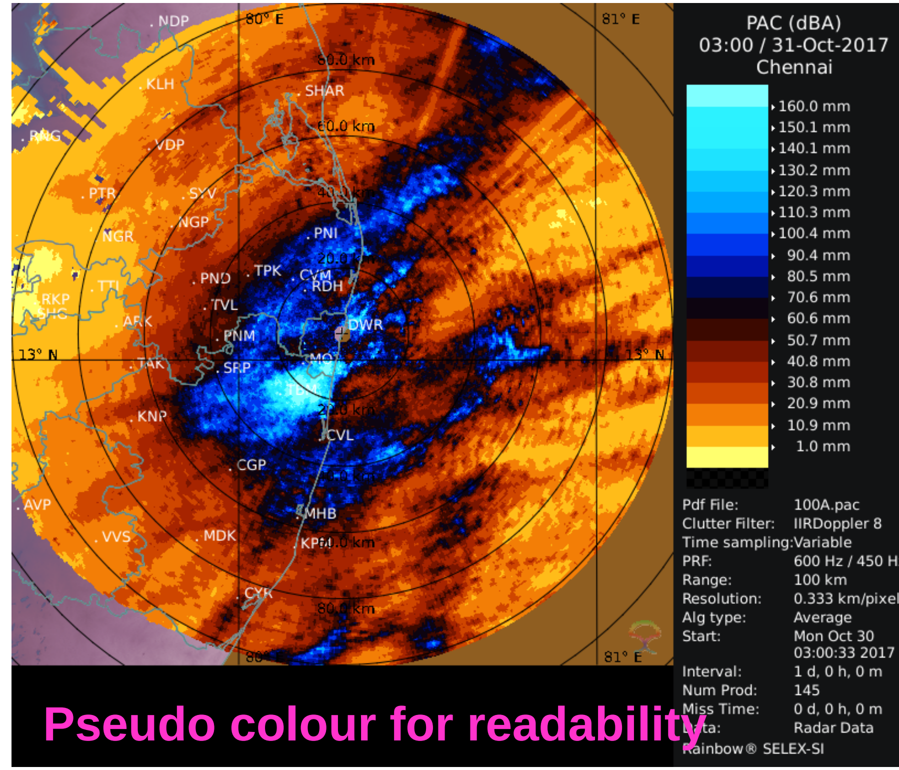
30-31Oct2017 Rain rate estimation $z=267R^{1.345}$





Observed 24 hrs ending 0300UTC/31 October2017 rainfall (in mm) at ORG / SRRG / ARG stations are :

- **PND 40; TVL 51; PNM 70; CGP 70;**
- **SRP 130; MO 168; TBM 170;**

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Radar Hydrology .. Advantages/Limitations

Radar estimation of rainfall is useful in view of its

a) Wide area coverage. Supplements rain gauge measurements.

b) High spatial and temporal resolution.

c) Real time measurement.

- ➔ **Quite useful for water resources management especially over catchments in the absence of dense R/G network.**
- ➢ **Helps to issue Flash flood forecasting.**
- ➢ **Helps to understand the rainfall variability in microscale.**
- ✓ **Quite useful for physical initialization of NWP models.**

- ❖ **Over estimation from Bright band, Hail stones.**

62 dBZ = 639 mm/hr ; 60 dBZ = 454 mm/hr

58 dBZ = 322 mm/hr ; 56 dBZ = 229 mm/hr

(***Suresh et al, 2004, Mausam, p655-670***)

(***Suresh , 2004, IJRSP, p435-447)***

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Physical initialization of Rain rate in NWP models enhances predictability

Tarbell et al (1981, Mon. Wea. Rev., 77-95 &
IAMAP Symp, Hamburg 25-28 August 1981).
Krishnamurti et al (1991 Tellus, 51-81 & 1994 ECMWF workshop, 31).
Krishnamurti et al (2016, Capital Publishing co., ISBN 978-93-88119-11-7).

Physical initialization & Predictability

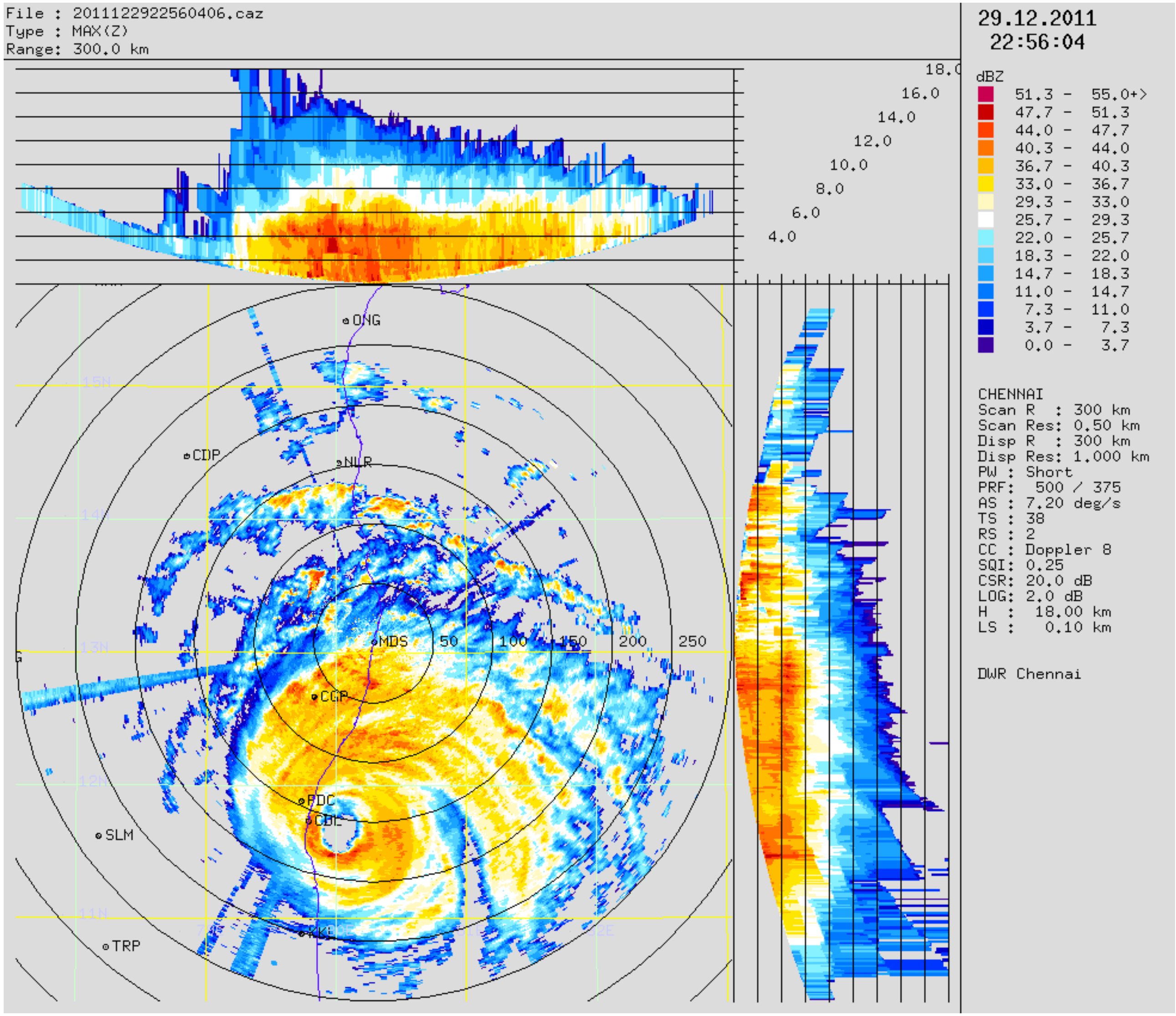
- Tarbell (1981).
- Static initialization (nondivergent initial condition) of model is inaccurate on short term precipitation forecast.
  - 🡐 Several hours to develop consistent vertical velocity field.
  - 🡐 Mesoscale moisture field cannot be resolved by U/A data.
- ✓ Divergent initialization was proposed [vertical velocity using diabatic term based on rainrate, to compute velocity potential, divergent wind components, finally geopotential (using both div /nondiv wind) to ultimately compute hydrostatic temperature].
- ✓ On meso scale, the diabatic term in the omega equation is dominant in regions of precipitation (🡐 Radar/Satellite rainrate).
- ➢ Physical initialisation - an analysis to improve basic state variables using non-conventional data (Radar Rainrate, OLR, condensation heating rate using rain rate) - significantly improved short range FCST.
- ➢ Greater improvement possible with higher rainrate at the initial time.

Thane cyclone, 22:56Z / 29Dec2011

Physical initialization using rainrate was attempted by Krishnamurti et al. (2016).

Landfall around 0200Z/30Dec2011 between Cuddalore and Pondichery.

Rainfall 03Z/30Dec.
Pondicherry 15cm
Kalpakkam 10cm
Cuddalore 8cm
Chennai 7cm.



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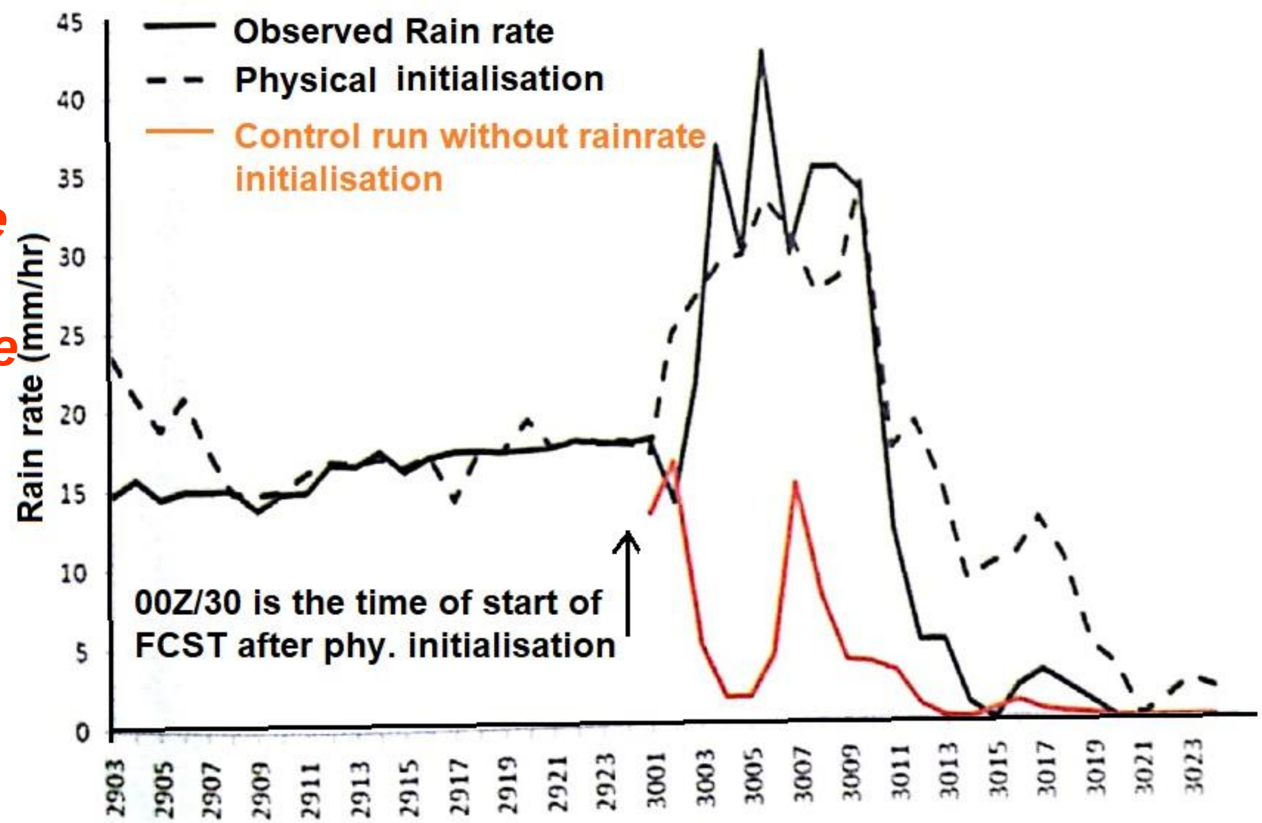
Thane cyclone .. Krishnamurti etal(2016)

- **Physical initialization for cloud resolving non-hydrostatic model**
- **Diagnostic calculation of surface flux, humidity analyses.**
- **Newtonian relaxation at each FCST time step.**

"1 day forecast of Heavy rain rate of 40mm/hr at Cuddalore during the passage of Thane after the landfall is the impressive aspect of physical initialization".

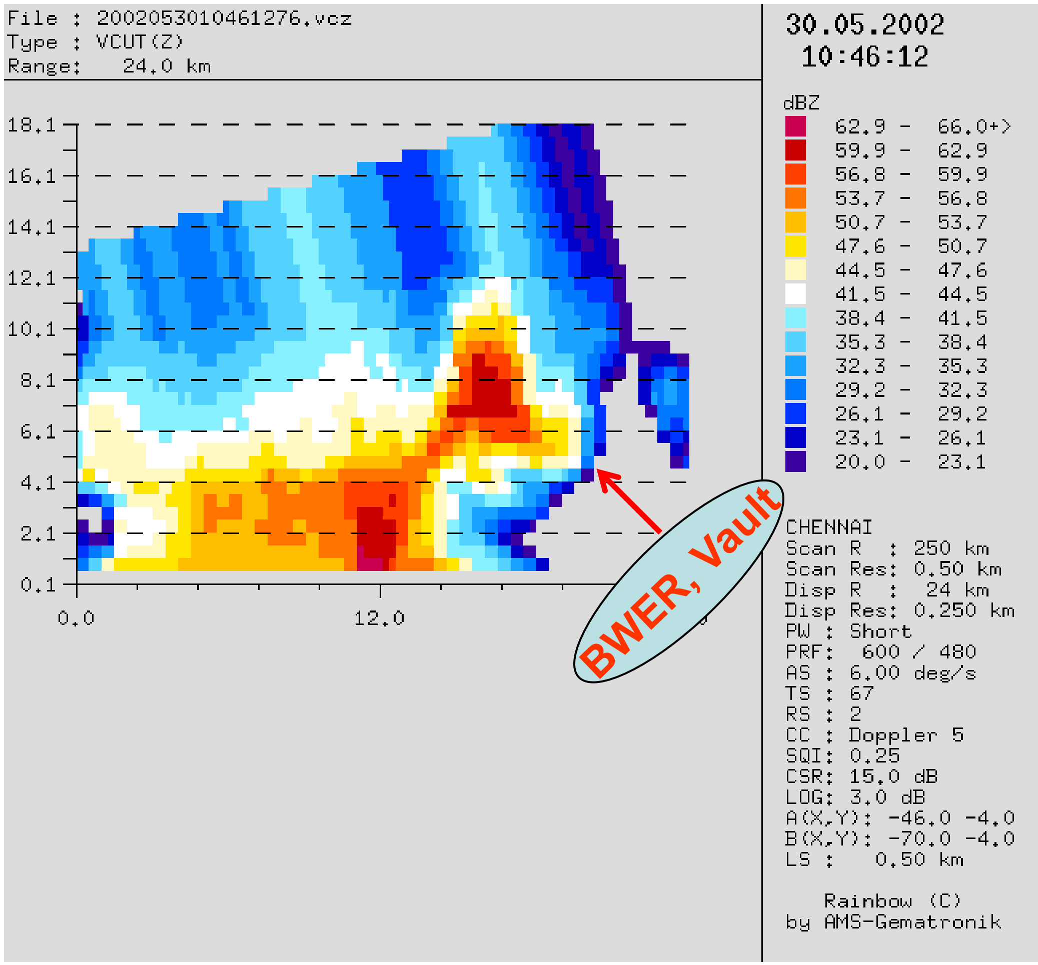
✓ **Reverse Similarity Theory.**

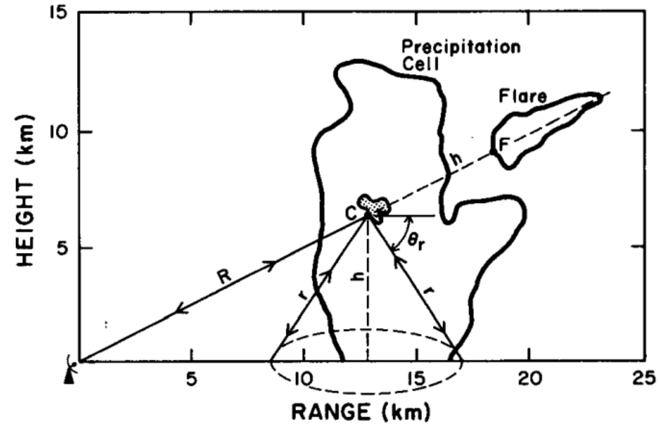
✓ **Reverse Cumulus Parametrization.**



Time history of Physical Initialisation and prediction at Cuddalore - Thane cyclone during 03Z/29 to 23Z/30 December 2011.

Interpretation of Radar echoes – Hail stone





<u>Flare echo</u> … ***Three body scatter Spike (TBSS) from Z > 60 dBZ***

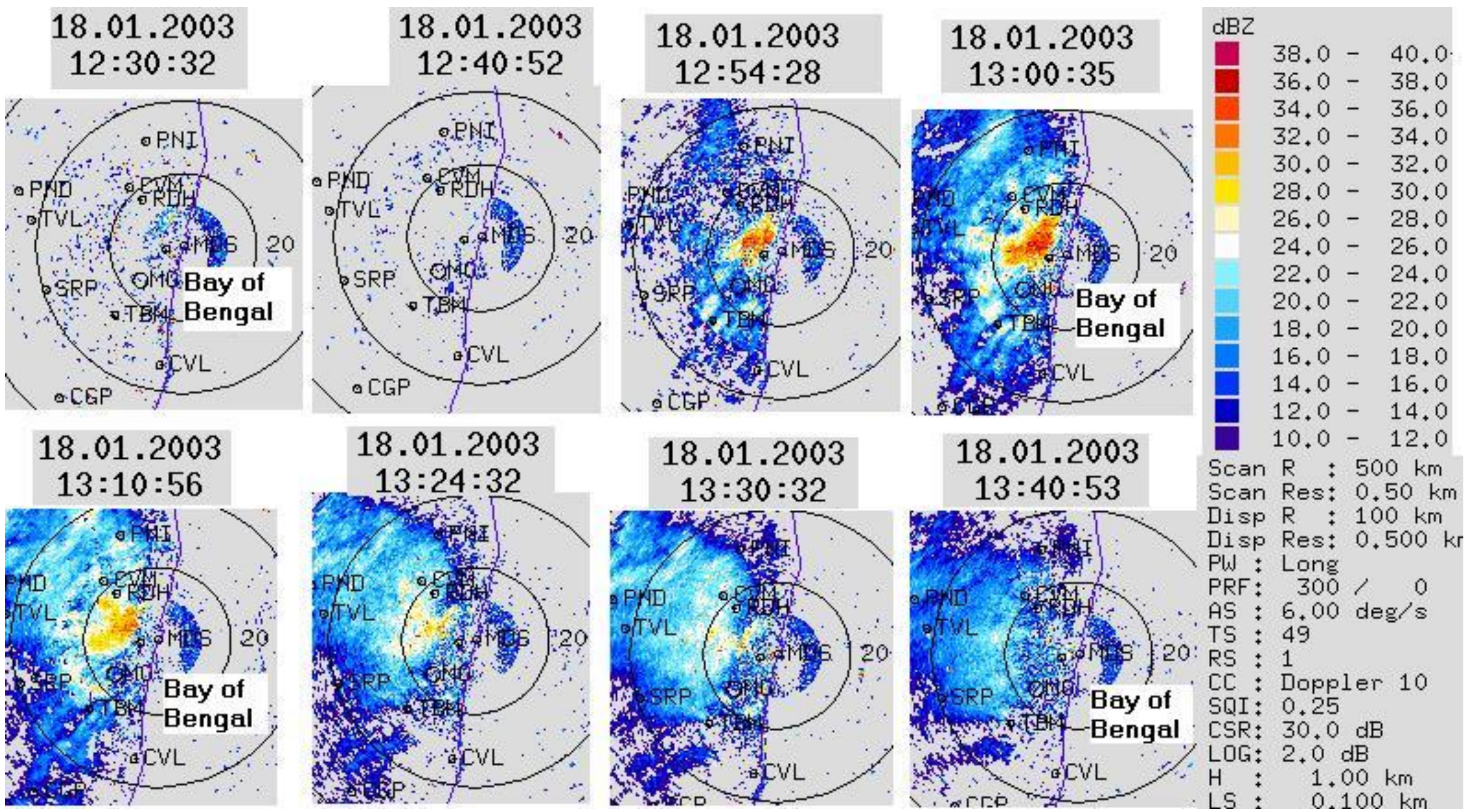
(i) Scattering by hydrometeors to the ground.

(ii) Back scattering from ground to hydrometeors.

(iii) Scattering back to the antenna.

Winter precipitation over Chennai

January 2003 Radar echoes (~ 2 to 10 mm/hr) during morning and evening hours forced us to learn more about product interpretation.



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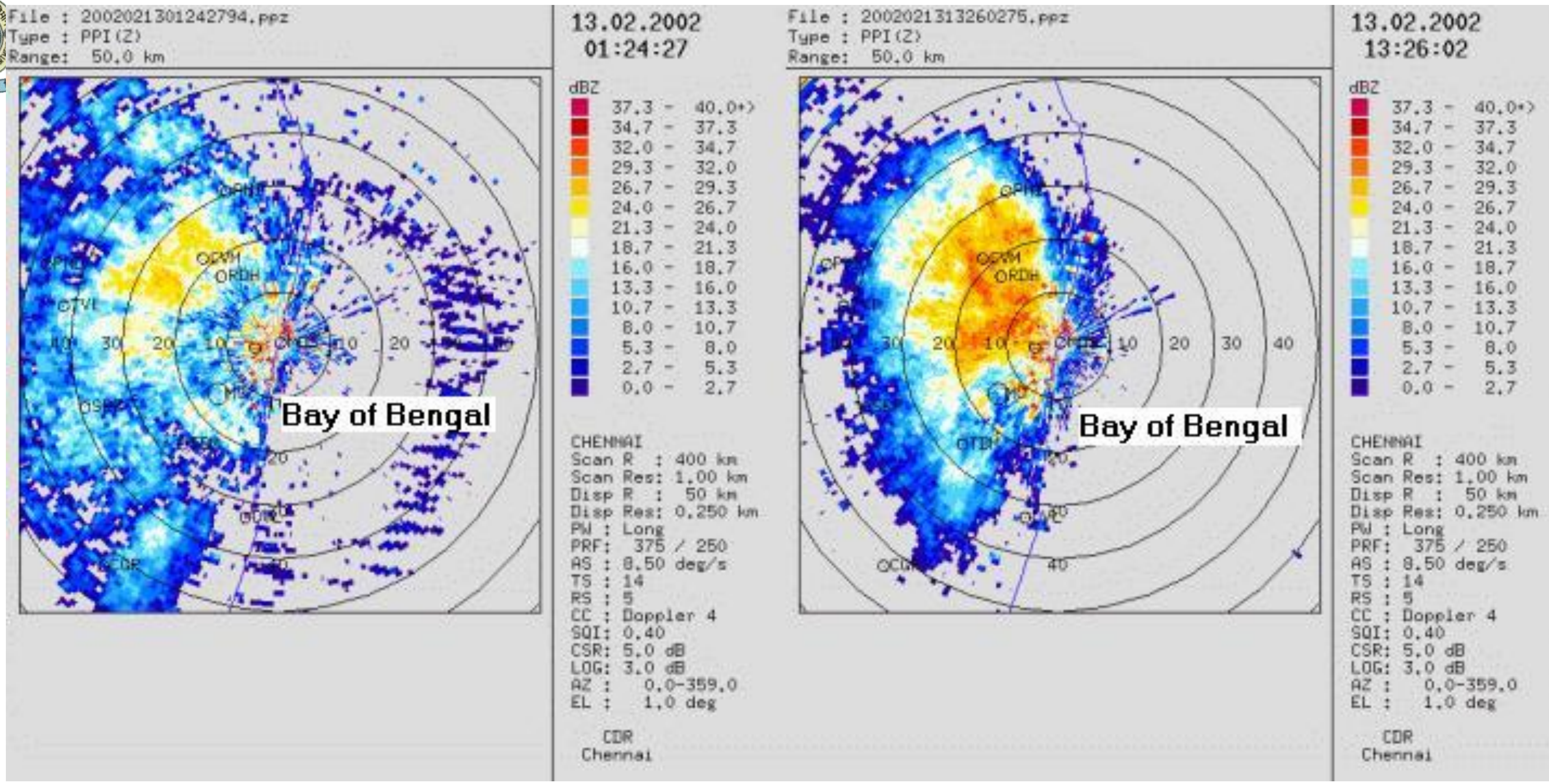
Winter precipitation over Chennai



- ***In the month of February 25 – 38 dBZ (~ 1 to 12 mm/hr rain rate) was measured continuously during dawn and dusk.***
- **Echoes seen upto 4^{o} elevation.**

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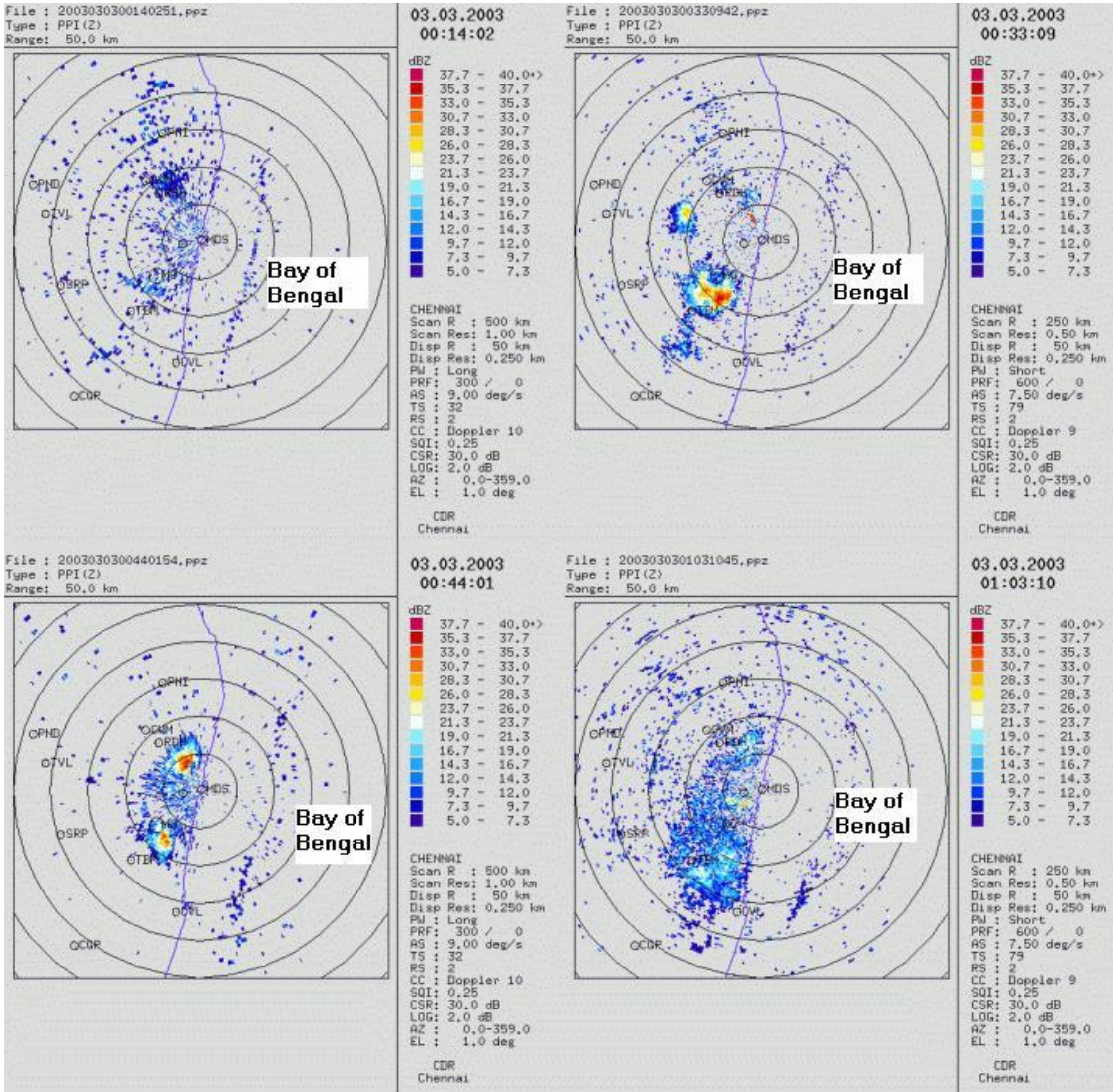
Winter precipitation over Chennai



- Radar echoes revealed that ***during March, the driest month,*** **Chennai experienced rain in the northern and southern suburbs.**

- **Why does Chennai have water scarcity *<u>when it receives good rain even during winter ??</u>*.**

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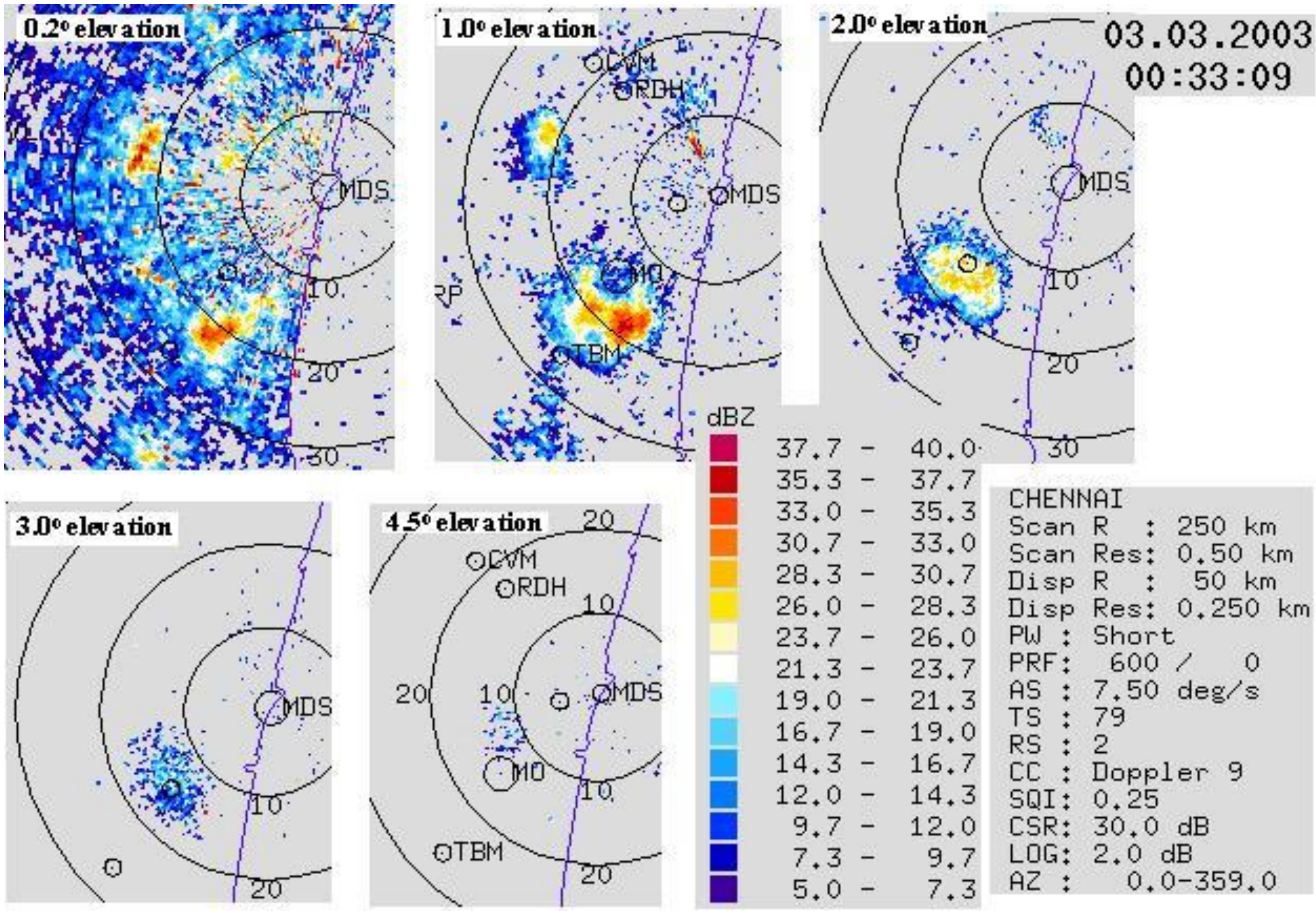
Was it raining around Chennai during December 2002 - March 2003?



No report of rainfall from Met. office/ public / media over these areas.

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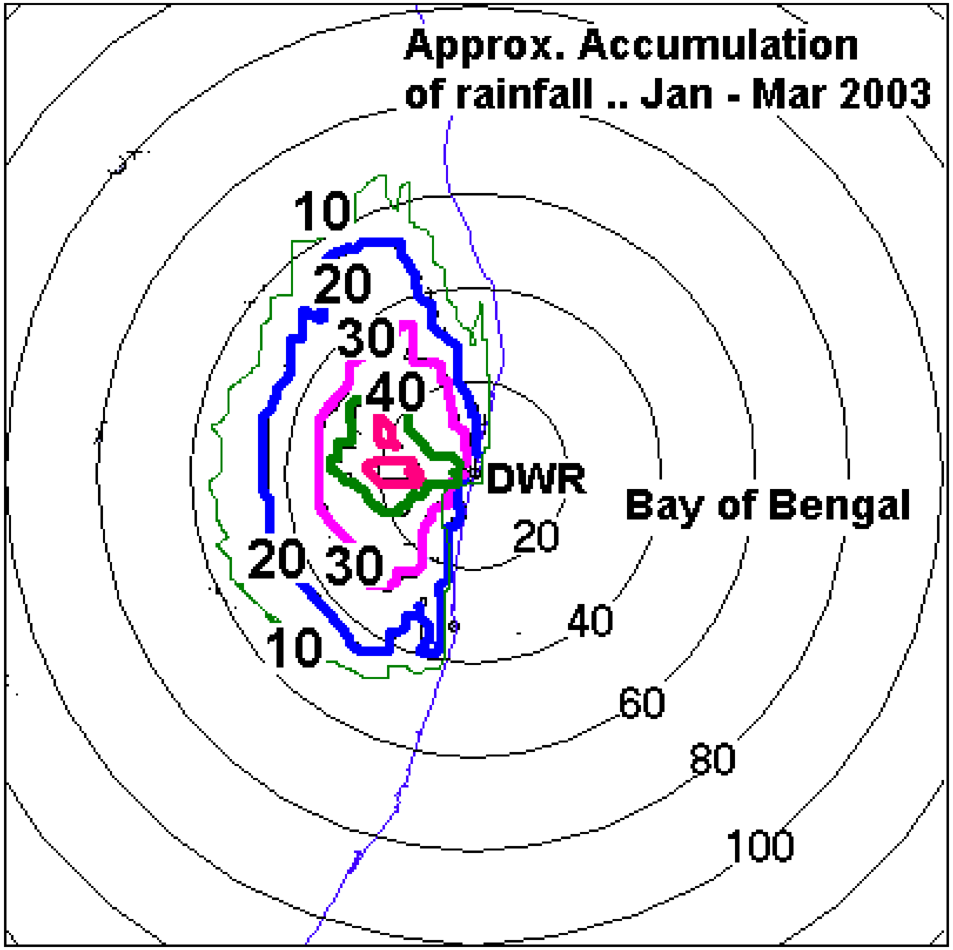

- Radar measurements indicate as if 20-60 cm rainfall received over an area of about 600-1600 km^2 around Chennai during Jan – Mar2003.

- Had there been such an accumulated rainfall, no water scarcity could have been experienced in Chennai during 2003 !!!.

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Results of analysis on enhanced Z during Dec 2002 – March 2003

- No enhancement in reflectivity was observed over Bay of Bengal.
- The enhanced Z was observed during 0530 – 0700 and during 1700 – 1900 IST.
- The Z maximum was concentrated mostly over North and South Chennai.
- Spurious estimation from clutters is ruled out as clutter filter of 1 ms^{-1} notch-width & proper Signal quality index were activated in those scans.
- Reflectivity from pollutants (SPM) hardly worked out to -0.9 to 4dBZ only and nowhere near the 25-30dBZ observed.

Probable cause for enhanced Z, December – March.

<u>The likely origin of enhanced Z was from birds</u> **(and possibly from insects).**

- **the time of enhanced Z coincides with the activity of birds.**
- **the activity of 8000 – 10000 birds over the area and period of study <u>have been confirmed by Chennai based ornithologists and naturalists</u>.**
- **Equivalent reflectivity factor (Z_e) based on volume reflectivity(η) [which depends on radar cross sections of scatterers / volume] confirms 8000-10000 migratory birds *(Jacanas, Egrets, Cormorants, Herons, black winged Stilts, Rosy Starlings)* of various cross sections ← as supported by naturalists and bird watchers.**
- **Computation of C_n^2 (within one hour after Sunrise and Sunset) shows that these values increase (from that computed earlier using Z as well as from RS/RW) by more than two orders of magnitude due to enhanced reflectivity caused by the migratory birds and insects.**

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Probable cause for enhanced Z, December – March ..contd

- **In the morning (evening), the activities of birds <u>commence</u> during Astronomical twilight (Civil twilight), the <u>peak activity</u> during Civil twilight (beyond Civil twilight but well within Nautical twilight) and cease about 1 - 1½ hours after Sunrise.**
- **<u>Knowledge of the source and time of clear air reflectivity may help the forecaster to improve his nowcasting capabilities</u>.**
- **Mere watching radar echoes is NOT sufficient. One should understand the source of echoes.**
- **<u>DWR is NOT the panacea of the meteorologist's forecasting problems</u>.**
- **One should know the climatology of the place as well and continuously monitor the products (as is the case with satellite imageries as well) to interpret / understand the intricacies of data and the concept of the products *(Rinehart, 1999)*.**

[*Suresh et al, 2005, Mausam, p 447-464*]

Summary

- Radar Hydrology application supplements R/G measurements.
- Physical initialization of high resolution rain rate improves the short range predictability.
- DWR is an efficient observation tool for nowcasting but NOT a panacea of Meteorologist's problem of weather forecasting.
- Interpretation of DWR products requires experience and vast literature survey.

Murmuration of 4000-5000 Rosy starlings at 0030Z/21.3.2019 over Pulicat lake (Chennai-SHAR) ➔ ➔ ➔

(The Hindu, Chennai 28.3.2019).

Thank you

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