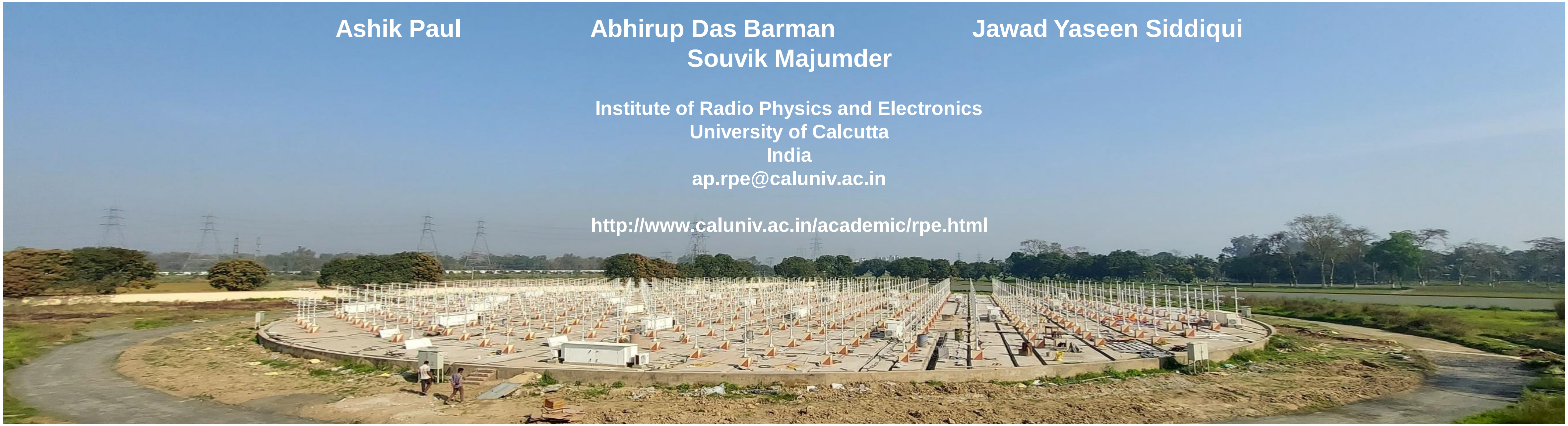
# University of Calcutta ST Radar Project

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*CU ST Radar User Awareness Program, May 6, 2022*

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# *League of Extraordinary Scientists*

➢Prof. S. K. Mitra was one of the first in the world to suggest use of HF atmospheric radars with his observations in 1935

Professor S.K. Mitra and Dr. A.P. Mitra
URSI General Assembly, Sydney, 1952

- The *first experimental evidence of E layer predicted* by Heaviside and Kennely was obtained by Mitra and Rakshit in 1930.

- His seminal book 'The Upper Atmosphere' has been considered a Bible for researchers in the field.

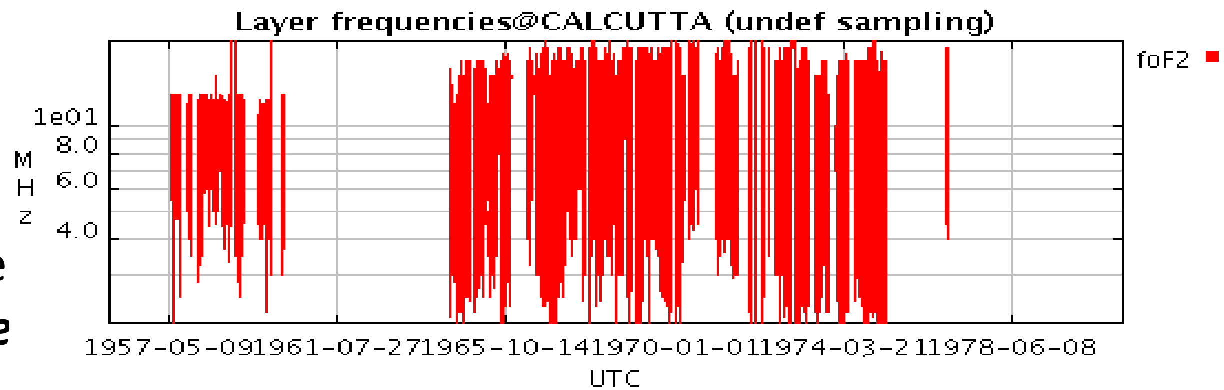
- This Department was one of the First in India to start Post-Graduate teaching in Electronics

- Ionospheric studies conducted from University of Calcutta since early 1930s spearheaded by Late Professor Sisir Kumar Mitra, have made seminal contribution in advancement of the subject (*Mitra et al., Nature*, 1933; *Mitra and Syam, Nature*, 1935; *Mitra, Nature,* 1936, 1938; *Mitra et al., Ind. J. Phys.*, 1938; *Mitra and Kundu*, Nature, 1954).

- The Ionosphere Field Station was established in 1953 at Haringhata, about 50km north-east of Calcutta at a place of relatively low radio frequency interference.

- Professor Mitra assembled one of the **First manual Ionospheric Sounding System** in Asia in *1954* and established it at the *Ionospheric Field Station in 1956* thereby putting University of Calcutta in an elite global chain of Ionospheric Sounders.

- **NBS-C2 Ionosonde data** for the period 1957-1976 from *Ionosphere Field Station* at Haringhata available at the **Space Physics Interactive Data Resources (SPIDR)** website under the ***National Geophysical Data Cente located at Boulder, Colorado, USA***



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# UNIVERSITY OF CALCUTTA
# VHF ACTIVE PHASED ARRAY RADAR

- The advent of **Stratosphere-Troposphere (ST) Radars** in the last few decades has added a new dimension to scientific research and applications in atmospheric sciences.

- University of Calcutta is implementing a 53 MHz fully active phased array radar at Ionosphere Field Station, Haringhata of University of Calcutta

- The radar site at Haringhata is located ~50 km north-east of Kolkata, a major city in the eastern part of India, on the eastern bank of Hooghly river.

- Notably, it is right on the Tropic of Cancer and just beneath the Equatorial Ionization Anomaly (EIA).

- The region around Kolkata is unique in its tropical climatology with yearly total rainfall of ~1600 mm and experience 'very high damage risk' owing to Kalbaisakhi (Nor'wester) and tropical cyclones.

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- This region is also known for deep convection, thunderstorm and lightning activity. While being part of the Indo-Gangetic Plain (IGP), the phenomenology of this part of IGP is quite different from the rest owing to the atmospheric processes governed by Bay-of-Bengal.

- Moreover, the region is characterized as 'wetland' and has been recognized as a 'wetland of international importance' under 'Ramsar Convention'.

- It also hosts the largest sewage fed aquaculture in the world and serves as a robust carbon sink. All these make Haringhata an important location to study atmospheric dynamics and coupling processes up to the ionosphere over a tropical location.

- **All these make Haringhata an important location to study atmospheric dynamics and coupling processes up to the ionosphere over a tropical location.**

✓This radar is indigenously developed, state-of-the-art 53 MHz VHF fully-active phased-array Radar and is being established with support from ***Science and Engineering Research Board***, **DST**, Government of India under its scheme – **Intensification of Research in High Priority Area (IRHPA).**

✓It is conceived as a National Facility, open to all academicians and researchers across the country, and those in the eastern and northeast India, in particular.

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✓The ST Radar project was initiated and strongly defended by renowned scientist **Professor Ashish Kumar DasGupta** on behalf of **University of Calcutta**

His student and renowned researcher, Prof. Animesh Maitra supervised this project during 2011-2017

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## Project Implementation Committee (PIC)

| | |
|---|---|
| • Prof. G.S. Bhat, IISc | Chair |
| • Er. R. Ranga Rao, ISTRAC (Retd.) | Member |
| • Dr. A.K. Patra, NARL | Member |
| • Dr. K. Rajeev, SPL | Member |
| • Prof. B. Gupta, JU | Member |
| • Prof. K. Mohankumar, CUSAT | Member |
| • Dr. V.K. Anandan, ISTRAC | Member |
| • Mr. S.B. Thampi, IMD (Retd.) | Member |
| • Dr. Prahlad Ram, SERB | MS |
| • Prof. Shiv Mohan Singh, SERB | Program Advisor |
| • Principal Investigator | Member |

## Technical Committee (TC)

| | |
|---|---|
| • Er. R. Ranga Rao, ISTRAC (Retd.) | Chair |
| • Prof. C.K. Anandan, CUSAT | Member |
| • Prof. K.P. Ray, DIAT | Member |
| • Dr. V.K. Anandan, ISTRAC | Member |
| • Er. M. Durga Rao, NARL | Member |
| • Dr. Prahlad Ram, SERB | MS |
| • Prof. Shiv Mohan Singh, SERB | Program Advisor |
| • Principal Investigator | Member |

## Project Management Group (PMG)

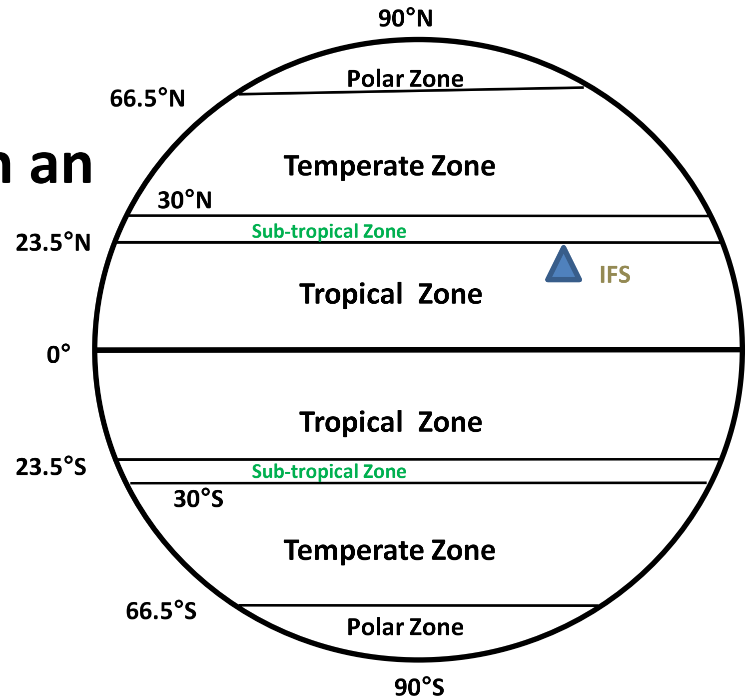
| | |
|---|---|
| • Vice Chancellor, CU | Chair |
| • Pro-Vice Chancellor (A), CU | Member |
| • Pro-Vice Chancellor (BA&F), CU | Member |
| • Registrar, CU | Member |
| • Dean, Faculty of Engg. & Tech., CU | Member |
| • Head, Inst. of Radio Phys. & Elec. | Member |
| • Head, Dept. of Atmos. Sc., CU | Member |
| • Development & Planning Officer, CU | Member |
| • Engineer, CU | Member |
| • Prof. Arup Raychaudhuri, SNBNCBS (Retd.) | External Expert |
| • Prof. Dibyendu Nandi, IISER Kolkata | External Expert |
| • Principal Investigator | Member |
| • Co-Principal Investigator(s) | |
| • Co-Investigator(s) | |

# Uniqueness of the Radar & Radar Site

- **Uniqueness of the Radar Site:** The location of this radar is situated at the verge of the **transition region between the tropics and subtropics**, and near the northern crest of the Equatorial Ionization Anomaly (EIA).

- **Uniqueness of the Radar:** The ST Radar at Ionosphere Field Station **(22.93°N, 88.50°E geographic; magnetic dip: 34°N)**, is the only radar at this **frequency (53MHz)** in the entire **Eastern and North-Eastern India** as well as **South-East Asian longitude sector**

**First 50MHz active phased-array Radar in an Indian University and the 3rd such Radar In India (the others being at SHAR and NARL)**



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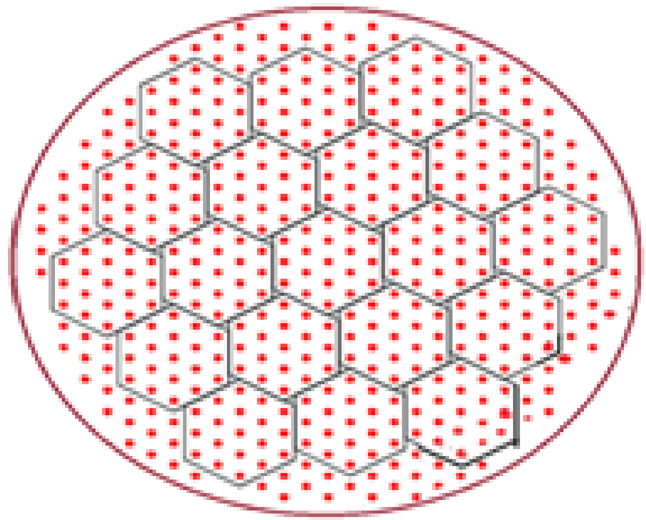
## Experimental Capabilities

- Fully Active Phased Array Radar, operating at 53 MHz with a bandwidth of 3MHz.
- Planar antenna array with 475 three-element Yagi antennas
- Beam Steering up to an off-zenith angle of 30°
- Organized into 25 sub-array groups each with 19 Yagi antenna elements and a shelter for housing TRMs



ST RADAR ARRAY
With Near-Circular Shape

| Performance Parameters | |
|---|---|
| **Height coverage** | 0.5-20km for 90% of time |
| **Height resolution** | i) 50m up to 3km<br>ii) 150m from 3-20km |
| **Horizontal wind velocity** | 1-70m/s |
| **Vertical wind velocity** | 0.1-30m/s |
| **Time resolution** | 5-15min for full profile |
| **Average power aperture product** | $3\times10^8$ $Wm^2$ |

**Digital receiver has 25 channels – first in India – Huge challenge for data throughput and storage**

**Table 1**
*Specifications of the 53 MHz Radar Under Construction at Haringhata*

| Parameter | Value |
|---|---|
| Location | Haringhata (Long. 88.5°E; Lat. 22.93°N)Dip angle: 36.2°N |
| Frequency | 53 MHz |
| Antenna | Near Circular shaped array of 475 Yagi antennas |
| Antenna aperture | ~7,000 $m^2$ |
| Antenna gain | 34.1 dB |
| Antenna beam width (3 dB) | 3.6° |
| Total peak transmitter power | 950 kW |
| Duty ratio | 5% |
| Receiver | 25 super-heterodyne receivers |
| Receiver bandwidth | 8 MHz |
| Receiver dynamic range | 80 dB |

# ST Radar Pilot Array (19-Element)

Developed as a proof-of-concept and familiarization of the radar operation for the Calcutta University team

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**ST Radar Pilot Array, Ionosphere Field Station, Haringhata**
**University of Calcutta (22.93°N, 88.50°E Geo.)**

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# CU ST Radar

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# Radar Antenna Grid area

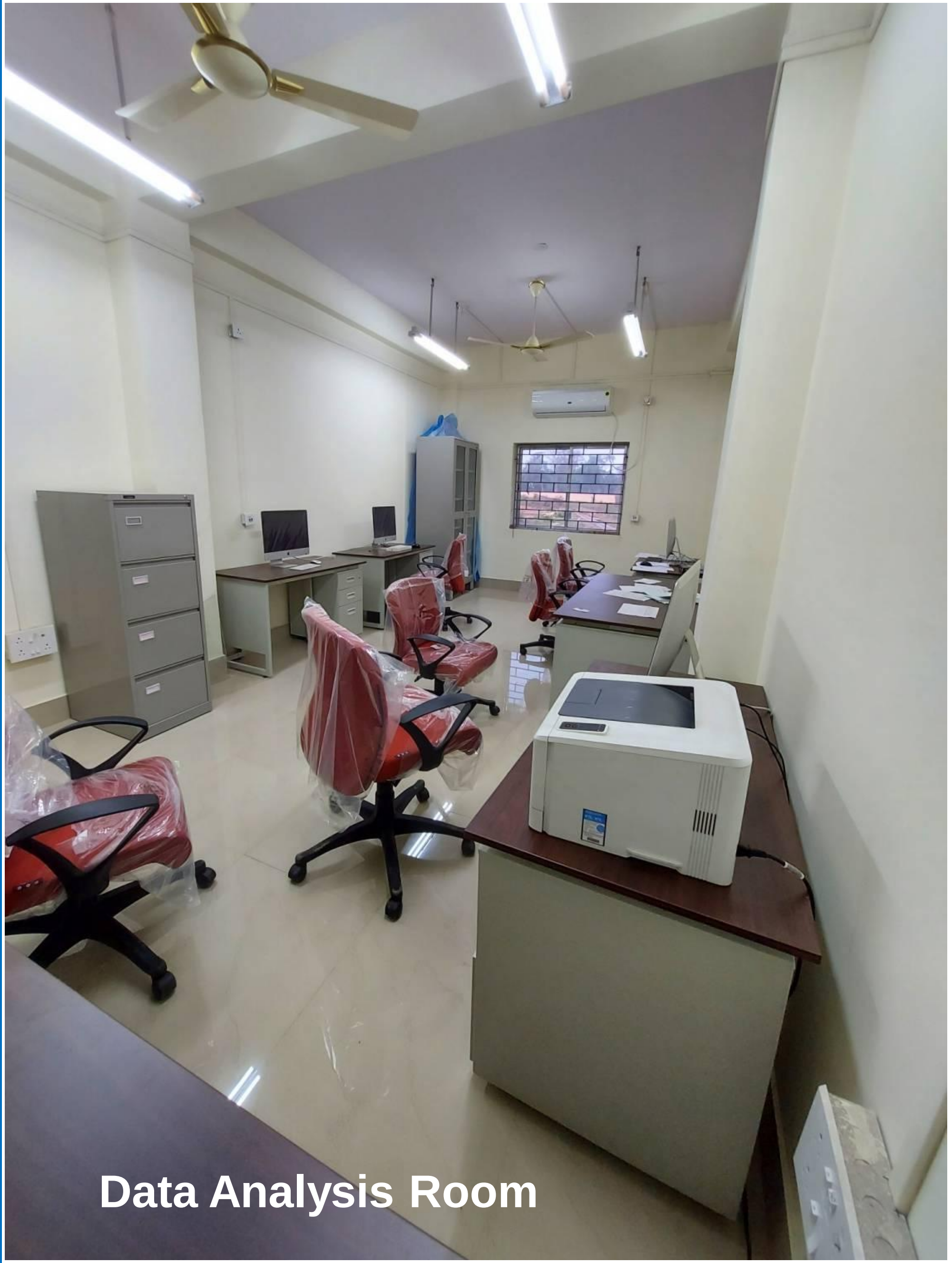
# CU ST Radar

CU and M/s AMPL Team

Transmitter Receiver Modules

Radar Control Room

# CU ST Radar



Data Analysis Room

Test and Measurement Laboratory

Meeting Room

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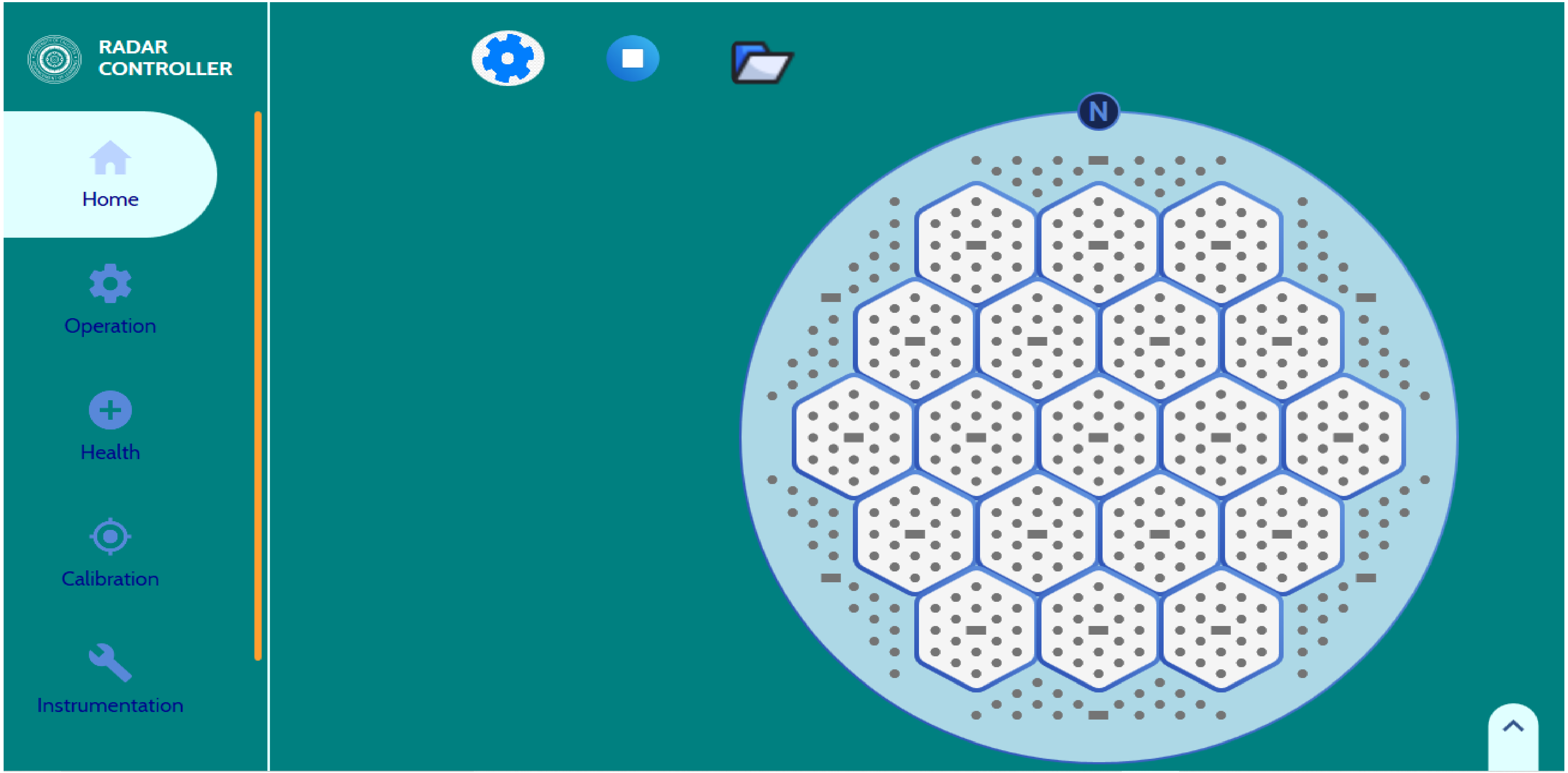
# Radar Control software



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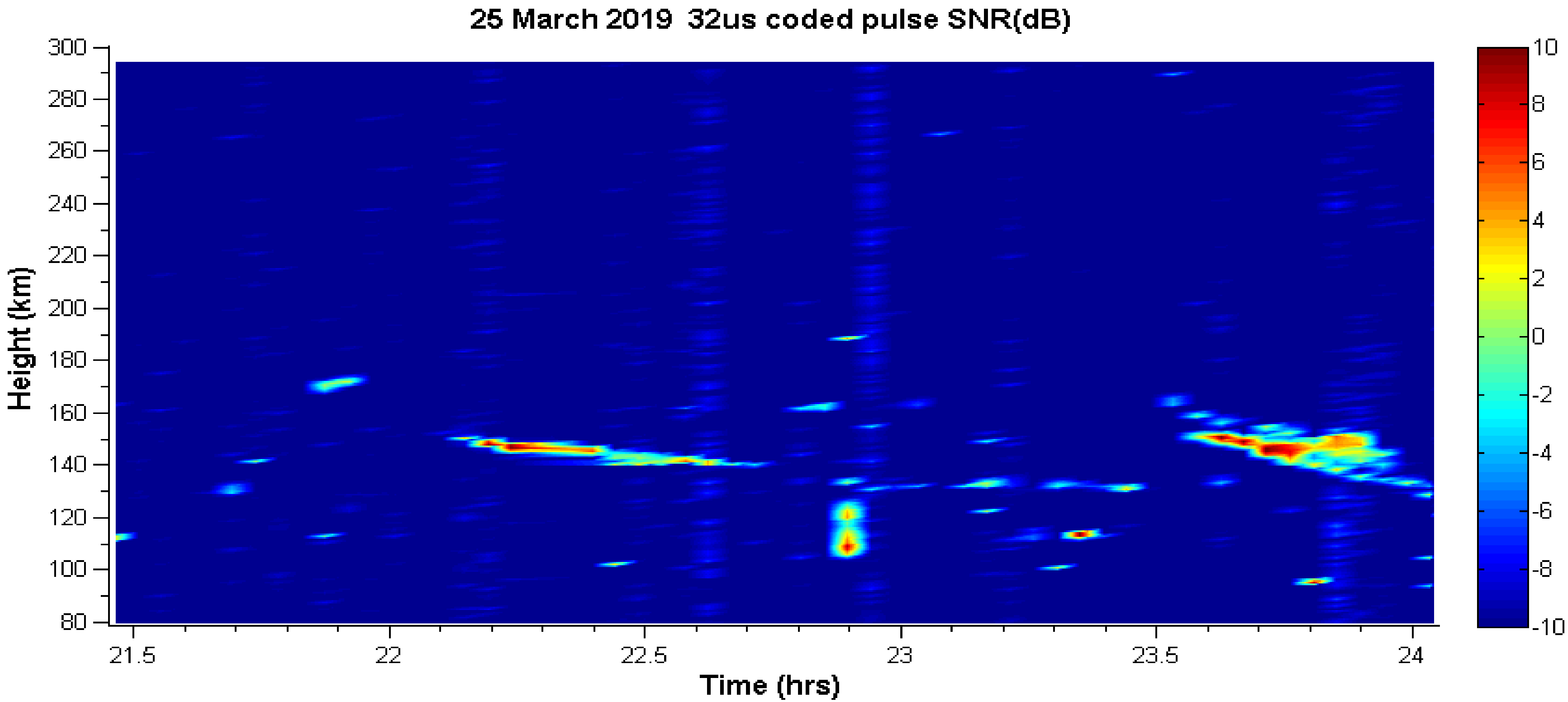
# 25.03.2019 , 21:00 – 24:00 IST



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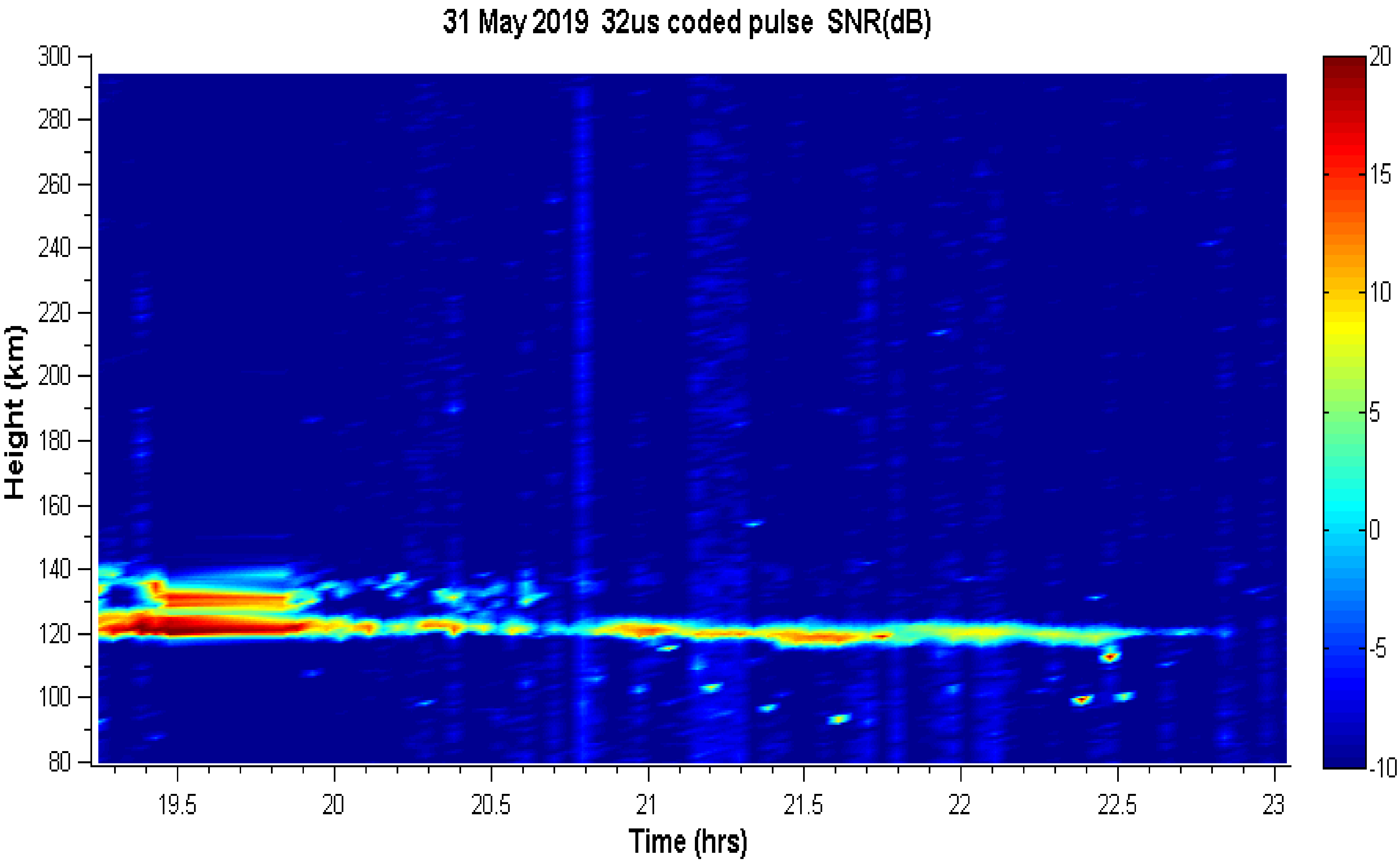
## 31.05.2019 , 19:00 – 23:00 IST



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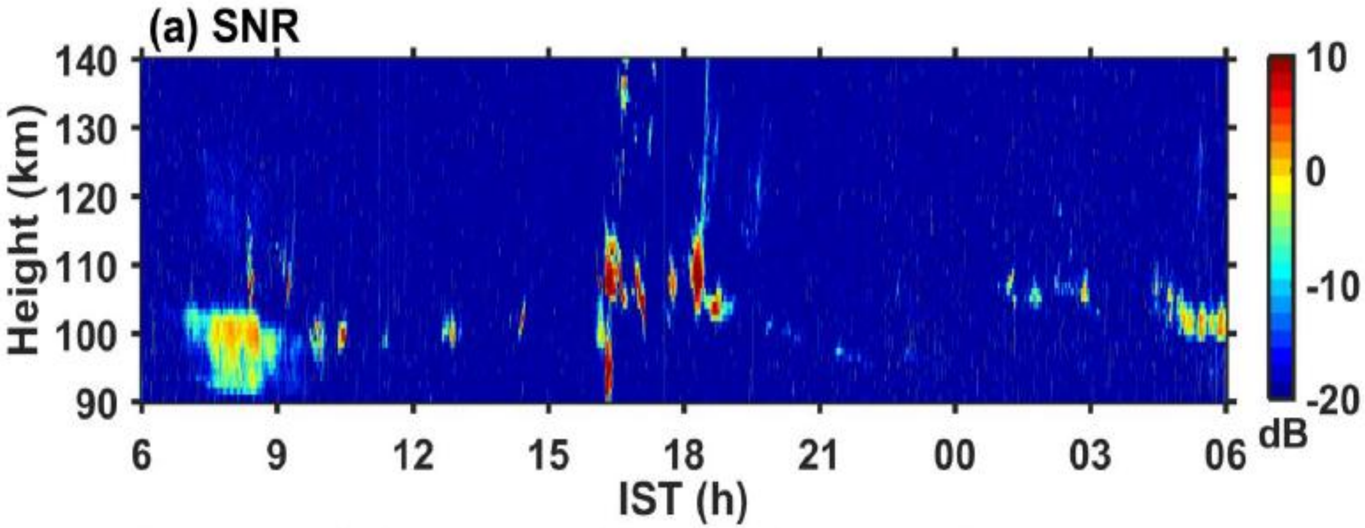
## Campaign mode observations in collaboration with NARL




- Echoes mostly confined to altitudes of 90–120 km - SNR varying between -13 and 15 dB.
- Daytime echoes confined to 100 km.
- Echoes appeared in patches - one can also notice descending pattern of the echoing region.

- Doppler spectra confined to ±50 Hz with mean Doppler limited to ±15 Hz.
- For the radar frequency of 53 MHz, the Bragg scale responsible for the echoes is 2.83 m.
- This implies that the Doppler velocities are within ±42 m s-1 and spectral spread is ±140m s-1.
- Haringhata is located at a magnetic dip of 36.2°N and hence the Doppler spectra are quite similar to those of off-equatorial low latitudes and mid-latitudes.

*Paul et al.*, *Radio Sci.*, 2021

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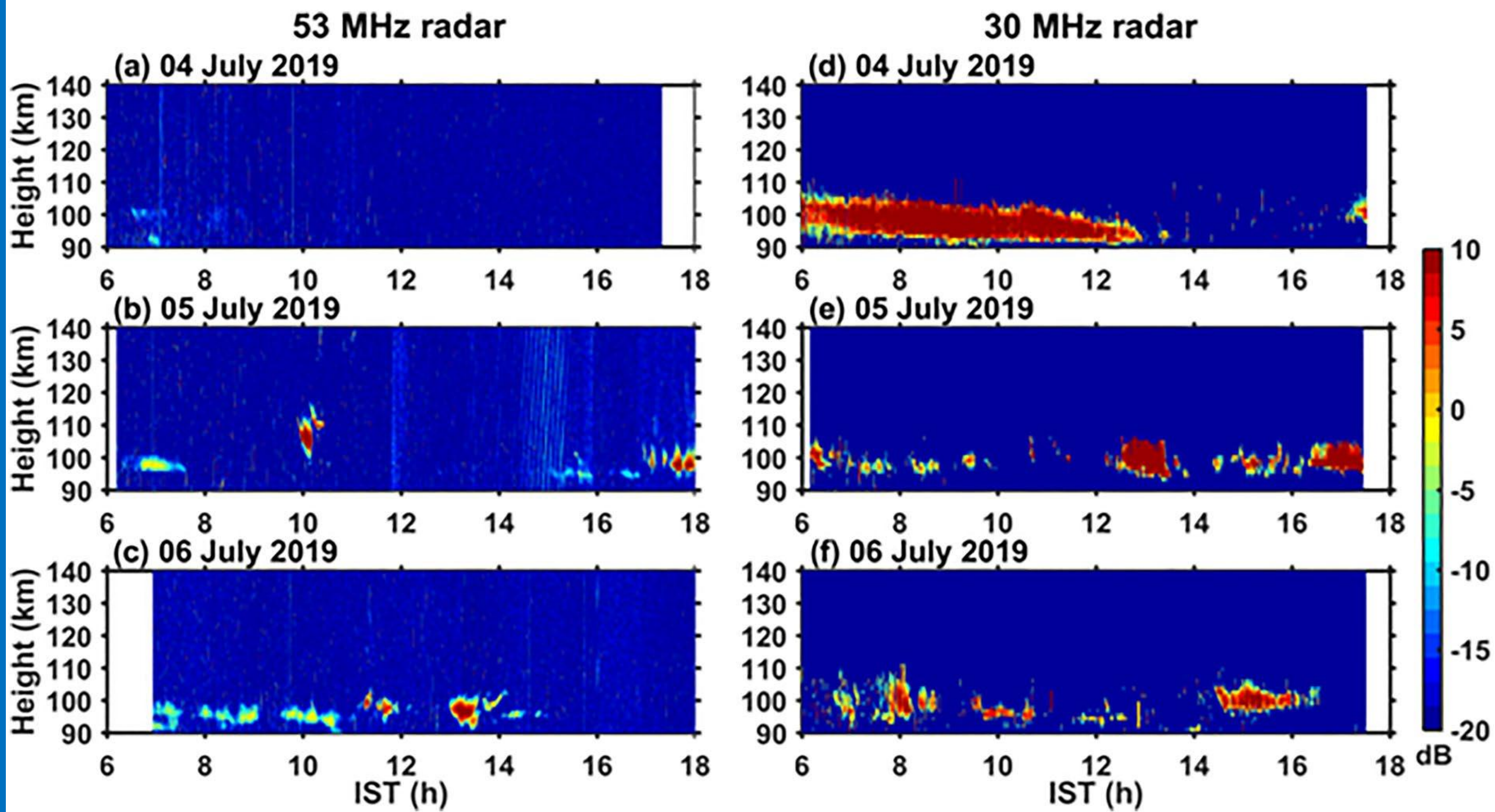


**Figure 5.** (a–c) Height-time variations of signal-to-noise ratio of the E region field-aligned irregularities observed during July 4–6, 2019 by the 53 MHz radar at Haringhata (d–f) Same as (a–c), but for observations made by the 30 MHz Gadanki Ionospheric Radar Interferometer at Gadanki.

- Although echoes occur in similar height region at both locations, considerable difference can be observed in the FAI observations.
- On 4 July, strong echoes were observed in the form of a descending echoing layer at Gadanki, but echoes were weak or nearly absent at Haringhata.
- On 5 and 6 July, the echoing regions were patchy in nature at both locations, but there is no correlation in terms of their height and time of occurrence.

*Paul et al.*, *Radio Sci.*, 2021

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Radio Science

RESEARCH ARTICLE

10.1029/2021RS007289

**Key Points:**

- First radar experiment conducted at 53 MHz from Haringhata located in the EIA crest region in the Indian longitudes
- First observations of ionospheric E-region irregularities from Haringhata
- Quasi-periodic nature of radar echoes noted from Haringhata

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# First Results on *E* Region Irregularities From a 53 MHz Radar Experiment From Haringhata, India

**Ashik Paul[1], P. Pavan Chaitanya[2], A. K. Patra[2], P. Nandakumar[1], and Tanmay Das[1]**

[1]Institute of Radio Physics and Electronics, University of Calcutta, Kolkata, India, [2]National Atmospheric Research Laboratory, Gadanki, India

**Abstract** We present the first results on *E* region field-aligned irregularities (FAIs) observed using a 53 MHz radar experiment conducted from Ionosphere Field Station, Haringhata (geographic latitude 22.93°N; geographic longitude 88.5°E; magnetic dip angle 35.2°N) of University of Calcutta, a location just on the Tropic of Cancer and below the Equatorial Ionization Anomaly. Results show that the *E* region FAI echoes, which occur with signal intensity as high as 35 dB above noise, are mostly confined to altitudes of 90–120 km with daytime FAI being confined to 100 km. The FAI echoes are often found to occur in the form of descending echoing region that includes continuous, quasi periodic and discrete

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# Validation of CU ST Radar Pilot array wind measurements through balloon-borne GPS-radiosonde launches conducted by Space Physics Laboratory(SPL), VSSC, ISRO.

| Radar Specifications during operation in July and August 2019 | |
|---|---|
| Number of Range bins | 70 (upto 512) |
| Number of FFT points | 256 (upto 4096) |
| Numberof Coherent Integrations | 128 (1 – 1024 selectable) |
| Number of In-Coherent Integrations | 4 (1 – 100 selectable) |
| Inter Pulse Period | 250 µs (125 – 1000µs) |
| Pulse Width | 8µs (0.5 - 128µs) |
| Number of beams | 5 (max 100) |
| Duty Ratio | 3.2% (max 5%) |

Expected balloon trajectory for balloon burst at 25km on July 8, 2019 at 09:24 IST

Team members of **CU-STR** and **SPL,VSCC, ISRO** during Balloon borne GPS-radiosonde launch campaign at IFS, Haringhta during July &August 2019

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AGU ADVANCING EARTH AND SPACE SCIENCE

Radio Science

RESEARCH ARTICLE
10.1029/2020RS007246

**Key Points:**

- Validation of zonal and meridional wind measurements using a Stratosphere-Troposphere Radar with radiosondes during July-August 2019
- Good correspondence of about 90% is noted between the two measurements
- Validation has been classified into precipitation and non-precipitation cases up to 8 km height

**Supporting Information:**

Supporting Information may be found in the online version of this article.

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# Validation of Wind Measurements From a 53 MHz ST Radar Pilot Array Located at University of Calcutta With Collocated Radiosonde Launches

**P. Nandakumar[1], D. Jana[1], S. V. Sunilkumar[2], P. R. Satheesh Chandran[2], R. Vishnu[2], T. Das[1], Maria Emmanuel[2], G. Singh[1], S. Majumder[1], J. Y. Siddiqui[1], and A. Paul[1]**

[1]Institute of Radio Physics and Electronics, University of Calcutta, Kolkata, India, [2]Space Physics Laboratory, Vikram Sarabhai Space Centre, Indian Space Research Organization, Thiruvananthapuram, India

**Abstract** A Stratosphere-Troposphere (ST) Radar operating at 53 MHz is being installed at Ionosphere Field Station (22.94°N, 88.51°E, and 34°N geomagnetic latitude) of University of Calcutta in the eastern part of India adjoining northern Bay of Bengal. This radar is unique, being the only one operational at this frequency in the entire eastern and northeastern part of the country and also in the south-east Asian longitude sector. Two components of horizontal winds (zonal and meridional) measured by the Pilot version of this radar have been validated with 90 collocated simultaneous balloon-borne radiosonde observations during July and August 2019. A good correlation of the order of 90%–99% and 75%–95% up to 8 km has been observed between the radar and radiosonde measured zonal winds and meridional winds respectively. This correlation is much stronger between 2 and 6 km altitudes. The correspondence is better for the zonal winds than meridional. However,

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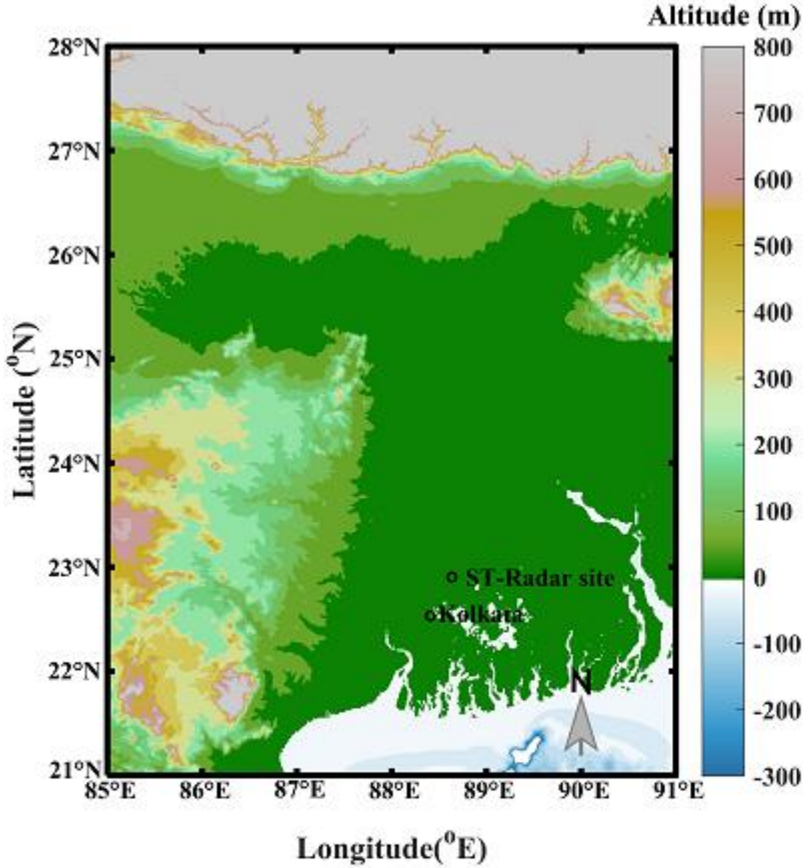
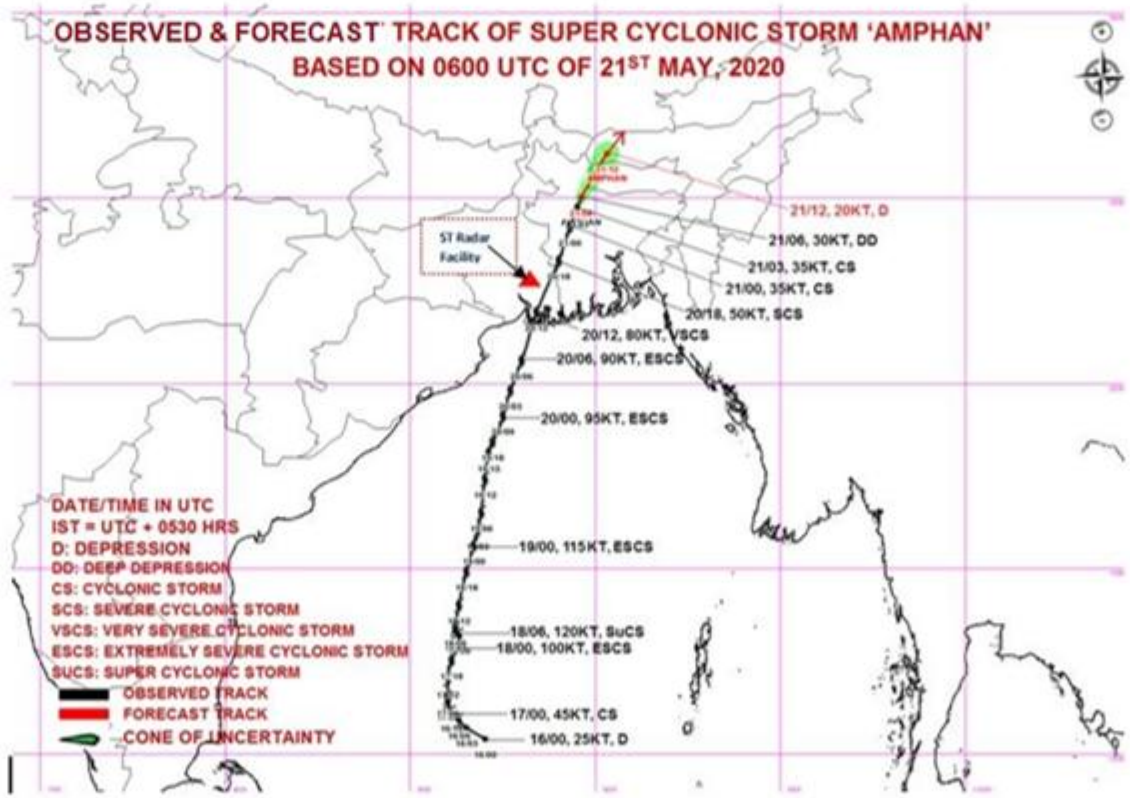
Tropical Cyclone Phailin
8 PM EDT Thu Oct 10 2013
Position 15.8 N 88.8 E
Maximum Winds 155 mph
Gusts 190 mph
Movement WNW at 6 mph
Blue Marble basemap imagery courtesy NASA
Satellite 5:27 AM UTC
1:27 AM EDT

# CU ST Radar




a

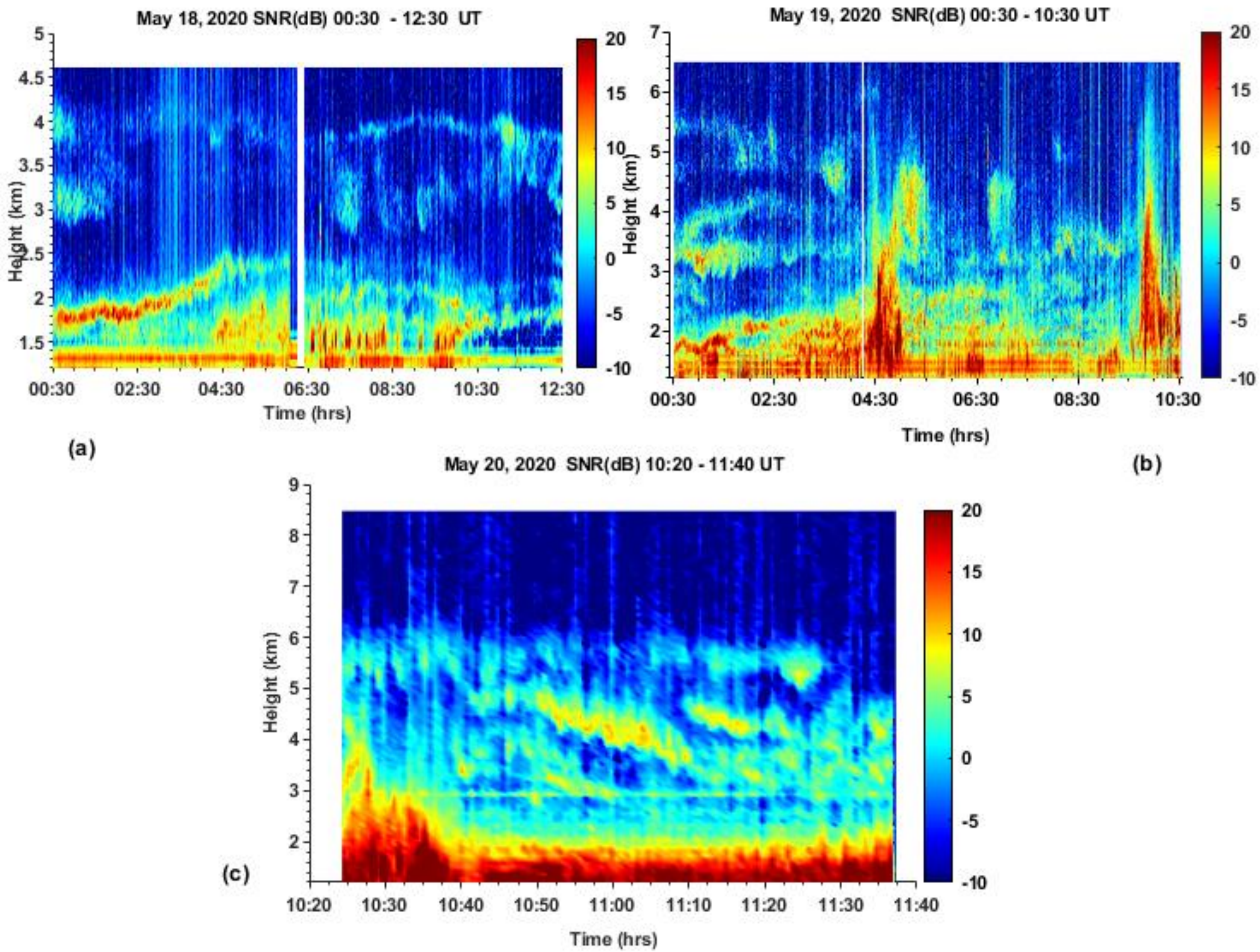



b

Track of cyclone AMPHAN on a map of India. The location of the CU-STR Pilot array at Haringhata and DWR at Kolkata is indicated in the map

## Severe Weather Monitoring

# CU ST Radar




*Nandakumar et al.*, *Radio Sci.* (under revision)

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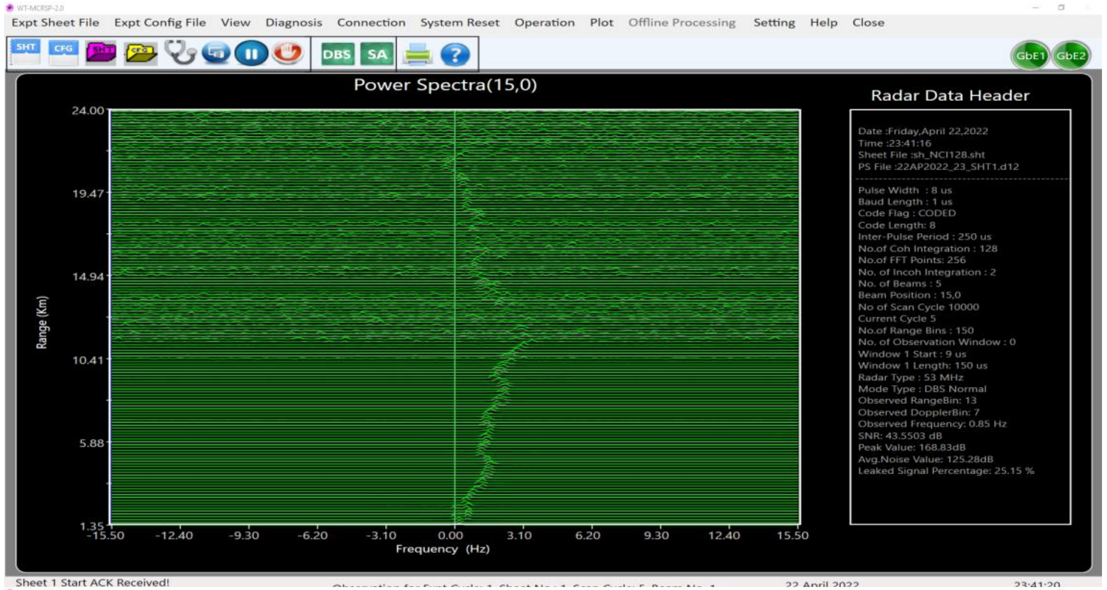
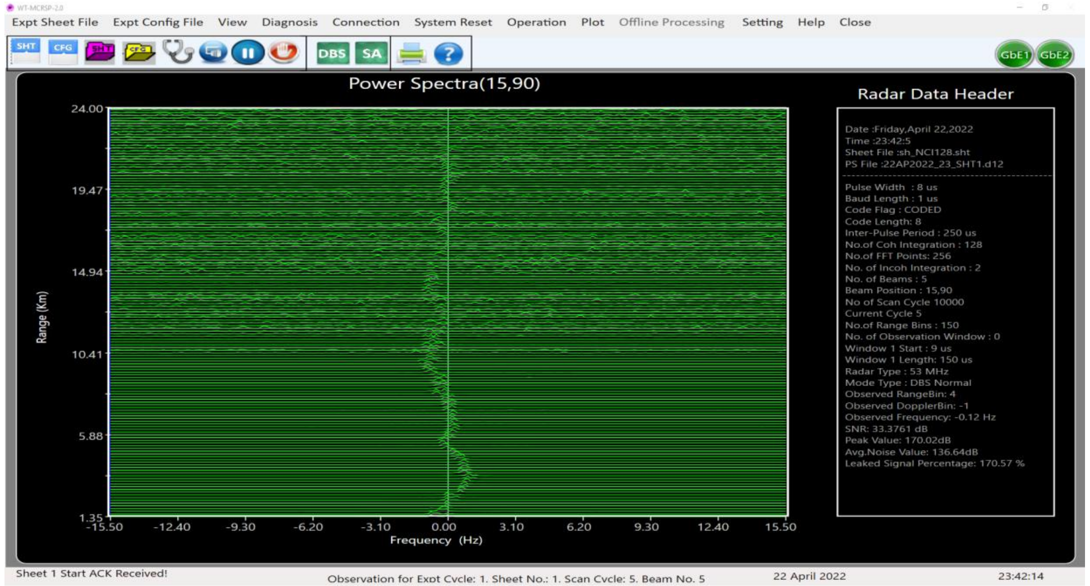
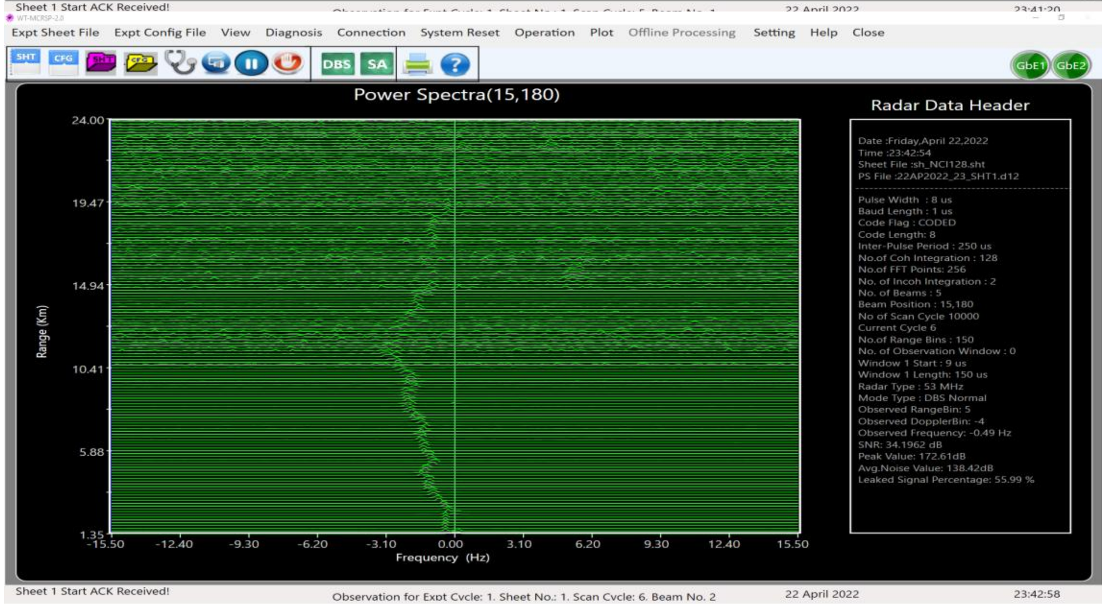
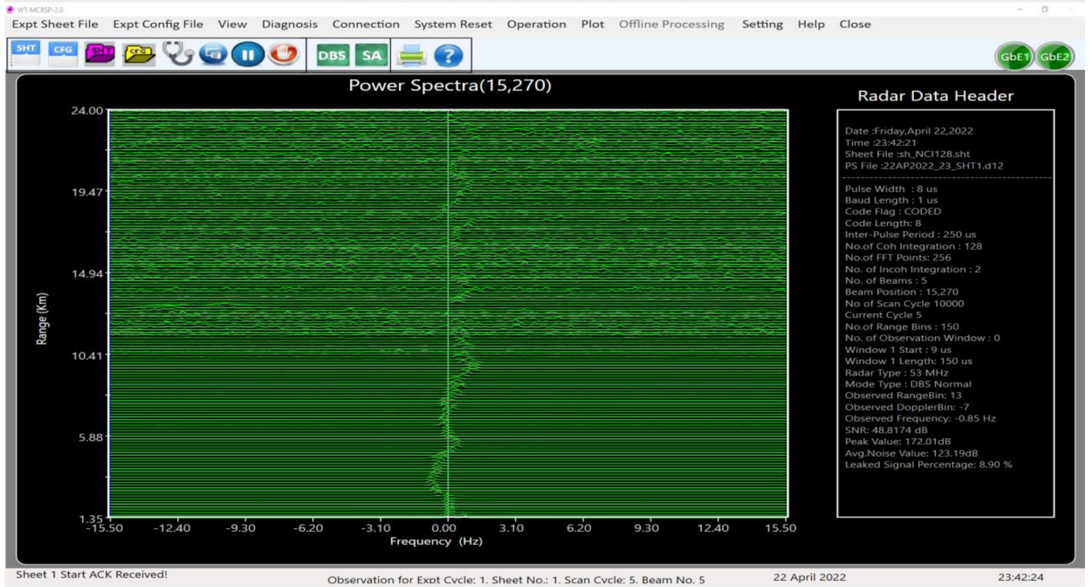
# Status of ST Radar as on 22.4.2022



**Using this ST Radar as a central facility at University of Calcutta, emphasis will be given to the following:**

- Core research activities (scientific and technical) using the radar alone
- Research activities, academic and research collaborations linking other institutions and experimental facilities with broader science goal
- **Develop an ecosystem where faculties and researchers from different allied subjects could converge** and conduct research and training
- Provision will be made for **inviting national and international-level experts as Adjunct Faculties** for conducting research using this radar
- Facilities will be provided for students from other institutions to undertake **summer internships and student projects** using this facility
- Cooperative research at both national and international level, like coordinated observations with **National Atmospheric Research Laboratory (NARL), Cochin University of Science and Technology (CUSAT), Gauhati University** etc. and participation in international programs like VarSITI and the upcoming PreSTo of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP)
- Training students and researchers and capability building

# CU ST Radar

- In recent years, the study on the inter-relations between different phases of water namely, water vapour, cloud liquid water content and rain has been a subject of interest in view of long term variation of Indian summer monsoon. Also, the study on the convective system in relation to the tropical weather and climate system has been in the focus in the present activities.

- The study on the precipitating atmosphere has been made with a number of ground-based measurements carried out at IRPE and also with the data from TRMM satellite. The tropopause structure over the Indian region was identified using the temperature profile obtained with the CHAMP data and tropopause height and temperature were sensed on the basis of cold point tropopause.

- The **high resolution data from ST Radar is expected to provide significant information about the highly dynamic stratosphere-troposphere exchange processes and the main drivers and their relative roles in generation of atmospheric gravity waves**. These waves could affect development of regional weather systems. A detailed study may give some interesting clue to understand the large scale spatio-temporal variability of weather systems, effect of global changes on climate, formation and development of cyclones and depressions over Bay of Bengal, etc.

- The **information available in the troposphere and lower stratosphere can be assimilated in the General Circulation Models (GCM) for the improvement of prediction of tropical weather systems, especially over our country**.

- **Regional scale forecasting can also be improved by using the high quality ST Radar data** up to the lower stratosphere, which will be useful for agriculture and fisheries sector.

- **Wind data obtained from ST Radar can also be utilized to verify the quality of NCEP/ECMWF gridded data and their reliability in the tropical belts**. This will be useful for modifying/improving the input data in atmospheric mode.

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**Scientific Experiments which may be planned using the CU ST Radar:**

- **To study the dynamics of the tropopause and Stratosphere Troposphere Exchange (STE)**
- **To study the convection process in the troposphere**
- **To characterize rain structure based on radar signatures of precipitating layers**
- **To study lower atmospheric turbulence**
- **To study gravity waves and planetary scale waves and their effects on the upper atmosphere**
- **D, E and F region irregularities/sporadic E /150km echoes**
- **Study the Tidal Cycles**
- **Sky temperature map obtained from the observations of ST radar**
- **Vertical Coupling From the Lower Atmosphere to the Ionosphere**
- **Moon Echo**
- **Meteor trail/Head Echo/Meteor Shower Observation**

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Applications of the radar and its data products could be manifold

- Characterizing the near-Earth space environment
- High power solid state device (each TRM transmits 2KW)
- Antenna
- Digital signal processing
- Data Analytics

**Involves departments**
**of**
**ECE, EE, CSE, IT, Physics,**
**Statistics, Applied Mathematics,**
**Environmental Science**

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- Potential stakeholders of the Calcutta University ST Radar Facility will be academic and research institutions and operational agencies as potential users of the data when the radar will be commissioned. These institutes distributed in the eastern, north-eastern as well as other parts of India will participate in ST Radar User workshops and identify possible research areas of their interest towards utilization of data from the radar from the approved themes or their own.

- **A Brainstorming meeting involving the probable users of this major research facility was held during January 18-19, 2019 wherein participants and responses were received from the following institutions:**

1. Dibrugarh University
2. Gauhati University
3. Assam University
4. National Centre for Medium Range Weather Forecast (NCMRWF)
5. Jadavpur University
6. Burdwan University
7. Bose Institute
8. IIT Kharagpur
9. IISER Kolkata
10. ISI Kolkata
11. IIT Indore
12. IIEST Sibpur
13. IITM Pune
14. NARL Gadanki
15. CUSAT, Kochi
16. ARIES Nainital
17. SPL VSSC, Thiruvananthapuram
18. NRSC, Hyderabad
19. IMD
20. Department of Space, Govt. of India
21. Kohima Science College
22. IIIT Kalyani
23. Department of Atmospheric Science, Calcutta University
24. Department of Environmental Science, Calcutta University
25. A.K. Choudhury School of Information Technology, Calcutta University

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# Stratosphere Troposphere Radar at University of Calcutta (CU-STR) Team

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# Virtual Tour of University of Calcutta ST Radar Facility

https://youtu.be/w5Mru-jqRAc

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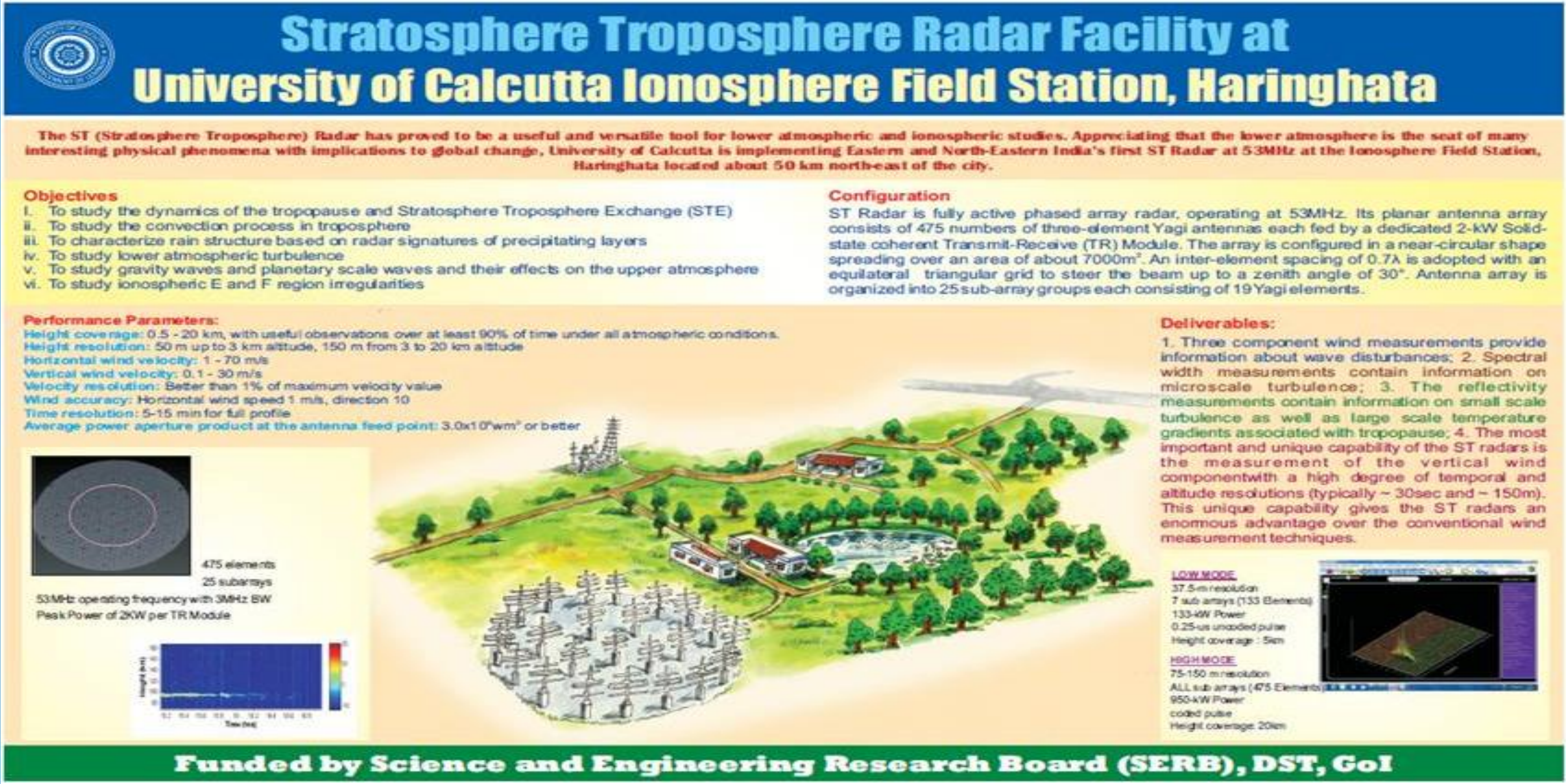
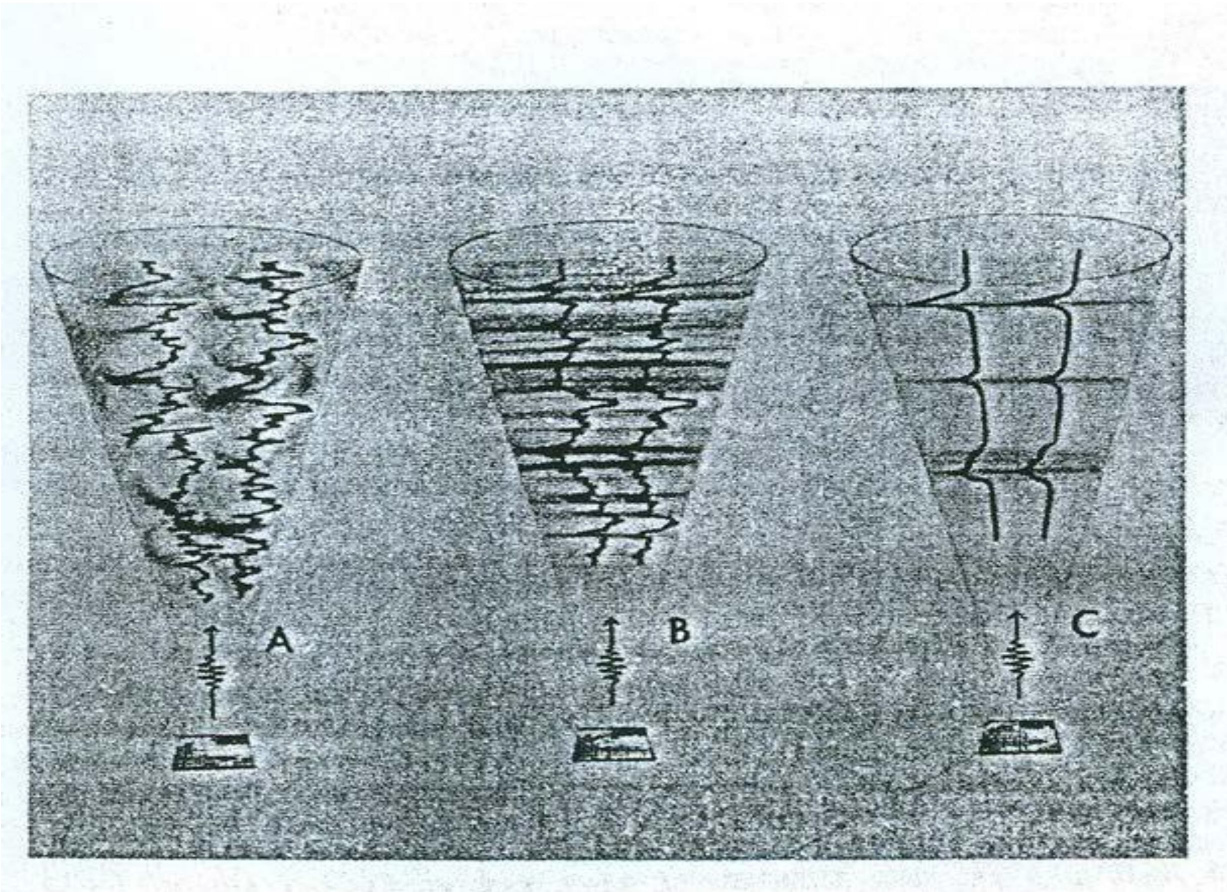



# Thank You

CU ST Radar

CU ST Radar

# A Conceptual view of Atmospheric Structure relevant to Scatter Mechanisms




(A) Bragg Scatter

(B) Fresnel Scatter

(C) Fresnel Reflection

Gage and Balsley, 1981

CU ST Radar

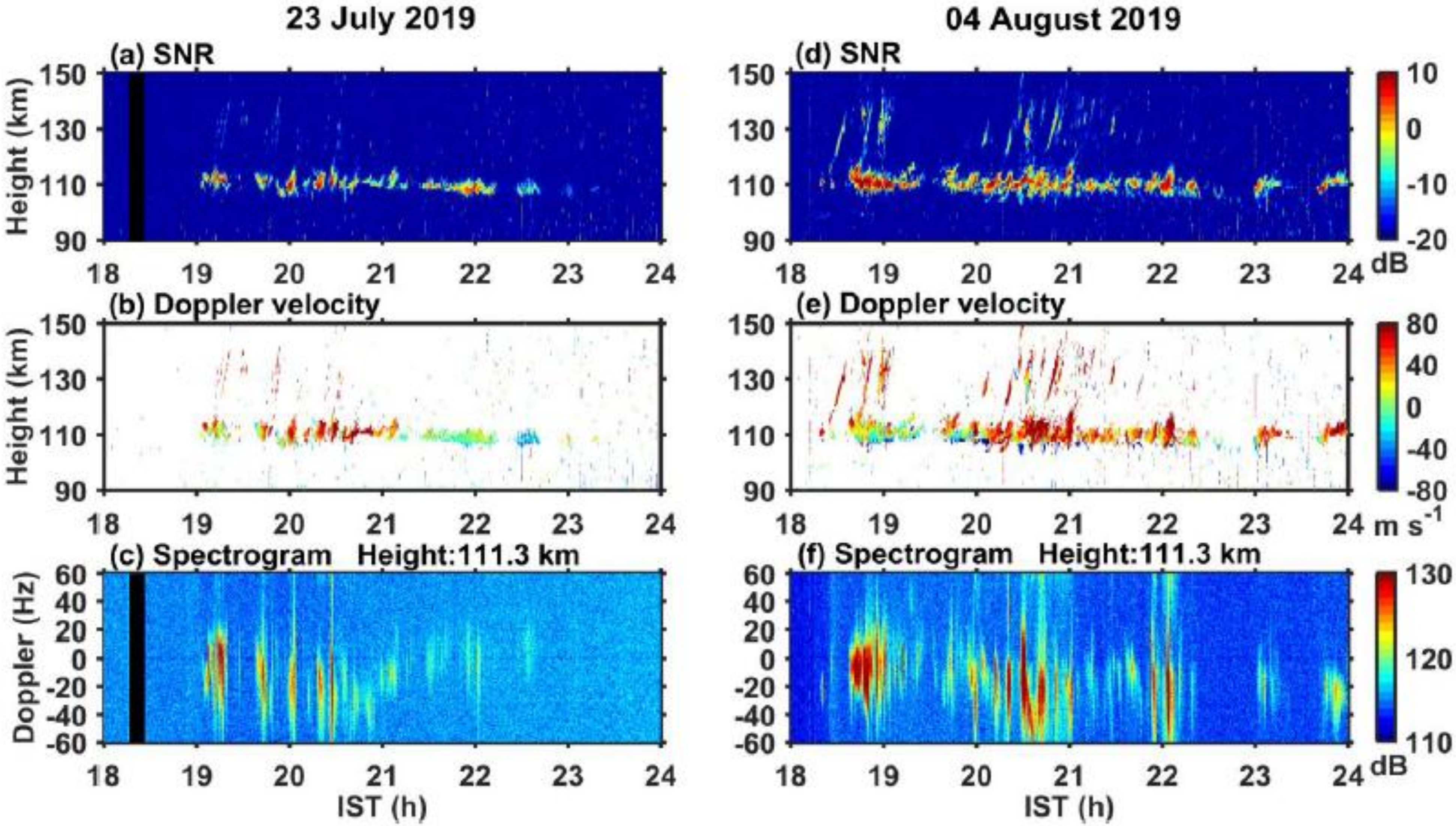



**Figure 4.** Height-time variation of (a) SNR and (b) Doppler velocity, and (c) time variation of Doppler spectrum at 111.3 km in association with QP echoes observed on 23 July 2019.(d-f) Same as figure (a-c), but for QP echoes observed on 4 August 2019.

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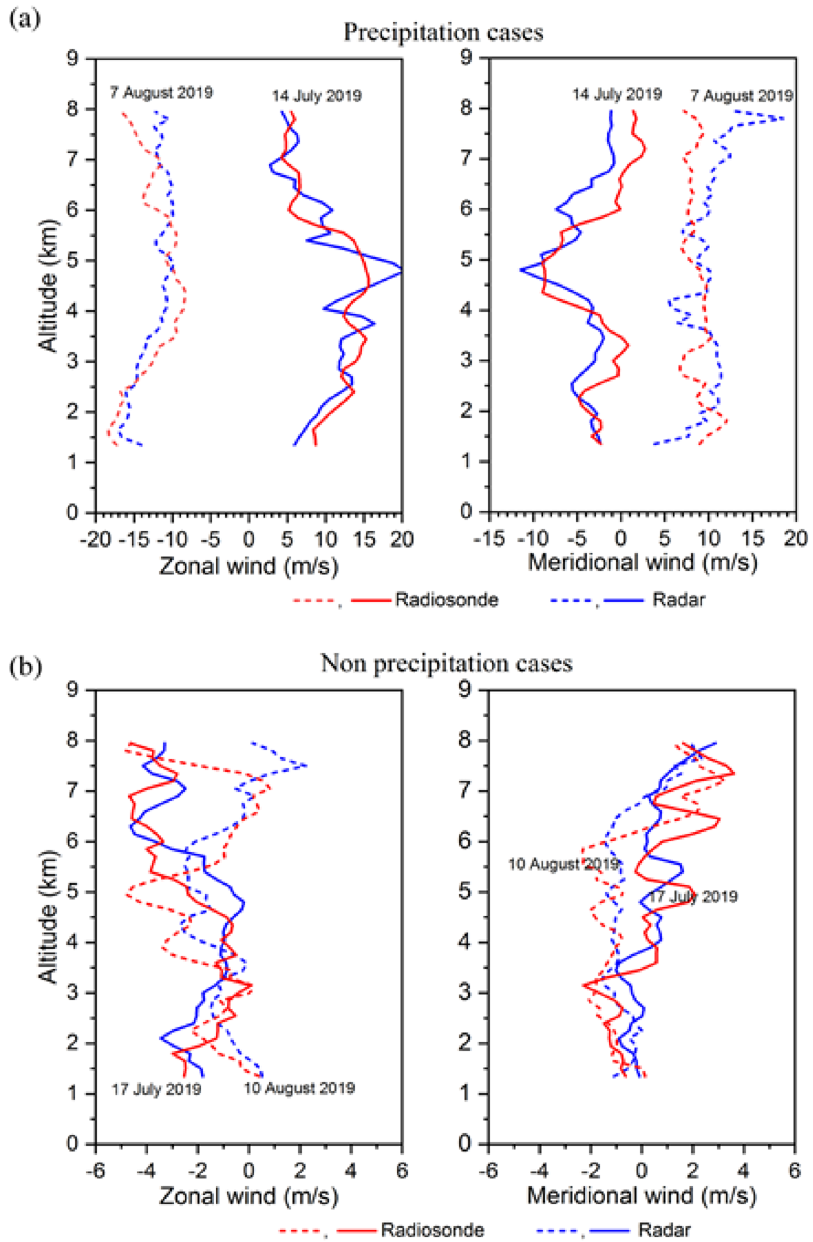
# CU ST Radar




▪**14 July 2019** > the zonal wind is westerly with a maximum value of +20 m/s and meridional wind is northerly with a maximum value of -10 m/s.

▪**07 August 2019** > the zonal wind is easterly having a maximum value of about 20 m/s and the meridional wind is southerly with a maximum value of around +15 m/s.

▪In general, the **radar and radiosonde observations of zonal wind and meridional wind shows good correspondence especially in the lower altitudes** on both the days with minor differences in the upper altitudes especially for meridional winds above 6 km.

•**Moderate correspondence between radar and radiosonde measurements** in the altitude region 1.35-8 km with zonal wind ranging from +3 m/s (westerly) to ~5 m/s (easterly) and meridional winds ranging from ~3 m/s (northerly) to +4 m/s (southerly).

•**Small disagreements (within approximately ±3 m/s) especially in the altitude region 3-6 km** between the CU-STR and radiosonde measurements which may be due to the different spatial and temporal resolutions of the measuring instruments or due to large beam width (18deg) of the CU-STR Pilot Array.

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# CU ST Radar

❑**Precipitation cases** > the mean difference has similar altitude structure for both zonal and meridional wind with positive value (1-4 m/s) below 3 km and negative value (generally 1-2 m/s) in the altitude region 5-7 km.

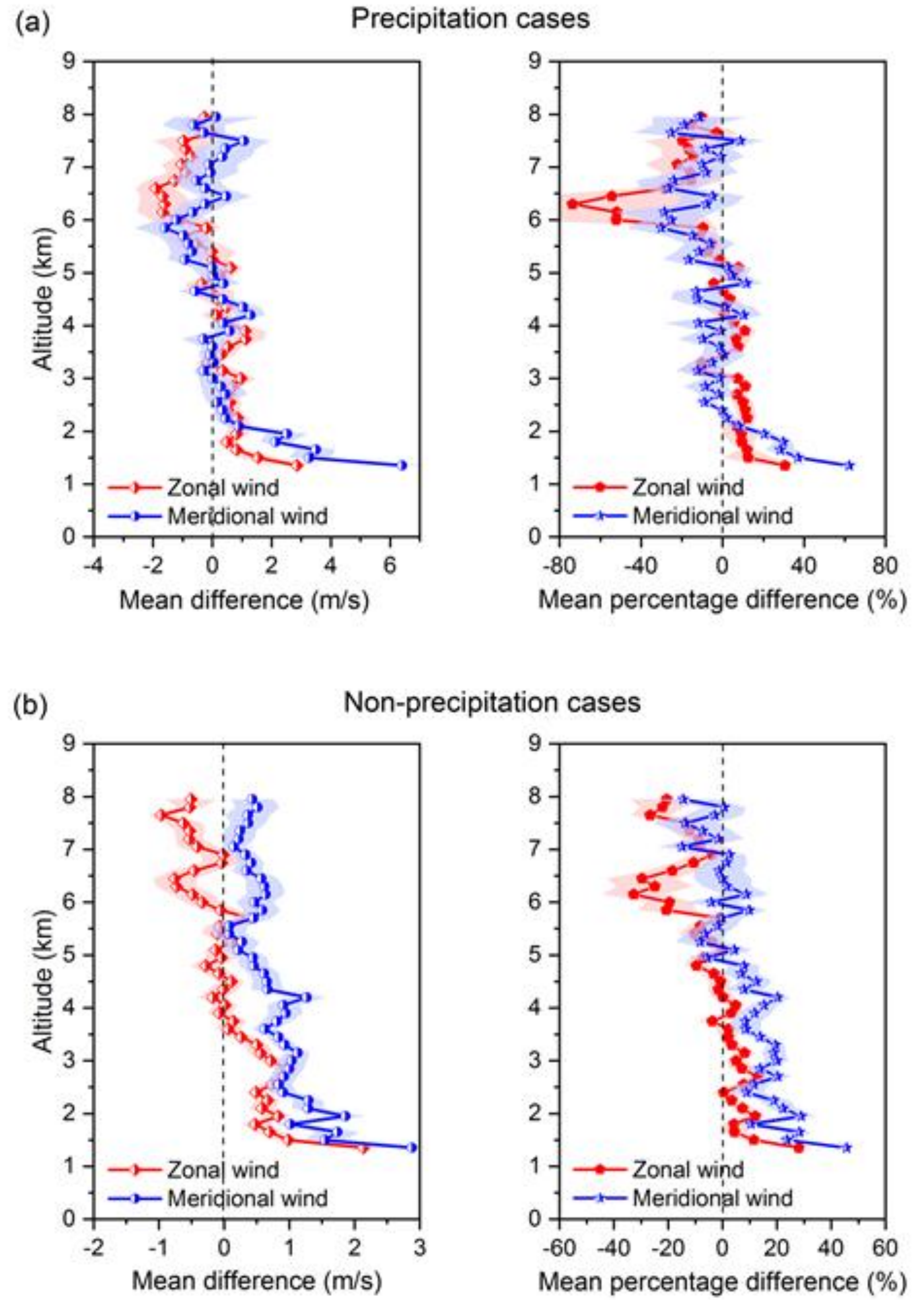
❑The difference is within ±1 m/s in the altitude region 3-5 km. The percentage difference is within ±20 % in throughout the altitude region above 2 km, except for the altitude region around 6.5 km.

❑In the altitude region 1-2 km, the percentage difference is greater than 20 %.

❑**Non-precipitation cases** > the mean difference in meridional wind is positive throughout the altitude with values less than 1 m/s above 2 km.

❑The mean difference in zonal wind is positive in the altitude region below 5 km and negative in the altitude region above it with a value within ± 1 m/s.

❑The percentage difference is within ± 20 % throughout the altitudes for both zonal and meridional wind except for zonal wind in the altitude region around 6.5 km.

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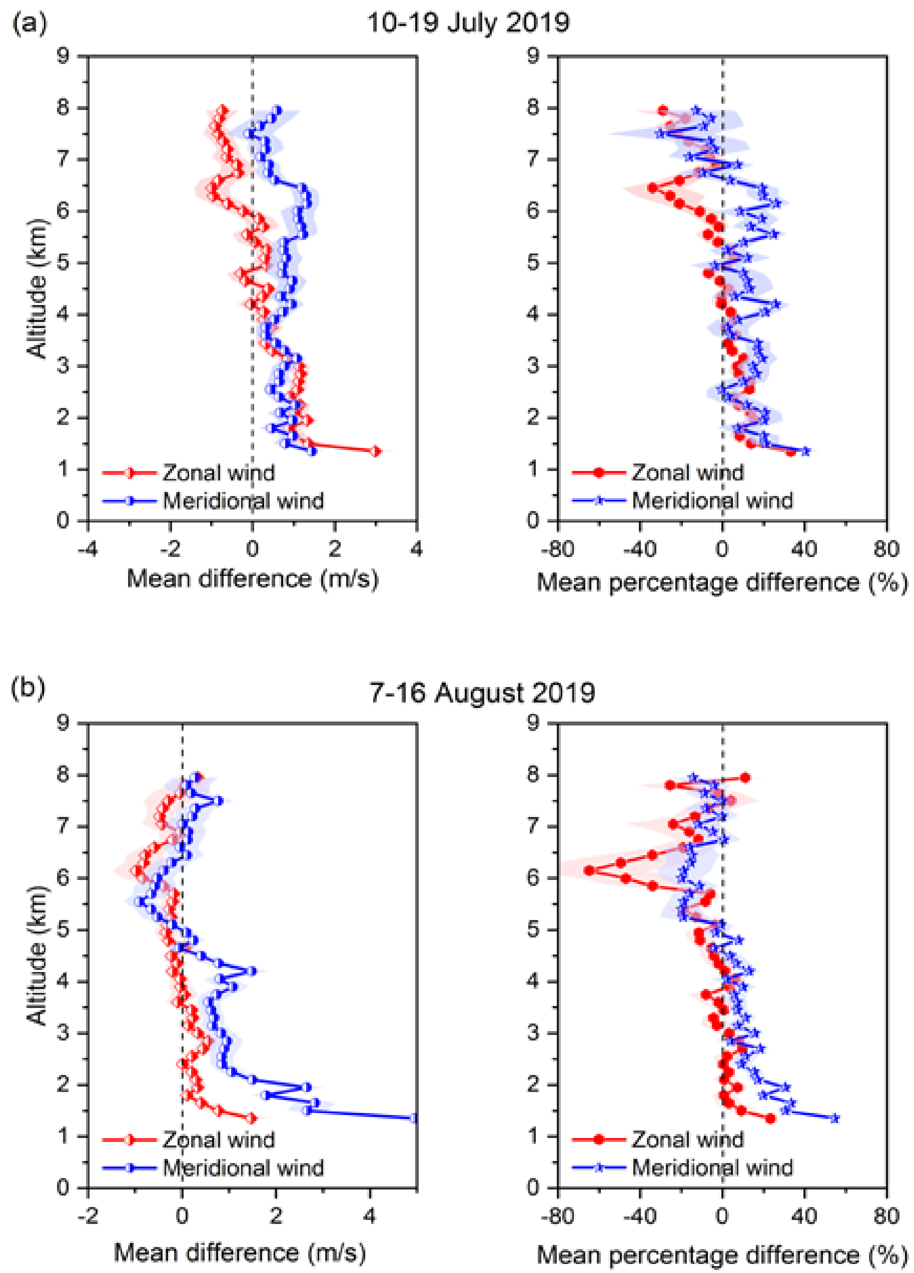
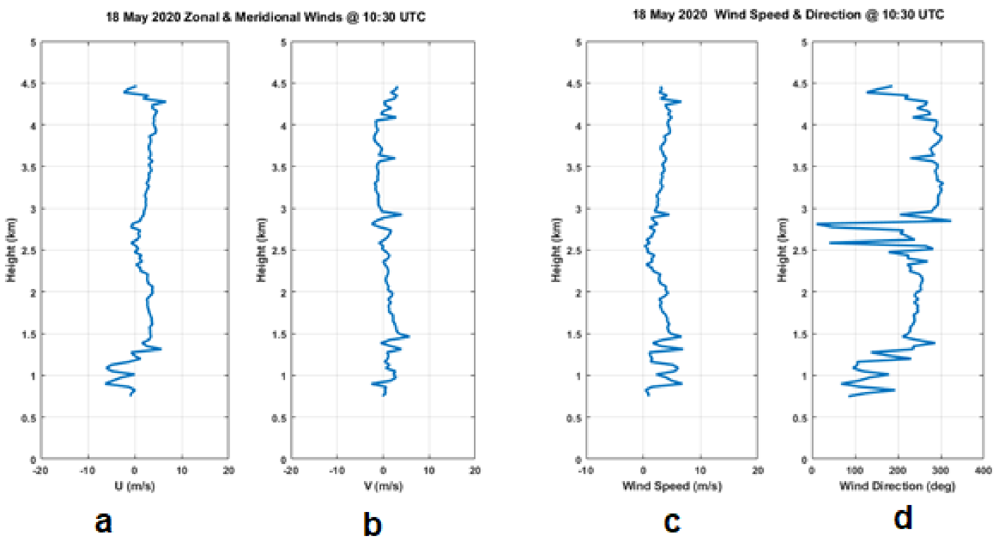
# CU ST Radar



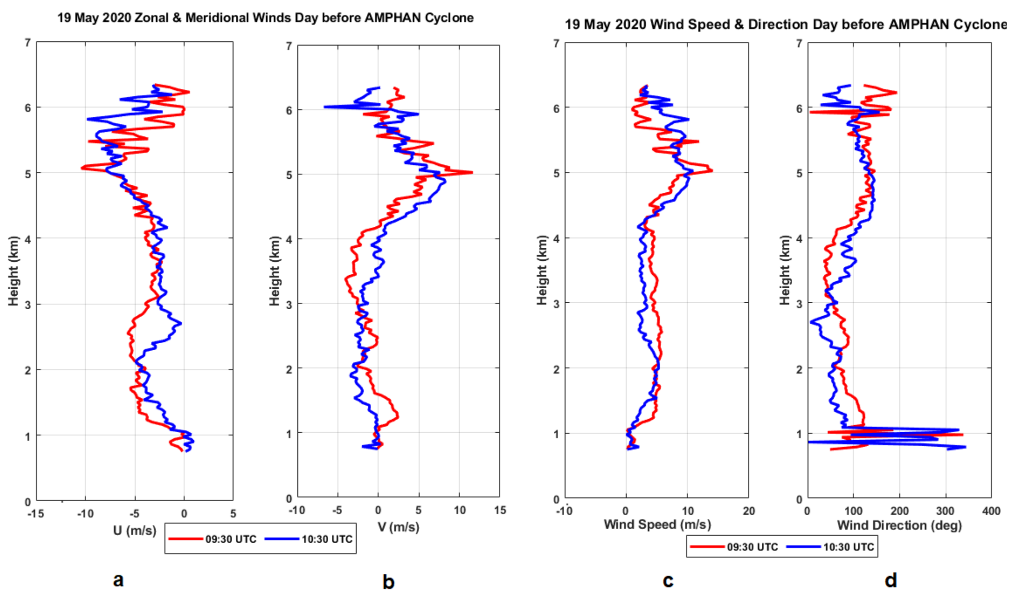

- In July 2019, the mean difference in zonal wind is positive with a value of about +1 m/s in the altitude region 1-3 km, within ±0.5 m/s in the altitude region 3-6 km, and is negative with values in the range □0.5 to □1 m/s, with a standard error of less than 0.5 m/s.
- The mean difference in meridional wind between the radar and radiosonde measurements is in the range 0.5-1.5 m/s in the altitude region 1-7 km with a standard error ~of 0.5 m/s at all levels.
- The percentage difference in zonal wind is +10 % in the altitude region 1-3 km and is maximum with a value of approximately □30 % around 6.5 km altitude.

- The percentage difference in meridional wind varies in the range 5-25 % in the altitude region 1-7 km. In August, the difference in zonal wind is within ±0.5 m/s throughout the altitudes from 1-8 km, with a small negative bias of about □1 m/s at 6 km.
- The standard error in zonal wind is less than 0.6 m/s in almost all the levels. The difference in meridional wind is high with mean value of 2-2.5 m/s in the altitude region 1.5-2 km. The difference is about 1 m/s in the altitude region 2-4 km and is negative in the altitude region 5-6 km (□0.5 to □1 m/s), with a standard error less than 0.5 m/s.
- The percentage difference is within ± 20 % for both zonal and meridional wind throughout the altitude region, except for the zonal wind at 6 km where it shows a peak of □60%.

# CU ST Radar

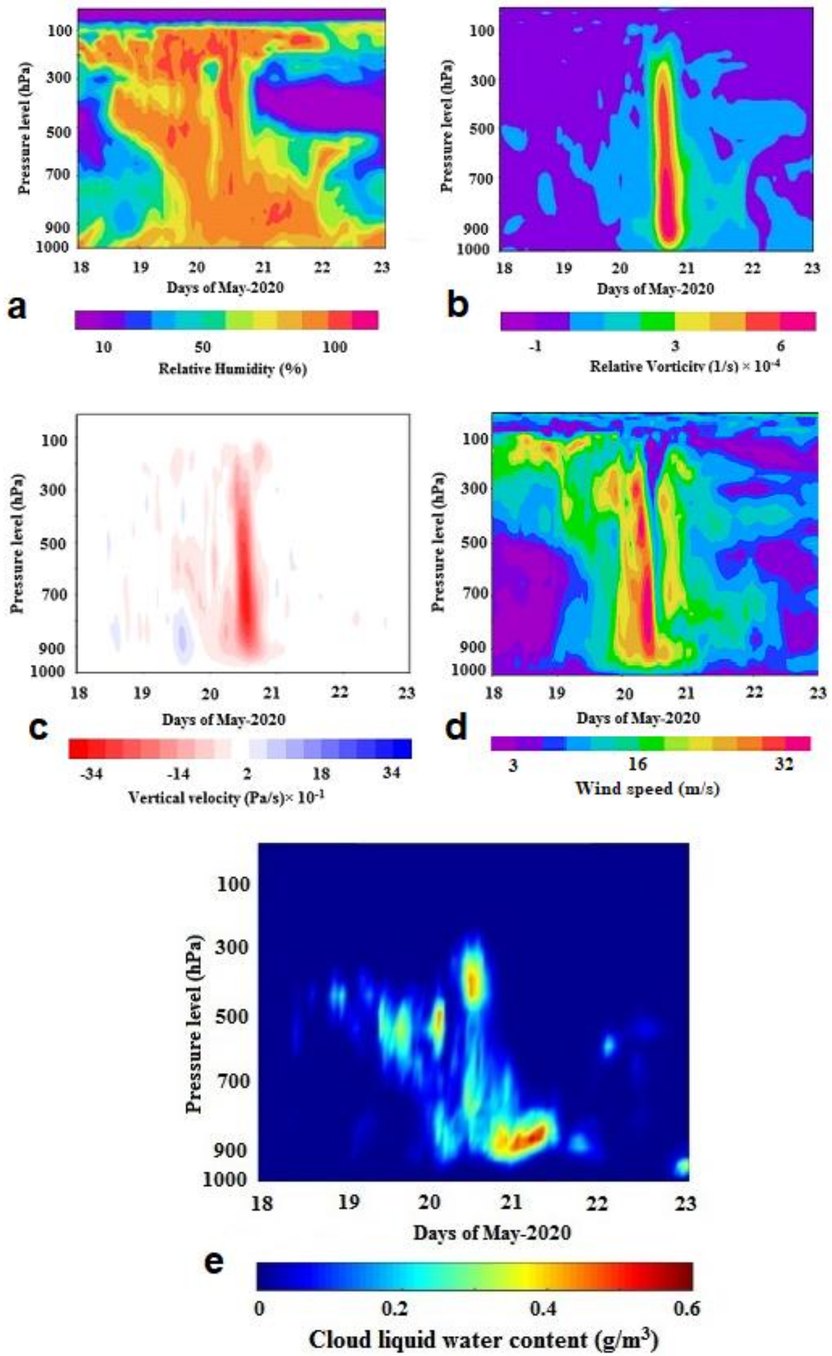



- ❑It is found that the zonal and meridional wind values lie between ±5 m/s (18 km/h) as evident from the Figures (a) and (b).
- ❑The wind speed is also about 6 -7 m/s. The wind directions exhibit fluctuations over the altitude range 0.75 – 1.5 km and 2.5 – 3 km compared to other altitudes due to the high resolution of 37.5 m and low pulse width of 2 µs shown in the panels of Figures (c) and (d).




- ❑On 19th May, the zonal winds are in the range of 0 - 10 m/s (36 km/h) over an altitude range of 1 - 5 km. Similarly, the meridional winds are in the range of -5 m/s to 10 m/s within the 1- 5 km vertical range.
- ❑The corresponding wind speeds and directions at 09:30 UTC and 10:30 UTC, shown in the Figures (c) and (d), are around 0-12 m/s and less than 180 degree. In the lower altitude range around 1 km, the wind direction exhibit fluctuations due to the high vertical resolution of 37.5 m.

# CU ST Radar

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➢**Vertical profile of relative humidity shown in Figure (a)** > mid-level humidity started to increase around 500 – 350 hPa on May 19, 2020 which further intensified on May 20, 2020 to 100%.

➢**Vertical profile of relative vorticity shown in Figure (b)** > projects its highest value during the second half of May 20, 2020.

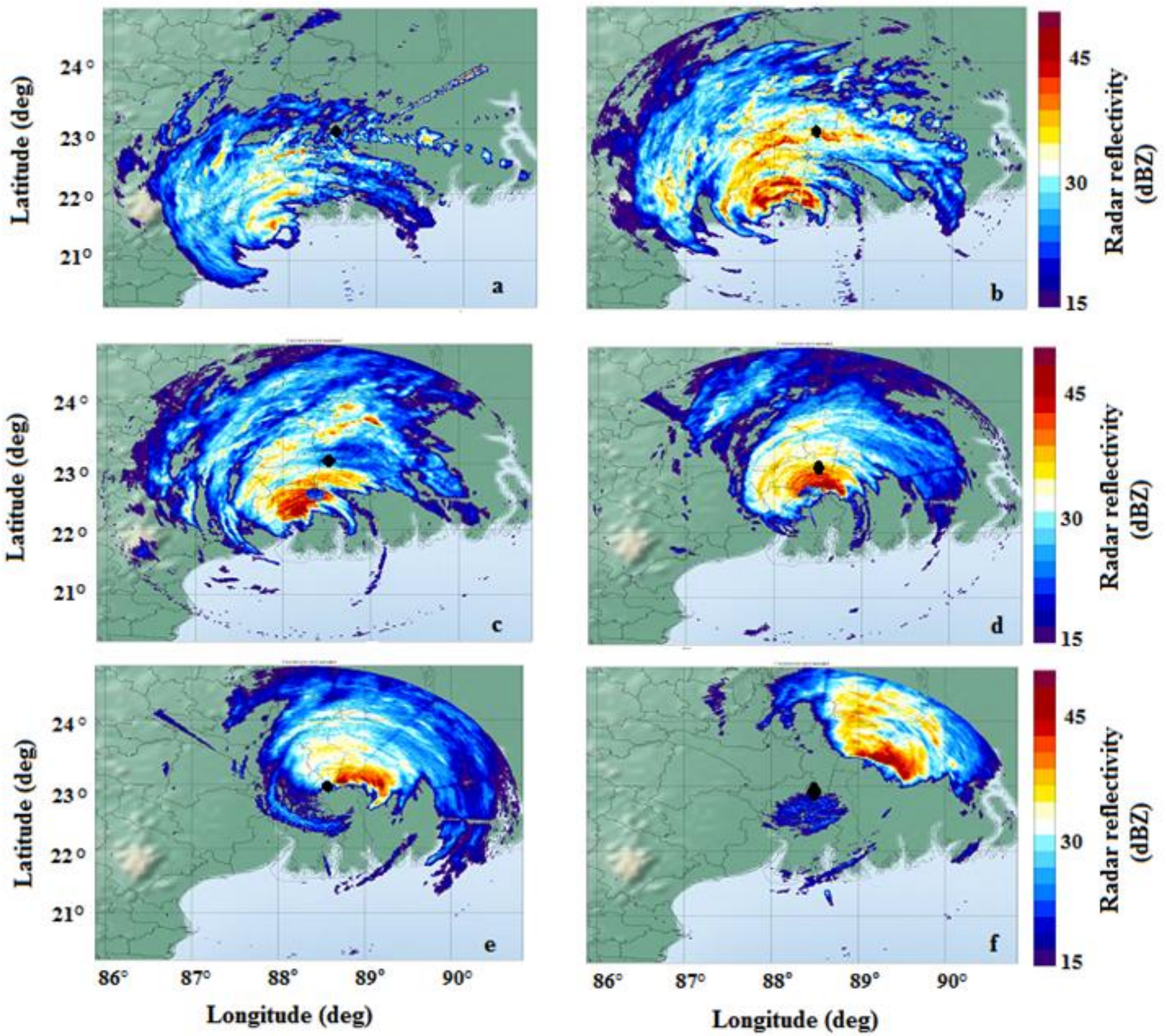
➢Similar features are also reflected in case of **vertical velocity shown in Figure (c)** - highest ascent around the same time of May 20, 2020.

➢**Vertical profile of wind speed Figure (d)** > Wind speed started to increase over the site from May 20 onwards till it reaches its highest value of more than 32 m/s around the second half of the day - higher wind speeds are also extended to upper atmosphere (i.e at an altitude of 300 hPa) during the same time period after which it started to decrease.

➢**Profile of microphysical parameters over the region during the cyclone > mid-level Liquid Water Content (LWC) shown in Figure (e)** - develop into the system from 650-450 hPa in the second half of May 19, 2020 - With the rise in intensity of the cyclone over the region of study, LWC became more prominent and hence their density also increased to the upper atmosphere upto the pressure level of 300 hPA in the late evening of May 20, 2020.

# CU ST Radar

- **Spatial variability of clouds for the cyclone "AMPHAN" during its passage over the ST radar site of University of Calcutta - radar reflectivity as observed from the S-band Doppler Weather Radar (DWR) placed at Kolkata Figure (a)**
- Principal rainbands of cyclone starts to appear over the radar site from 08:00 UTC which is followed by the secondary rainbands at 10:00 UTC **> Figure (b)**.
- With the advent of the cyclone towards the radar site, the secondary eyewall of the cyclone is visible over the site at 14:00 UTC **Figure (d)**.
- Finally the primary eyewall of the cyclone makes its presence over the radar site at 16:00 UTC **Figure (e)** and at last the trailing edge of the cyclone appears over the site at 18:00 UTC **Figure (f)**, before the associated rain bands propagate away from the region.

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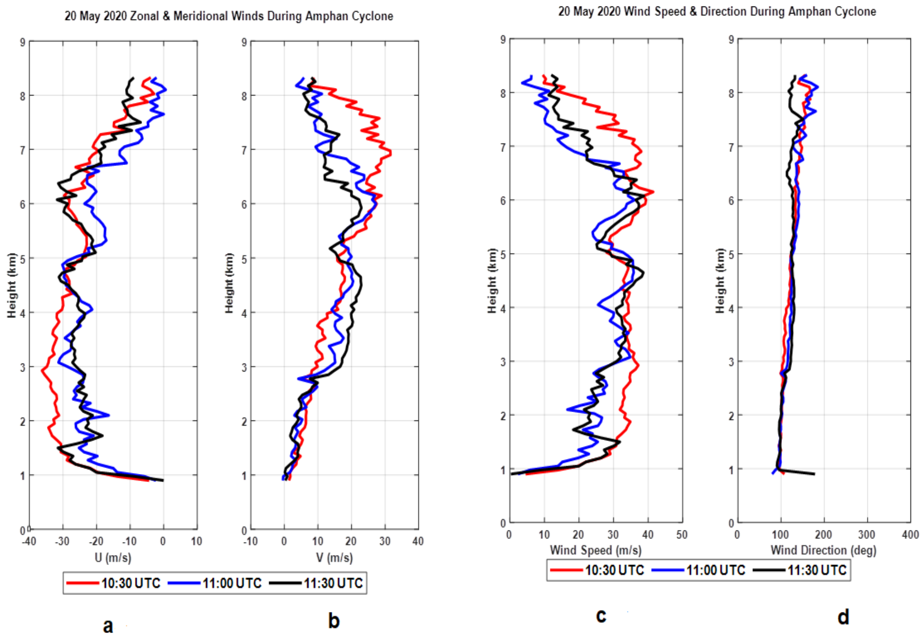
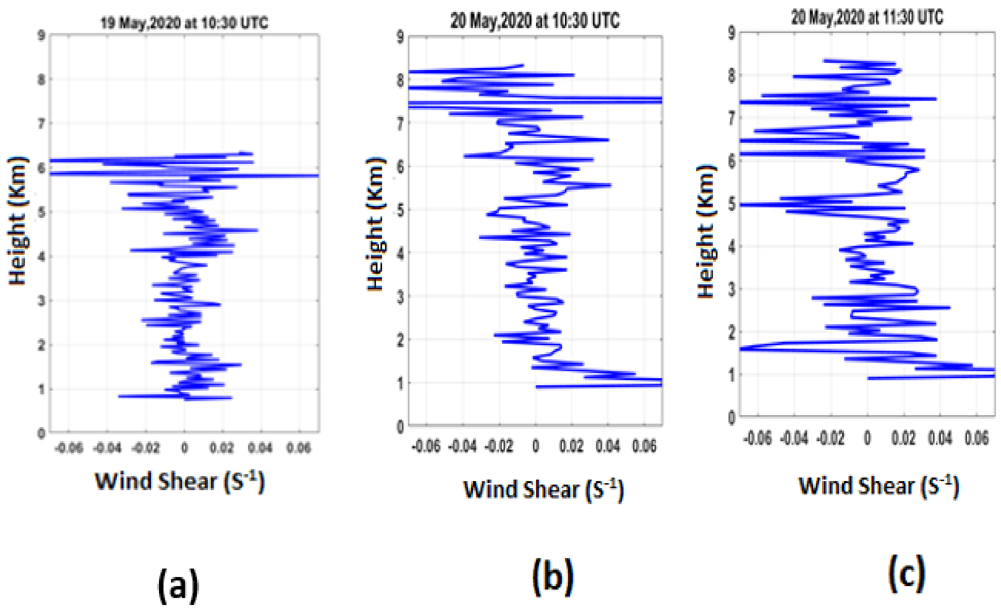
CU ST Radar




○**Figures (a) and (b)** > at 10:30 UTC, zonal winds reached magnitudes of up to 35 m/s (126 km/h) and the meridional wind magnitudes are up to 30 m/s (108 km/h) - 11:00 UTC, zonal and meridional winds were approximately 32 m/s and 28 m/s respectively

○Wind speed or the horizontal winds maximum value 41 m/s (148 km/h) and the vertical gradient in the direction was almost linear in between 100 - 200 degrees at 10:30 UTC - Comparing the wind speed and direction with May 18, 2020, the maximum wind speed increased from 5 m/s to 40 m/s

- Wind shear for May 20, 2020 at 10:30 UTC is stronger than May 19, 2020 at 10:30 UTC but weaker than May 20, 2020 at 10:30 UTC.
- **Figures (a), (b) and (c)** show the comparison of wind shear variation for the day before cyclone and the time prior to cyclone AMPHAN on May 20, 2020.

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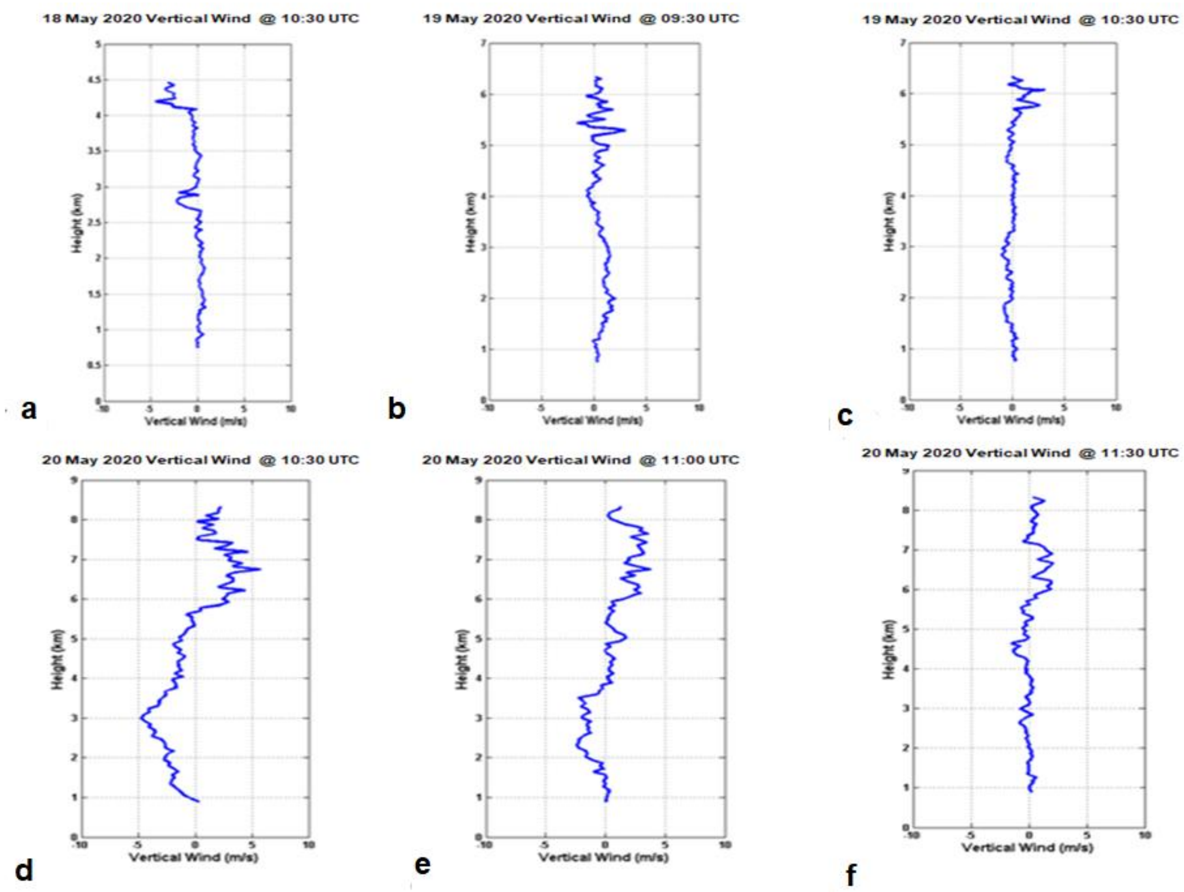
CU ST Radar

- Vertical velocities were unperturbed over the 1 – 4 km height range on May 18, 2020 and up to 5 km on May 19, 2020.

- On May 18, 2020 the vertical velocity had values of about -3 m/s and on May 19, 2020 it varied from about -2 m/s to +3 m/s.
- Prior to the cyclone AMPHAN, the vertical velocities were measured at 10:30 UTC, 11:00 UTC and 11:30 UTC shown in **Figures (d), (e) and (f)**.

- On May 20, 2020 the vertical velocity was quite high in the vertical range of 0.9 - 6 km due to the cyclone because of severe winds accompanied with drizzles during 10:20-10:30 UTC. On this day, the vertical wind values varied from -4 m/s to +5 m/s.

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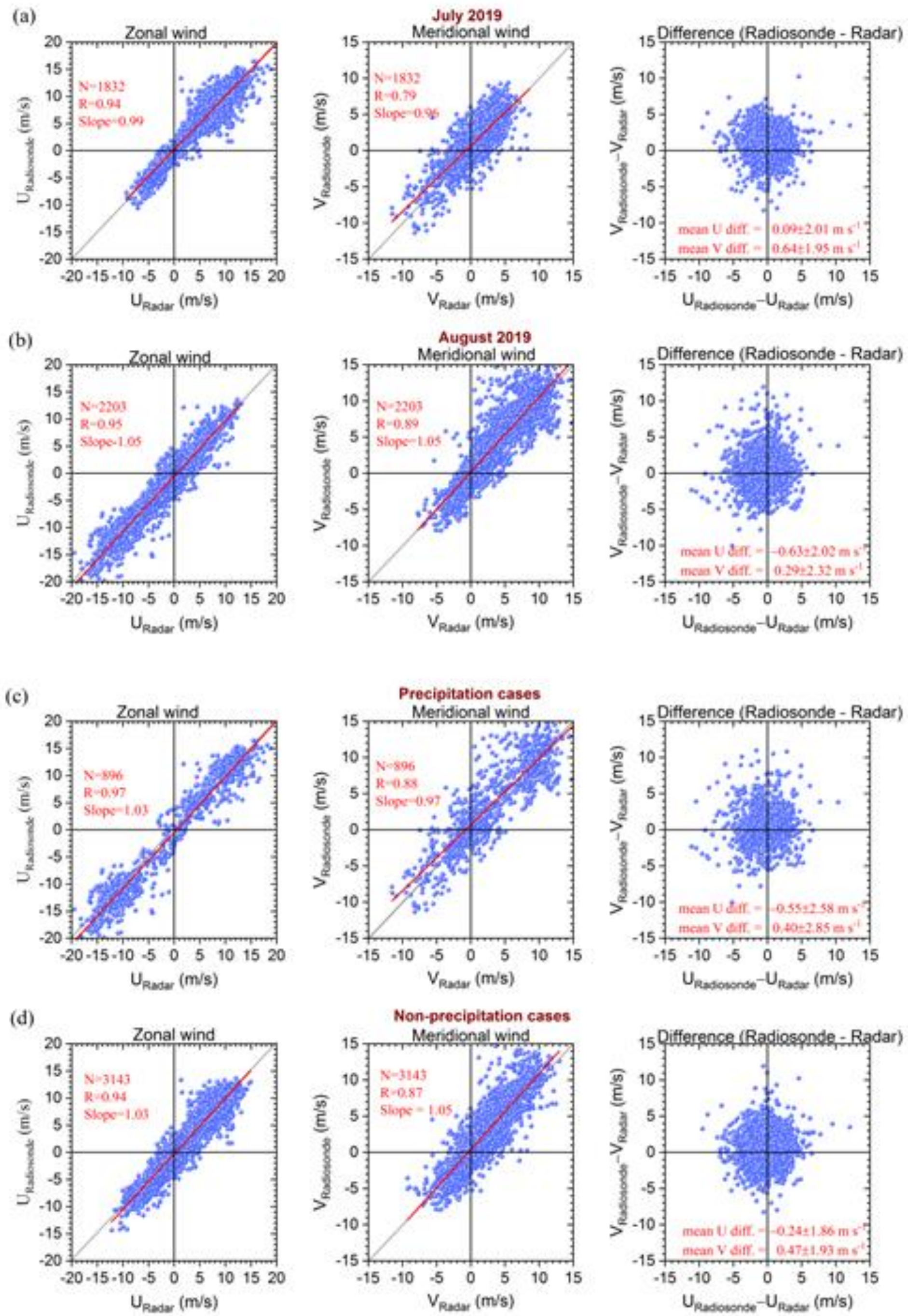
# CU ST Radar




○**July 2019** > radar and radiosonde measured zonal and meridional winds show a good agreement - correlation coefficient of 0.94 and 0.79 - linear regression slopes are close to unity with values of 0.99 and 0.96.

○Scattered points much away from the regression line could be due to different measurement techniques coupled with large integration time of radar measurements and large beam width (18deg) of the single sub-array in Pilot CU-ST radar.

○**August 2019** > Good agreement between the radar and radiosonde measured horizontal winds - Correlation coefficient values of zonal and meridional wind components are 0.95 and 0.89 - linear regression slope of 1.05 for both the components.

○Difference of zonal and meridional wind components show a mean value of ~0.63 m/s and 0.29 m/s - standard deviation of 2.02 m/s and 2.32 m/s.

○**Precipitation case >** data points for zonal wind are evenly spread with a correlation coefficient of 0.97 (slope is 1.03).

○For meridional wind, the data points are widely spread across the regression line and the correlation coefficient is 0.88 (slope is 0.97).

○Mean difference for zonal and meridional wind measurements by radiosonde and radar are ~0.55 m/s and 0.40 m/s - standard deviation of 2.58 m/s and 2.85 m/s.

○**Non-precipitation case** > correlation coefficients for the zonal and meridional wind measurements 0.94 and 0.87 - slope of 1.01 and 1.09 [Figure (d)].

○Data points for non-precipitation cases lie closer to the diagonal or regression line compared to the precipitation case.

○The mean wind differences for zonal and meridional wind components are found to be ~0.24 m/s and 0.47 m/s - standard deviation of 1.86 m/s and 1.93 m/s.

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CU ST Radar

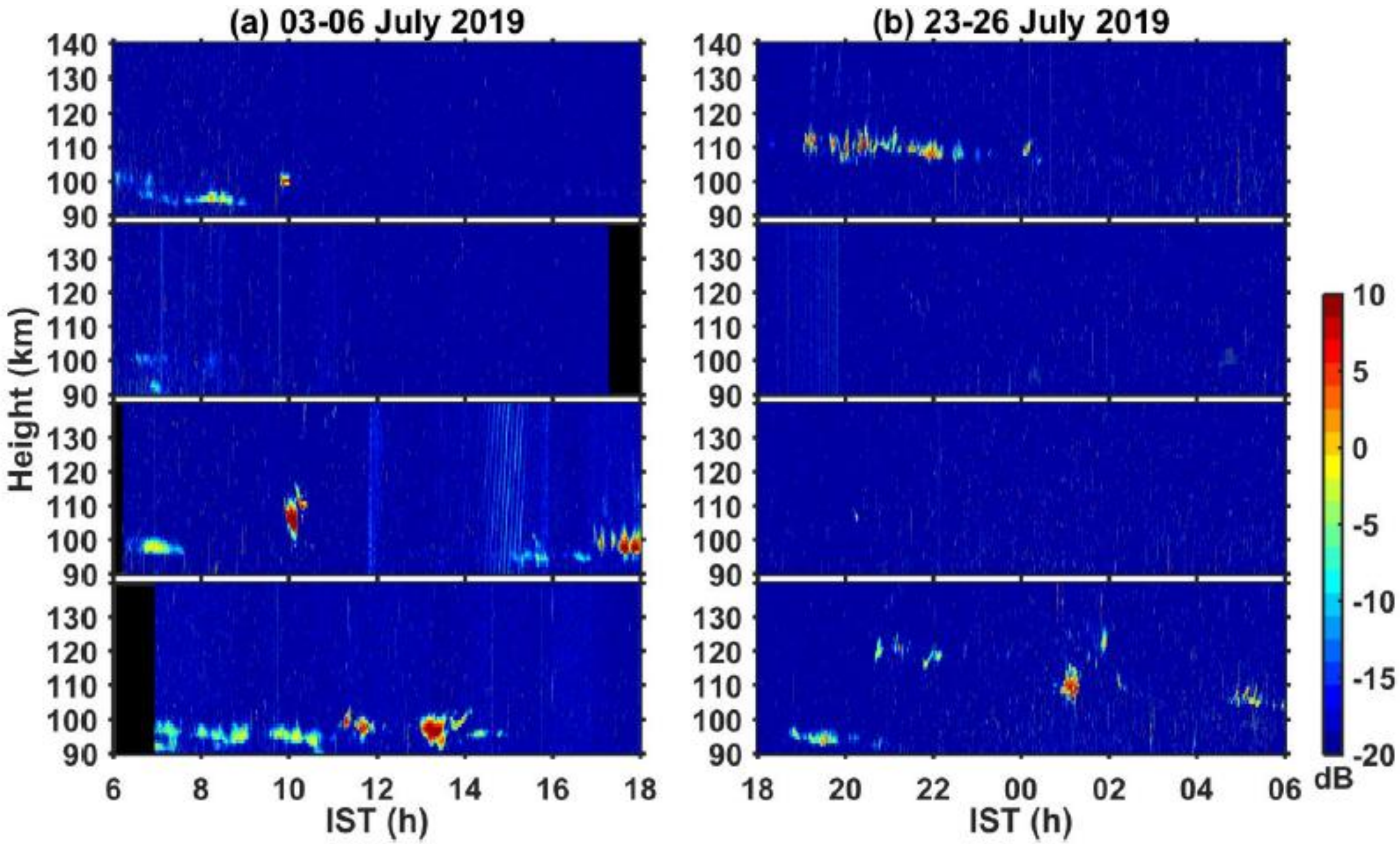


**Figure 2.** Height-time variations of signal-to-noise ratio (SNR) of the E region FAI observed during (a) 03-06 July 2019 during daytime (6-18 IST) and (b) 23-26 July 2019 during nighttime (18-6 IST).

- Large day-to-day variability in the occurrence of the *E* region FAI echoes for both daytime and nighttime.
- Large height and local time variations.
- Some common features observed are the descending pattern and patchiness in the echoing morphology.
- *E* region FAI echoes over Haringhata can be characterized by type-2 echoes with occurrence morphology dominated by patchiness and descending pattern.
- Quasi-periodic (QP) echoes occurred on July 23. These echoes are embedded in a slowly descending echoing layer.

*Paul et al., Radio Sci.*, 2021