A layman’s approach to Radar-Raingauge rainfall inter-comparison.

Presented by

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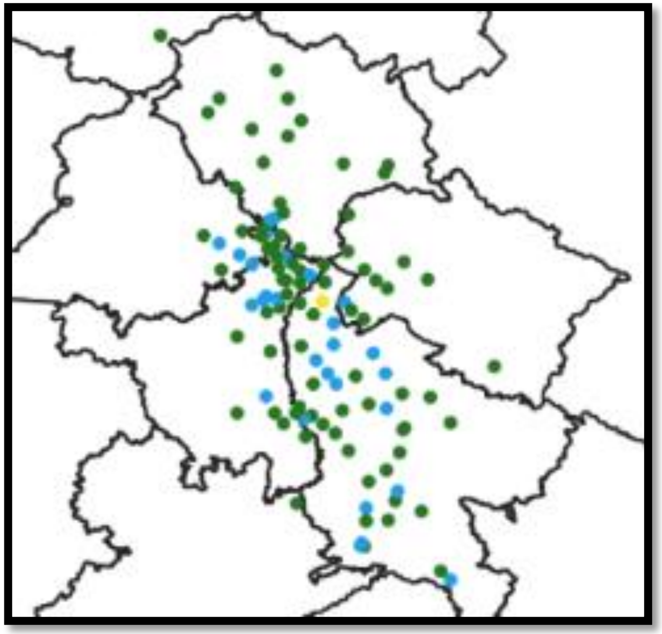
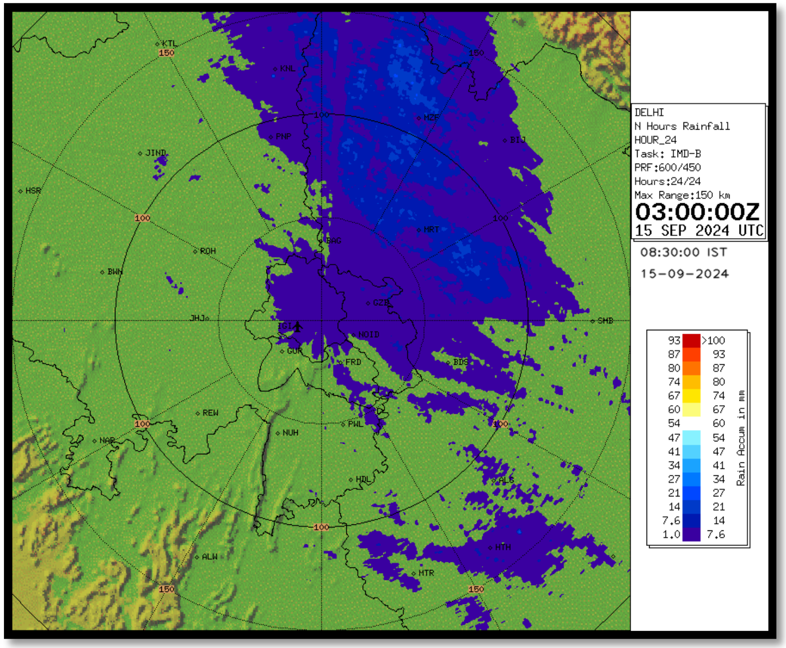
Introduction

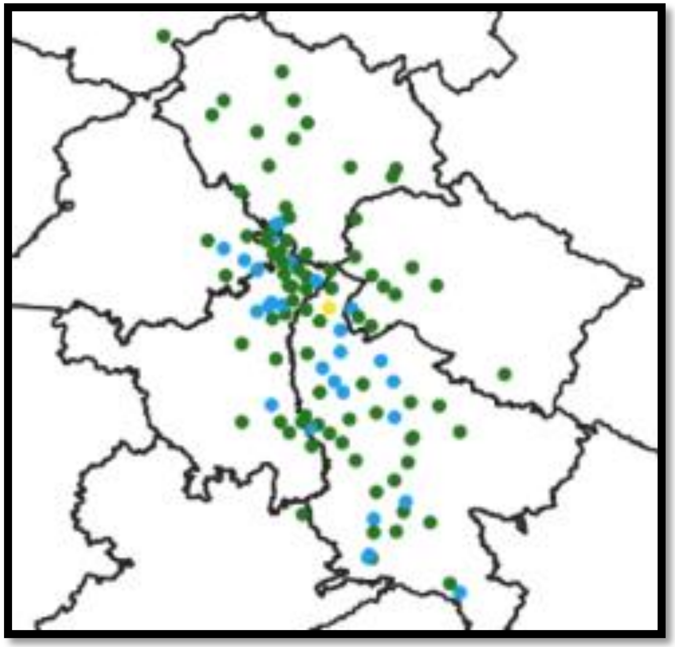
- Rainfall information is represented differently by raingauge and radars.

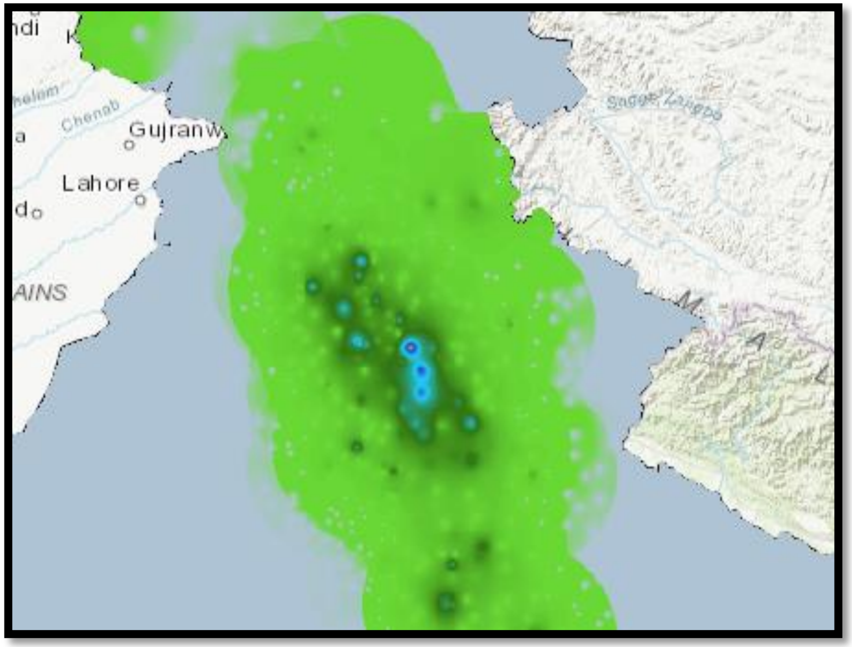




- For intercomparison there are two choices:
  - Point-wise comparison
  - Spatial comparison
- It is impossible to measure every point in a space. **Spatial interpolation** is the prediction of a given phenomenon in unmeasured locations

Introduction

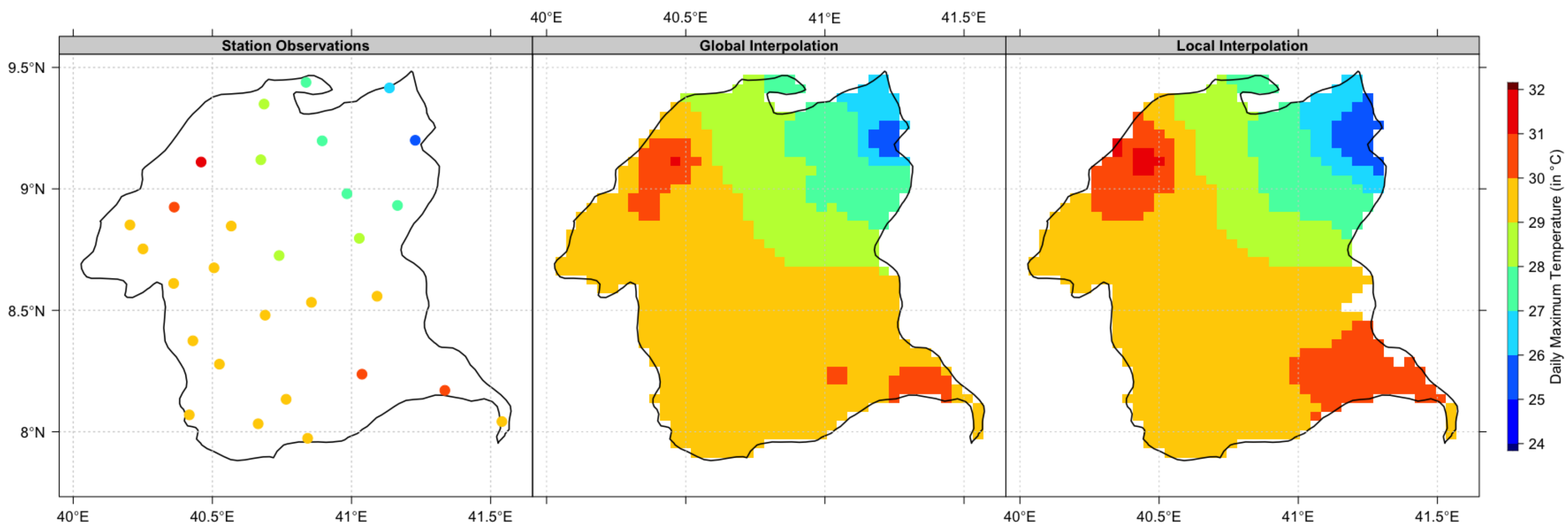




- **Deterministic models**—Models using arbitrary parameter values, for example: IDW
- **Statistical models**—Models using parameters chosen objectively based on the data, for example: Kriging
- **Global and local interpolation**

Global vs. local interpolation

- A global interpolation uses all available known points in the study area to estimate the unknown value of a point located within the study area. Local interpolation on the other hand, uses a sample of known points to estimate the unknown value.
- Local interpolation is designed to capture the local or short-range variation, while global interpolation assess global spatial structures and the local or short-range variation.
- Global interpolation generally produces smoother surfaces. The difference between local and global interpolation lies in the number of points used in the estimation of the unknown value.



Arithmetic mean method

- The simplest and most common spatial interpolation method, particularly in relatively flat zones, is to use the simple average of the number of stations.
- This method is suitable when large number of precipitation stations are spaced uniformly

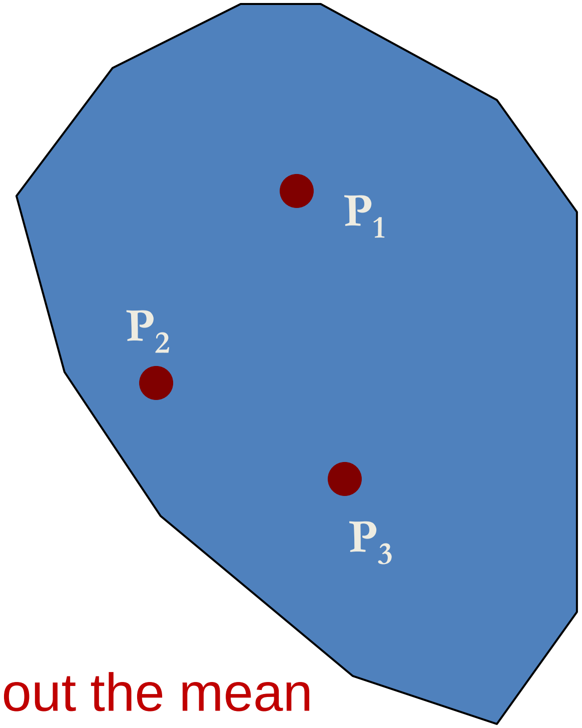
$$\overline{P} = \frac{1}{N}\sum_{i=1}^{N} P_i$$

$P_1 = 10$ mm

$P_2 = 20$ mm

$P_3 = 30$ mm

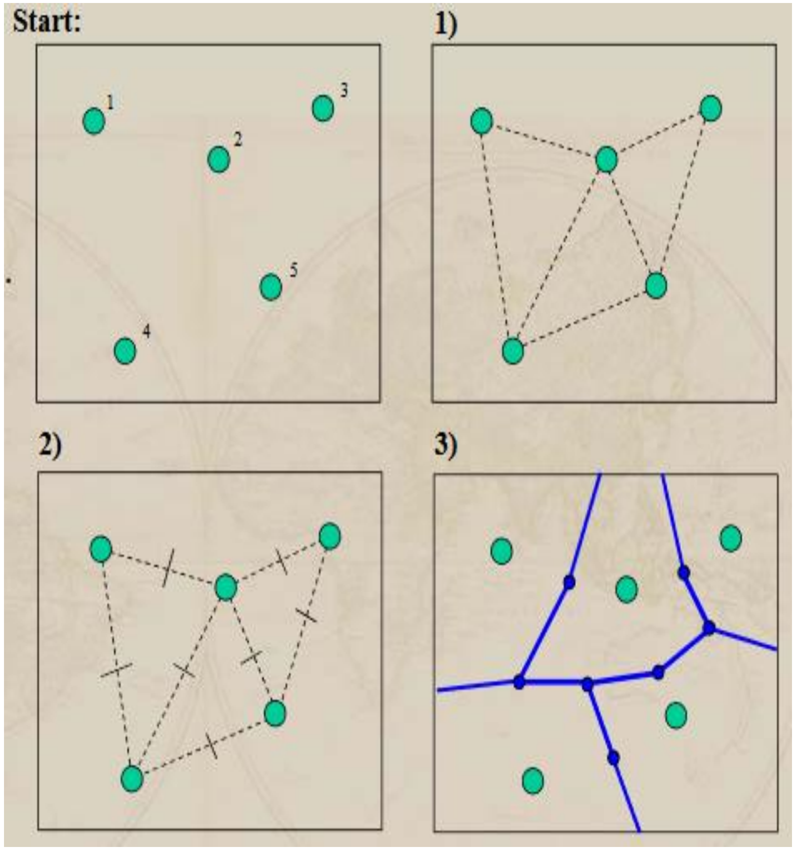
$$\overline{P} = \frac{10+20+30}{3} = 20 \ mm$$



- Gauges must be uniformly distributed
- Gauge measurements should not vary greatly about the mean

Thiessen Polygon Method

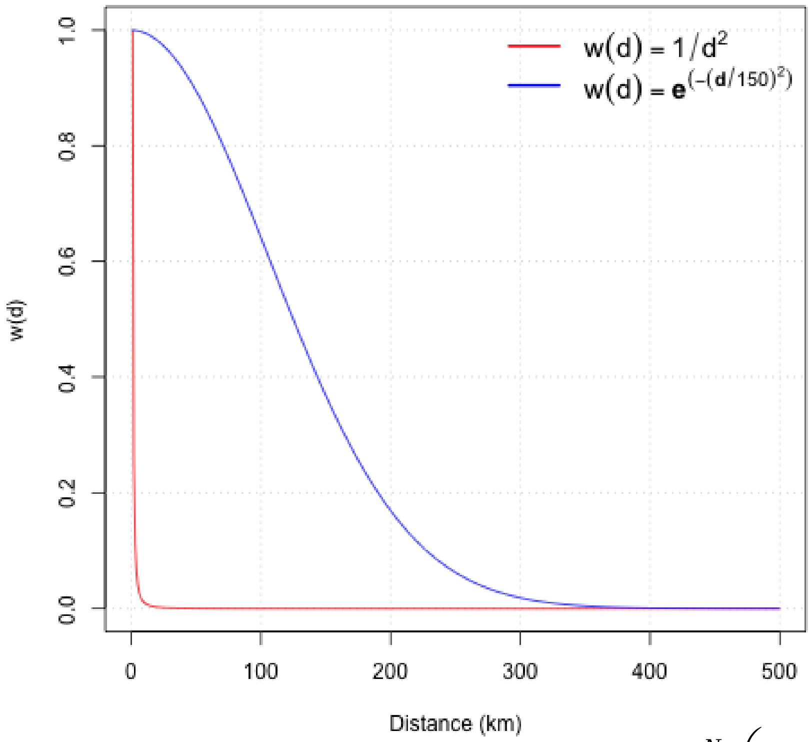
- It is assumed interpolated value equal to the value found at the nearest sample location.
- Gives weightage to the each observation depending upon the area of influence of each raingaue station.
- Steps in Thiessen polygon method
  1. Draw lines joining adjacent gages
  2. Draw perpendicular bisectors to the lines created in step 1
  3. Extend the lines created in step 2 in both directions to form representative areas for gages
  4. Compute representative area for each gage
  5. Compute the areal average using the following formula



$$\overline{P} = \frac{1}{A}\sum_{i=1}^{N} A_i P_i$$

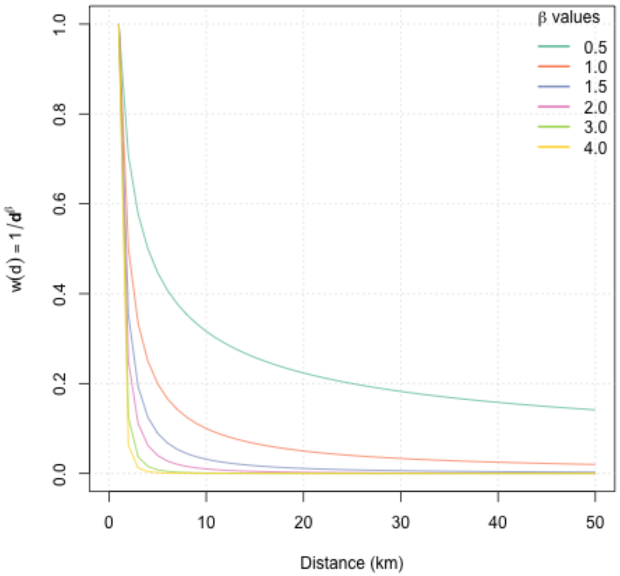
Inverse Distance Weighting (IDW)

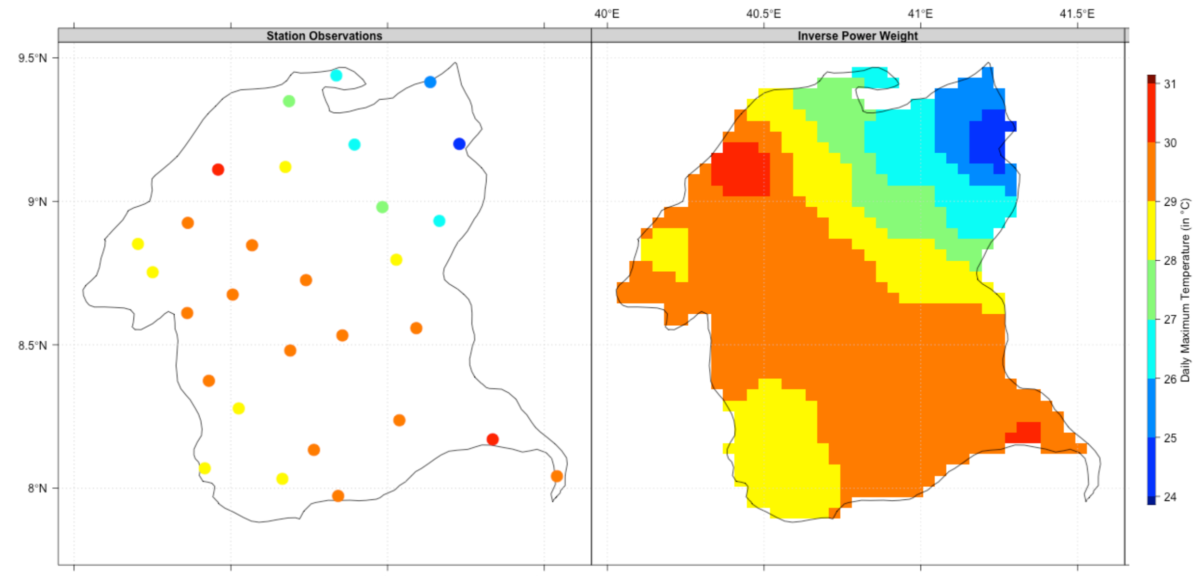
- The method is based on the functions of the inverse distances in which the weights are defined by the opposite of the distance. The weights decrease as the distance increases.
- Comparison between inverse power and exponential weighting functions.
- The choice of this weighting power can significantly affect the estimation quality. Higher weighting power values emphasize the influence of the points nearest to the grid node, resulting in a more detailed and less smooth interpolated surface.
- A smaller power value gives more influence to distant points, and results in a more averaged and smoothed interpolated surface.

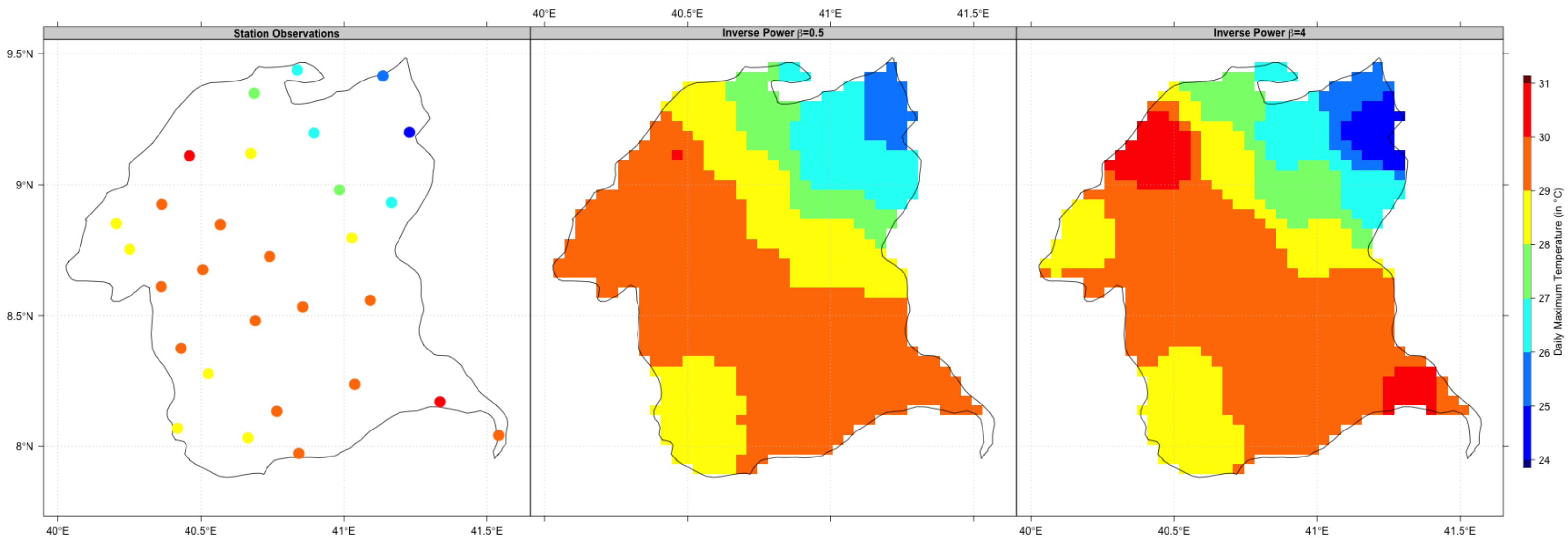


$$\hat{P} = \frac{\sum_{i=1}^{N}\left(\frac{P_i}{d_i^{\,2}}\right)}{\sum_{i=1}^{N}\left[\frac{1}{d_i^{\,2}}\right]}$$

Inverse Distance Weighting (IDW)

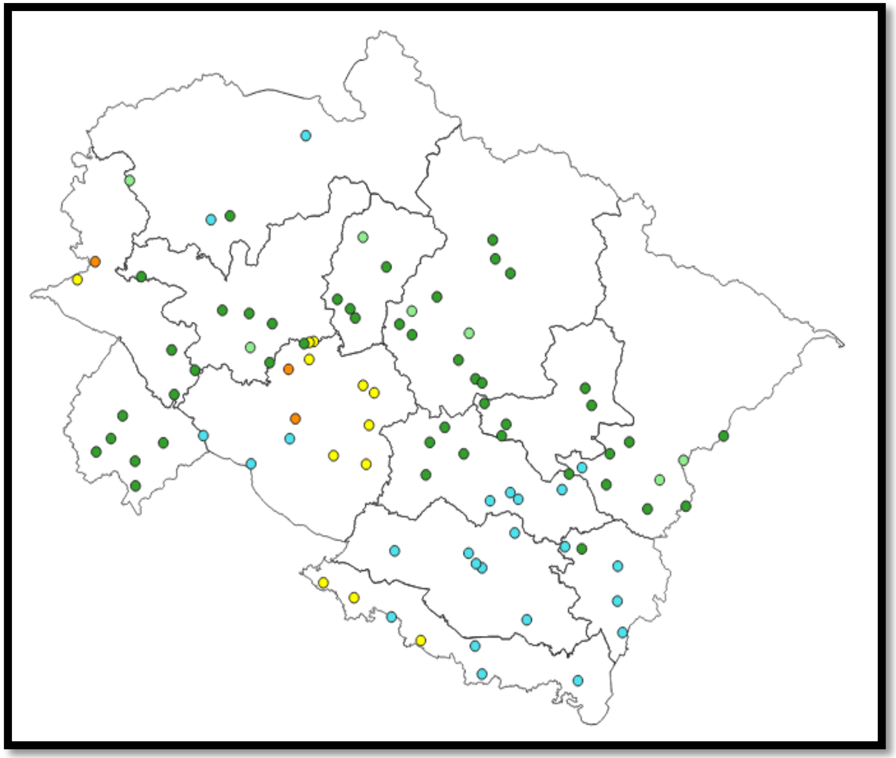


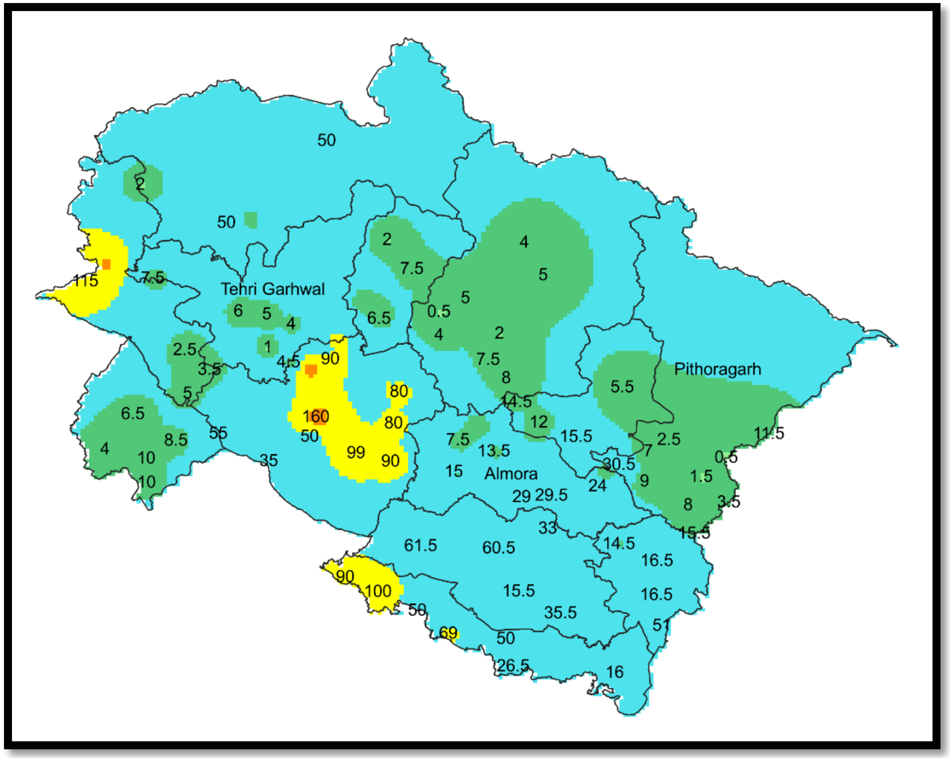




Inverse Distance Weighting (IDW)

- Rainfall interpolation with β=2.



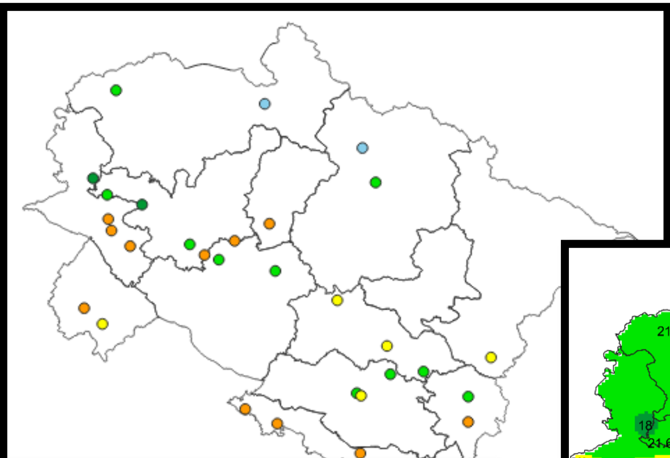


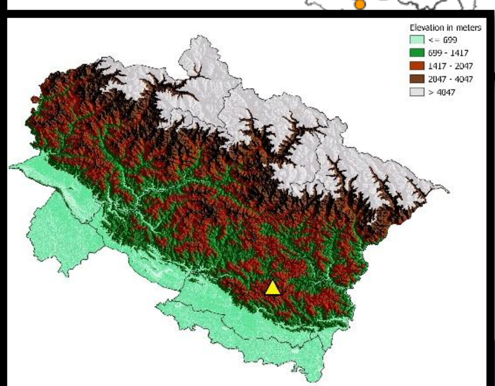
Rainfall in mm

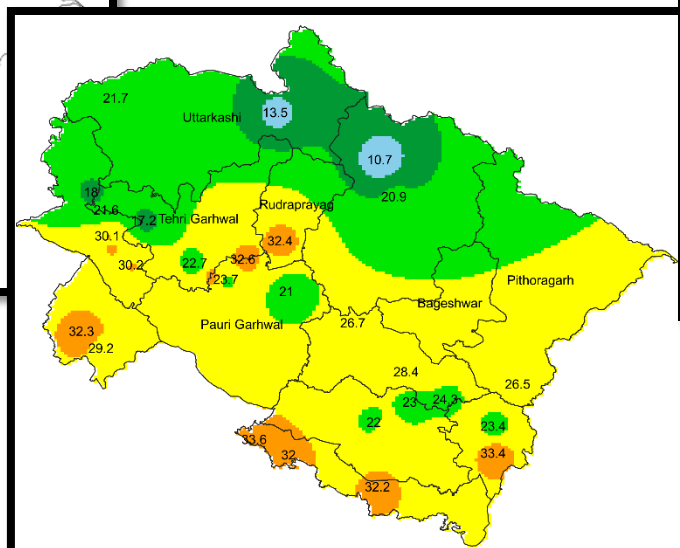
- Very Light/Dry (0 to 2.4)
- Light (2.5 to 15.5)
- Moderate (15.6 to 64.4)
- Heavy (64.5 to 115.5)
- Very heavy (115.6 to 204.4)
- Extremely heavy (> 204.4)

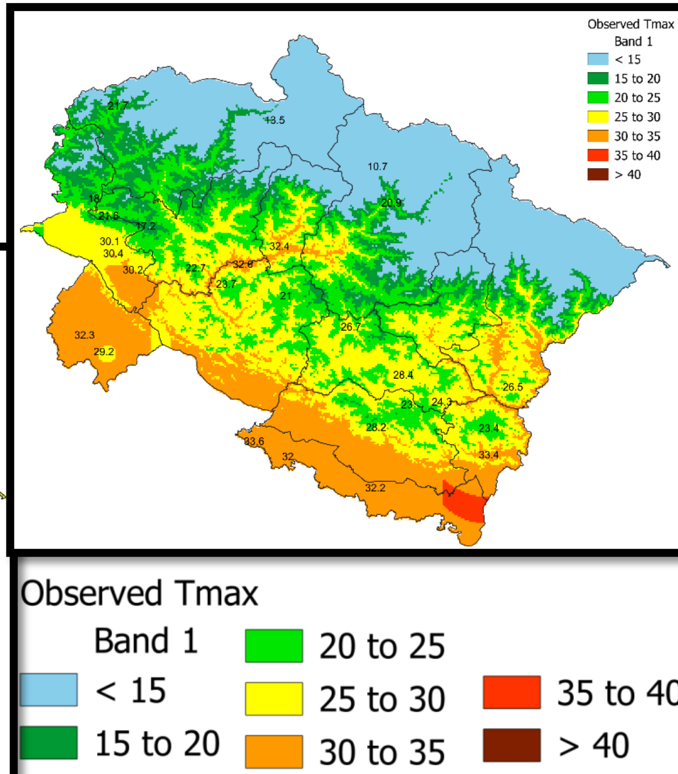
Other methods

- **Kriging** is a geostatistical interpolation method that considers both the distance and the degree of variation between known data points when estimating values in unknown areas.
- **Spline** interpolation method is based on a mathematical model for surface estimation that fits a minimum-curvature surface through the input points.
- **Orographic based (Elevation, aspect, slope etc.) interpolation.**









Importance

- India Meteorological Department has introduced impact based forecast (IBF) in its short to medium range forecasts and Nowcast.
- The IBF indicates likely impact of the heavy rainfall in different sectors and required response actions. The areal data of 24-hours accumulated rainfall is one of the most important information for short to medium range impact based forecasts. Similarly the past 3/6 hourly or cumulative rainfall information is essential for issuing IBF in nowcasts.
- Areal/spatial Rainfall is a critical aspect of meteorology and hydrology, influencing flood forecasting, agricultural planning, disaster management, urban planning and water resource management etc.
- Limitation of interpolation is that the highly localized phenomenon may be shown on larger area depending on selecting the radius of influence. But it is most closest estimation analysis.

Radar rainfall estimation and intercomparison

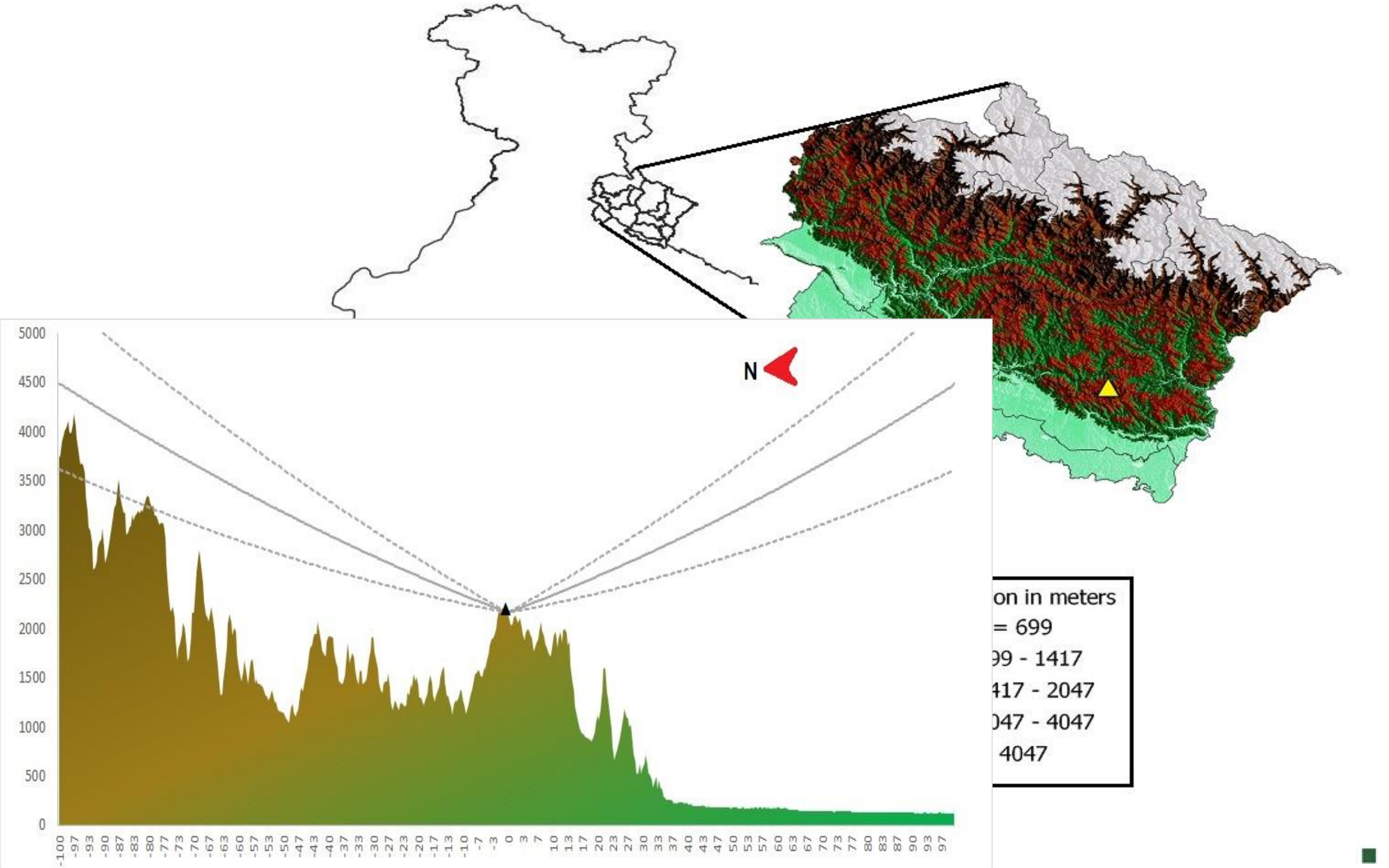
Radar rainfall estimation

- First, Marshall et. al. (1947) established the fundamental relationship between radar reflectivity and precipitation intensity.
- The formula is linked to the drop size distribution of rain
- In this study the rainfall is estimated from Maximum Reflectivity (Max (Z)) product images of radar.
  - This provides user the flexibility to devise own Z-R relationship different from Z-R parameters set by radar centres
  - Address the uncertainty of estimated rainfall in complex terrains.
  - Fast

Relevance

- Traditional methods used the 3D radar volume scan data or 2D data like CAPPI/PPI for rainfall estimation.
- These radar data are
  - big,
  - available at the radar centres only
  - often difficult to obtain at real-time.
- The decoder software for binary encoding is not easily available.
- However, the radar product images available at real-time in public domain.
- Generation of qualitative rainfall estimations simpler and faster though image processing of publically available radar products images.
- In the past many researchers have attempted to carry out areal rainfall estimation through image processing (Cho et. al., 2017; Kumar & Prasadpati, 2015).

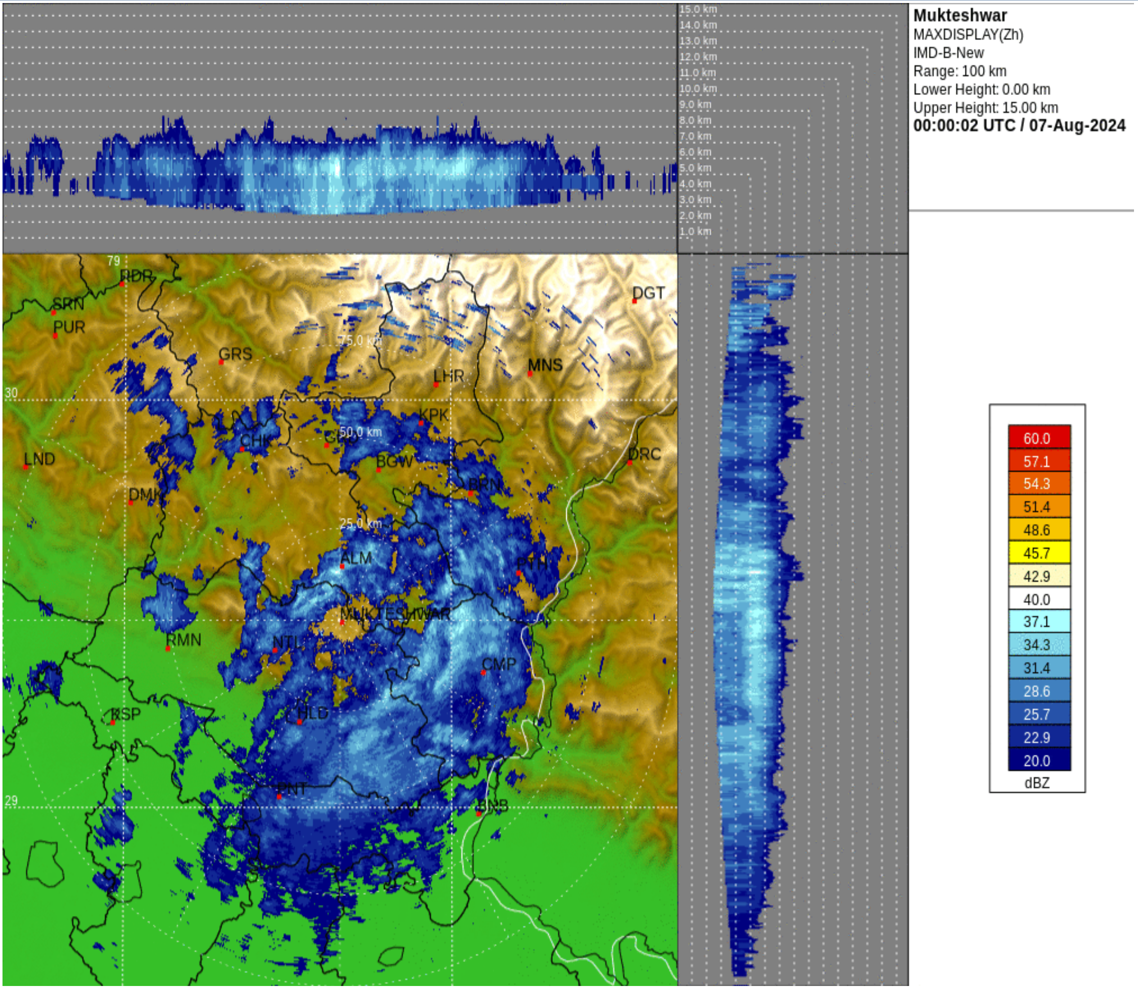
Case study area

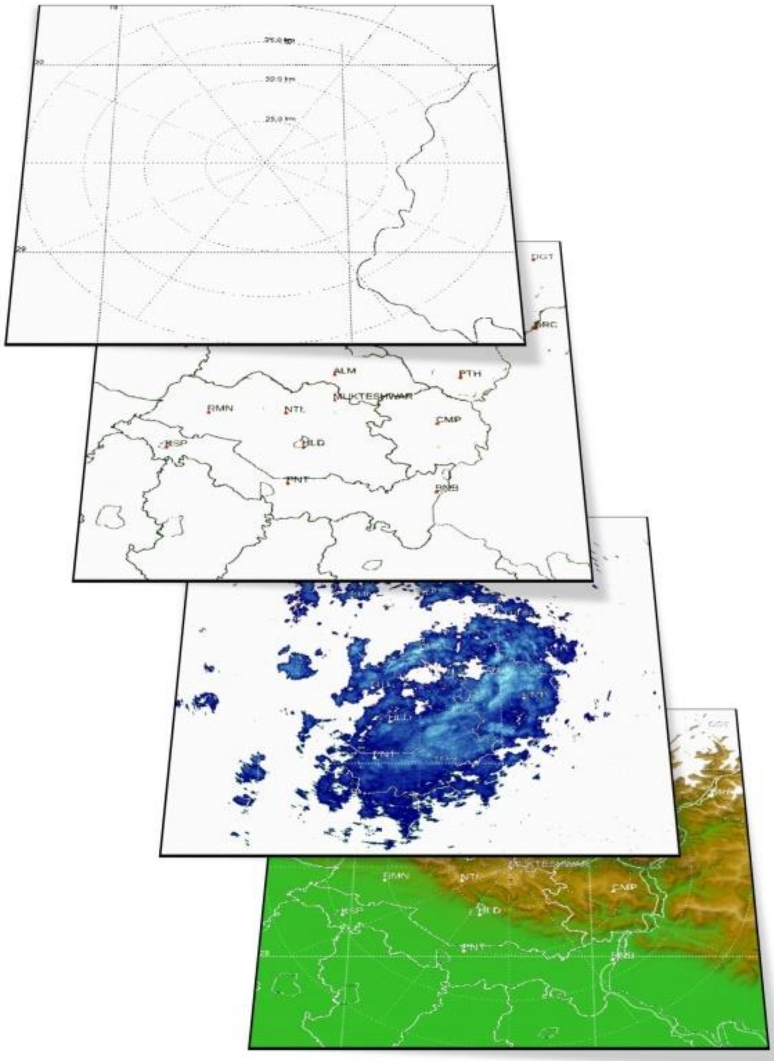


Methodology

Input	Image processing	Output
Max(Z) images at 10 minutes interval.	Extraction of reflectivity	Accumulated estimated rainfall image
One clean Max(Z) image with no reflectivity values	Rainfall estimation	Custom image based on user schemes
Digital elevation map of the region (optional)	User scheme implementer	Geo-referenced rainfall raster.
Different user schemes to optimize the results e.g. multiple Z-R relation based on reflectivity values, based on range, based on DEM, clutter filter etc.		

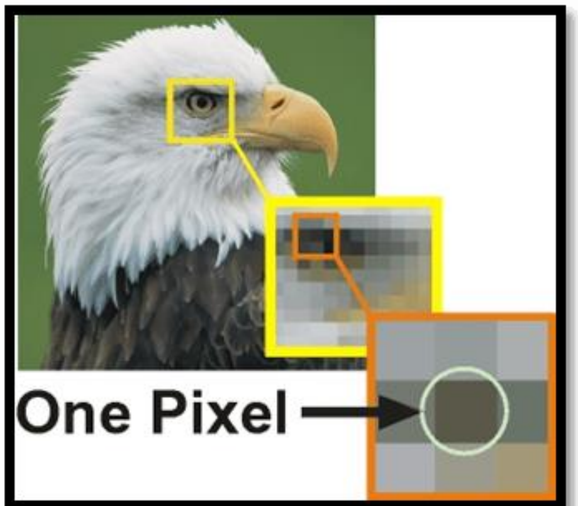
Reflectivity extraction

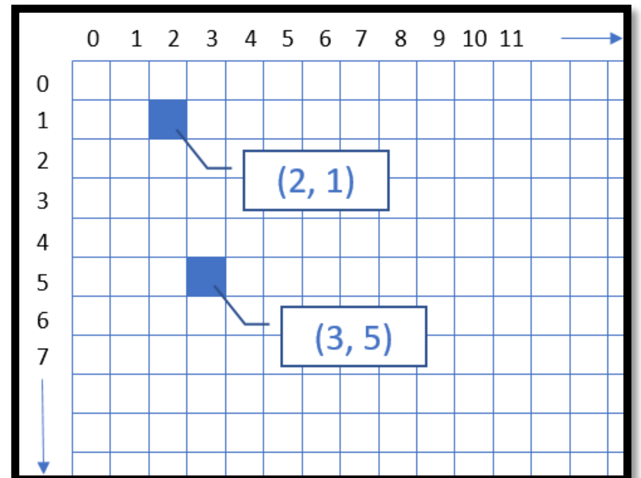




Reflectivity extraction

- Pixel have information about the color.
- The color information is stored as RGB additive color model. color can range from 0 to 255.

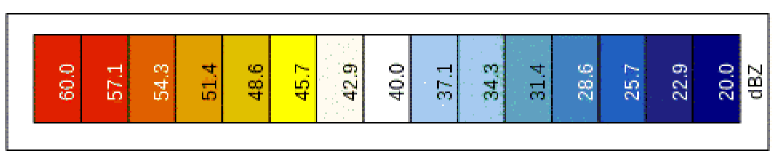




- In next step the radar echoes are assigned their corresponding Decibel relative to Z values.
- The dBZ values are then converted to radar reflectivity factor (Z) using following equation:

$$Z = Z_0 \, 10^{(dBZ/10)} \qquad \text{-------(1)}$$

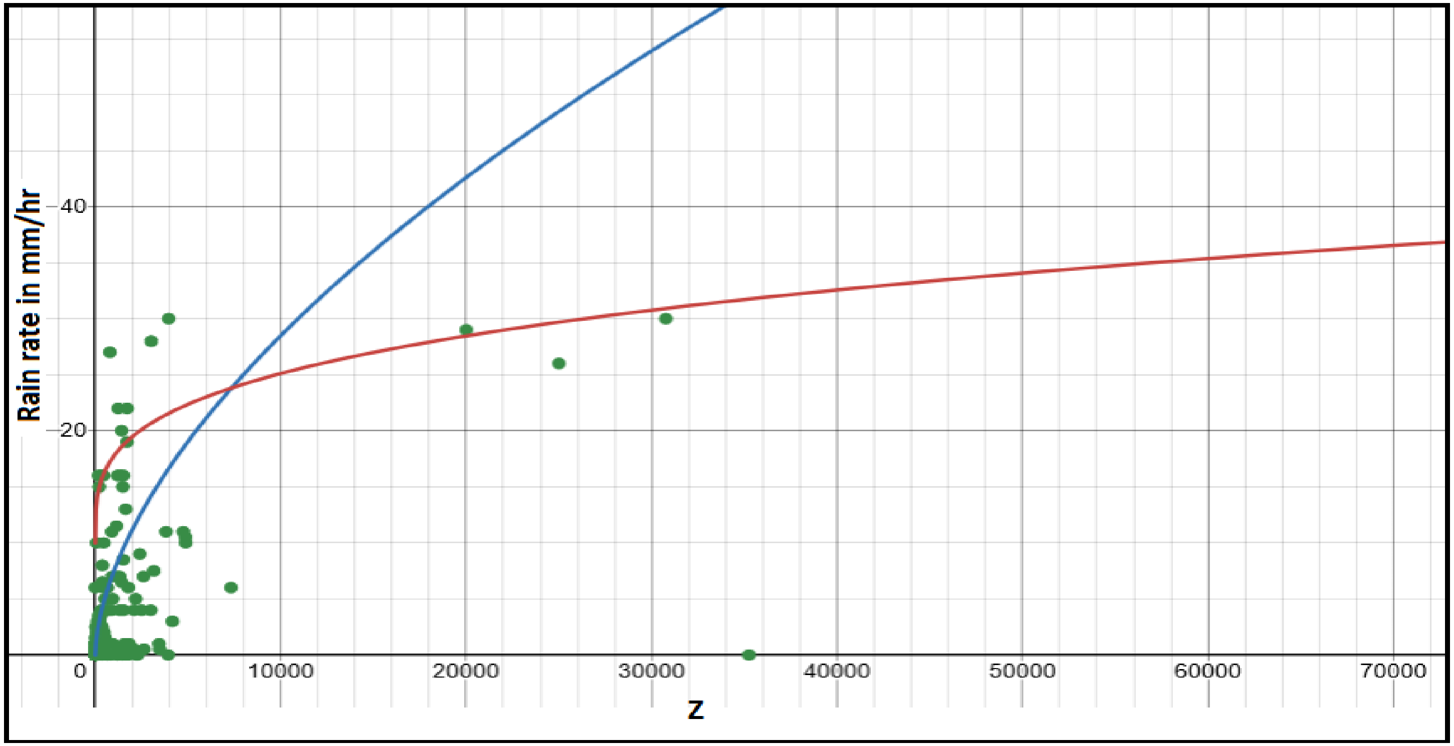
Where Z_0 is equivalent return of a 1 mm drop in a volume of a meter cube.



Rainfall estimation

- The Z-R relationship is used for rainfall estimation at each pixel.
- For lower reflectivity values, more aggressive power curve can be used while for higher reflectivity less aggressive power curve can be used for monsoon rainfall in mountainous region. The two curves intersects at Z=7000.

$$Z = \begin{cases} 31R^{1.71}\ for\ Z\ \leq 7000\ (\text{Blanchard, 1953}) \\ 0.828R^{3.46} + 10\ for\ Z > 7000 \end{cases} \quad \text{------ (2)}$$



Rainfall estimation

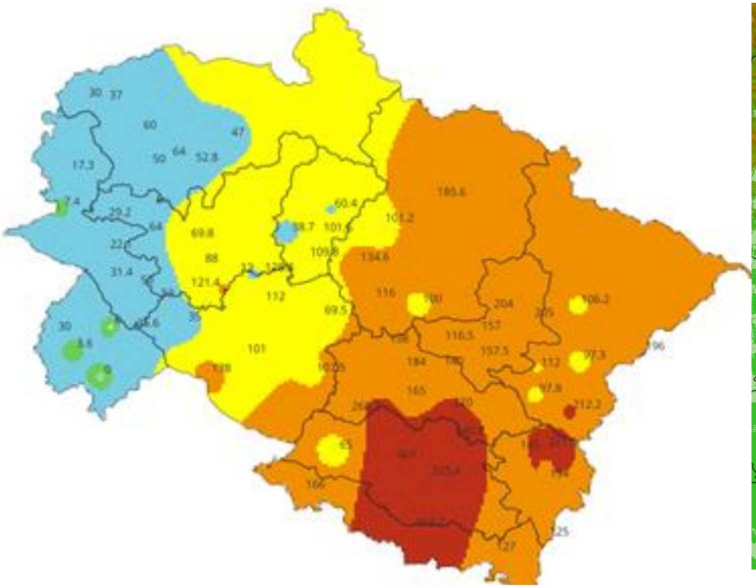
- A case of exceptionally heavy rainfall event that occurred on 18th October 2021 over Uttarakhand.
- The x-band radar at Mukteshwar was completely blanketed by low-medium clouds on 18th October 2021.

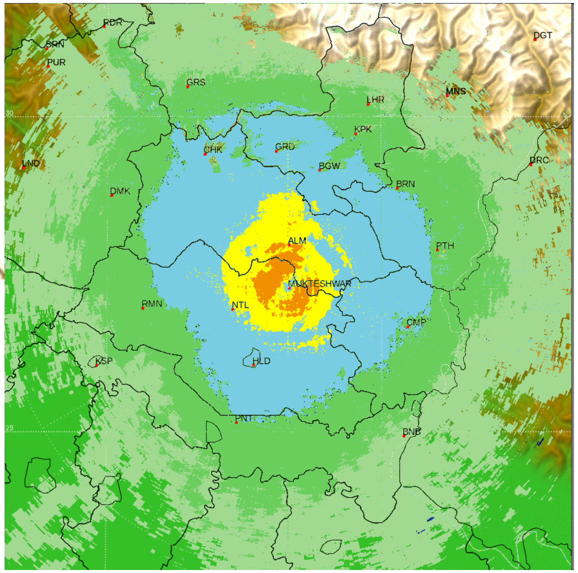
24-hours accumulated rainfall based on Raingauge

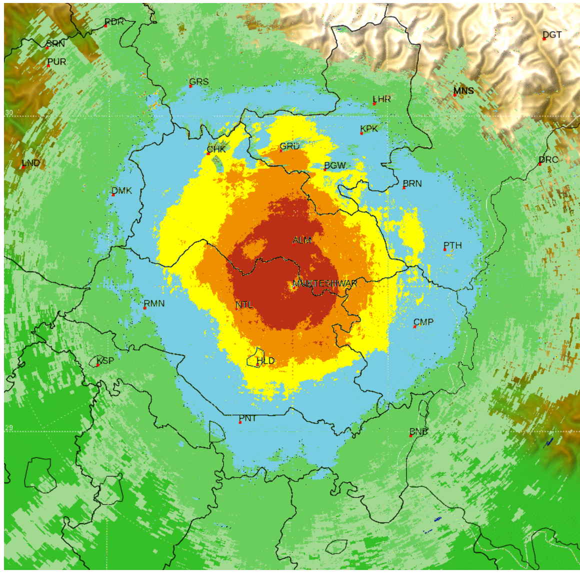
Marshall–Palmer formula

$$Z=200R^{1.6}$$

Equation (2)







Rainfall in mm

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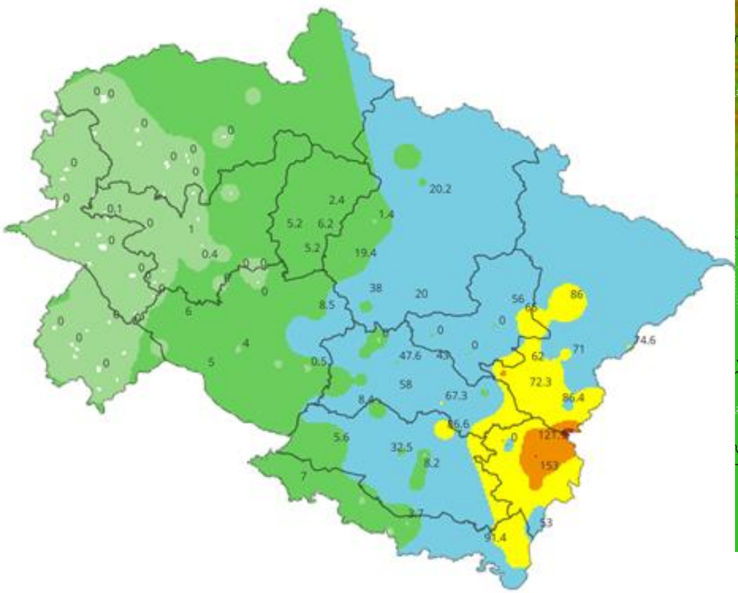
Rainfall estimation

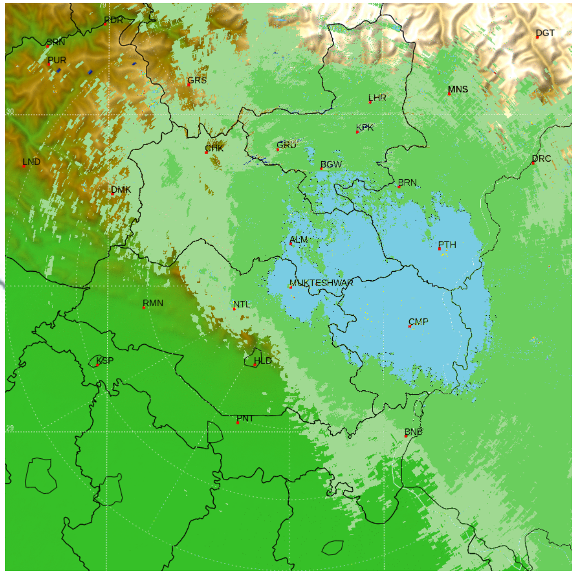
19.10.2021

24-hours accumulated rainfall based on Raingauge

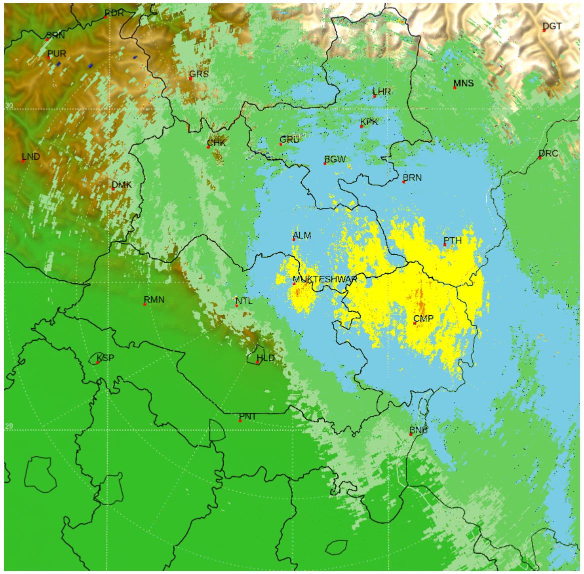


Marshall–Palmer formula

$Z=200R^{1.6}$



Equation (2)



Rainfall in mm

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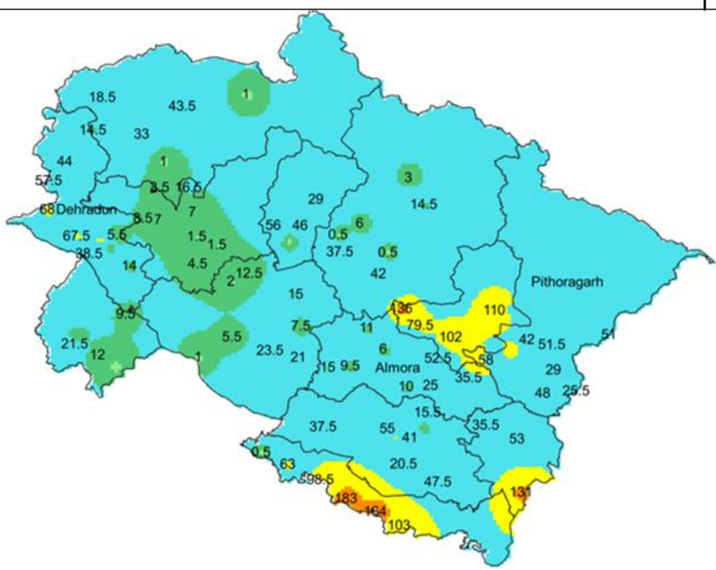
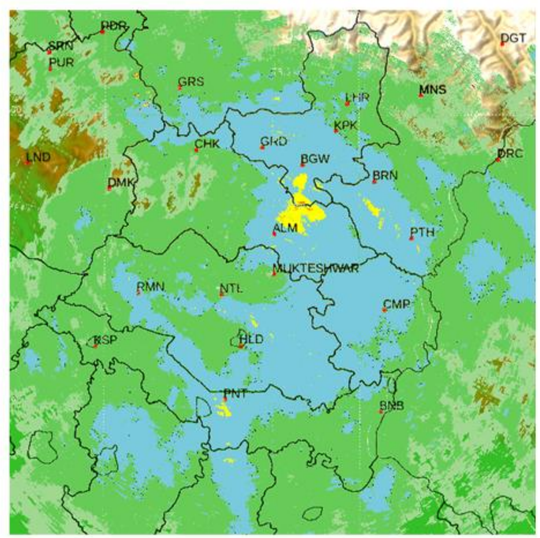
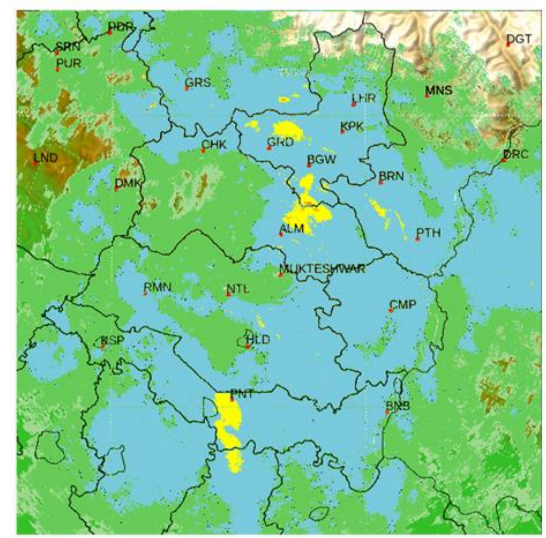
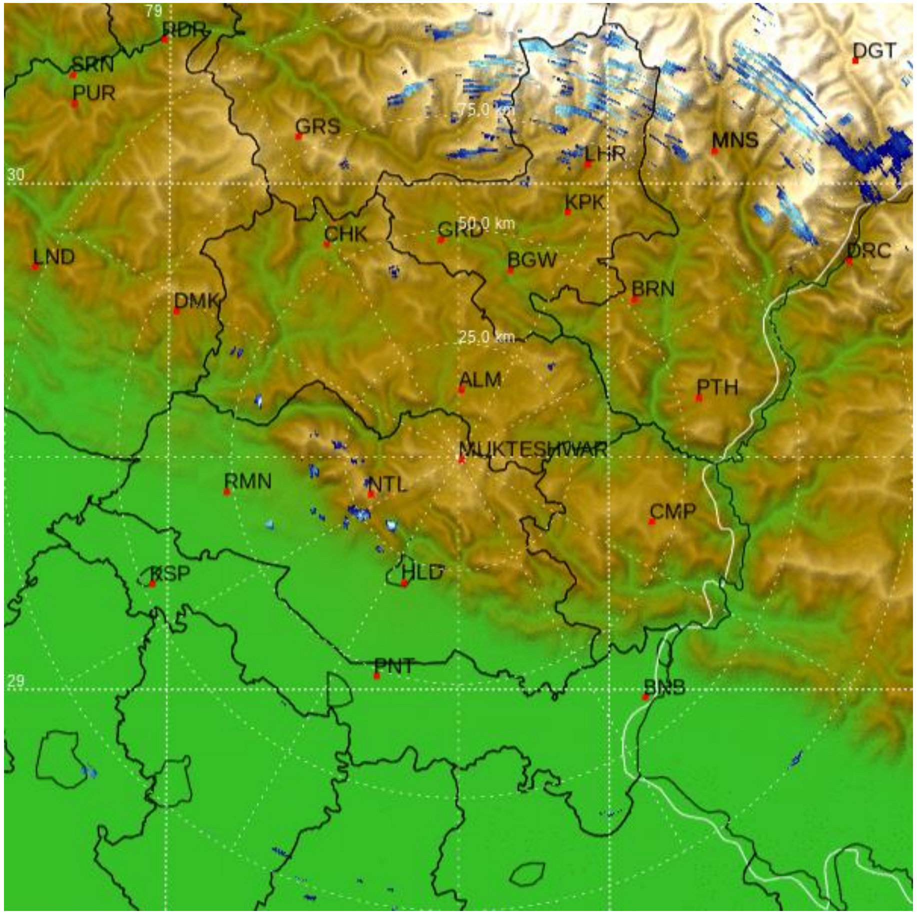
User scheme customization

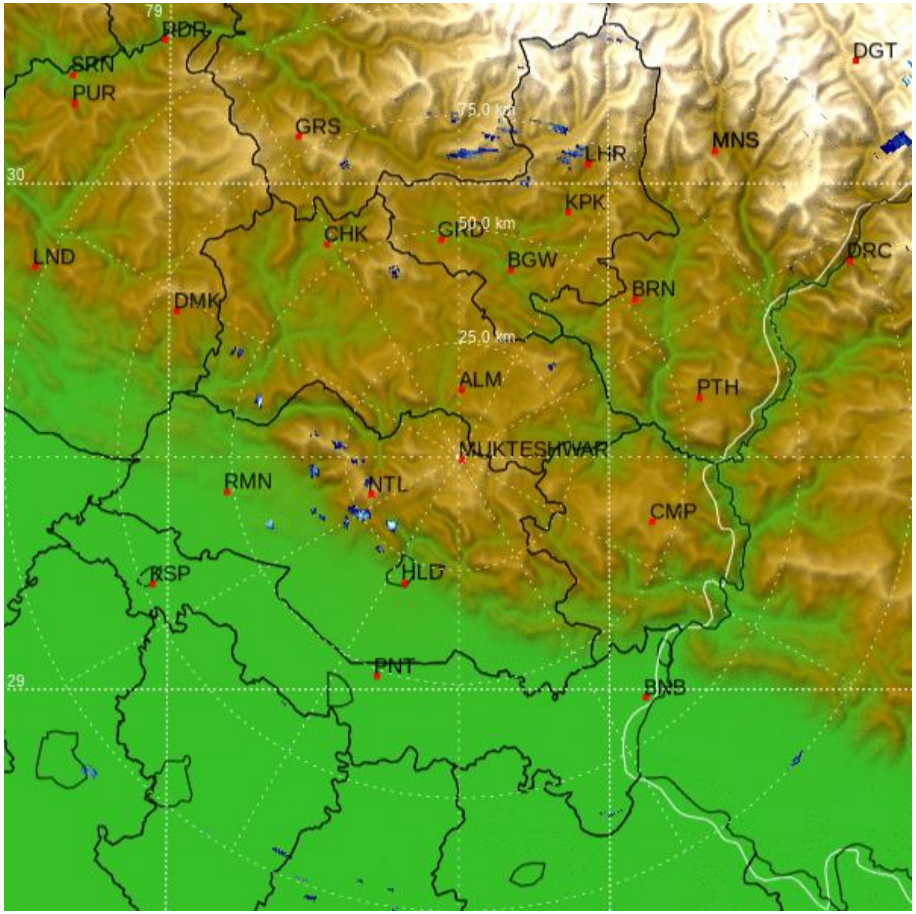
- The height of radar beam increases as the distance from the radar increases.
- The rainfall estimation can be carried out using distance varying power law in which the b parameter decreases with distance.
- $$Z = \begin{cases} \begin{cases} 31R^{1.71}\ for\ Z \leq 7000 \\ 0.828R^{3.46} + 10\ for\ Z > 7000 \end{cases} for\ d < 50km \\ \ldots \end{cases}$$ ------ (3)

24-hours accumulated rainfall based on Raingauge	Radar rainfall estimation based on	
	Equation (2)	Equation (3)
		

Clutter suppression

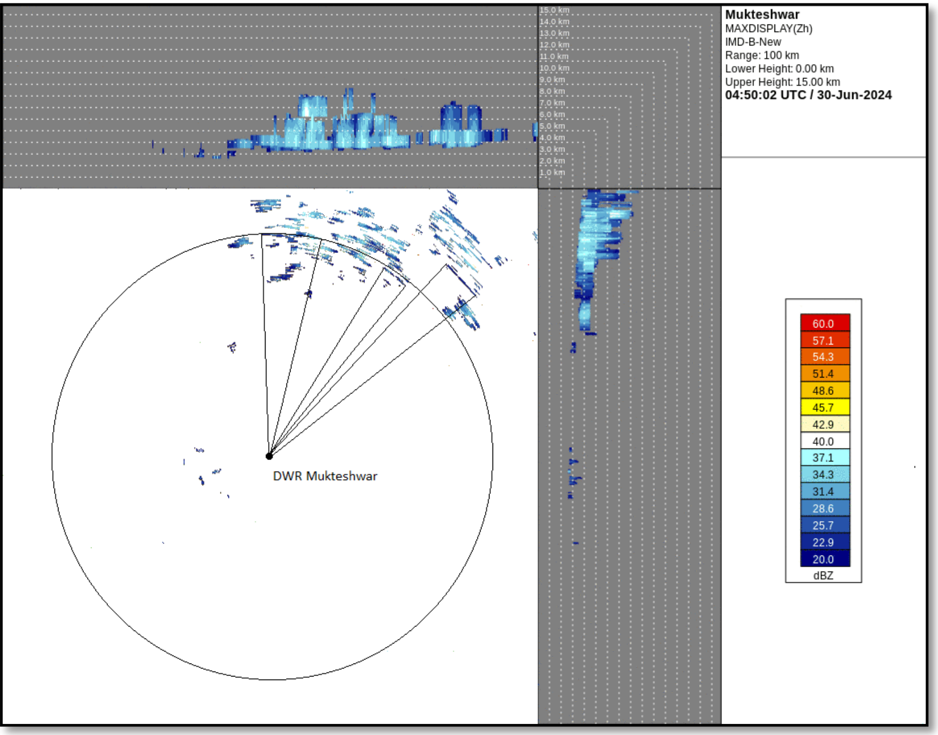
- There are higher Himalayas in the north of DWR, Mukteshwar that cause partial or total beam blockage at lower elevation angles.

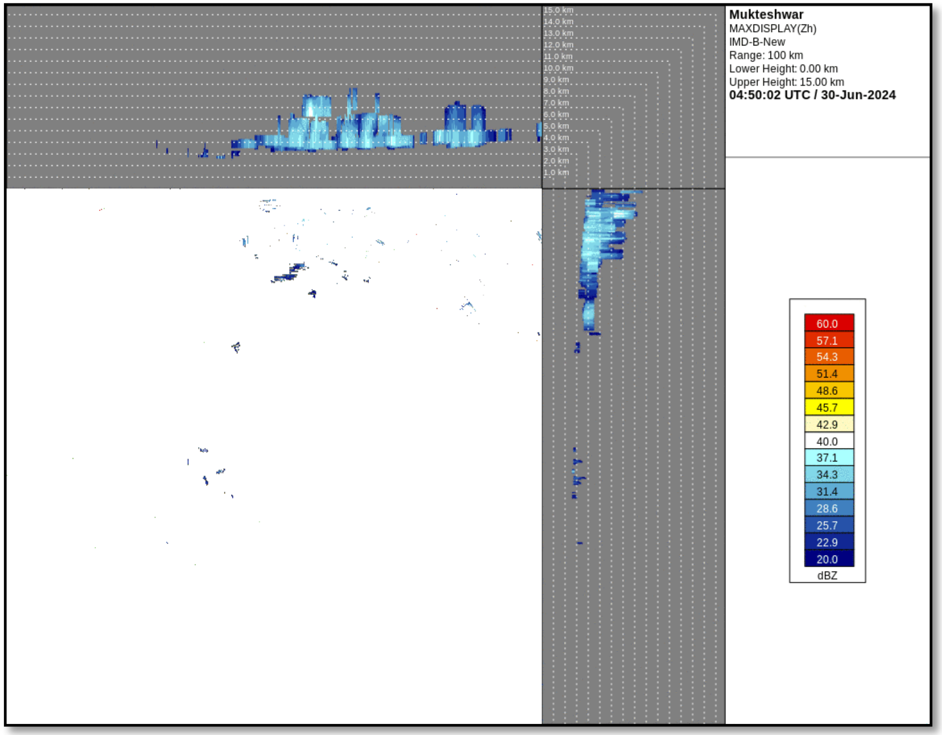




Clutter suppression

- Max(Z) image generated by DWR Mukteshwar at 04:50 UTC on 30th June 2024.
- Let radius of circle containing the clutter arc be *d* and width of arc be *w*.
- clutter suppression using *w=10 pixels*. The value of *w* can be adjusted to tune the amount of desired clutter suppression.



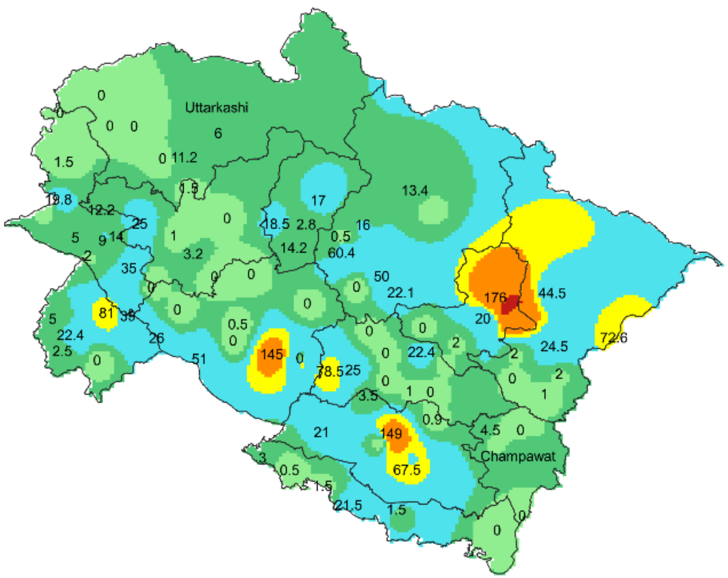


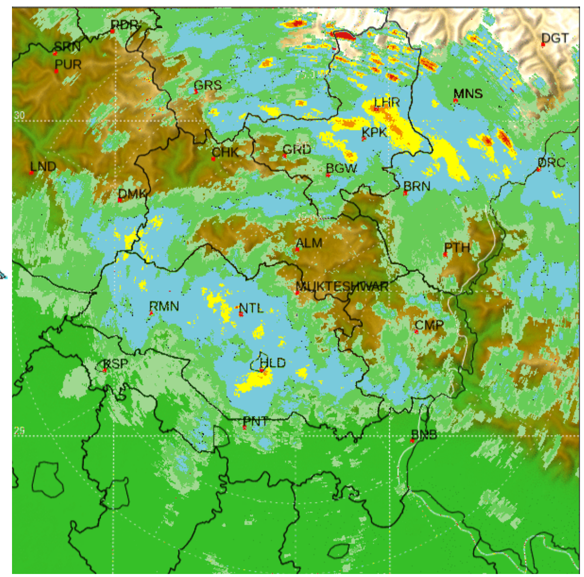
Clutter suppression

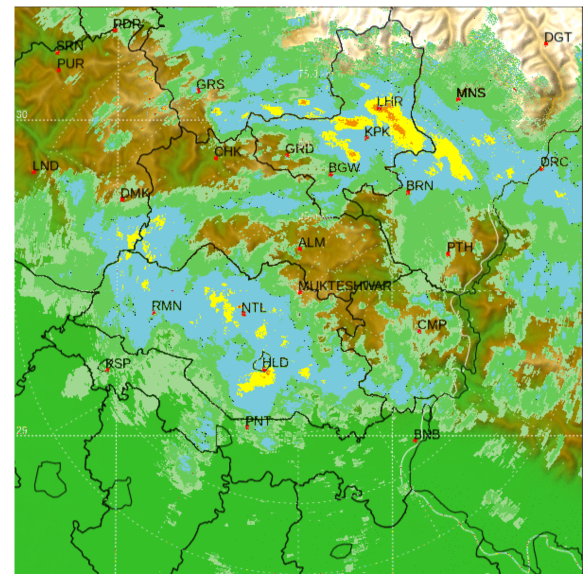
Raingauge interpolated 24-hours accumulated rainfall observed on 30th June 2024.

24-hours accumulated rainfall estimation using equation (2) without clutter suppression.

Rainfall estimation using equation (2) after clutter suppression.







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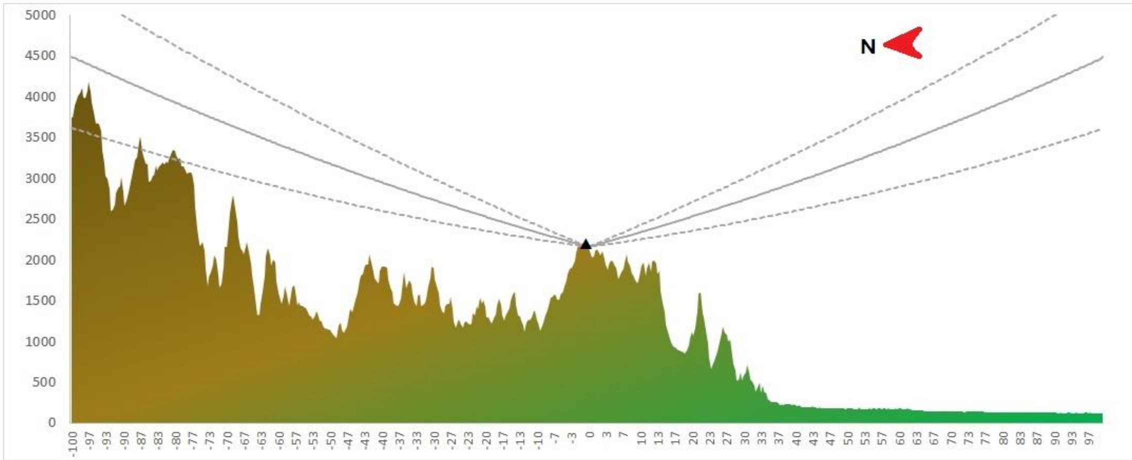
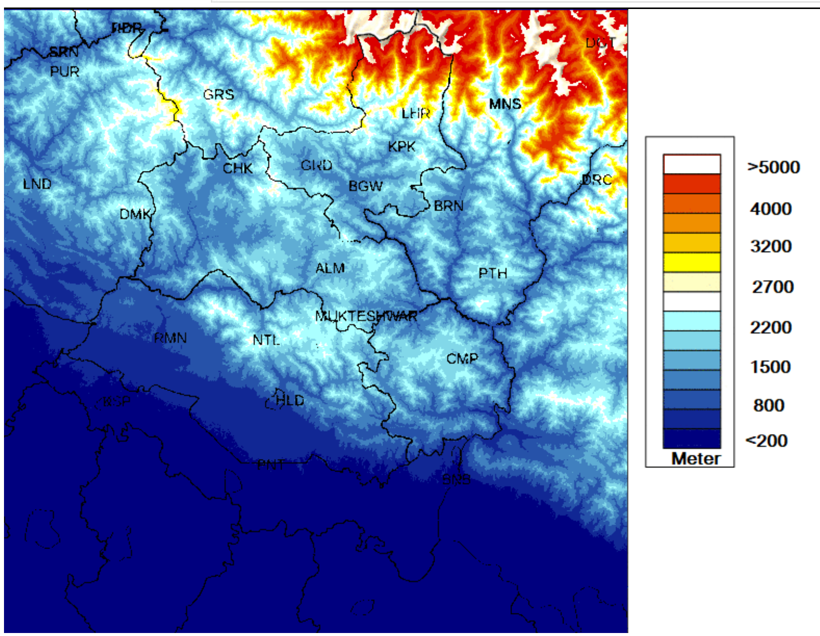
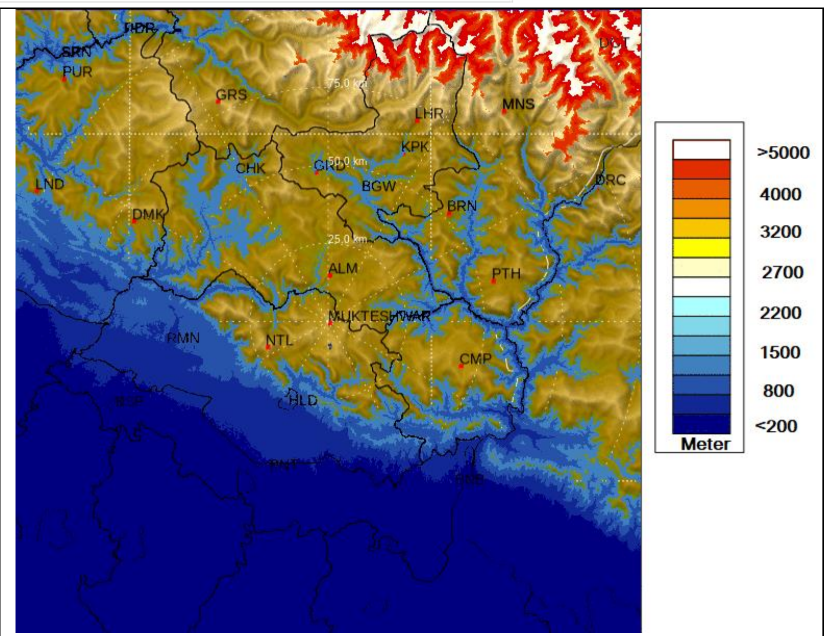
Elevation dependent customization





DEM of region covered by DWR, Mukteshwar
(a)



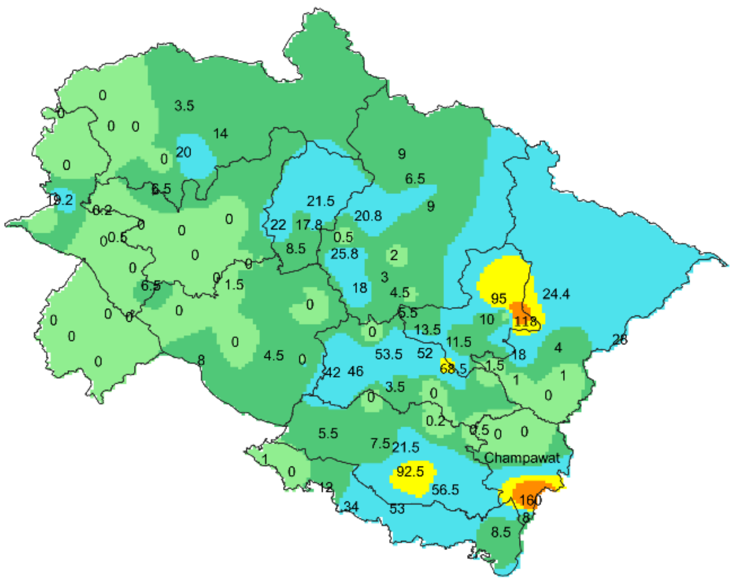
Elevation lower than 1000 m or higher than 4000m
(b)

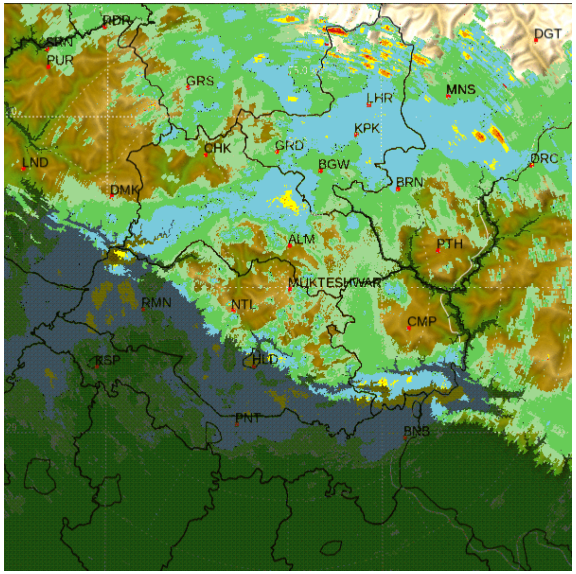
Uncertainty representation

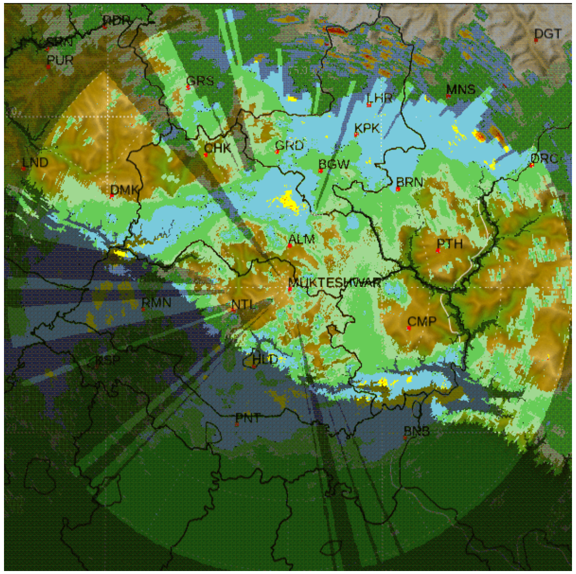
24-hours accumulated rainfall on 20th July 2024

elevation difference of 1500m or more from the elevation of DWR, Mukteshwar

radar beam blockage calculated at 0.5° elevation angle







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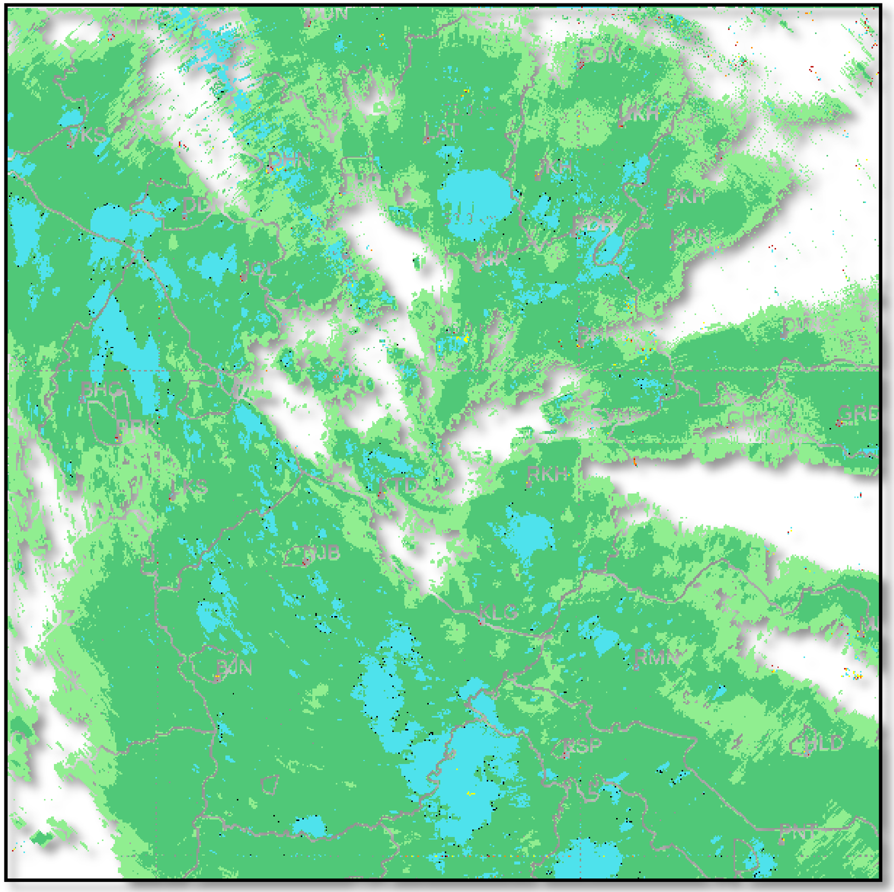
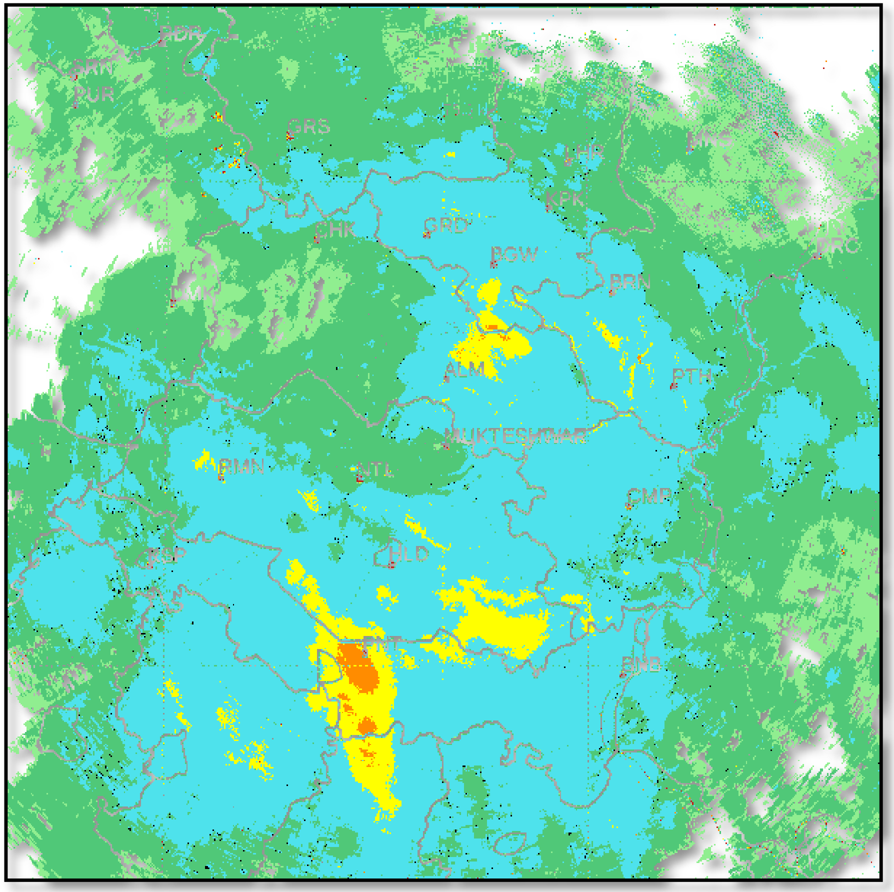
Geo-referencing

GIS raster image of 24-hours accumulated rainfall from DWR, Lansdown, 06th August 2024



GIS raster image of 24-hours accumulated rainfall from DWR, Mukteshwar, 06th August 2024



Geo-referencing

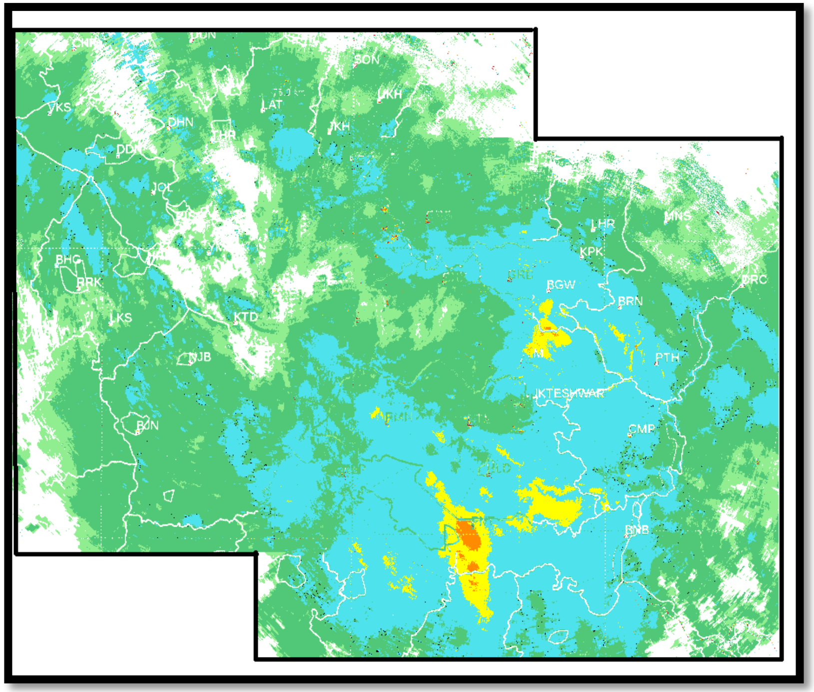
- Another important feature is creation of rainfall mosaic using more than one neighbouring radars. The pixels are represented in WGS84 geographical coordinates using map extent and haversine formula.

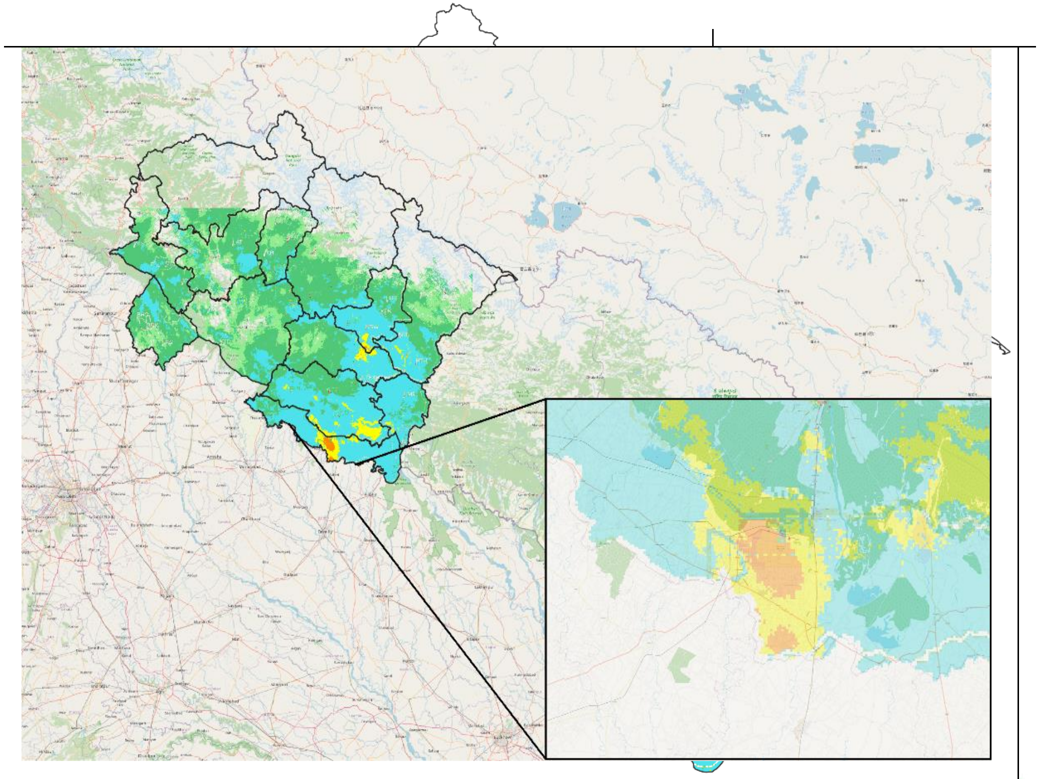
$$a = sin^2\left(\frac{\Delta\varphi}{2}\right) + cos\varphi_1 . cos\varphi_2 . sin^2\left(\frac{\Delta\lambda}{2}\right)$$

$$c = 2. atan2(\sqrt{a}, \sqrt{1-a})$$

$$d = R.c$$

- Where φ is latitude, λ is longitude, R is earth's radius and taken as 6371 km.





Thank You

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