Radar Systems End-Term Project
ECE432

Synthetic Aperture Radar
Group-2

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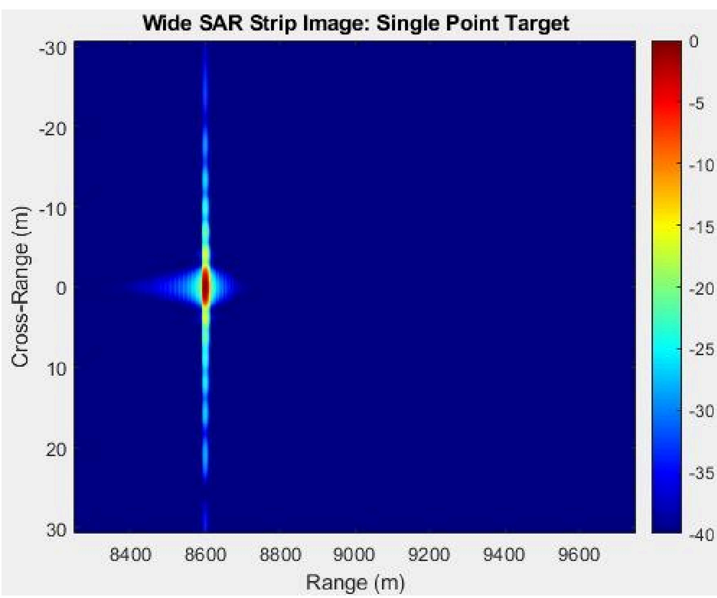
1. Setting up a Synthetic Aperture Radar problem on MATLAB.

- Radar and System Parameters:
  1. fc=10GHz
  2. lambda=0.03m(3*10^8 / 10*10^9)
  3. B=20MHz
  4. Pulse Width=10us
  5. Chirp rate(K)=2*10^12 Hz/s
  6. vp=150mps
  7. altitude(h)=5km
  8. P_tx = 1W
  9. G= 0dB
- Target Placement
  1. Single point target at a fixed slant range of 7000m.
  2. n_pulses=4096
  3. slant range=sqrt(7000^2 +h^2)



Observations:

1. Bright and dark stripes are observed denoting the point object at a range of near about 8600m where we expect it to be.
2. Side lobes in all four directions.

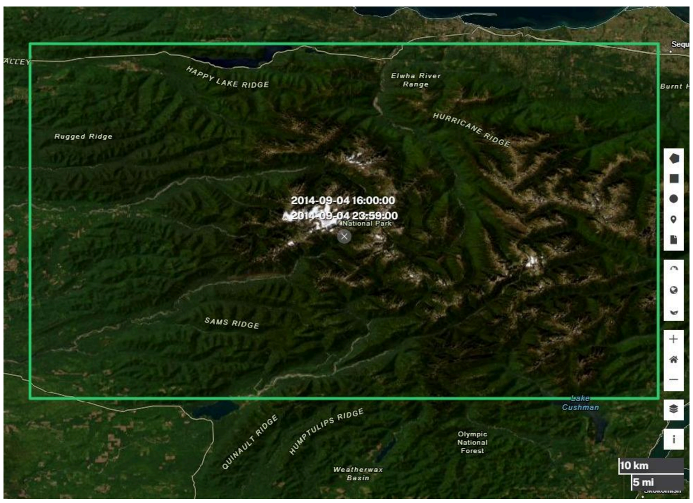
2. Using DEM(Digital Elevation Model) for real target and it's strip map image

DEM represents the Earth's surface elevation in 2D. It helps in simulating performing topography based SAR processing. The DEM data was obtained in (.tif) format, link for the website having the data:- [link]

.tif file name:

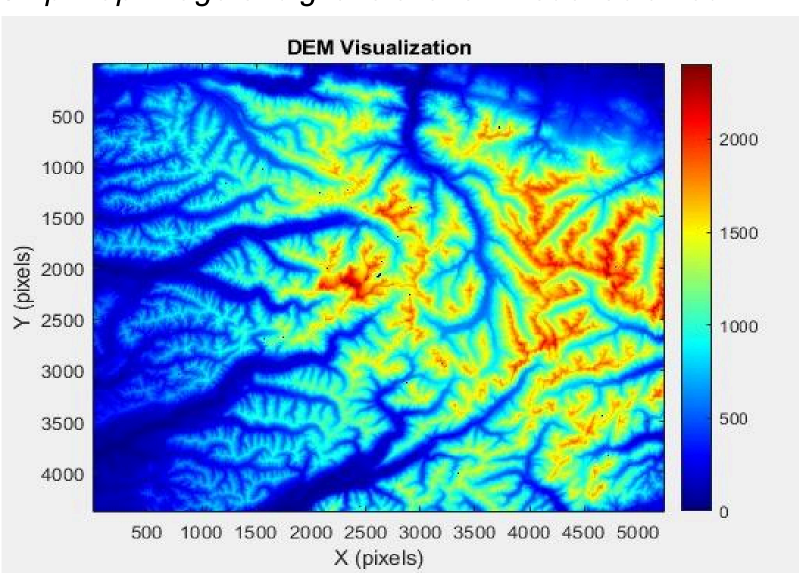
olympex_ASO_USWA_OL_20140904_f1a1_mcc_bareDEM_3p0m_despiked.tif

Image of the topography from the NASA website.

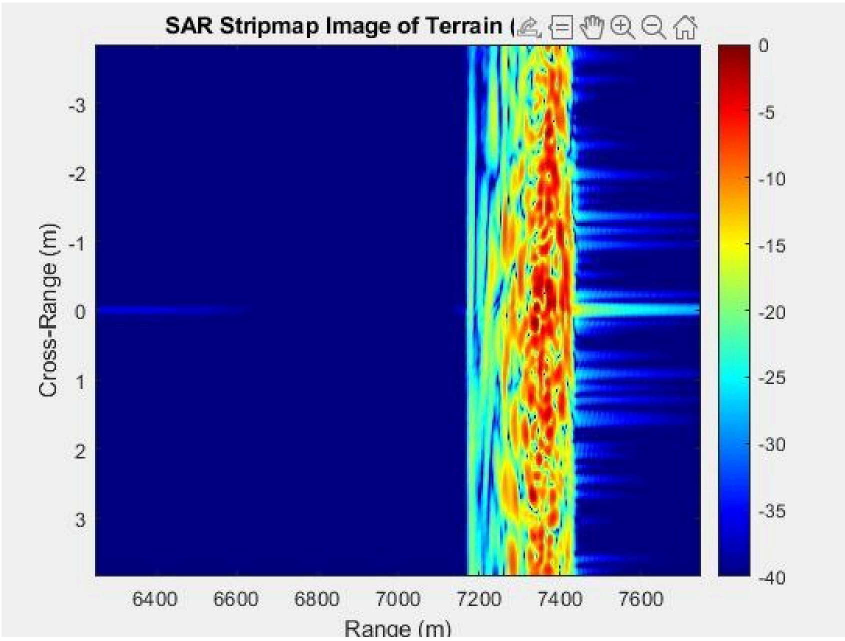


Outcomes and Results

Strip map image of digital elevation model obtained in tif file.



SAR strip image of Terrain obtained:



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(Note: The observed range differences when using .tif files are most likely due to a combination of georeferencing inconsistencies, terrain correction effects, data padding/cropping, and visualization scaling-all of which can shift or distort the range axis relative to the ideal, simulation-based image .)

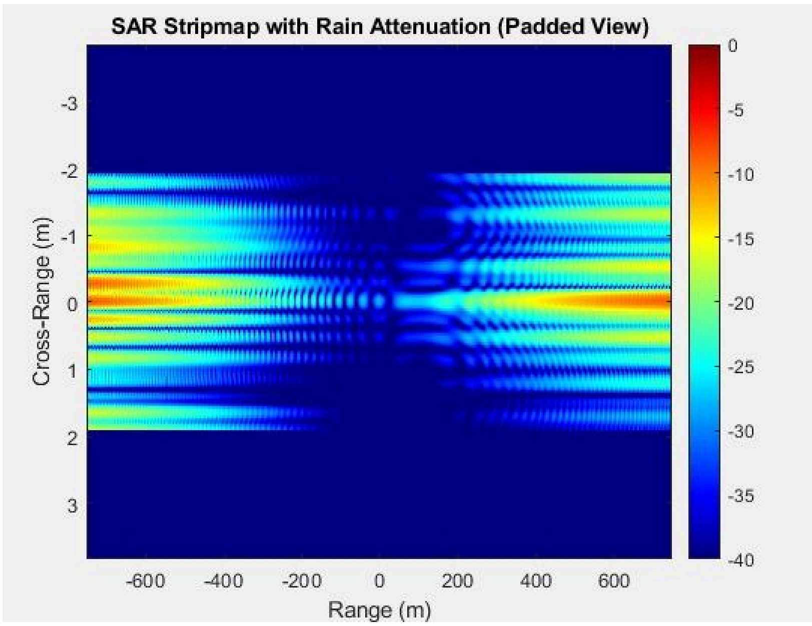
<u>Observations:</u>

1. High elevations: red to yellow shades(nearly above 1200 m and going beyond 2000 m)
2. Low elevations: blue shades. They represent lower elevations ranging between 0 to 500m. They could be valleys or plains.
3. Hence, DEM is ideal for SAR simulations in mountainous terrains.
4. The areas left of 7200m and right of 7450m show flat terrain with little elevation change.

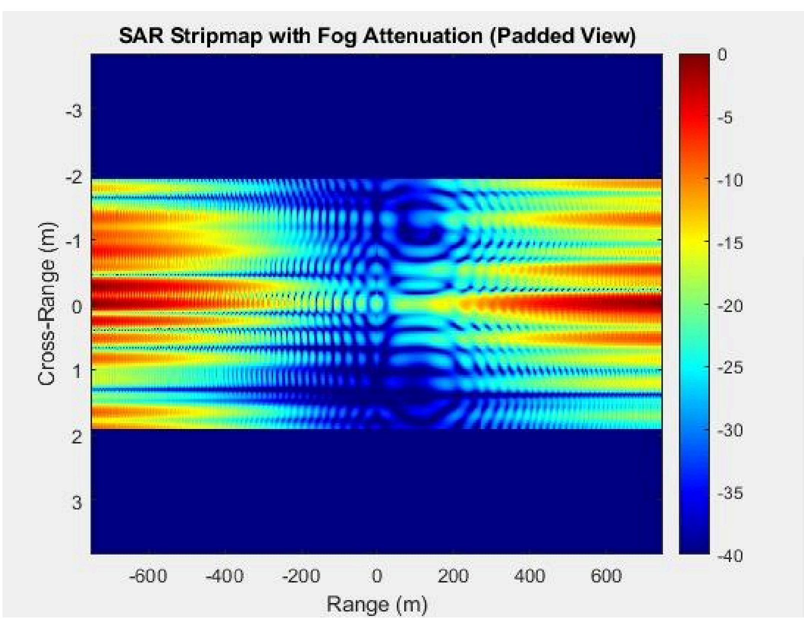
3. Incorporating weather conditions to see the changes

We have done zero padding for a distinguishable view between different weather conditions like rain, fog and snow.

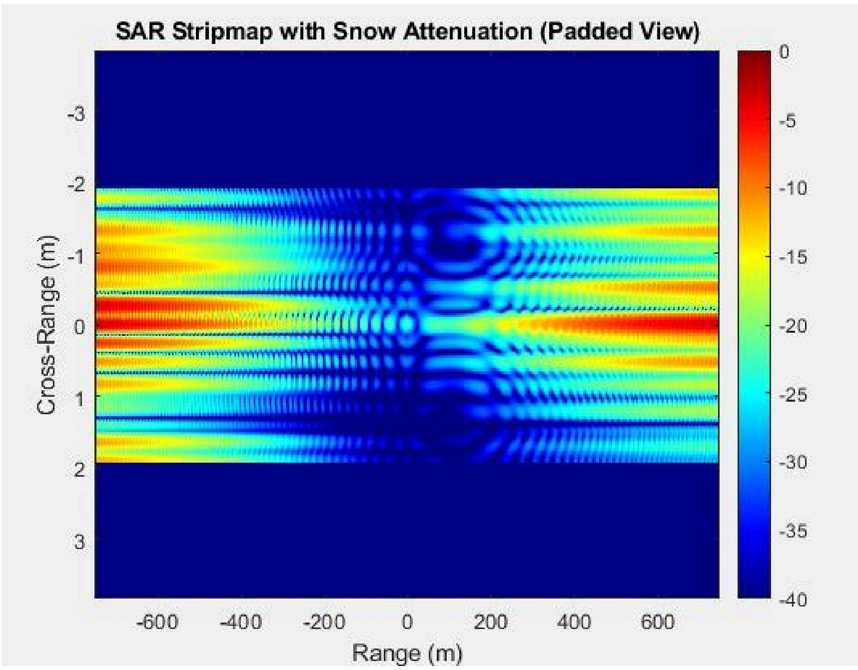
1. Rain



2. Fog



3. Snow



(Note: The observed range differences when using .tif files are most likely due to a combination of georeferencing inconsistencies, terrain correction effects, data padding/cropping, and visualization scaling-all of which can shift or distort the range axis relative to the ideal, simulation-based image .)

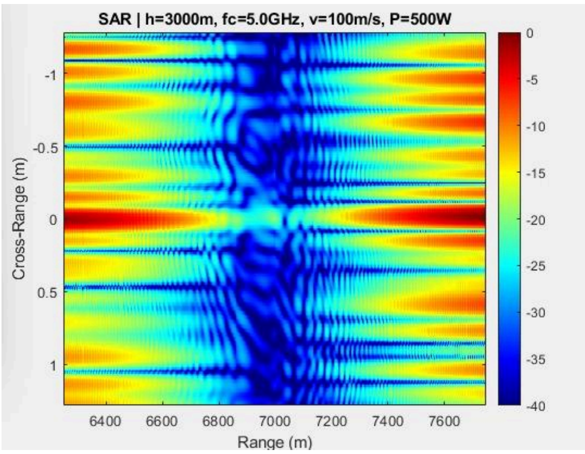
Data Source:

- **Filename**: olympex_ASO_USWA_OL_20140904_f1a1_mcc_bareDEM_3p0m_despiked.tif
- Negative height values in the DEM were removed and replaced with Nan, and missing values were filled using the mean elevation of the selected region.

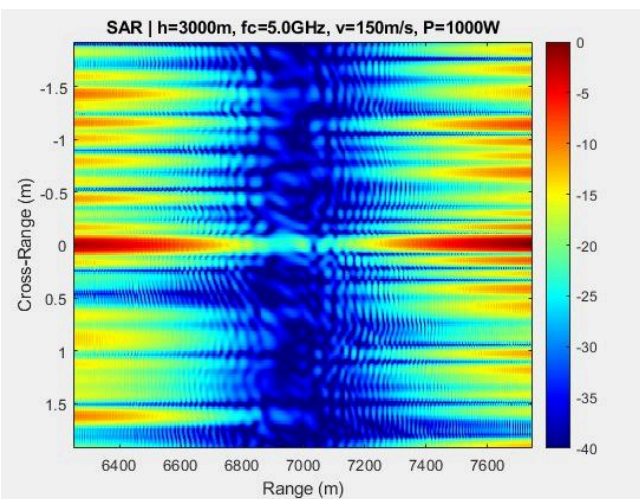
Observations:

1. ***Fog****:Good target visibility.Mild signal loss (colors still vibrant).*
2. ***Snow****:Slightly more fading in edges than fog.Still preserves moderate contrast.*
3. ***Rain****:Strongest attenuation — reflectors much dimmer.Higher loss in brightness especially near edges.Central region still visible but weaker. It shows rain impact.*

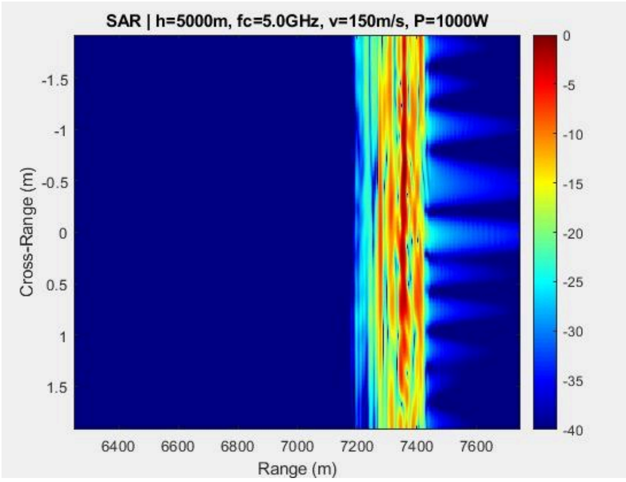
4. Combinations of different altitudes, elevation angles, antenna gains, wavelength,velocity, PRI and power



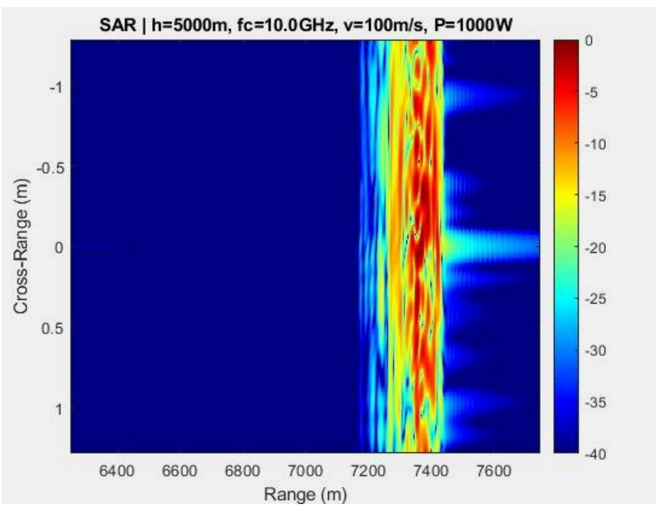
Conclusion: the SAR image will be of coarse resolution, showing reflectors that are blurred.



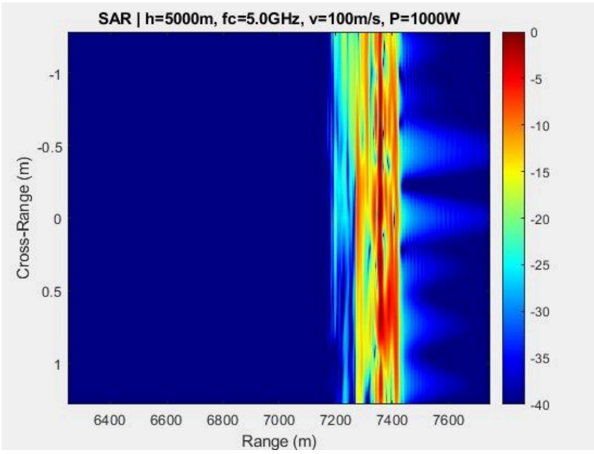
Conclusion: This configuration combines sharper azimuth resolution (150 m/s) with better signal strength (1000 W) — ideal for high-quality imaging in real-world applications



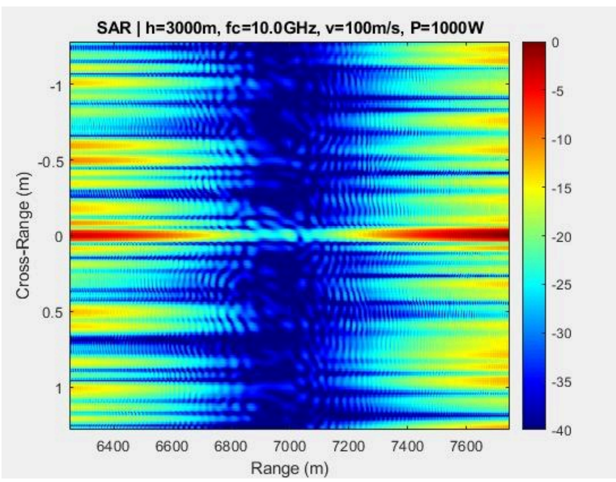
Conclusion: This configuration results in a narrow, high-altitude stripmap return, showing compressed terrain visibility



Conclusion: This configuration provides good range resolution but weaker azimuth sharpness due to slower platform speed



Conclusion: This configuration yields a narrow, lower-resolution image in both range and azimuth



Conclusion: Lacks sharpness across cross range but well suited for fine structured ranging.

We had more than 20 simulations done but it was not feasible to add all of them therefore we've added only 5. The below were cases that we had run the code for:

```
%% --- Parameter Sets ---
altitudes = [3000, 5000];                 % in meters
frequencies = [5e9, 10e9];                % in Hz
velocities = [100, 150];                  % m/s
powers = [500, 1000];                     % in Watts
PRI = 1e-4;                               % Pulse Repetition Interval
T_p = 10e-6;                              % Pulse width
B = 20e6;                                 % Bandwidth
Fs = 2 * B;
K = B / T_p;
n_pulses = 256;
c = 3e8;
```

In a **Synthetic Aperture Radar (SAR)** system, essential parameters such as altitude, elevation angle, antenna gain, wavelength, platform velocity, pulse repetition interval (PRI), and power transmitted have major roles in specifying performance, image quality, and usefulness for numerous applications. Every parameter has specific benefits and trade-offs that should be well managed during radar system design and operation.

Altitude directly affects the radar's ground resolution and swath width. Increased altitude provides increased view angle and larger coverage, which is advantageous for mapping large areas such as glaciers or forests. Increased altitude, however, also means increasing the slant range to targets, causing signal attenuation caused by the R4R^4R4 dependence of the radar equation, thus weaker echoes and worse signal-to-noise ratio (SNR), unless made up by increased power or gain. Equivalently, elevation angle impacts radar beams intersecting the terrain. Lower elevation angle provides more ground coverage per pulse but generates higher geometric distortions such as foreshortening and layover in mountainous terrain. On the other hand, a greater elevation angle provides better resolution in steep terrains but compromises swath width.

Antenna gain raises the directional concentration of the radar and increases power received without boosting transmitted power. More gain enhances SNR and resolution, particularly valuable in high-resolution imaging or detection of small objects. It does degrade beamwidth, though, tending to shorten it and making the radar smaller per pulse coverage. Wavelength, generally at microwave levels with SAR, also influences penetration and scattering. Greater wavelengths (e.g., L-band) are able to penetrate vegetation and soil, perfect for forest and agricultural uses, whereas smaller wavelengths (e.g., X-band) offer better resolution but are more apt to be attenuated by rain or snow. Wavelength selection therefore needs to take into account the application requirements.

Platform speed is important for SAR since it defines the synthetic aperture length and thus cross-range resolution. A platform with higher speed causes larger Doppler spread, and thus higher azimuth resolution, but demands higher sampling rates (lower PRI) to prevent aliasing. The slower platform, however, gathers more of the same target's echoes, enhancing resolution but slowing coverage. Pulse Repetition Interval (PRI) governs the temporal distance between pulses and determines maximum unambiguous range and Doppler sampling. A longer PRI permits imaging of far targets but restricts maximum measurable velocity because of Doppler ambiguity. A shorter PRI images high-speed targets more accurately but can cause range ambiguities if the echoes from one pulse arrive after the next pulse is transmitted. Properly balancing PRI is essential to prevent image artifacts and proper SAR focusing.

Lastly, transmitted power directly scales the signal strength. Increased power guarantees more energetic returns and more improved image contrast, particularly from remote or low-RCS targets. Yet, it raises power usage and could necessitate more substantial and heavier hardware, which is less desirable for light UAV or miniature satellite platforms. Thus, trade-offs frequently include a mix of playing with antenna gain, system bandwidth, and pulse duration along with power to ensure a desirable performance range.

In short, the design of SAR systems is an N-dimensional optimization problem in which each parameter will be tuned with respect to application objectives—whether high-resolution urban mapping, forest biomass estimation, or ocean monitoring—and subject to platform and environmental limitations.

Team Members Contributions:

- **Abhinav Saxena:** strip map image of point target, report making, weather conditions, incorporating different combinations.

- **Devanshu Chandela:** DEM visualization, report making, weather conditions, incorporating different combinations.

- **Naman Garg:** strip map image of point target, report making, incorporating different combinations, weather conditions.