

SUSTAINABLE MINING AND GEOINFORMATION

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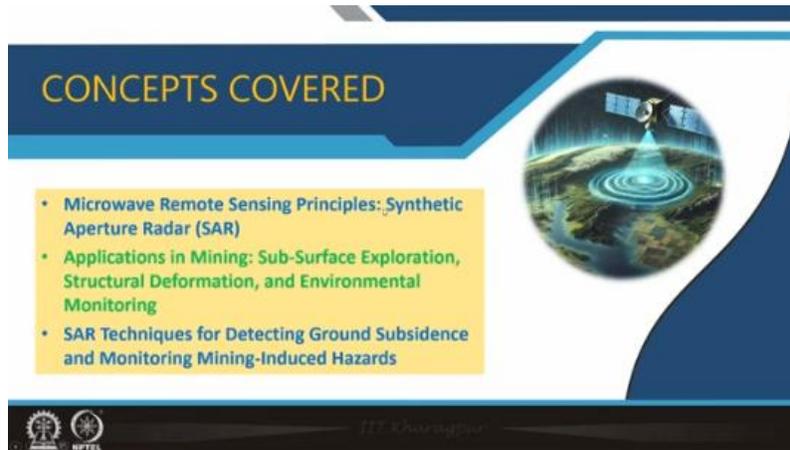
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Week – 01

Lecture 04: Microwave Remote Sensing

Welcome to the fourth lecture. Let's talk about microwave remote sensing in the course Sustainable Mining and Geo-Information. We also know it in parallel as SAR remote sensing. Sometimes we call it synthetic aperture radar. So, let us understand what microwave remote sensing is and how it is useful for the sustainable mining sector. So, the concepts we are going to cover are these three. The first one is microwave remote sensing principles. Let us understand what the principles of microwave remote sensing are, especially the SAR synthetic aperture radar.



And through that, we will also try to understand what interferometry is and what differential interferometry is, and how this interferometry or differential interferometry has an added advantage over SAR, as well as its applications for mining industries. Second, we will also talk about different applications of microwave remote sensing in the mining sector, particularly subsurface exploration, structural deformation, and environmental monitoring-related activities. So, SAR techniques are used for detecting ground subsidence and monitoring mining-induced hazards. So, how this deformation, in terms of subsidence and deformation, can also be understood and studied using

microwave remote sensing. Let us also learn from this particular fourth lecture on microwave remote sensing.

So, the overview of microwave remote sensing includes these six: it uses, if we remember, the electromagnetic spectrum that starts, in order of increasing wavelength, from cosmic rays, X-rays, gamma rays, ultraviolet, visible, then infrared, microwave, and radio waves. Towards the last but one, I mentioned the term microwave, which means it ranges between one millimeter to one meter in wavelength. And the frequency is between 300 megahertz to 40 gigahertz. So, that is the range within which the microwave wavelength falls or resides. So, microwave remote sensing can be both passive and active.

The slide is titled "Microwave Remote Sensing" and is divided into two main sections. The top section, "OVERVIEW", lists six key points: it uses wavelengths from 1 mm to 1 m (300 MHz to 40 GHz); it can be both active and passive; it penetrates clouds, haze, and light rain for all-weather, day-and-night observations; it captures unique environmental data like sea wind, soil moisture, and precipitation; it utilizes frequency characteristics, Doppler effects, polarization, and backscattering; and it requires sophisticated data analysis. The bottom section, "Examples of Microwave Remote Sensing Satellites", lists Radarsat-1 and 2, Sentinel-1A and 1B, and RISAT-1, 2, 2B, and 2BR1. A small video inset shows a speaker in the bottom right corner.

Microwave Remote Sensing

OVERVIEW

- Uses Microwave Wavelengths from 1 mm to 1 m (300 MHz to 40 GHz)
- Microwave Remote Sensing can be both **Active** and **Passive**
- **Penetrates** Clouds, Haze, and Light Rain, enabling **All-Weather, Day-n-Night** Observations
- **Captures unique environmental data** not possible with visible and infrared sensors, including Sea wind and wave direction, **Soil moisture, Precipitation**, Sea-surface temperature, **Snow cover and water content**, Atmospheric and cloud water content
- Utilizes **Frequency Characteristics, Doppler effects, Polarization and Backscattering**
- Requires **Sophisticated Data Analysis and Processing** due to its Complexity

Examples of Microwave Remote Sensing Satellites

- **Radarsat-1 and Radarsat-2** (Canadian Microwave Remote Sensing Satellites)
- **Sentinel-1A and 1B** (Part of the European Union's Copernicus Space program)
- **RISAT-1, RISAT-2, RISAT-2B and 2BR1** (Indian Microwave Remote Sensing Satellites)

[Ghosh and Behara, 2021]

Passive means it does not use any source on its own. Active means it has its own source of transmission or emission. So, microwave has an advantage over microwave remote sensing has an advantage over the traditional optical remote sensing in overcoming the limitations as far as cloud penetration hedge or light rain penetration is concerned. thereby the microwave remote sensing is often regarded as all weather remote sensing or day and night observational remote sensing so it has an added advantage of cloud penetration haze and light rain penetration and through microwave remote sensing what it does it helps in capturing unique environmental data which have lot of application in terms of soil moisture, precipitation, snow and water content and few more that have implications in terms of mining sector.

The microwave remote sensing utilizes frequency characteristics so we remember a bit of physics as far as Doppler effect is concerned the term polarization and the backscattering sometime we measure it in terms of backscatter coefficient. So, microwave remote sensing requires sophisticated data analysis and processing due to lot of complexities it

involves. So, it is unlike optical remote sensing microwave data processing is much more complex. We received lot of noise in the data. So, noise reduction is very very important and a challenge still on the with in use of the microwave data.

and then how to extract the feature which is of our interest and unlike the optical remote sensing where the principle is reflectance or absorption here the principle is backscattering or the response what we get is we say we receive it in terms of or we analyze it in terms of backscatter coefficient so let us understand this in comparison to optical remote sensing. So, the examples of microwave remote sensing satellites are we remember in past or early days the ERS-1 and ERS-2 given by European space agency. And then the Canadians they have also launched the satellites in microwave domain. Those are regarded as Radarsat-1 followed by Radarsat-2. Recently the again the European Union under their Copernicus space program a very comprehensive program the first two that is sentinel series of 1A and 1B are the microwave data.

So, we have microwave data in SAR. So, the Sentinel-1A and Sentinel-1B are microwave remote sensing datasets. As far as Indian microwave remote sensing is concerned, we have RISAT-1, RISAT-2, RISAT-2B, and also the 2BR1. So, there are a few more examples as far as microwave remote sensing satellites are concerned. Coming to the first one, passive microwave remote sensing, let us understand this so that we can differentiate passive from active microwave remote sensing.

Passive Microwave Remote Sensing

<p>Passive Microwave sensors are typically Radiometers or Scanners that use Antennas to Detect and Record Microwave Energy</p>	<p>All Objects Emit small amounts of microwave energy, which a passive microwave imager detects within its field of view</p>
<p>The Emitted Energy Relates to Temperature and Moisture properties of the Emitting Object or Surface</p>	<p>These Sensors generally record Energy in the 0.15 cm to 30 cm range (1 GHz to 200 GHz), beyond the Thermal Infrared Region</p>
<p>Examples of Passive Microwave Imagers are SSM/I, TMI, AMSR-E and NSMIR</p>	<p>Microwave Energy Recorded by Passive Sensors may come from: The Atmosphere (A) Surface Reflections (B) Surface Emissions (C) Sub-surface Transmissions (D)</p>

(a) Passive Microwave RS Satellite

(b) Process of Passive Microwave RS

(Bhatta, 2020)

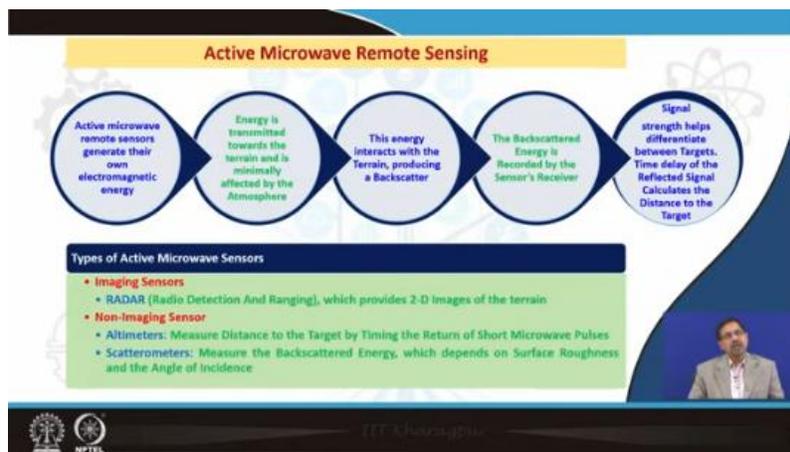
So, passive microwave sensors are typically radiometers or scanners. They use a kind of antenna to detect or record the microwave energy emitted from the target or emitted by the target. So, you can also see the picture on the upper right-hand side: the passive microwave antenna solar array. So, all objects emit small amounts of microwave energy, which a passive microwave imager can detect within its field of view. So, once detected,

the emitted energy relates to or corresponds to the temperature or moisture properties of the emitting object or the surface of interest.

So, the energy emitted corresponds to the amount of temperature or moisture it has. So, that way, we get some quantification of the heat content in terms of temperature or moisture of the target. So, these passive microwave sensors generally record energy in the range of 0.15 to 30 centimeters, which corresponds to 1 gigahertz to 200 gigahertz in the frequency domain. It goes beyond the thermal infrared region. So, sometimes this sensing is also compared with normal land surface temperature or thermal remote sensing.

So, examples of passive microwave imagers are SSM/I, TMI, AMSR-E, and MSMR. There are a couple more passive remote sensing sensors; active means acting in the microwave domain. So, let us focus on the lower right corner figure, which is figure B, depicting the process of passive microwave remote sensing. You can see A, B, C, D, and on the left-hand side, you have the source of the antenna or antenna source from where the energy is emitted, and this is the receiver. So, microwave energy recorded by passive sensors may come from the atmosphere (look at A), or it could also come from surface reflections (B), surface emission (C), or subsurface transmission.

So, microwave energy may come from these four different sources and can be recorded by the passive sensors. So, it is left to the interpreter to understand these four different variations of the energy source and differentiate or account for them. Let us talk about active microwave remote sensing. We can understand this in five different stages. Active microwave remote sensors generate their own electromagnetic energy.



This energy is transmitted from their own source toward the terrain or the object of interest, and it is minimally affected by the atmosphere. Since you regulate it, you have control, so you optimize and take advantage to minimize atmospheric hindrance. Once this energy is transmitted, it interacts when it falls on the terrain or the object of interest, producing a backscatter. This backscatter energy, produced after hitting the target or terrain, is recorded by the sensor's receiver. Once the sensor receives this signal, the signal strength helps differentiate between the targets.

So, it is the strength of the signal which helps in differentiating between the target—what was the target on the ground—from where the backscatter has been generated, and similarly, the time delay of the reflected signal calculates the distance to the target. Accordingly, the types of active microwave sensors are imaging sensors and non-imaging sensors. So, radar, which is expanded as radio detection and ranging, provides two-dimensional images of the terrain. The non-imaging sensors, such as altimeters or scatter meters, measure the distance to the target by timing the return of short microwave pulses, whereas scatter meters measure the backscattered energy, which depends on surface roughness and the angle of incidence. So, while discussing the applications, we will discuss more on surface roughness and the angle of incidence—they are very, very important and also influence the backscatter signal strength.

Coming to the understanding of SAR, the synthetic aperture radar, it is a high-resolution radar imaging technology for observing the Earth's surface, including mining areas, the mining sector, or the mining industry. Unlike optical systems, SAR can penetrate clouds and operate in any weather conditions, day or night, because it is independent of sunlight. It has its own source, which is why it falls under active microwave remote sensing, thereby making it an effective tool for continuous day and night observation of Earth's surface features. So, the working principle of SAR can be broadly understood as SAR works by transmitting radar signals from a moving platform, like satellites or aircraft, to scan the target area. So, the platform could be a satellite or an aircraft because it needs to be mounted on something so that it is able to transmit the signals. As the platform moves, like a satellite or aircraft, the SAR combines the radar signals from multiple positions to simulate a longer antenna.

Synthetic Aperture Radar (SAR)

OVERVIEW

- It is High-resolution radar imaging technology for observing Earth's surface
- Unlike optical systems, SAR can penetrate clouds and operate in any weather, day or night, making it an effective tool for continuous Earth observation

WORKING OF SAR

- SAR works by transmitting radar signals from a moving platform, like a satellite or aircraft, to scan a target area
- As the platform moves, SAR combines radar signals from multiple positions to simulate a longer antenna—known as a "synthetic aperture"

Differential Interferometric Synthetic Aperture Radar (DInSAR)

- It is an advanced SAR technique used to detect minute changes in the Earth's surface
- Utilizes Interferometry by comparing two or more SAR images of the same area taken at different times
- Measures surface displacement down to a few millimeters allowing to detect ground deformation, such as subsidence, landslides, or seismic activity, with high precision

So, that is why the term is 'synthetic'. So, physically, it does not have a longer antenna, but virtually, it synthesizes one, which is parallel to a longer antenna. So, importantly, SAR combines the radar signals from multiple positions to simulate a longer antenna, known as—or we understand it as—a synthetic aperture, which is why the term is 'synthetic aperture radar.' Coming to the third component, which is important as far as the new term is introduced: differential interferometric SAR, or you could say differential interferometric synthetic aperture radar (DInSAR). It is an advanced SAR technique which is useful for detecting very minute changes in the Earth's surface and is very well utilized in terms of interferometry. This is done by comparing two or more SAR images of the same area taken at different times.

So, like a change detection in two different time period if the SAR images have been taken simultaneously. So, then you generate an interferometric image. So, what it does that it helps in measuring the surface display displacement the even if up to a few millimeters allowing to detect any ground deformation, any variation or change as far as the height or the volume or the terrain is concerned, we can put it under ground deformation heading. So, thereby it helps us in studying the subsidence the subsidence the landslide the any other activities like seismic activities with a very high precision. So, this InSAR or SAR interferometry and the differential interferometric SAR technique is very very useful for these kinds of applications having deformation on ground including subsidence, landslide and other seismic related things with very high precision thereby helps in mining industry as far as the or piling stockpiling or change of the iron ore or the deposition everything is can be monitored with very high precision using the SAR or the synthetic aperture radar data.

So, now let us understand the difference between SAR and the differential interferometric synthetic aperture radar. On the left hand side we have put five points the difference as far as the data capture is concerned, difference as far as the output is concerned, the sensitivity is concerned, temporal analysis is concerned and several application as far as mining is concerned. So, the SAR and the differential SAR interferometry as far as the SAR is concerned the data capture point of view SAR captures the images of the earth surface using radar backscatter whereas the using differential SAR interferometry technique it uses a phase difference okay unlike the broader backscatter it uses a phase difference between SAR images taken at different time different time intervals so the phase difference is very very important as far as the data capture method is concerned using the differential SAR interferometer and let us talk about the output the variation in terms of output between SAR and DInSAR

Difference Between SAR and DInSAR		
Aspect	SAR	DInSAR
Data Capture	Captures images of the Earth's surface using radar backscatter	Uses phase difference between SAR images taken at different times
Output	High-resolution images of reflectivity and surface texture	Detailed maps of surface deformation, showing changes over time
Sensitivity	Limited to surface characteristics	Sensitive to sub-centimeter deformations, suitable for detecting small movements
Temporal Analysis	Provides a single snapshot of surface conditions	Tracks changes over time for monitoring ground deformation
Applications in Mining	General terrain mapping, infrastructure monitoring	Monitoring ground subsidence, tracking minute changes in stability, hazard warnings

As far as SAR is concerned, we have a very high resolution images of reflectivity and surface texture as far as the output is concerned. Whereas, in case of DInSAR, detailed maps of the surface deformation showing the changes over time we get. So, that means DInSAR is in terms of output is giving us a change over time A or $T1$ minus $T2$. So, over a time how much is the change in terms of the deformation or surface deformation we get it. Then coming to the sensitivity level as far as the sensitivity is concerned the SAR is limited to surface characteristics dominantly it is limited to surface characteristics unlike in case of the differential SAR interferometry it is sensitive to certain extent the sub centimeter deformation.

So, that is why or thereby it is suitable for detecting very small moments sensitive as far as the deformation is concerned. We can attribute to any causes for which it is derived. So, the sub centimeter level deformation can be observed using the differential SAR

interferometry technique. Then coming to the temporal analysis using SAR data the SAR data provides a single snapshot of surface conditions whereas differential InSAR helps us in tracking changes over time for monitoring the ground deformation. So, here you take it over time in case of DInSAR, whereas SAR it gives you a single snapshot and then you have to take several snapshots to understand how the change has happened if that is the subject of concern.

Then coming to different applications in mining sector. So, generally because of the property of SAR or microwave remote sensing it is useful for terrain mapping and other infrastructure monitoring. Whereas by nature of this differential InSAR, SAR interferometry it helps in monitoring the ground subsidence, the tracking of minute changes in stability, hazard warning, stockpiling and things like that. So, basically the basic difference between SAR and differential InSAR is that SAR gives us one time period whereas the differential InSAR gives us the change over a time. Now let us move on to understand the importance of microwave remote sensing in mining.

We have put it under four categories the subsurface exploration first second the structural deforestation monitoring third the environmental monitoring fourth the risk assessment and management and the upper line talks about the various techniques used in this domain. And the lower side, the lower boxes talks about different applications as far as the examples are concerned. So first, subsurface exploration. We can use the GPR. I have not yet mentioned about GPR, ground penetrating radar.



It is mostly a kind of handheld equipment where a radar sensor has been mounted, and it gives us some information to within a certain centimeter at the soft surface level. Thereby, it helps us in laying the cables or finding out if something is there just at the soft surface level. So, GPR is used to penetrate the subsurface layers and provides reflected

data on the hidden structures, including geology, mining, or any other infrastructure. So, the application could be using this subsurface exploration. The applications could be detecting and mapping ore bodies, such as iron ore, copper ores, or any other rare earth minerals.

So, thereby it helps in characterizing geological features like faults, fractures, and other features that affect mineral presence. So, it is a very important application as far as the radar principle is concerned, using handheld GPR technology. Let us come to the second one, which is known as structural deforestation monitoring. So, as far as the technique is concerned, interferometric SAR or interferometric synthetic aperture radar is used to capture detailed images of surface displacement over time, as we just discussed about differential. So, it gives us the change.

So, thereby the applications could be monitoring of subsurface conditions, monitoring of slope stabilization or slope stability, and other changes in the geotechnical sectors. Now, let us discuss the third one, which talks about environmental monitoring. As far as the technique is concerned, SAR imagery is used to monitor vegetation changes, pollution spread, and water quality changes. So, we can use this imagery for monitoring vegetation, pollution spread, and water quality. This could have applications in tracking pollution, surveying various properties as far as the ecosystem or the mining ecosystem is concerned, and also the habitats emerging around mining areas. So, the fourth one we put under the risk assessment and management category. So, as far as the technique is concerned, microwave remote sensing applications in the mining sector, particularly risk assessment and management.

The technique is concerned with integrating internal data with predictive models for forecasting the risk, or you could say risk forecasting. So that way, it could be applied or it can have applications in predicting hazard models. Okay, we can have a lot of hazard modeling in terms of the risk—how much risk, low, high, and different gradations of hazards—we can predict in advance. Thereby, you can take some precautionary measures, and then we can also comply with various safety protocols accordingly. Thereby, proactively, we can do hazard management and mitigation. Now, let us see or let us discuss two case studies. One is Case Study One, which has used the differential InSAR technique in Jharia coal field to detect underground mining-induced land subsidence.

Case Study 1: Detection of Underground Mining Induced Land Subsidence using Differential Interferometric SAR (D-InSAR) in Jharia Coalfields, India

- Employed D-InSAR using ALOS PALSAR data (L-band) to detect subsidence rates and identify affected areas
- 6 ALOS PALSAR data pairs from 2007-2008 to monitor subsidence across 7.2 Sq. km within the Jharia region

Process Flow: Data Processing → Interferogram Generation → Filtering and Geocoding → Subsidence Analysis

FINDINGS

- D-InSAR identified numerous subsidence fringes concentrated in the eastern part of the coalfield.
- The data indicated both gradual and rapid subsidence, with some areas experiencing displacement rates exceeding 50 cm/year.
- The Jharia case demonstrated that L-band SAR data could effectively monitor subsidence and its progression over time, providing insights critical for mitigating potential hazards in mining areas.

CONCLUSION

- SAR and D-InSAR Techniques offer essential insights into subsidence and structural deformation in mining regions.
- For Jharia Coalfields, the application of D-InSAR provided detailed temporal and spatial data, revealing high-risk zones and enabling proactive safety measures.
- This study validates D-InSAR as a reliable tool for tracking mining-induced hazards and suggests it could be similarly effective in other coal mining regions facing subsidence issues.

(Borah et al., 2017)

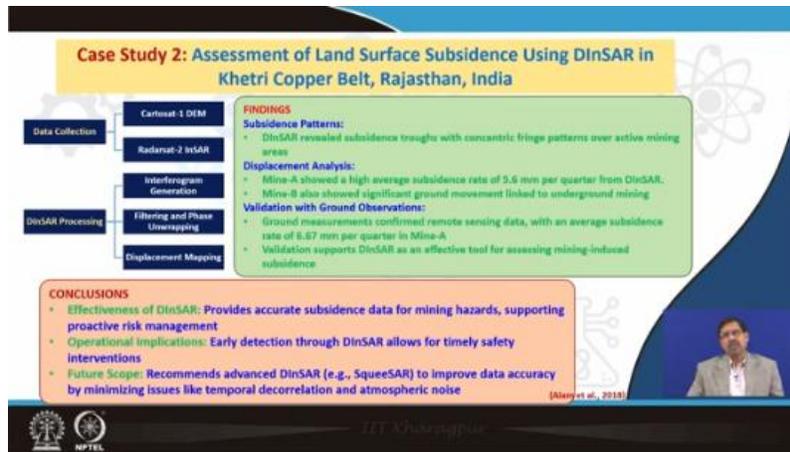
So, the DInSAR technique has been used to detect land subsidence, and that has been attributed to underground mining activities. So, it is really interesting to observe something and then attribute it to the causes that induced it. So, that involved employing DInSAR images using ALOS PALSAR data—the L-band. We have not yet discussed, or I have not yet spelled out, the nomenclature of the bands, starting from X, C, L, X, C, S, L, and P, in terms of increasing order of wavelength. And that actually we do with respect to the object or the target size on the ground.

So, we will see about the terminology—X, C, S, L, P—all these different bands, as far as microwave remote sensing is concerned, when we take some application-related lectures. So, this study employed differential InSAR using ALOS PALSAR data—the L-band data, which is a longer wavelength dataset—to detect the land subsidence rate and identify the affected areas. So, the rate has been detected because if you are starting it across time, then we have a control, and we can say something about the rate of change across time—how much per year or percent per month or per season, something like that. Then, six pairs of ALOS PALSAR data were taken during the period of 2007 to 2008 to monitor the subsidence across a small area of 7.2 square kilometers within the Jharia region. So, then, let us understand the interesting findings. The first one is that the DInSAR identified numerous subsidence fringes concentrated in the eastern part of the coal field.

The data indicated both gradual and rapid subsidence, with some areas experiencing displacement rates exceeding up to 50 centimeters per year. That means half a meter—half a meter, as you say—of subsidence has been observed per year. So, look at the beauty of using differential SAR interferometry in these kinds of subsidence studies. The Jharia case demonstrated that L-band SAR data could effectively monitor subsidence and

its progression over time. So, the use of L-band data has been justified and has been very well applied using the differential InSAR protocol. Then, let us see what conclusions have been drawn from this. Before that, the data has been processed—meaning first the interferogram has been generated, and filtering and geocoding have been done. Only then will we know how much where the subsidence happened and how much in terms of quantity. The change gives us the subsidence quantification in terms of analysis. In conclusion, SAR and differential InSAR techniques offer essential insights into subsidence and structural deformation in mining regions. These kinds of studies have proven the strength of DInSAR technology for temporal and spatial analysis. Thereby, its usefulness lies in revealing high-risk zones and providing information for proactive safety-related management and measurement protocols. This study validates DInSAR as a reliable tool for tracking mining-induced hazards and suggests it could be similarly effective in other mining areas with subsidence issues.

Let us take another case study in the Khetri copper belt in Rajasthan, where the assessment of land surface subsidence has again been done using differential InSAR. The data collection included Cartosat-1 DEM and Radarsat-2 InSAR data. Look at this: Cartosat-1 is an optical sensor providing very high-resolution data, and this Radarsat-2 InSAR data has been used in a hybrid mode. The DInSAR processing involved these three steps: interferogram generation (so that you get a change), filtering, and phase unwrapping. That is how we can get the displacement, which is the subsidence. The major findings are: DInSAR revealed subsidence drops with concentric fringe patterns over active mining. Mine A showed a very high average subsidence of 5.6 millimeters per quarter, whereas Mine B showed significant ground movement linked to underground mining. So, what I can say here is that, using the hybrid data principle—data merging—we got good results in terms of displacement amount or quantification, which was revealed as 5.5 millimeters per quarter from the DInSAR studies. The conclusions highlight the effectiveness of DInSAR.



So, it provides accurate subsidence data in mining hazards, thereby supporting proactive risk management. Operational implications? Yes, early detection through DInSAR allows for timely safety intervention. We can also, based on this, practice some modeling based on the data, which can also serve as a future precaution or provide information for future management. So, the future scope that emerges from this case study could be. Recommendation of advanced DInSAR used to improve data accuracy by minimizing issues like temporal decorrelation and atmospheric noise. We will talk more about that decorrelation and atmospheric noise in the case studies when we discuss the DInSAR processing techniques. So, in short, case studies 1 and 2 very well depict the power of the DInSAR technique in deformation and subsidence studies, including very high-precision assessment of the movement or the subsidence rate in quantitative terms.

And these are the references that have been used for preparing the slides. And the conclusions could be: yes, microwave remote sensing, SAR, and DInSAR enable precise, continuous, and all-weather monitoring, thereby allowing for early detection of ground movement, helping prevent hazardous events, and supporting responsive risk management. Second, microwave wavelengths penetrate surfaces, going up to the subsurface, aiding in detailed subsurface mapping of ore deposits and environmental assessment. So, subsurface ore mapping is one of the good practices using microwave remote sensing. And with improvements in DInSAR technologies, we can get very precise assessments of terrain deformation and shifts, thereby boosting safety and sustainability measures as far as the mining sector is concerned. Microwave remote sensing provides critical data, which has the potential

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CONCLUSION

- Microwave RS, SAR and D-InSAR, enables precise, continuous, and all-weather monitoring
Allows for early detection of ground movement, helping prevent hazardous events and supporting responsive risk management
- Microwave wavelengths penetrate surfaces, aiding in detailed subsurface mapping for ore deposits and environmental assessments
- Improved D-InSAR technology enhances precision, boosting safety and sustainability
- Provides critical data supporting both operational stability and environmental safeguarding in mining operations



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to support both operational stability and environmental safeguarding in mining operations. So, friends, in this Lecture 4, we discussed and introduced microwave remote sensing. We discussed passive, active, and SAR, as well as differential InSAR technologies. And we also discussed their utilities or potential applications in the mining sector. Through two case studies or examples, we tried to see the deformation rate assessment over two mining areas: the Jharia coalfield and the copper Khetri mines. Our nearest in Rajasthan, we found the quantitative displacement using the DInSAR technique. So, you can see it is a good revelation that microwave remote sensing is very useful for the mining sector. Thank you very much.