SAR applications in Coastal/Geological studies

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Agenda

1. Brief introduction to SAR
2. Potentials of SAR for geological applications.
3. Possible Applications of SAR in geology
4. Processing and interpretation SAR data in geology
5. Case Studies/Examples

SAR Imaging Principle

Structural mapping: Side looking imaging geometry of SAR enhances the structural features such as folds and faults. Structures perpendicular to look direction get better enhanced.

Lithological mapping: SAR data in general is not directly used for lithological mapping. However, sensitivity of SAR signals to surface roughness can be exploited to infer the lithology. Variations in surface roughness arising from differential weathering of rock units can be used to infer the lithology.

Mapping geomorphological features: SAR data is extremely useful to map geomorphological features of arid regions in particular. Penetration capability of SAR signals enables mapping of palaeo-drainages.

Mineral exploration: SAR data is useful for understanding geological controls of mineralisation. It is not directly useful in mineral exploration as it doesn’t measures spectral features associated with various minerals like VNIR optical data.

Active fault mapping: Interferometric Synthetic Aperture Radar (InSAR) is capable of measuring surface deformation with sub centimetre accuracy.

Potentials of SAR for geologic applications
Potentials of SAR for geologic applications

Study of geological disasters:

**Earthquakes:** Interferometric Synthetic Aperture Radar (InSAR) is very useful for understanding of stress accumulation and release related to earthquake cycle and mapping of causative faults.

**Volcanoes:** InSAR is used to map volcano deformation. Polarimetric SAR has been used to map lava flows.

**Land Subsidence:** Subsidence caused by over extraction of groundwater and oil, dissolution of carbonates (sinkholes) and mining can be mapped. Monitoring of CO2 sequestered reservoir and coastal subsidence can also be done.

**Landslides:** Multi-temporal SAR data is very useful for mapping landslide scars. Interferometric SAR can be used to monitor slow moving landslides and may be be helpful for developing early warning systems.

Further, SAR data in conjunction with optical datasets can be used to map the area affected by disasters such as earthquakes and landslides.

SAR Vs Optical imaging

- **VIS/IR radiation:** Absorbed, reflected, or transmitted. Absorption based on the molecular bonds in the (surface) material. Provides information on the chemical composition of the target.

- **Radar energy:** Backscattered according to the physical and electrical properties of the surface (Slope, roughness, and dielectrical properties). The conductivity of a target area is related to the porosity of the soil and its water content.

- Radar and VIS/IR data are complementary; they provide different information about the target area. An image in which these two data types are intelligently combined can present much more information than either image by itself.

Basic advantages of SAR data in Geosciences

- Synoptic view (Large Area coverage)
- Terrain in three dimension (DEM)
- Controllable illumination (Enances landforms and structures)
- Sensitive to surface roughness (Textural information – Landforms)
- Sensitive to dielectric properties (Penetration through soil cover)
- Imaging during cloud cover (Hydrological information)
- Provides information on subtle changes of earths' surface (Land subsidence/Neo-tectonics)

Processing of SAR data for Geological applications

- **Speckle Suppression:** Speckle appear as graininess in SAR imagery. They are Result of coherent nature of SAR systems. Speckles should be suppressed prior to image interpretation.
Processing of SAR data for Geological applications

Merging (Optical + SAR):

Landsat ETM+ FCC (4,3,2)
Relict Valleys
Merged product (ETM+ RISAT - SAR) FCC (4,3,2)

Processing of SAR data for Geological applications
Interpretation of radar images

Variations in tone of radar imagery is caused by changes in radar backscatter that occurs due to variation in physical/geometrical (slope, roughness), electrical (dielectric constant) properties of target and polarisation (cross or like polarized)

Type of interaction between radar signal and images surface:

1. Reflection: It occurs at smooth surfaces causing most of the radar energy to reflect away from receiving antenna. As no return signal is detected, object with smooth surfaces appear black.

2. Backscattering: It occurs when radar signal encounter rough surfaces. It depends upon roughness relative to radar wavelength.

3. Volume Scattering: It occurs when the returning radar signal follows a path with more than one direction. Double bounce and penetration are two types of volume scattering.

Interpretation of radar images

Effect of Surface Roughness: Surface roughness is function of radar wavelength and incidence angle. A surface is considered rough if:

\[ R = \frac{\lambda}{4.4 + \cos \theta} \]

Where R is mean height of irregularities.
Interpretation of radar images
Effect of Surface Roughness

Electrical conductivity:
Radar backscatter is a function of dielectric constant of the medium. A rise in moisture content in geologic material enhances the dielectric constant, thereby decreasing the penetration capability. Most of the geologic material (rock and soils) have narrow range of variations in dielectric constant. Hence, dielectric constant variation is of secondary importance to surface roughness.

Interpretation of radar images
Effect of Dielectric constant

RISAT SAR + Landsat ETM Merged FCC
Interpretation of radar images

Effect of look angle/direction for structure/lineament enhancements

Penetration capability of SAR: A brief Introduction

Following are the factors that permit subsurface imaging using SAR:

Environment related:
1. Smooth surface of fine grained and well sorted sediments
2. Very dry condition (moisture content less than 1 percent)
3. Limited depth of sand cover
4. Rough sand-bedrock interface

System related:
5. Longer wavelength results in deeper penetration.
6. Cross polarization enhances radar penetration
7. Look angle greater than 30°

Simultaneous analysis of optical sensor data to determine whether the radar has detected surface or subsurface feature.

Effect of wavelength on penetration

- L (24 cm)
- C (6 cm)
- X (3 cm)

Penetration capability Examples

VIEW OF LOST VEDIC SARASWATI RIVER AS SEEN ON ALOS PALSAR AND LANDSAT ETM MERGED FCC
Penetration capability Examples

• Interferometric Synthetic Aperture Radar (InSAR) is space based technique which has evolved as a powerful tool for measurement of surface deformation with sub centimetre to mm level accuracy.

• Measurements in changes in earth shape provide critical insights into processes of interest to earth scientists.

\[
\Delta \phi = \phi_1 - \phi_2 = \frac{4 \pi}{\lambda} (R_1 - R_2)
\]

\[
\Delta \phi = \Delta \phi_{\text{defo}} + \Delta \phi_{\text{topo}} + \Delta \phi_{\text{atm}} + \Delta \phi_n
\]

InSAR applications in Geosciences

- InSAR interferometry, images acquired from two orbits with slightly different spatial and temporal baselines are combined to exploit the phase difference of the signals.

Methodology

- Co-registration
- Orbital data
- Differential Interferogram Generation
- Remove Topography
- Flat earth correction
- Phase Unwrapping
- Estimate Displacement
- Understanding of processes governing subsidence/uplift

Case Study: Santa Clara Valley (Chaussard et al., 2014)
Surface deformation associated with 24 February 2004 Al Hoceima earthquake. Blue line is best model fault and barbed lines are inactive thrust. (Cakir et al., 2006, BSSA)

InSAR for fault modelling studies

InSAR measurements of coastal subsidence

- InSAR measurements of compaction and subsidence in Ganges-Brahmaputra Delta, Bangladesh.
- Subsidence in delta is controlled by sediment loading, compaction, and tectonics mainly. Secondary causes may be groundwater and hydrocarbon over extraction and reduced aggradation. InSAR is helping us to decipher the processes controlling the subsidence.
NISAR is L and S band Synthetic Aperture Radar (SAR) being developed jointly by NASA and ISRO. It will make global measurements of causes and consequences of Land Surface Change. It will help in resolving highly and spatially and temporally complex processes. It will measure surface deformation which will be helpful in study of earthquakes, Volcanoes, Land subsidence and Carbon dioxide sequestered reservoirs.