InSAR Technology

for Assessing Wetland Hydrology and Dynamics

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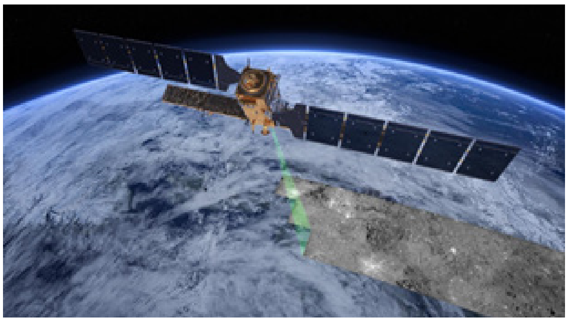
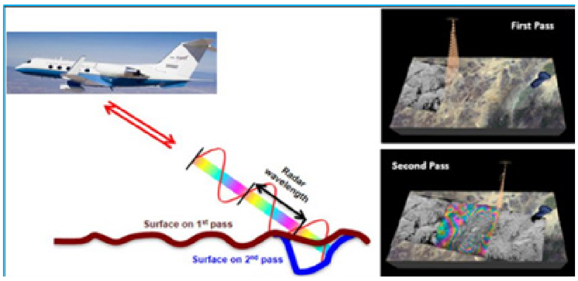
INTRODUCTION

Wetlands are areas that are either permanently or intermittently flooded or saturated with water. It is a very diverse and fragile ecosystem that provides a wide range of environmental services. It provides critical habitats for diverse flora and fauna, freshwater storage, natural water purification, flood regulation, and groundwater recharge. Furthermore, biodiversity-rich ecosystems provide essential services, including biodiversity conservation, and play a vital role in climate regulation. However, over the past century, many wetlands have been lost, degraded, or stressed primarily due to human activities such as water diversion, agricultural development, and urbanization, along with natural processes like sea level rise and climate change. This increasing pressure has made wetlands vulnerable and in need of robust monitoring and management strategies. Traditional wetlands observation methods, such as field surveys and aerial photography, are time-consuming, expensive, and limited in scope. In contrast, remote sensing technologies have provided opportunities for large-scale, efficient, and accurate wetland monitoring. Among these technologies, interferometric synthetic aperture radar (InSAR) has emerged as a powerful tool for assessing wetland dynamics with unprecedented detail and precision. It is an active radar technology using microwaves to capture detailed images of the Earth's surface. The system works by transmitting an electromagnetic signal towards the ground and then receiving the signal reflected from the surface. The reflected signal is processed



and converted into a two-dimensional image. InSAR is a radar-based remote sensing technology that is valuable for wetlands monitoring. It has the potential to penetrate cloud cover, work in all weather conditions, and capture subtle variations in land surface elevation and water level changes. This technology has proven to be useful in monitoring subsidence, floods, vegetation growth, and other hydrological phenomena that are critical for understanding wetland health and sustainability.

PRINCIPLE OF INSAR



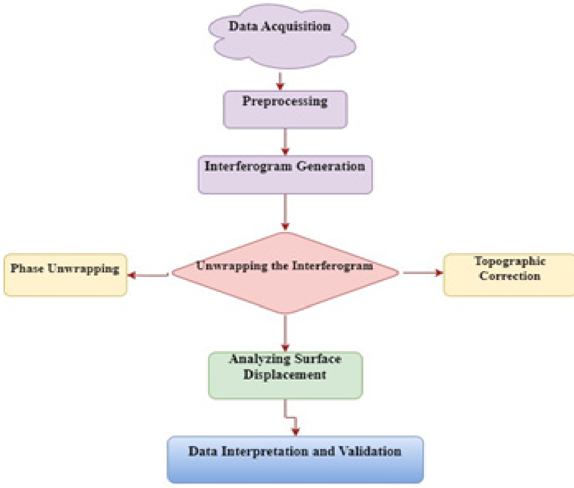
When the radar instrument is flown over a patch of ground the first time (first pass), it transmits microwave pulses towards the surface of the Earth and receives the reflected echo of the radar signal. The incident and reflected signal can be compared in terms of change in amplitude and phase. During the second pass, the radar instrument flies again over the same region to measure new reflection and change of range (distance between instrument and land surface) along line-of-sight direction through the relative change in the phase of the returned signal.

APPLICATION AND ADVANTAGES OF INSAR

Application in hydrology studies	Advantages
Soil moisture detection	High spatial resolution
Flood mapping, Flood risk assessment	Use in all-weather condition, Day and night operation
Inundation extent and Water level change detection	Large area cover, High precision
Wet land water level monitoring	Cost effective over time
Snow cover extent and scattering properties	Time series analysis

SAR INTERFEROMETRY PROCESS FOR WETLAND MONITORING

InSAR is a radar-based microwave remote sensing technology used to derive information about the Earth's surface by analyzing the phase difference between two or more radar images of the same area. This method is particularly effective in monitoring wetlands, as it provides detailed insights into changes in land surface elevation, water levels, and hydrological dynamics over time. As shown below, outline the key steps involved in the SAR interferometry process for wetland monitoring.



SENSORS USED IN INSAR FOR WETLAND MONITORING AND SURFACE DEFORMATION ANALYSIS

Various high-resolution InSAR sensors (summarized in Table 1) are used to monitor wetland conditions, providing critical data for understanding wetland dynamics. These sensors are essential for tracking surface changes such as subsidence, flooding, and vegetation shifts, playing a key role in InSAR-based wetland studies.

Table 1. InSAR Sensors for wetland monitoring

Satellite/ Sensor	Country/ Agency	Band	Resolution	Primary use in wetlands
Sentinel-1	European Space Agency (ESA)	C-band	High (10-20 m)	Water level changes, vegetation monitoring
ALOS PALSAR	Japan Aerospace Exploration Agency (JAXA)	L-band	Medium (10-100 m)	Penetrating dense vegetation, surface deformation
Radarsat-2	Canadian Space Agency (CSA)	C-band	High (3-100 m)	Surface water dynamics, land surface movements
TerraSAR-X	German Aerospace Center (DLR)	X-band	Very High (1-3 m)	Detailed wetland structure analysis
COSMO-SkyMed	Italian Space Agency (ASI)	X-band	Very High (1-3 m)	High-resolution surface monitoring
ERS-1/ERS-2	European Space Agency (ESA)	C-band	Medium (20-30 m)	Early wetland surface studies
JERS-1	Japan Aerospace Exploration Agency (JAXA)	L-band	Medium (18-20 m)	Monitoring vegetation and subsidence in wetlands

FUTURE OF WETLAND MONITORING WITH INSAR

Advanced InSAR technology for monitoring wetlands is a major improvement in how we can safeguard these vital ecosystems. With more satellites equipped with InSAR being launched, it will become more possible to monitor wetland conditions in real-time, on a global scale. This advancement could allow for better, faster detection of changes or threats to wetlands, which would enhance efforts to conserve and manage them. The latest SAR mission, NISAR, launched in March 2024, provides additional and more frequent InSAR observations, enabling more regular space-based monitoring of water level changes in wetland areas around the world.

CONCLUSION

Wetlands are very fragile ecosystems that provide important ecosocial services. Over the past century, many wetland areas have been lost, degraded, or stressed mainly due to anthropogenic activities. Since wetlands depend on water availability, protecting this important ecosystem requires careful hydrological monitoring. Interferometric synthetic aperture radar (InSAR) has emerged as a promising tool for hydrological monitoring, and it has the ability to obtain high-resolution imagery under all weather conditions. It is a unique application that provides high spatial resolution maps of hydrological observations over wetlands. Since 2000, InSAR has proven to be an effective tool for hydrological monitoring. It provides high spatial resolution and centimetric accuracy in mapping 2D water-level changes, even beneath vegetated wetlands.