Acceleron Aerospace Journal || AAJ.11.2106-2458
Volume 3, Issue 5, pp (563-572)
Review Paper
E-ISSN- 2583-9942 || DOI: 10.61359/11.2106-2458

Technical Overview of ISRO and NASA's First Joint Mission: NASA-ISRO Synthetic Aperture Radar (NISAR) Satellite

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Abstract: The NASA-ISRO Synthetic Aperture Radar (NISAR) mission represents a groundbreaking collaboration aimed at comprehensively monitoring Earth's surface dynamics. Through the fusion of L-band and S-band radar frequencies, NISAR promises unprecedented precision in detecting subtle surface changes, ranging from ecosystem disruptions to ice sheet collapses and natural hazard occurrences. This paper explores the mission's objectives, technology, and significance in advancing our understanding of climate change impacts and hazard mitigation. The partnership between NASA and ISRO, culminating in the signing of agreements in 2014, underscores the international cooperation vital for addressing complex global challenges. With its targeted launch, NISAR heralds a new era in Earth observation, enabled by the fusion of cutting-edge technology and collaborative scientific endeavour.

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1. Introduction

The history of synthetic aperture radar (SAR) satellite missions traces back to NASA's pioneering SEASAT mission in 1978, marking the inception of civilian SAR observations. Despite SEASAT's short operational span due to a power system failure, it sparked a trajectory of spaceborne SAR advancements globally, inspiring subsequent missions, including those on NASA's space shuttles. However, the realization of a standalone scientific SAR satellite in the United States has remained elusive, despite persistent demand from the scientific and applications community. In response to the National Research Council (NRC) Decadal Survey of 2007, NASA conceptualized the Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI) mission to address critical gaps in Earth science data and insights. Over the years, the DESDynI concept underwent iterative revisions, ranging from significant alterations to minor adjustments, in collaboration with international partners.

Conversations between NASA and the Indian Space Research Organization (ISRO) revealed mutual interest in radar mission objectives, leading to the formulation of the joint NASA-ISRO SAR (NISAR) mission. ISRO's identified scientific and application priorities, such as agricultural monitoring, landslide studies, and glacier monitoring, complemented the primary DESDynI objectives. The inclusion of an S-band polarimetric capability promised enhanced sensitivity and expanded measurement capabilities, mitigating ionospheric and soil moisture effects. Since the initial proposal of the L- and S-band SAR mission concept in 2012, teams from NASA's Jet Propulsion Laboratory (JPL) and ISRO have collaborated to refine the mission's scientific plan. Subsequent approvals from the Indian government and the establishment of technical agreements paved the way for the formalization of the NISAR mission, culminating in the signing of implementing arrangements in September 2014. The partnership between ISRO and JPL entails ISRO's contribution of a significant portion of the mission infrastructure, including launch services, the spacecraft bus, and the S-band instrument, while JPL provides the L-band InSAR instrument and associated components. The anticipated data rates from the combined InSAR

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** Received: 09-October-2024 || Revised: 25-October-2024 || Accepted: 26-October-2024 || Published Online: 30-October-2024.

instruments pose logistical challenges for data transmission, underscoring the need for robust ground infrastructure to handle the influx of high-resolution SAR data from orbit.

Figure 1 NISAR Satellite (Image credit: NASA)

2. A Short Overview of NISAR

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission is an innovative Earth observation satellite equipped with two state-of-the-art synthetic aperture radars (SARs)—an L-band SAR and an S-band SAR. It will be the first spaceborne mission to utilize dual-frequency radar, providing unprecedented monitoring capabilities. The L-SAR, operating at a 1.25 GHz frequency with a spatial resolution of 3-48 meters, is optimized for observing landscape topography and penetrating dense vegetation cover. The S-SAR, at 3.2 GHz with a 3–24-meter resolution, specializes in monitoring soil moisture, especially in polar regions where ionospheric effects are minimized. Both SARs will map a 242 km swath width, ensuring frequent global coverage, enabled by the satellite's sun-synchronous orbit at 747 km and the advanced SweepSAR imaging technique. SweepSAR transmits and receives radar pulses across the entire swath in rapid succession, processing them simultaneously for efficient wide-area mapping.

The mission features an innovative deployable 12-meter mesh antenna reflector—the largest ever launched by NASA. This lightweight antenna unfurls from a 9-meter boom integrated with ISRO's I3K spacecraft bus, allowing for compact stowage during launch. With its powerful multi-frequency radar imaging capabilities, NISAR will significantly enhance our understanding of Earth's dynamic environments and climate processes through systematic observations of terrestrial biomass, surface deformation, sea ice dynamics, and more.

3. Scientific Instruments Aboard NISAR

The NISAR mission is equipped with advanced L-band and S-band radar systems, providing robust capabilities for Earth observation. Here are the key specifications and benefits:

Radar System Specifications

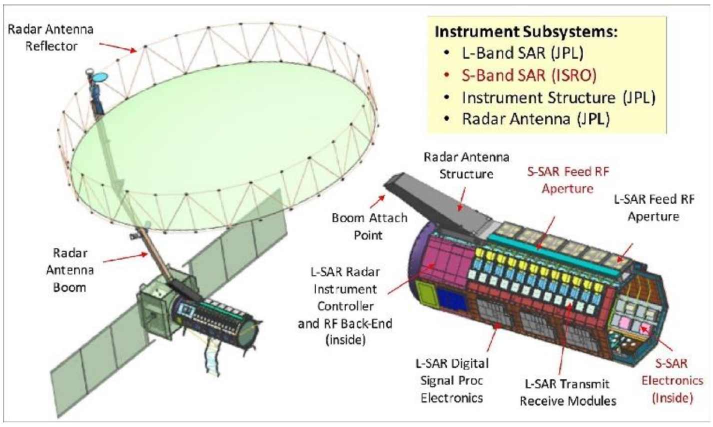

Figure-2. NISAR spacecraft in deployed configuration, with annotation of key instrument elements. Spacecraft bus is provided by ISRO. There are 24 L-band transmit receive modules (12 per polarization) and 48 S-band modules [Courtesy: NASA/JPL, ISRO]

Frequencies:
- S-band: 3.2 GHz ± 37.5 MHz
- L-band: 1.257 GHz ± 40 MHz

Polarimetric Modes:
- S-band: Single Pol (HH or VV), Dual Pol (HH/HV or VV/VH), Compact Pol (RH/RV), Quasi-Quad Pol (HH/HV and VH/VV)
- L-band: Single Pol (HH or VV), Dual Pol (HH/HV or VV/VH), Compact Pol (RH/RV), Quad Pol (HH/HV/VH/VV)

Bandwidth Options:
- S-band: 10 MHz, 25 MHz, 37.5 MHz, 75 MHz
- L-band: 5 MHz, 20 MHz, 40 MHz, 80 MHz

Swath Width: Greater than 240 km (except for specific high-bandwidth modes)

Spatial Resolution:
- Azimuth: 7 meters
- Slant Range: 3-24 meters (S-band), 3-48 meters (L-band)

Incidence Angle Range: 33º-47º

Noise Equivalent σ0: Baseline -25 dB, Threshold -20 dB for S-band and L-band required modes

Ambiguities: Less than -20 dB for all modes except for specific values in S-band Quasi-Quad Pol and certain L-band modes.

Sensor Complement

L-SAR and S-SAR:

Conventional SAR systems have trade-offs between swath width and resolution due to antenna size limitations. The ScanSAR technique, using burst mode data acquisition and electronically pointed radar beams, provides wider swath coverage by compromising azimuth resolution. Originally demonstrated on NASA/JPL's SIR-C mission (1994) and crucial for the SRTM mission, this technique mapped over 80% of Earth's topography.

Key Parameters Recap:
- Frequency: L-band (1.257 GHz ± 40 MHz), S-band (3.2 GHz ± 37.5 MHz)
- Polarimetric Modes: Single Pol, Dual Pol, Compact Pol, Quad Pol
- Bandwidth: Up to 80 MHz for L-band; up to 75 MHz for S-band
- Swath Width: Over 240 km (except for certain high-bandwidth modes)
- Resolution: Azimuth 7 m, Slant Range 3-48 m
- Incidence Angle: 33º-47º
- Noise and Ambiguities: NE σ0 -25 dB baseline, ambiguities below -20 dB

SweepSAR Technology

Developed with the German Aerospace Center (DLR), SweepSAR technology enables wide swath imaging with full resolution and polarimetric diversity. This technique processes signals on each radar feed element independently, allowing continuous echo tracking across a 244 km swath. It supports parallel processing in spaceborne electronics, ensuring high accuracy and comprehensive coverage.

Dual-Frequency Operation

The L-band and S-band radars, developed by NASA's JPL and ISRO, operate independently or together, utilizing a shared reflector with precise optical alignment. Dual operations involve synchronization of pulse repetition frequencies and minimal feed aperture coupling.

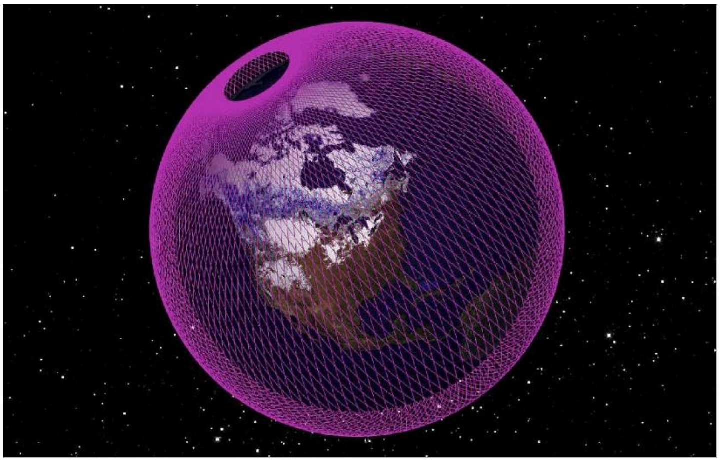

Figure-3. A snapshot of the Reference Science Orbit orbital elements at the first ascending equator crossing are given in the following table and are specified in an Earth-Centered True Equator and Equinox of Epoch coordinate frame. During every 12-day repeat cycle, NISAR will execute 173 orbits, which will provide global coverage of the Earth [Image Credit: NASA/JPL-Caltech)

Benefits of Multi-Frequency Operation

The dual-band setup provides several key advantages:

- Reduced ionospheric effects in polar regions
- Enhanced biomass estimation and sensitivity to surface deformation
- Improved classification of natural surfaces via differential surface roughness and volume scattering analysis
- Enhanced interferometry-based change detection through decorrelation rate studies

By balancing dual-frequency operations with high data downlink capacities, NISAR will offer researchers unprecedented global data access and insights into Earth's dynamic systems.

Table-1 L & S Band Parameter

Parameter	**S-band**	**L-band**
Frequency	3.2 GHz ± 37.5 MHz	1.257 GHz ± 40 MHz
Available polarimetric modes	SP (Single Pol): HH or VV DP (Dual Pol): HH/HV or VV/VH CP (Compact Pol): RH/RV QQP (Quasi-Quad Pol): HH/HV and VH/VV	SP: HH or VV DP: HH/HV or VV/VH CP: RH/RV QP (Quad Pol): HH/HV/VH/VV
Available range bandwidths	10 MHz, 25 MHz, 37.5 MHz, 75 MHz	5 MHz, 20 MHz, 40 MHz, 80 MHz (Additional 5 MHz iono band for 20 & 40 MHz modes at other end of passband)
Swath width	>240 km (except for QQP mode)	>240 km (except for 80 MHz BW)
Spatial resolution	7 m (azimuth), 3-24 m (slant range)	7 m (azimuth), 3-48 m (slant range)
Incidence angle range	33º-47º	33º-47º

Noise equivalent σ0	-25 dB (baseline) -20 dB (threshold)	-25 dB (for required full-swath modes)
Ambiguities	<-20 dB for all modes except QQP	<-23 dB swath average in SP or DP modes <-17 dB swath average in QP mode
Data and product access	Free and open	Free and open

(a) The L-SAR (L-band Synthetic Aperture Radar) instrument, essential to NASA's science objectives for NISAR, will be active for 45-50% of each orbit, with peak usage reaching 70%. Key features of the L-SAR include:

- Side-looking, fully polarimetric, interferometric radar: Operates at a 24 cm wavelength, with the capability for 242 km swaths, a 7 m resolution along-track, and a 2-8 m resolution cross-track.
- Polarization modes: Supports quad-polarimetric modes, transmitting in both vertical and horizontal polarizations and receiving in both same and cross-polarizations.
- Precision: Generates repeat-pass interferograms that can detect land deformation as small as 4 mm per year.

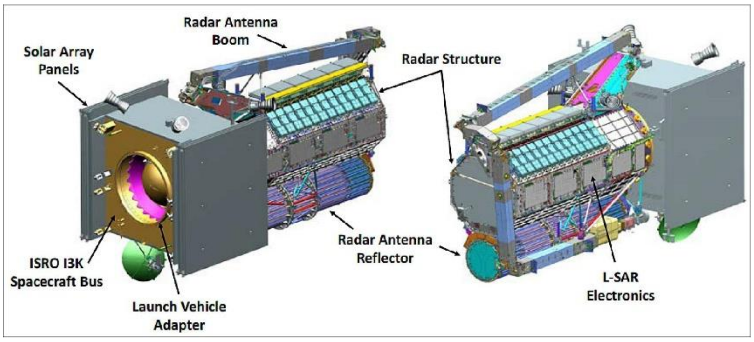

Figure-4. Spacecraft in stowed configuration [Image Credit: ISRO, NASA]

(b) Technological Innovations

NISAR's design leverages the innovative "SweepSAR" technique, developed in collaboration with the German Aerospace Center (DLR) during the DESDynI study phase. SweepSAR enables:

- Wide swath coverage: 244 km with fast sampling and global access.
- Continuous echo tracking: Digitized signals are combined in real-time to maintain high resolution.
- Dual-frequency operation: L-band and S-band radars operate independently or together, with synchronized timing and a shared reflector.

(c) Operational Implementation

The instrument configuration includes:

- 12 m diameter mesh reflector: Shared by both L- and S-band radars.
- Patch array: S-band (2 x 24) and L-band (2 x 12) with timing synchronization.
- Digitization and real-time combining: Achieved through FPGAs or ASICs for both radar systems.

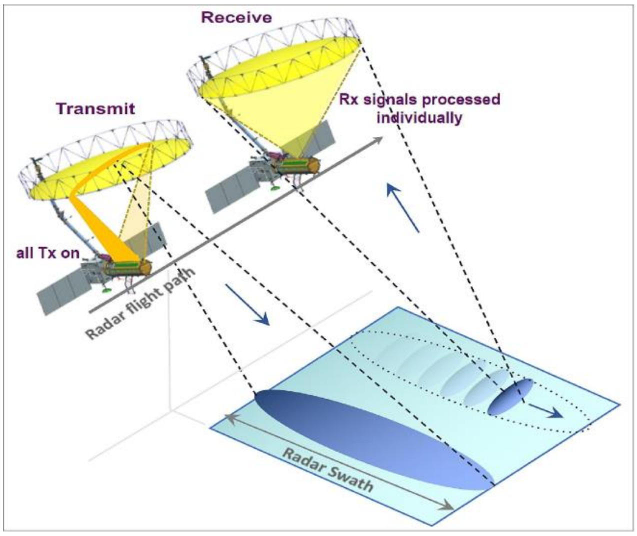

Figure-5. Illustration of the SweepSAR technique enabling full-resolution, multi-polarimetric observations across an extended swath (> 240 km). Energy is transmitted across the full feed aperture to illuminate a wide swath on the ground. Each patch element on the feed can receive independently, allowing localization in time and space of the return echo scattered from the ground. Note: Transmit and Scanning Receive events overlap in time and space; along-track offset is shown for clarity (Image Credit: NASA/JPL).

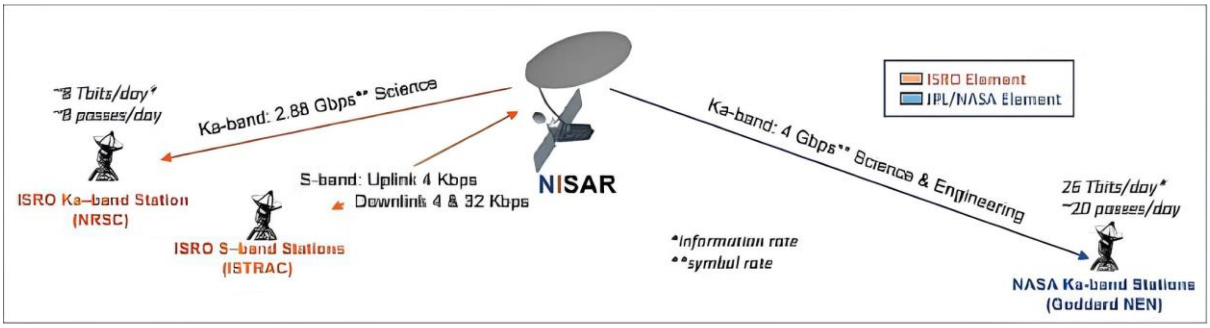

Figure-6. NISAR telecommunications links include Ka-band downlink to NASA and ISRO stations at 4 Gbit/s and 2.88 Gbit/s, respectively, with S-band uplink and downlink for communication with ISRO ground stations [Image Credit: NASA, ISRO).

(d) Performance

- Bandwidths and Polarizations: Various combinations of bandwidths and polarizations to support a range of science targets.
- Resolution and Ambiguities: Achieves 3-10 m range resolution, sub-pixel geolocation, and ~7 m azimuth resolution.

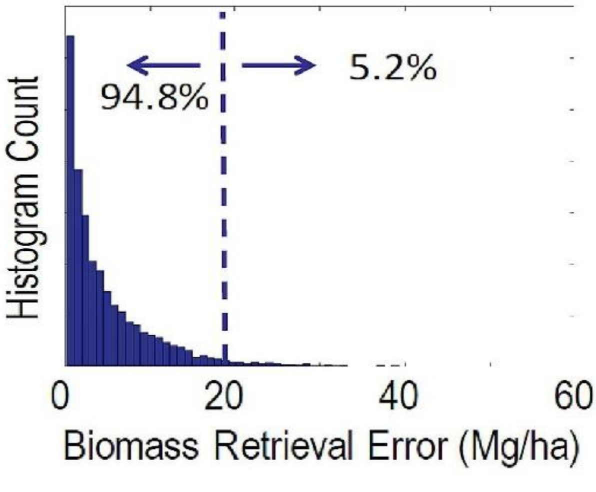

Figure-7. Example output from the NISAR biomass performance model, showing a global histogram of errors based on planned observations, including transmit gaps. The requirement specifies that 80% of regions where biomass is below 100 Mg/ha must have an error under 20 Mg/ha. The final paper will present similar results for additional requirements (Image Credit: NASA).

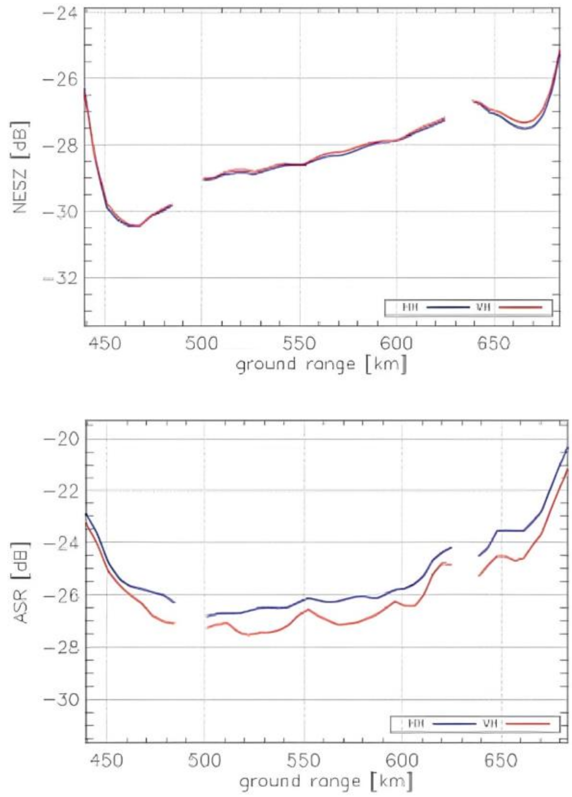

Figure-8. NESZ (top) and Ambiguities (bottom) for the dual-pol mode and constant PRI operation (Image Credit: NASA)

4. Launch

The NISAR (NASA-ISRO Synthetic Aperture Radar) mission is scheduled for launch in 2024. The launch will take place from the Satish Dhawan Space Center (SDSC) in Sriharikota, Andhra Pradesh, India, utilizing an ISRO GSLV (Geosynchronous Satellite Launch Vehicle) Mark II.

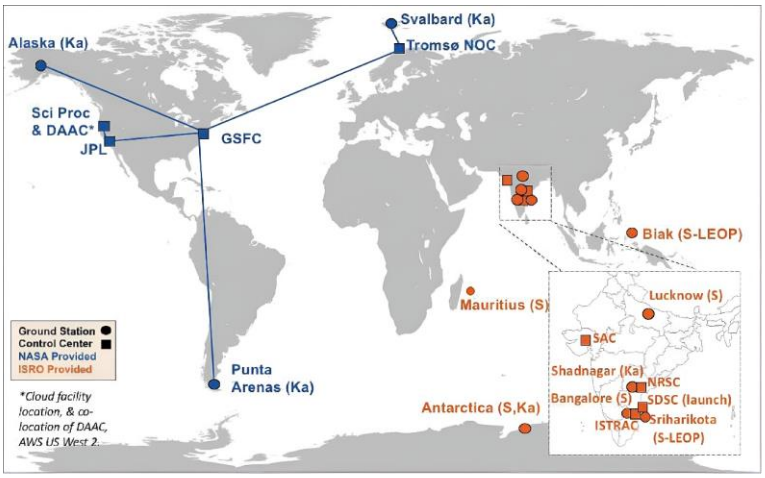

Figure-9. NISAR ground stations include NASA Near-Earth Network stations in Alaska, Svalbard, and Punta Arenas; ISRO stations in Antarctica, Shadnagar, Bangalore, Lucknow, and Mauritius; and a station in Biak. The control center and launch location are also at Sriharikota (SDSC), India (Image Credit: NASA/JPL).

During its science operations, NISAR will function within a diamond-shaped orbital corridor designed for each of the 173 orbits in the repeat cycle. This corridor is aligned with the rotating Earth, enabling precise correlation of science observations from pass to pass and cycle to cycle, thereby supporting the assessment of

5. Orbital Configuration

- Orbit Type: Sun-synchronous dawn-dusk orbit
- Altitude: 747 km
- Inclination: 98.4º
- Local Time of Ascending Node (LTAN): 18 hours
- Repeat Cycle: 12 days

The diamond corridor is defined to accommodate acceptable error bounds related to phase unwrapping errors, geometric decorrelation, and topographic leakage, with phase unwrapping errors being the dominant factor. The center of the diamond is determined by the 173-orbit reference trajectory, known as the Reference Science Orbit, which is fixed to the Earth's surface and repeats exactly every 12 days.

To maintain this orbital corridor, the JPL Navigation team plans to execute maneuvers primarily over long ocean passes (Atlantic and Pacific) to minimize the impact on science data collection. This approach ensures the integrity and accuracy of the collected data, which is crucial for monitoring and assessing various environmental and geological phenomena.

Figure-10. Locations of NISAR Ka-band ground stations (NASA stations in Alaska, Svalbard, and Punta Arenas, and ISRO stations in Shadnagar and Antarctica are shown). Image Credit: NASA, ISRO.

6. Conclusion

The NISAR mission represents a pioneering collaboration between NASA and ISRO, combining advanced Synthetic Aperture Radar (SAR) technologies to achieve unprecedented global Earth observation capabilities. By leveraging dual-frequency SAR instruments—L-band (L-SAR) and S-band (S-SAR)—NISAR will provide comprehensive and high-resolution monitoring of Earth's surface dynamics, independent of weather conditions and vegetation cover. This dual-frequency approach enables the mission to capture detailed data on landscape topography, forest structure, soil moisture, and various surface changes with remarkable accuracy and temporal resolution. NISAR's innovative use of the SweepSAR technique, coupled with its extensive swath coverage of 242 km, facilitates frequent global data acquisition, significantly enhancing our ability to detect and analyze subtle geological and ecological changes. The L-SAR, operating at 1.25 GHz, and the S-SAR, operating at 3.2 GHz, offer versatile observational modes that cater to a wide range of scientific inquiries, from measuring crustal deformations to assessing biomass and soil moisture levels.

Operating in a sun-synchronous orbit at an altitude of 747 km, NISAR's design ensures consistent and repeatable observations, crucial for time-series analysis and long-term environmental monitoring. The mission's 12 m diameter radar antenna, the largest ever deployed by NASA, exemplifies cutting-edge engineering and collaborative innovation, maximizing observational capabilities while maintaining robust structural integrity.The scientific and operational synergy between NASA and ISRO underpins NISAR's capacity to address critical Earth science questions. The mission's ability to detect changes on the order of centimeters will advance our understanding of natural hazards such as earthquakes and volcanic activity, as well as climatic phenomena including ice sheet dynamics and ecosystem disturbances. Furthermore, NISAR's free and open data policy ensures that the wealth of information generated will be accessible to the global scientific community, fostering widespread research and applications. In summary, NISAR's deployment marks a significant milestone in Earth observation, promising to enhance our understanding of the planet's changing landscape with unparalleled detail and frequency. The mission exemplifies the power of international collaboration in advancing space science and addressing global challenges, setting a precedent for future joint endeavors in Earth and planetary exploration.

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8. Conflict of Interest

The author declares no competing conflict of interest.

9. Funding

No funding was received to support this study.