Impact of Gaps in the NASA-ISRO SAR Mission Swath

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Abstract

The NASA-ISRO Synthetic Aperture Radar (NISAR) mission will carry L-band and S-band SAR instruments, each with a 240 km swath width. The L-band instrument has the capability to map the entire Earth's land and ice covered surfaces from both ascending and descending orbit positions, continuously in an exact 12 day repeating cycle, given temporally dense (better than 6-day on average) sampling of Earth over the life of the mission. To achieve this swath coverage without loss of resolution or polarimetric capability, NISAR uses a reflector-feed based antenna system with scan-on-receive ("SweepSAR") capability. One of the characteristics of SweepSAR is that the pulse repetition interval of the radar is shorter than the echo receive window for the 240 km swath. Therefore, transmit events occur during the receive window and the receivers must be blanked periodically, creating gaps in the coverage. For fixed pulse rate operations, these gaps are persistent strips of blanked ranges. NISAR is being designed to allow variation of the pulse rate in order to spread out these gaps throughout the synthetic aperture, but processing these variably-acquired data is more challenging and can lead to compromises in image quality. At the highest level NISAR places requirements on science measurements rather than image quality, so there is often a debate among science and engineering team members as to whether to operate with fixed pulse rates – leading to range strips consistently blank from cycle to cycle but with optimal image quality – or to vary the pulse rate, fill in the gaps, and live with degraded image quality. NISAR's performance team has shown that science requirements can be met with the gaps. However, scientists are eager for maximum and coverage within a swath. A companion paper (Villano et al.) describes image quality for NISAR using a variable PRF approach, but does not go further to science requirements. This paper explores the issues when gaps are present in the swath due to fixed PRF operations.

1 Introduction

The National Aeronautics and Space Administration (NASA) in the United States and the Indian Space Research Organisation (ISRO) are developing the NASA-ISRO SAR (NISAR) mission, which will use wide-swath synthetic aperture radar to map Earth's surface every 12 days, persistently on ascending and descending portions of the orbit, over all land and ice-covered surfaces [1]. The mission's primary objectives will be to study Earth land and ice deformation, and ecosystems, in areas of common interest to the US and Indian science communities. NISAR carries a NASA-provided L-band (24 cm wavelength) radar system, comprising a 12 m deployable reflector at the end of a 9 m deployable boom, and a phased array feed with 12 elevation receivers, each of which can independently digitize the receive echo just past the low noise amplifier direct to baseband for subsequent filtering, decimation, and beamforming [2]. In addition, an ISRO-provided S-band (10 cm wavelength) radar electronics and radiating aperture suite shares mechanical structures provided by the L-band SAR, using the same technological approach. Each radar has a swath of over 240 km at fine resolution, using polarimetric modes where needed. Azimuth resolution is determined by the 12-m reflector diameter, and is of order 7-8 m. The radars each have a large number of independent and joint modes, with a range of possible resolutions and polarizations. L and S-band are being designed such that they share clock and frequency references, allowing them to be operated simultaneously. Over most of the world, however, the instruments will be operated independently.

NISAR's SweepSAR scan-on-receive timing is illustrated in Figure 1 for a typical L-band mode of operation – dual-pol (HH/HV) 20 MHz bandwidth split spectrum mode. In this mode, the 20 MHz signal is positioned at one end of the allowable spectrum and a separate 5 MHz bandwidth signal is transmitted sequentially in time at the opposite end of the spectrum (see also Table 1). This is performed using linear frequency modulated waveforms

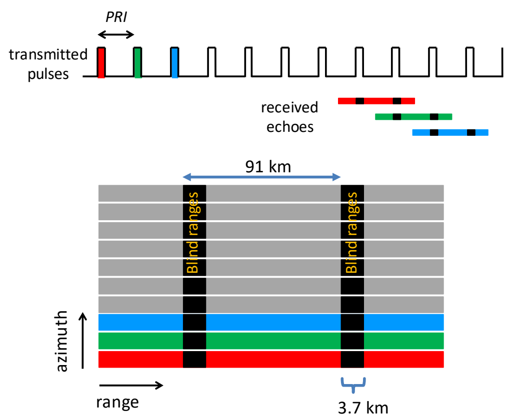

Figure 1 (After M. Villano, DLR: Time and spatial scales at issue in NISAR's SweepSAR implementation, and illustration of gaps in the swath for fixed PRI operations. NISAR's PRI is 606 µsec for the nominal mode of operation, which corresponds to a range distance of around 91 km, or 140 km – 180 km of ground range, depending on the incidence angle, while the full extent of the received echo is greater than 240 km ground range. The pulse duration for nominal modes is 25 µsec, corresponding to a 3.7 km range extent over which the receivers are blanked to avoid interference by the transmit pulse, leading to blind range gaps of 5.6 km (far range) – 6.8 km (near range) on the ground. Other PRIs and pulse durations lead to different spacing and extent of gaps.

with identical chirp rates, but with different pulse extents: the 20 MHz pulse extent is 20 msec, while the 5 MHz pulse extent is 5 µsec, giving a total pulse extent of 25 µsec. This split spectrum approach is implemented for the purpose of ionospheric correction of interferometric products. The 20 MHz band provides the main dual-pol observation, with repeated observations over time allowing interferometric comparison, while the 5 MHz band of the same co- and cross-pol measurements is used primarily for forming low-resolution maximally band-separated dual-pol interferograms. By unwrapping and scaling the phase of the 5 MHz band, it is possible to derive an estimate of the ionospheric contribution to the interferogram [3,4].

Note that since NISAR has dual waveform generators, it is possible also to create HH and VV signals simultaneously with different center frequencies. This allows 20 split-band operation (HH/HV in one band and VV/VH in the other band) using a 20 µsec pulse duration for each. This so-called "quasi-quad pol" mode of operation is being considered for optimizing some science retrievals.

Parameter	Value
Center frequency	1.2575 GHz (L-Band)
Wavelength	0.238 m
Orbit height	747 km
Incident angle	33.88° - 47.2°
Pulse width	(20 + 5) µs
Chirp bandwidth	(20 + 5) MHz
PRF	1650 Hz
Processed Doppler Bandwidth	1100 Hz
Backscatter Model	Ulaby, L-Band, shrubs
Processing Window	Hamming (alpha = 0.85)

Table 1: System and processing parameters for nominal dual-pol operation of NISAR.

The pulse repetition interval (PRI) for this mode of 606.06 µsec corresponds to the 1650 Hz pulse repetition frequency needed to balance ambiguities against data rate. The entire incidence angle range is imaged at once as a single strip-map swath, at full resolution depending on the mode, and with full polarization capability if re-

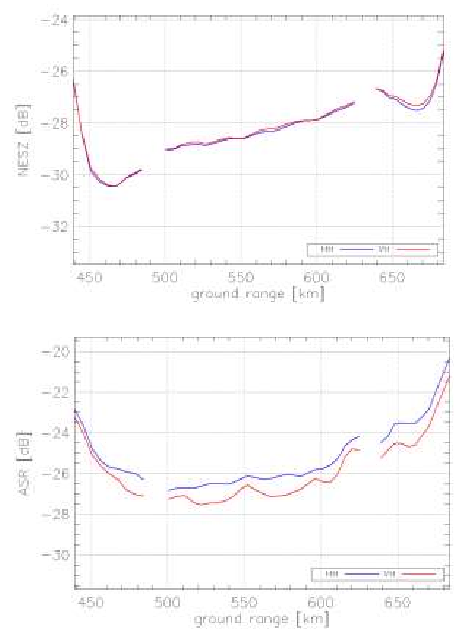

Figure 2: NESZ (top) and Ambiguities (bottom) for the dual-pol mode and constant PRI operation.

quired for a given area of the interest. Because the received echo extends in time longer than the PRI, transmit events will occur during the receive window. The receivers are blanked during these transmit events creating blind ranges as illustrated in Fig 1.

For fixed PRI operations, these gaps are persistent strips of blanked ranges. The extent of the gaps is doubled in processing: Because range resolution is achieved by a matched filtering operation with a replica of the transmitted chirp, data near the edges of the gap are only partially resolved. The impact of gaps are therefore felt over a 13.4 km extent (mean over the swath), with full resolution at the edges, degrading to coarser and coarser resolution as the middle of the gap is approached from each edge.

For the purpose of tracking requirements, the gap is bookkept as containing no useful data. Hence in Fig. 2, which shows the noise performance of the L-band radar, there are two gaps in the curves indicating this 13.4 km region. This creates three distinct subswaths, with no coverage in the gaps unless the PRF is altered in some way to move the gaps around [5, 6]. Ascending and descending coverage can mitigate this coverage loss to an extent. This paper discusses the implications of these gaps on achieving NISAR science objectives and on the overall usability of the data.

2 Impacts of Gaps

2.1 Locations where there would be no coverage

NISAR has an observation plan that covers all Earth's land and ice covered surfaces at least once each 12-day cycle from the ascending and descending portions of the orbit. Except for the fine resolution observations of ice sheets in the polar extremities, there is no attempt to narrow the swath of any acquisition as a function of latitude, though above 60 degrees north latitude, every other observation is culled since there would be complete redundancy in these observations. The fact that the ground tracks converge with increasing latitude does not help to fill the gaps in by combining ascending-only or descending-only swaths, as it does to build up overlap at the swath edges, since gaps are at a fixed ground range and don't converge with latitude. When there is substantial swath overlap approaching 60 degrees north, these gaps may be filled in by neighboring swaths, but then above 60 degrees, the swath culling will open the gaps again. Thus for ascending-only or descending-only coverage, certain regions of Earth will simply not be mapped. The two gaps in the dual-pol swath are roughly 10% of the total area, so 10% of Earth would not be covered from ascending or descending directions in any given 12-day cycle. The gap could be moved around from cycle to cycle, to ensure every area is mapped.

Most areas however will be covered by using both ascending and descending observations. Given that ascending swaths will fill in at least 90% of the area missed by descending passes, and vice-versa, only about 1% (10% of 10%) will not be mapped in the combined ascending or descending passes, leaving diamond-shaped holes. In this case orbit convergence will help to fill in gaps in this 1% in the higher latitudes.

2.2 Science Performance

The NISAR mission is designed to meet a specific set of measurement requirements, which are summarized in Table 1 of [7], and which have been quite stable over the period of mission development. (NISAR is planned for launch in 2021 and is presently in its critical design phase.) The science measurements are characterized in terms of quantities that are derived from radar imagery, not in terms of the imagery itself: For solid earth and cryosphere objectives, the measurements are expressed in terms of vector displacements of the surface of Earth. For ecosystems, the measurements are in terms of biomass, disturbance, and areal classification of wetlands and active agriculture. For all these requirements, the algorithmic approaches mandate the use of data acquired over time and from ascending and descending orbits to synthesize the data products. As such having gaps in the swath of any given scene do not necessarily mean that requirements cannot be met.

The NISAR project has developed an end-to-end science performance estimation tool [8,9] that utilizes the mission observation plan, the performance of the radar instrument (for example as shown in Fig. 2), and a detailed error model for propagating radar measurement errors to errors in the science measurements described above. In the model simulations to date, the gaps in the swath are assumed to exist. In all cases, the impact of the gap is felt in loss of samples in time and space, but the models predict that requirements can be met. Figure 3 shows an

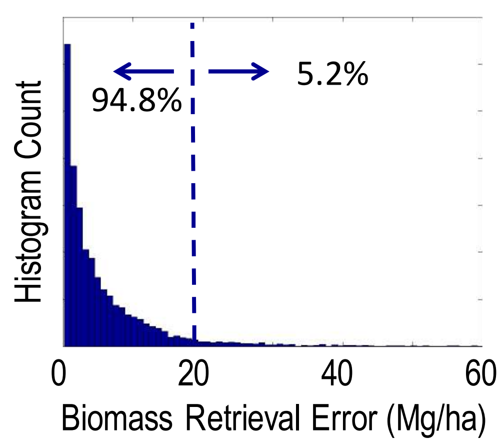

Figure 3: Example of output of the NISAR biomass performance model [9] showing accumulated histogram of errors over the globe based on the planned observations and including transmit gaps. The requirement specifies that 80% of the regions where biomass is below 100 Mg/ha must be have an error better than 20 Mg/ha. The final paper will show similar results for other requirements.

example of a simulation output for biomass estimation, wherein a year of dual-pol observations are used to estimate biomass from the observed backscatter.

2.3 Partially resolved gaps

One concern of having gaps in the swath relates to impacts on the ability to unwrap the phase in interferograms used for solid earth science. Generally speaking it is preferable to have continuous interferograms to perform phase unwrapping to avoid ambiguity errors. The same strategy employed to combine interferograms from track to track can be employed to link these subswaths to some extent, except from track to track the swaths actually overlap so there are tie points to track the phase.

To minimize the gap in an interferogram for the purpose of improving phase continuity across the gaps, it is possible to use the partially resolved data in gaps. Interferometric processing generally requires multilooking to reduce noise, so the eventual resolution of the data is coarser than the full resolution imagery. If the interferograms are formed using data that extend 75% of the way into the gap, then the resolution will be degraded in range by a factor of 4, but the gap will be reduced from 13.4 km to 3.4 km. One could even extend to coarser resolution and narrow the gap further. The coarser the resolution, the noisier the measurement will be: further study of the tradeoff between resolution and phase continuity needs to be done to optimize this.

3 Gap mitigation strategies

3.1 Varying the PRF – Staggered SAR

The NISAR instruments have the ability to vary the PRI continuously during observations. This allows the gaps to be distributed throughout the swath and the synthetic aperture, such that continuous imagery can be obtained after processing, albeit at the cost of greater noise in the imagery [5,6]. Villano et al. have a companion paper for this conference addressing the image performance, but more work needs to be done to assess the overall impact on science performance. This will be described in the final paper.

3.2 Moving the gap around

By keeping the PRI fixed, but changing it slightly from cycle to cycle, the gap can be moved around over the year. For the nominal dual-pol model, shifting each cycle by one gap width (3.7 km) would cover the 91 km PRI distance in 24 cycles. Since there are 30 cycles in a year, for any given location on the ground, nearly continuous yearly time series can be constructed, with a little over 1 missing time step per year. Given the inherently higher quality of fixed PRI observations, the fact that generally many time steps are needed to meet requirements, and that the algorithms are inherently robust to missing data, this strategy is a potentially good compromise for NISAR between temporal continuity and geographic coverage. The optimal shift per cycle deserves further study. The project has developed a number of simulation tools to aid the investigation. This will be explored further in the final paper.

4 Conclusions

The gaps that exist in the NISAR swaths have impacts on the continuity of imagery in space and time, but the requirements of the mission can be met formally. Scientists typically prefer to work with full-coverage imagery, however, but for NISAR may prefer higher quality imagery with gaps to continuous images that results from varying the PRI and processing across the gaps. Further work, to be presented in the final paper, is required to explore various mitigation strategies and their impacts on the science performance.

5 Acknowledgments

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