How Accurate Are My AIRSAR Data?

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Abstract – AIRSAR has served as a test-bed for both imaging radar techniques and radar technologies for over a decade. In fact, the polarimetric, cross-track interferometric, and along-track interferometric radar techniques were all developed using AIRSAR. In this paper, we present the up-to-date system configuration, the expected performance and data accuracy in the standard radar modes.

I. INTRODUCTION

The NASA/JPL airborne synthetic aperture radar (AIRSAR) system operates in the fully polarimetric mode at P-, L- and C-band simultaneously [1] or in the interferometric mode in both L- and C-band simultaneously. The system became operational in late 1987 and flew its first mission aboard a NASA operated DC-8 Airborne Research Laboratory. Since then, AIRSAR has flown missions every year and acquired data in North, Central, and South America, Europe, and participated in major campaigns in the Pacific Rim countries in 1996 and 2000 respectively. AIRSAR serves as a test-bed for both imaging radar techniques and radar technologies. Over the years, AIRSAR has been modified to collect data in a variety of along-track [2] and cross-track interferometric modes [3], to increase resolution, and to increase location and height accuracy. As a result, AIRSAR has become a very versatile and yet flexible system, allowing our investigators to collect data in a number of experimental modes. In addition, AIRSAR has been utilized to verify new data compression, calibration, and differential GPS techniques, new chirp generator technology, and new analog-to-digital converter (ADC) technology.

In the following section, we will describe the current configuration and characteristics of AIRSAR and the types of data acquisition modes. In section III, we will summarize the expected system performance in various standard radar modes.

II. SYSTEM CONFIGURATION AND CHARACTERISTICS

AIRSAR operates in three frequencies, P-, L-, and C-band, simultaneously. The system characteristics are summarized in Table 1. The flexibility of data acquisition in polarimetric, along-track interferometric, or cross-track interferometric mode is achieved by a suite of complicated antenna switching networks, allowing us to select any pair of antennas from each radar frequency at one time. There are two receive channels in each radar frequency, allowing us to record data from two antennas per frequency simultaneously. The six receive channels from all three frequencies are then multiplexed and routed to a single SONY digital recorder recording at 32 MB/s (256 Mb/s). In fact, the speed of the recording system is currently the bottleneck of AIRSAR limiting the range swath to 10 km in 40 MHz chirp bandwidth mode and 5 km in 80 MHz chirp bandwidth mode.

Motion and location measurement system is a key component of AIRSAR, enabling us to achieve better height accuracy in cross-track interferometric mode and better geo-location accuracy in all radar modes. AIRSAR utilizes a state-of-the art Honeywell H-764G embedded GPS-INS unit (EGI) for high precision motion measurements. The specified accuracy on this unit is 0.02° heading, 0.01° roll and pitch, 0.03 m/s velocity per axis, and 16 m in position with PPS. Our experience with this unit indicates that the angular accuracy is better than the specification.

An Ashtech dual-frequency GPS receiver and a Satloc differential GPS receiver were added to the system in 1998 to provide better location accuracy and to improve the height accuracy of the digital elevation models (DEM). Ashtech data collected in October 1998 demonstrated vertical accuracy of better than 70 cm and horizontal accuracy of better than 40 cm (post processing). In experiments conducted by the GPS group at JPL, the real-time vertical accuracy provided by the Satloc wide area differential GPS (WADGPS) was better than 50 cm. The network of Satloc ground receivers has since been purchased by Omnistar in April 2000 and the performance of the Omnistar WADGPS service is not yet determined. AIRSAR has collaborated with the GPS section at JPL for many years providing the GPS researchers a platform to check out the latest differential GPS techniques. This also gives us the opportunity to implement the latest DGPS technology in our radar system, providing the best possible geo-location accuracy. This year, the GPS researchers are validating the performance of NAVCOM's real-time differential GPS receiver that they helped develop. Initial assessment during the engineering flight showed real-time accuracy of better than 20 cm in all three directions.

AIRSAR has the capability to display in real-time low-resolution imagery of a single radar channel to verify imaging coverage as well as the health of the instrument. As the system becomes increasingly complex, there is a desire to better monitor the stability and performance of the system during the data flight. In 2000, we added extensive on-board health check capabilities to ensure the success of the long PacRim 2000 campaign. Some of the key parameters we monitored include the phase stability of the system, the quality of the GPS and motion measurements, and the fidelity of the interferogams.

In the following paragraphs, we will overview the different radar modes offered by AIRSAR.

A. Polarimetric (POLSAR) Mode

In polarimetric mode, the antenna switching network for each radar frequency is set up to acquire data from both H- and V-polarized antennas simultaneously. Quad-polarization (HH, HV, VH, and VV) is achieved by alternating the transmit signal between H- and V-polarization. In this mode, we can select the chirp bandwidth to be 20 MHz, 40 MHz, or 80 MHz (L-band only). The polarimetric mode has been available to the researchers since 1989 and has supported much of the algorithm development in terrain roughness estimation, soil moisture measurements, biomass estimation, salinity estimation, vegetation classification, land-use classification, etc.

B. Cross-Track Interferometric (XTI) Mode

In XTI mode, the C-band antenna switching network is set up to acquire data from the antenna pair located one above the other to form an interferogram. The phase information of the interferogram can then be translated into a height map or digital elevation model (DEM). At the same time, L-band radar can be configured to acquire either XTI data or POLSAR data whereas P-band radar continues to operate in POLSAR mode. We have been delivering DEMs routinely to researchers since 1995 in support of research in areas such as volcanic mapping, geologic mapping, slope estimates for natural hazard studies, land classification, etc. The standard configuration for XTI mode is to transmit off the top antenna and receive from both top and bottom antennas simultaneously in V-polarization only. The XTIP mode alternately transmits off the top and the bottom antennas from pulse to pulse while receiving from the top and bottom antennas simultaneously. This effectively doubles the baseline and hence results in better height accuracy.

C. Along-Track Interferometric (ATI) Mode

In ATI mode, the L- and C-band antenna switching networks are set up to acquire data from the antenna pairs located one in front of the other along the body of the aircraft to form interferograms. The phase information of the interferograms can then be translated into velocity maps. We have just begun to deliver ATI interferograms to the science community. Researchers are using ATI data for ocean current mapping, glacier studies, etc. The standard configuration for ATI mode is to transmit and receive in V-polarization since radar return of the ocean is stronger in V-polarization. However, we have operated the radar system in an experimental mode that acquired data in the polarimetric along-track interferometric mode (POLCAT). Some researchers believe that we could retrieve additional information about the ocean current by comparing current maps of HH and VV polarizations.

In addition to the radar modes described above, the DC-8 Airborne Research Laboratory also provides much flexibility. For example, we may acquire data at different altitudes, from as low as 2000 m to as high as 10000 m. We have also acquired data in a circular flight track once for a principal investigator.

TABLE 1
SUMMARY OF AIRSAR SYSTEM CHARACTERISTICS

	P-band	L-band	C-band
Chirp Bandwidth (MHz)	20, 40	20, 40, 80	20, 40
Chirp Center Freq. (MHz)	438.75 (427.5)	1248.75 (1237.5)	5298.75 (5287.5)
Peak Transmit Power (dBm)	62	67	60
Antenna Polarization	H/V dual microstrip		
Antenna Gain (dBi)	14	18	24
Azimuth Beamwidth (deg)	19.0	8.0	2.5
Elevation Beamwidth (deg)	38.0	44.0	50.0
ADC Sampling Rate (MHz) For 20, 40, 80 MHz BW	45, 90, 180		
Data Rate (MB/s)	10		
Nominal Altitude (m)	8000		
Nominal Velocity (Knots)	450		
PRF Per Polarization Channel	1(programmable)x ground speed in knots		
Ground Range Swath (km) For 20, 40, 80 MHz BW	15, 10, 5		
Slant Range Resolution (m) For 20, 40, 80 MHz BW	10, 5, 2.5		
Azimuth Resolution (m)	1		
DEM Posting (m) for 20, 40 MHz Bandwidths	10x10, 5x5		

The center frequencies in () apply to 40 MHz chirp bandwidth mode and also 80 MHz chirp bandwidth mode for L-band only.

III. SYSTEM PERFORMANCE

Table 2 is a summary of the system performance estimates for various data acquisition modes. Noise equivalent σ^o is a measure of the noise floor of the radar in terms of radar cross-section. Figures 1 through 3 show the noise equivalent σ^o as a function of incidence angle for P-band, L-band, and C-band radars respectively. The SNR of the system is then the difference between the radar back-scattering cross-section of the target and the noise equivalent σ^o. The lower the noise equivalent σ^o, the more sensitive is the radar system. The noise equivalent σ^o is a function of incidence angle. Typical operating range of look angle is from 20° to 60°. In Table 2, we quote the noise equivalent σ^o at 45° incidence angle. This parameter typically deteriorates in far range. Height error in the DEM is a function of SNR, baseline, and baseline angle

[4]. Figures 4 and 5 are plots of height error as a function of incidence angle for C-band and L-band respectively. Here we assumed that the radar back-scattering cross-section is –18 dB for C-band and –21 dB for L-band. Height error in C-band DEMs ranges from 1 m in near range (20° look angle) to 3 m in far range (60° look angle) whereas that of in L-band ranges from 2 m in near range to 10 m in far range. At 45° incidence angle, the height error is about 3 m for L-band DEMs and about 1 m for C-band DEMs for terrain of nominal roughness. The absolute calibration is about 2 dB for L-band and C-band whereas that of P-band is about 3 dB due to uncertainties introduced by RF interference.

IV. SUMMARY

In this paper, we described the current configuration of the AIRSAR system and the various data acquisition modes. We also summarized the system performance estimates for the standard radar modes. We continue to expand the capabilities of AIRSAR as well as the performance of the system both in accuracy and stability. One upgrade we just completed is a higher power transmitter for the P-band radar to improve the SNR by 3 dB and mitigate the effect of RF interference in P-band data especially near the urban areas. Another upgrade in progress is individual digital chirp generator cards for each radar band so we can select any chirp bandwidth for P-, L-, and C-band independently. In addition, we are planning to upgrade the digital subsystem to increase the recording bandwidth tremendously so that we could have larger range swath in 80 MHz chirp bandwidth mode. We also plan to improve the SNR of the C-band radar in order to collect data in POLTOP mode with comparable height accuracy to the standard XTI mode. Finally, we continue work in calibrating the experimental data acquisition modes so that we could provide calibrated data for our researchers to validate their algorithms.

REFERENCES

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TABLE 2
SUMMARY OF SYSTEM PERFORMANCE ESTIMATES FOR AIRSAR MODES

	P-POL	L-POL	L-XTIP	L-ATIP	C-POL	C-XTIP	C-ATIP
Frequency range (MHz)	410-450	1220-1300	1220-1260	1220-1260	5270-5310	5270-5310	5270-5310
Cross-pol isolation (dB)	< -20	-20	-20	-20	<-20	-22	-22
Noise equivalent sigma0 (dB)	-48	-48	-45	-40	-31	-30	-30
Baseline (m)	N/A	N/A	4.0	19	N/A	5.0	1.9
Baseline angle (deg)	N/A	N/A	68	N/A	N/A	65	N/A
Height error (m)	N/A	N/A	3	N/A	N/A	1	N/A
Absolute calibration (dB)	3	2	2	N/A	2	2	N/A
Relative calibration (dB)							
between pol. channels	0.5	0.2	-	N/A	0.2	-	N/A
between frequencies	1.5	1.5	1.5		1.5	1.5	

Note: Cross-pol. isolation and noise equivalent σ^o at 45^0 incidence angle. Height error computed using σ^0=-18 dB for C-band and -21 dB for L-band.

Figure 1. Noise Equivalent Sigma-0 versus incidence angle for PH and PV channels assuming 20 MHz chirp bandwidth.

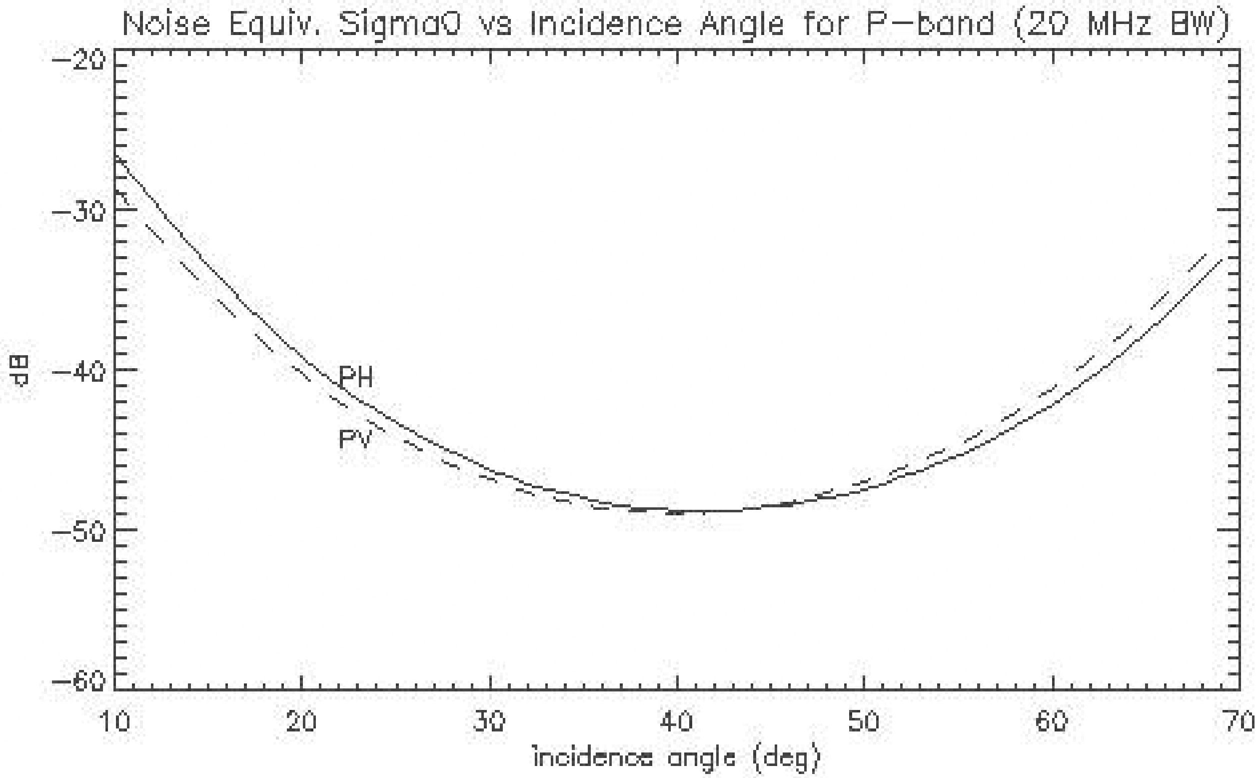

Figure 2. Noise Equivalent Sigma-0 versus incidence angle for LH, LV channels in POLSAR mode and for ATI and XTIP modes assuming 40 MHz chirp bandwidth.

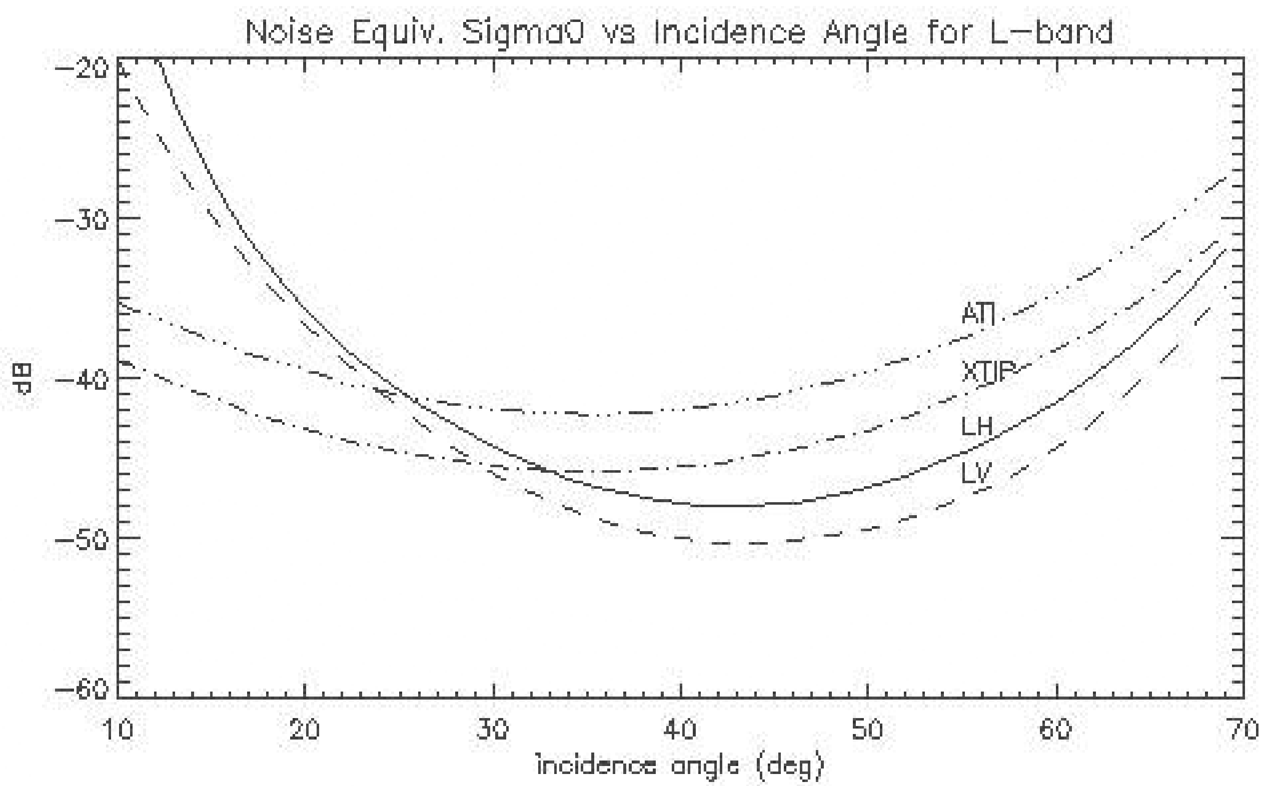

Figure 3. Noise Equivalent Sigma-0 versus incidence angle for CH, CV channels in the POLSAR mode and for ATI, XTI, and XTIP modes assuming 40 MHz chirp bandwidth.

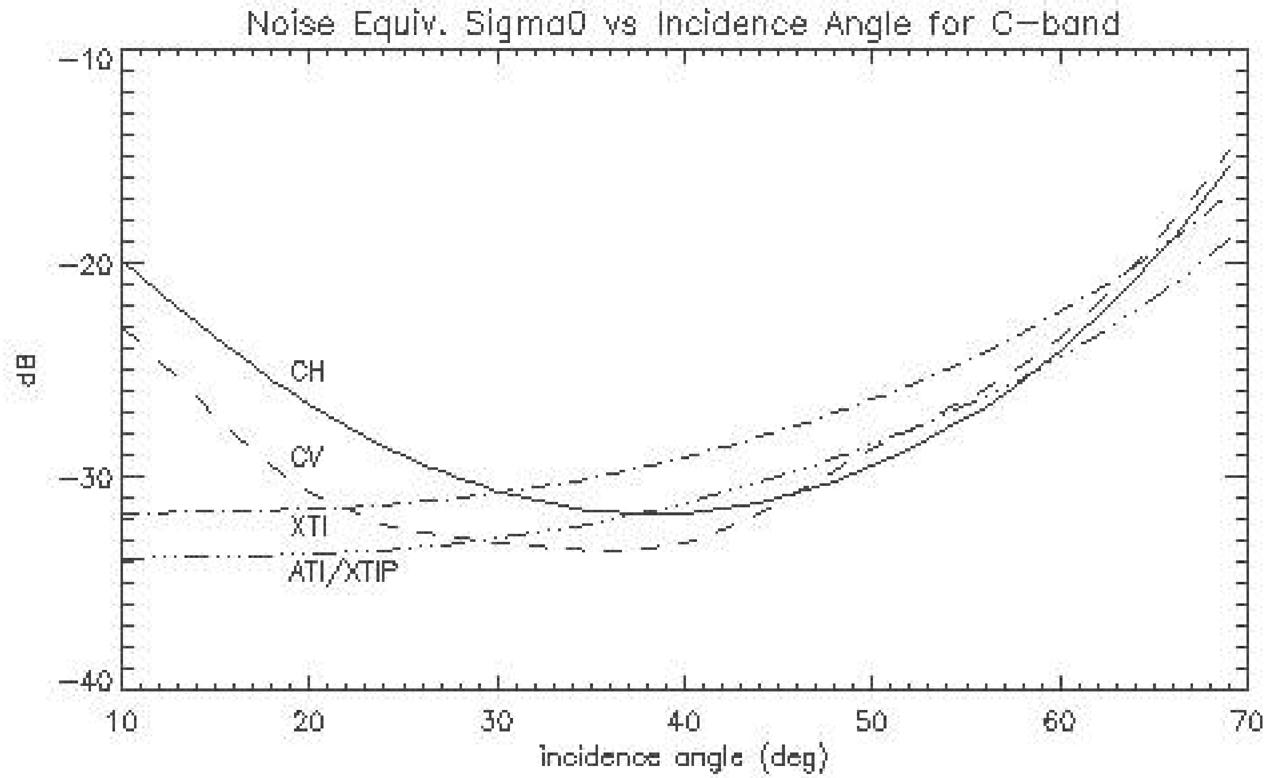

Figure 4. RMS height error versus incidence angle for C-band XTI, and XTIP modes assuming 40 MHz chirp bandwidth and radar back-scattering cross-section of –18 dB.

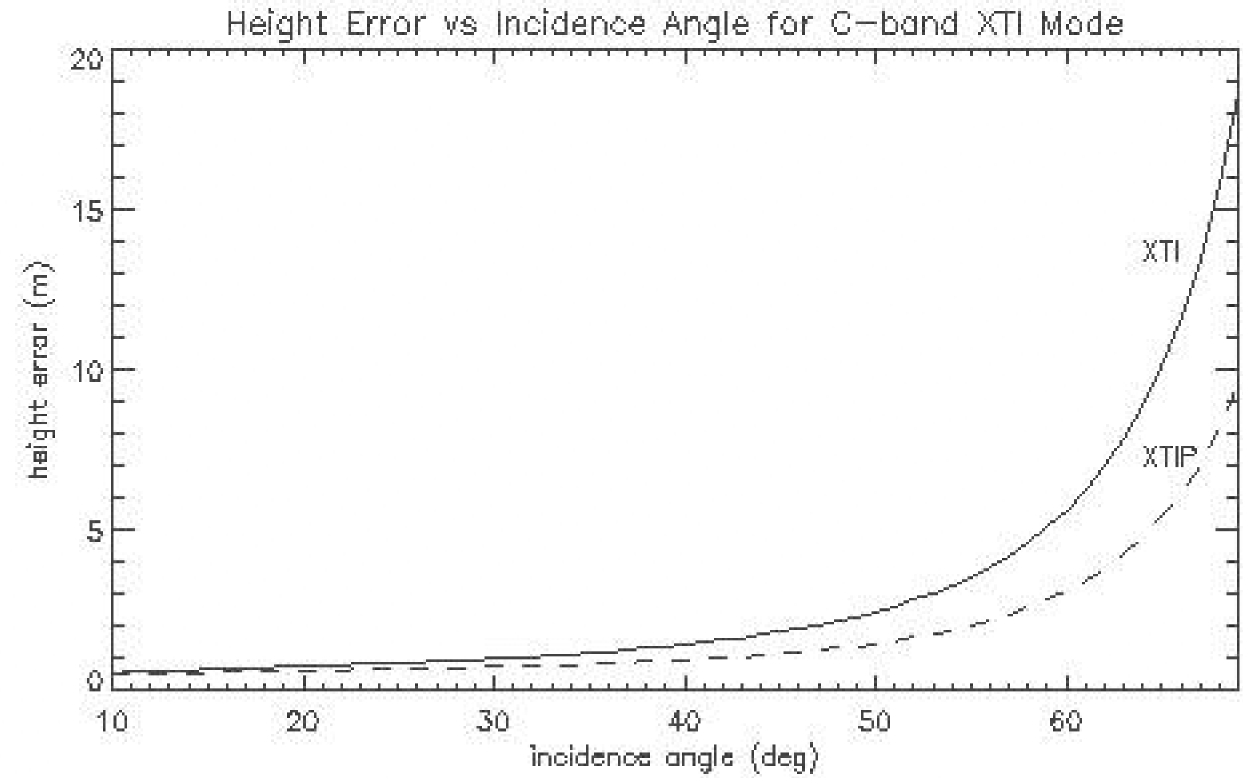

Figure 5. RMS height error versus incidence angle for L-band XTI, and XTIP modes assuming 40 MHz chirp bandwidth and radar back-scattering cross-section of –21 dB.