Flight Planning for Airborne SARs: guidelines to help AIRSAR users get the most out of their data collections

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Abstract- Good flight planning of the data takes imaging an investigator's site is necessary for the processed SAR data to meet the investigator's science objectives. AIRSAR is a flexible instrument that can be operated in a variety of modes with radar settings that can be selected to optimize the final product to meet the data user's needs. In this tutorial talk, I will discuss some considerations investigators should keep in mind when planning their flight requests. Specifically, I will discuss the advantage of long flight lines, how to select a primary heading, the impact of different radar parameters on the final data quality, and ways to reduce the effects of systematic errors.

I. FLIGHT LINE LENGTH

A flight plan conveys the information needed by the pilots, the AIRSAR operators, and the radar to collect the SAR data requested by investigators. A flight plan covers from take off until landing. The subsets of flight plans that cover imaging of a specific site are called site plans. Imaging at a site is made up of data takes or flight lines. The two terms are used interchangeably. The flight planning information for a data take includes the platform locations and the radar parameters.

For each data take, there is time before and after the desired region is imaged spent aligning the plane and building the synthetic aperture. Between each data take at a site, time is spent turning. For each site there is also transit time overhead which is variable site to site. Let us define the data gathering efficiency factor, η, as the ratio of the time mapping to the time flying. We use time since collection cost is accessed by flight hour.

$$\eta = \frac{\sum_{i=1}^{N} T_i/v_p}{\sum_{i=1}^{N} T_i/v_p + N(\tau_{PRE} + \tau_{POS}) + \sum_{i=1}^{N-1} \tau_i}$$

where v_p is the platform velocity, T_i is the target length for pass i, τ_i is the time for the turn after pass i, τ_{PRE} is the time set up time before the main data collection, τ_{POS} is the time clean up time after the main data collection, and N is the number of data takes per site. Note that my metric ignores the effect of the transit time on the overall efficiency, overestimating the true efficiency for all cases. Table I lists typical values of the data gathering efficiency.

Target Length (km)	Number of Data Takes	Efficiency (Percent)	Time to Fly (min)
10	1	29	3
10	2	11	16
10	4	8	41
10	8	7	93
100	1	81	10
100	2	54	31
100	4	47	71
100	8	44	153
200	1	89	19
200	2	70	47
200	4	64	105
200	8	61	219

TABLE I
Data gathering efficiency calculated assuming a platform velocity of 200 m/s, an turn time of 600 s per pass, 1.5 min of time of setup before the main collection begins, and 0.5 min of clean up time after the main data collection.

As Table I makes clear short lines are very inefficient! For example, flying 4 data takes imaging a 10 km long target takes roughly 60% of the time it would take to collect 4 data takes imaging a target 10 times bigger.

These efficiencies have large implications for investigators. Investigators are encouraged to think regionally not locally since the incremental cost is so low. Whenever possible, combine small (10 km x 10 km) sites into regional sites (100 km x 100 km). Communicate with colleagues in your region whose science might benefit from using SAR data.

II. PRIMARY HEADING

Most data takes in a given site plan are parallel to each other. The orientation of majority of the flight lines is called the primary heading. The criteria for selecting the primary heading depend on your science objectives. Often the primary heading is suggested by the topography of the site. Frequently the primary heading is chosen to match the orientation of a valley or mountain ridge imaged. Depending on the shape of the area to be mapped, sometimes the primary heading is driven by the desire for long, efficient lines. At windy locations, the direction of winds aloft may dictate the primary heading since motion errors are more of a problem when flying perpendicular to the wind direction. It is strongly recommended that you never plan a data take along a cardinal direction, such as due north. This is because of the enhanced backscatter from man made surfaces aligned with the radar imaging direction causes problems setting the gains, biases in other data sets you will compare your AIRSAR data to tend to be aligned along cardinal directions, and cultural features such as power lines and railroads tend to be aligned cardinally making interpretation of the AIRSAR data more difficult.

III. CHOICE OF RADAR PARAMETERS

In addition to specifying the locations where the aircraft is to fly, choosing the radar parameters is an essential part of flight planning. Every parameter has advantages and disadvantages. Trading off the parameters to select the values that best meets the science objectives for the site is a key part of the flight planning process.

Below is a list of the radar parameters specified for each data take and broad generalizations about the impact of each parameter. For more information about each parameter the reader is advised to consult the literature [1]. Additionally, AIRSAR users are cautioned against choosing a parameter space that is not calibrated as part of the standard AIRSAR process.

Altitude above the Terrain A lower altitude leads to higher signal to noise ratio (SNR) because the range to the target is reduced. Because small look angles are effected by lay over and the large look angles by shadow, lower altitudes also generally result in smaller usable swaths. Flying too low can result is problems with nadir echoes and receiver ringing.

Along Track Pulse Spacing (PRF Ratio) The pulse repetition frequency (PRF) of the the AIRSAR system is varied along track as the platform velocity changes to keep a fixed along track pulse spacing. The along track pulse spacing is determined by the PRF Ratio which is defined as the PRF in Hertz divided by the aircraft velocity in knots. Smaller along track pulse spacings result in better azimuth resolution. However, since the write rate to the tape is fixed for AIRSAR, more frequent pulses result in a smaller range swath being written to tape.

Platform Velocity For a given PRF Ratio, a slower plane speed will result in a larger range swath being collected and a longer time to collect a given flight line.

Bandwidth The system bandwidth determines the range resolution of the data collected. Larger bandwidths result in higher resolution. However, increased range resolution also means more samples are recorded to cover the same amount of range swath. Consequently, more bandwidth means less range swath.

Single Antenna Transmit and Ping-Pong In the single antenna transmit across track interferometric mode, the same antenna is used for transmit for every pulse, and data is received on two antennas separated by the physical baseline. In ping-pong across track interferometric mode, the antenna used for transmit alternates between the two receive antennas, but data is still received on both antennas. Because the interferometric baseline is effectively doubled for the ping-pong case the height accuracy is higher but the interferogram is much harder to unwrap. Therefore, ping-pong is inappropriate in steep terrain. Ping-pong data is collected such that data can be processed with two different effective baselines. However, since it takes two pulses before an identical channel repeats the effective along track pulse spacing for the ping-pong data is half what it is for the single antenna transmit data for the same PRF Ratio. To keep the pulse spacing down, the PRF Ratio is normally increased for ping-pong data resulting in a smaller range swath.

Initial Range (Digital Delay) The swath position is determined by the Digital Delay which fixes the time delay before the range sample will be collected for the range line. The initial collected range, ρ_0, is $\rho_0 = (\tau_D - \tau_E)(c/2)$ where τ_D is the digital delay, τ_E is the electronic delay, and c is the speed of light. For AIRSAR, the initial range is often set large enough to avoid contaminating the early collected ranges with nadir echoes. Science requirements for the look angles needed in the swath drive the determination of this parameter.

Pulse Length The advantage of transmitting a longer pulse length is an increase in SNR. The disadvantages are an increase in the recorded range swath that can not be fully range compressed and additional problems with nadir echoes contaminating the near range samples. The maximum limit on the pulse length normally set by the duty cycle of the transmitter.

Bit Reduction In the past, each AIRSAR range sample was 8 bits and all 8 bits were written to tape. AIRSAR is upgrading to allow an option of compressing the number of bits written to tape using a Block Floating Point Quantizer (BFPQ). The advantage of BFPQ is that it allows an increased range swath. The disadvantage is an increase in the quantization noise since the compression is lossy.

Gain Attenuation or gain is applied to the signal to set the signal level so that it will fully utilize the 8 bit analog to digital converters but will not saturate the receivers. The amount of gain to apply is determined by the AIRSAR staff. However, the receiver signal output power is proportional to the backscatter cross section. To set the gains appropriately, the AIRSAR staff needs information from the investigator about the land cover of the primary target.

IV. SYSTEMATIC ERRORS

In addition to the statistical errors which are largely determined by the radar parameters selected for a data take, the output products are degraded by systematic errors. It is important to be aware of the most common systematic errors, your science objective's tolerance to these errors, and how you can reduce your sensitivity to these errors through clever design of your plan. In my experience with TOPSAR data, the dominant systematic errors intrinsic to the data are platform position errors, errors due to motion so excessive that the processor can not properly compensate for it, and errors due to the unmeasured expansion and contraction of the across track interferometric baseline during flight [2] [3].

Platform position errors result from uncertainties in the plane's exact position during a data collection and translate the output data by an amount equal to the error in the plane's position. The on-board Honeywell inertial navigation unit has a position uncertainty of roughly 10 m. The platform position can be improved by blending the inertial navigation unit's positions with independent GPS measurements of the plane's location. Depending on your accuracy requirements and what is available at your site, the GPS measurements can be obtained by receiving broadcast GPS corrections or by collecting RINEX data on the plane for post processing. The RINEX data is not routinely collected and must be specially requested if needed.

The DC-8 is at the mercy of the winds, and errors due to excessive motion of the aircraft are sometimes unavoidable. If your site is prone to large winds aloft, plan you flight lines parallel to the dominant wind direction aloft or develop a contingency plan rotated perpendicular to your nominal plan. The effects on the data can also be reduced by choosing a smaller along track pulse spacing. Perhaps the most important thing is to convey to the on-board crew the criteria for when to abort your data collection.

Because the AIRSAR antennas are mounted on the fuselage of the aircraft, the separation between the antennas varies as the fuselage expands and contracts due to changes in pressure and temperature. For across track interferometry, this results in baseline errors which generally tilt the final digital elevation model (DEM) produced from the data. The most common way to mitigate this effect is to plan data takes perpendicular to the primary data collection orientation and spaced along track. Due to the difficulty in uniquely identifying targets viewed perpendicularly, it is recommended that crossing data takes be placed in areas with significant terrain or extremely easy to identify backscatter features such as suburban housing developments. Baseline errors can also be compensated for by sufficient three dimensional ground truth or the appropriate deployment of corner reflectors.

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