

# PacRIM II: A Review of AirSAR Operations and System Performance

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**Abstract**—NASA's AirSAR instrument has long been a heavily utilized resource in the international remote sensing community, including, most recently, the very successful PACRIM II mission. In this paper we briefly review the AirSAR system, its expected performance, and quality of data obtained during that mission. We discuss the system hardware calibration methodologies, and present quantitative performance values of radar backscatter and interferometric height errors (random and systematic) from PACRIM II calibration data. We also summarize the various anomalies experienced during the PACRIM II mission, their potential impacts on data quality, and possible solutions to those problems.

Finally, in light of these assessments, we discuss near-term system enhancements, and expected performance improvements for future AirSAR missions. In particular, we present a redesigned data acquisition system that promises to improve data reliability and system flexibility while increasing data throughput. One distinct advantage of this system is it will allow us to collect wide-swath high-bandwidth data thereby making data collection more efficient when high bandwidth area imagery is required.

## I Introduction

JPL's airborne synthetic aperture radar (AirSAR) [1], [2] is a unique system, comprising three radars at C-, L- and P-bands. AirSAR data collections are flexible; fully polarimetric data (POLSAR) can be collected at all three frequencies, while cross-track interferometric data (TOPSAR) and along-track interferometric (ATI) data can be collected at C- and L-bands [3]. This configurability has made AirSAR a heavily utilized resource within the USA and internationally. The 2000 PACRIM II mission was AirSAR's most ambitious deployment to date. In addition to collecting AirSAR data, hyperspectral data were also collected over most of the same sites by the Master instrument, an airborne Modis/Aster simulator.

Over a period of 3 months the AirSAR and Master instruments aboard the NASA/Dryden DC-8 aircraft collected data over 18 countries and territories around the Pacific rim. The plane was staged at 15 bases in 9 countries. Data were collected on 46 flight days over 318 flight hours. A total of 648 flight lines covering 54623km (along the flight path) were collected with a 94% success rate of planned vs executed lines. Some lines were cancelled due to weather or hardware considerations.

The PACRIM II mission was a collaboration between NASA and the participating countries. While data was

collected for NASA-funded US investigators, the majority of data were collected for researchers within each country. NASA/JPL worked with a central organization (university or research institute) to coordinate data collection in each country. In turn, these points-of-contact solicited requests for data from investigators within their country. A wide range of research objectives and applications will be addressed with the data that were collected. For AirSAR these applications include

- biomass estimation/carbon sequestration studies
- soil moisture measurements
- vegetation classification
- land-use classification
- urban mapping/growth studies
- radar techniques and calibration
- archeological exploration
- along-track interferometry to measure ocean current direction and velocity
- wetland, flooded forest classification
- natural hazard monitoring and studies
- geologic mapping

The individual applications determined the operational mode for each flight line. Table I summarizes the statistics of data collection modes for PACRIM II.

This paper reviews PACRIM II from the AirSAR system and operations perspective. Section II discusses in-flight system operations focusing on new utilities which were enhancements for PACRIM II. Section III focuses first on calibration methodology then moves on to itemize system performance issues we encountered. Finally Section IV forecasts improvements to AirSAR for a possible PACRIM III mission in 2003.

## II System Operations

For PACRIM II, AirSAR incorporated a number of enhancements to improve operations and in-flight system health monitoring. Perhaps most notable was the addition of a computer that generated near real-time interferograms and single channel SAR images (for the polarimetric modes). This allowed us to process small sections of selected datatakes through to images/interferograms, often on the same flight day. This ability provides a strong measure of confidence that the radars are operating satisfactorily and, in the case of interferograms, that our motion compensation data is not corrupted. This

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C, L & P-band POLSAR	30%
C, L TOPSAR, P POLSAR	9%
C TOPSAR, L & P POLSAR	51%
C & L ATI	6%
C & P POLSAR, L ATI	1%
Master only (altitude too low for AirSAR)	3%

TABLE I  
PACRIM II AirSAR Mode Statistics

RMS Height Accuracy (z)	
C-band:	1-3 meter
L-band:	2-10 meter
Image Calibration	
Absolute:	3 dB
Relative:	0.2 dB cross-pol

TABLE II  
Calibration Specifications

turned out to be a great asset given the embedded GPS INU (EGI) problems (discussed in Section III) encountered on the deployment. A further benefit of the on-board processor was that we were able to show PI's an, albeit uncalibrated, image preview. Some of these images were electronically sent back to JPL and posted on the AirSAR website, which for such a long deployment provided valuable feedback.

A second, critical utility was a program which checked the phase-stability of the digital chirp generators (DCG). As will be discussed in Section III, the DCG's suffered stability problems and by frequent checking in-flight we were able to prevent acquiring corrupted data.

Improved positional accuracy was achieved by incorporating data from a 12-channel GPS receiver into the headers. The improved position data is utilized in the processing and also provides some redundancy for the EGI.

One of our primary data-visibility tools during an acquisition is the real-time correlator which displays single-channel unfocused imagery. The correlator enables swath coverage verification by the planner and also the PI if they are onboard. A useful addition was a coregistered camera so the user could visually verify the optical and radar scene on one screen (provided there was no cloud cover).

Improvements to our flight planning software included incorporation of better digital elevation models for more accurate flight-line and coverage visualization and an html-based input interface to make initial planning more expeditious. During PACRIM II the flight log was sent back to JPL electronically at the end of each flight day for posting on our website. This gave immediate feedback to PI's and the JPL-based AirSAR team on the status of individual datatakes, the system and the mission.

### III Calibration and System Performance

#### III-A Calibration

This section briefly discusses system calibration methodologies from a deployment and logistics viewpoint. A more detailed description on data calibration processing is provided in [4].

Detailed system calibration parameters are derived pri-

marily from hard-target imagery of an array of corner reflectors, permanently deployed on the Rosamond Dry lake bed, Edwards Air Force Base in California. Before the deployment the reflectors were cleaned, inspected and resurveyed to minimize calibration errors due to target position and pointing errors. AirSAR calibration data over Rosamond were collected at the beginning and end of PACRIM II in all operational modes and bandwidths that were used during the deployment. A special dispensation allowed us to collect a calibration line transmitting P-band at 40MHz bandwidth (420-460MHz). This was critical to the program since many data collections outside of the USA utilized the full P-Band bandwidth. Further calibration data were obtained during the mission thanks to a number of investigators who deployed corner reflectors their science data collection sites. Table II summarizes calibration accuracy specifications.

The hard target information is used for both radiometric and interferometric calibration. The accuracy of this calibration is determined by the signal to clutter ratio and the number of reflectors to average over [5]. Rosamond lake bed houses 15 reflectors and is extremely radar dark, making for a good calibration site. In addition, dynamic variations of gain and the differential phase of the receive chain are removed by monitoring a calibration tone.

Interferometric calibration of AirSAR is complex and occurs in several stages; slant-range imagery of surveyed targets determines the common and differential range delays, EGI biases, and amplitude corrections; interferograms of surveyed targets are used to correct for static biases in the interferometric baseline and phase.

Calibration of the cross-polarized channels requires imaging of targets or scenes with known polarization properties. While polarimetric calibration can be achieved through imaging dihedrals or active devices, they are logistically difficult to deploy and maintain. For this reason AirSAR polarimetric data is calibrated using the scene calibration procedure detailed in [6].

#### III-B System Performance Issues

In general AirSAR operated with few incidents throughout the 3-month deployment. However there were

some operational issues which deserve mention.

One of the primary system problems encountered on PACRIM II was phase jitter in the digital chirp generators (DCG). The DCG's would only operate stably within a fairly narrow temperature range and it was often necessary to cool or warm the rack. This especially affected the P-band radar. A combination of closely monitoring the temperature and frequently checking the phase stability enabled us to minimize the impact of this problem. As a result we have not seen significant evidence of data corruption in the processing. The DCG problems have been traced to a design flaw and are currently being redesigned.

Another significant problem encountered in-flight was the stability of the EGI which provides critical motion compensation and position data. This was an issue throughout the mission which cost flight hours and some data lines. The most notable impact was that no AirSAR data was collected on the Townsville to Alice Springs, Australia transit after in-flight and ground resets of EGI failed. Following this a flight day was postponed and the DC8 remained in Alice Springs while the EGI was fixed under the guidance of the manufacturer in Florida. Despite this, EGI stability continued to be a major issue with in-flight and ground resets being necessary on a number of occasions. Since returning, the EGI has been updated with a new software version. We plan to fly with an EGI engineer on board for the engineering checkout flights of our next deployment.

#### IV Future Improvements

As previously mentioned, a critical improvement to AirSAR will be the new DCG's. Having identified a design flaw in the current DCG's, they have been redesigned and will be integrated into AirSAR by the end of 2001 and tested in our next deployment (early 2002).

A further upgrade/modification that will be integrated into AirSAR for the 2002 deployment is a smaller, more efficient P-band transmitter which will more than double the transmitted power from 850W to 2kW. The increase in power will mitigate our sensitivity to radio frequency interference which is very prevalent at P-Band. The new transmitter will first be flown 2002.

Before PACRIM III we propose to upgrade AirSAR's data acquisition system with a new state-of-the-art data acquisition system primarily using commercial off-the-shelf (COTS) componentry. The proposed design yields a number of improvements over the current AirSAR digital system. These include:

- increased reliability.
  - Data-glitches are observed in current system which serve to wipe-out entire range-lines.
  - The existing system also has several components which are "single-point-failures".

- the full beam-limited swath-width can be acquired, even at 80MHz bandwidth. Currently there is a data-flow bottleneck of 5MB/s per channel (30MB/s aggregate throughput) and higher bandwidth data can only be collected by reducing the swath-width. The new data acquisition system's aggregate throughput will exceed 120MB/s
- improved in-flight health monitoring and near-real-time processing. In-flight visibility of the data is critical for detecting system hardware problems expeditiously.
- compliance with industry standards and protocols. This will enhance AirSAR's readiness to act as a technology testbed. AirSAR's directive to demonstrate and develop new technology is dependent on a flexible, modular and standardized design.
- the modular design will make the addition of data channels (for single-pass Polarimetric interferometry or even another radar) relatively straight-forward and inexpensive.

We anticipate that, by PACRIM III, we will be using a new processor to process the data. This processor will improve the image quality, with better calibration and projection implementations. The result will be enhanced products in terms of both absolute and relative errors.

#### V Conclusions

This paper summarized AirSAR's participation in PACRIM II, detailing both system improvements and difficulties encountered. PACRIM II was an ambitious undertaking logistically, technically and scientifically that overall can be deemed a success. A number of improvements are anticipated for PACRIM III in 2003. These enhancements promise to benefit AirSAR users in terms of data quality delivered.

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