# First P-Band Results Using the GeoSAR Mapping System

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## INTRODUCTION

GeoSAR is a program to develop a dual frequency airborne radar interferometric mapping instrument designed to meet the mapping needs of a variety of users in government and private industry. Program participants are the Jet Propulsion Laboratory (JPL), Calgis, Inc., and the California Department of Conservation with funding provided initially by DARPA and currently by the National Imagery and Mapping Agency. Begun to address the critical mapping needs of the California Department of Conservation to map seismic and landslide hazards throughout the state, GeoSAR is currently undergoing tests of the X-band and P-band radars designed to measure the terrain elevation at the top and bottom of the vegetation canopy. Maps created with the GeoSAR data will be used to assess potential geologic/seismic hazard (such as landslides), classify land cover, map farmlands and urbanization, and manage forest harvests. This system is expected to be fully operational in 2002.

In this paper we describe an experiment conducted at California's Latour State Demonstration Forest located near the city of Redding. This experiment marks the first operation of the P-band radar in a vegetated area.

## GeoSAR SYSTEM OVERVIEW

The GeoSAR radar flies onboard a Gulfstream-II aircraft and is a dual-frequency (P- and X-band) interferometric Synthetic Aperture Radar (SAR), with HH and HV (or VV and VH) polarization at P-band and VV polarization at X-band. The radar hardware onboard the Gulfstream-II aircraft is supplemented with a Laser-Baseline Measurement System (LBMS) which provides real-time measurements of the antenna baselines in a platform based coordinate system which is tied to onboard Embedded GPS/INU (EGI) Units. GeoSAR maps a 20-km swath by collecting two 10-km swaths on the right and left sides of the plane as shown in Figure 1.

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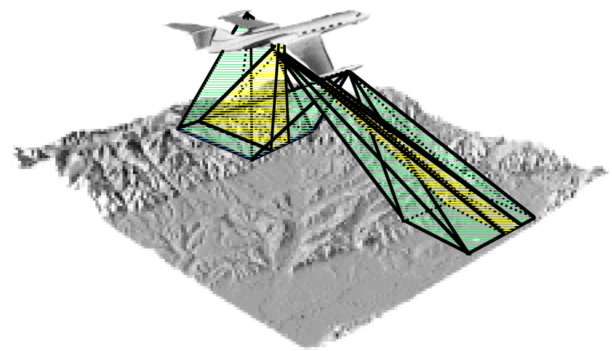

**Figure 1.** GeoSAR collects 10 km swaths simultaneously on both left and right sides of the aircraft at both X and P-bands.

The P-band antenna system is mounted in the port and starboard wingtip pods providing a long antenna-baseline of about 20 meters. X-band antennas are mounted in pairs under the fuselage with an antenna-baseline of 2.5 meters. Radar operations are controlled by a command disk generated preflight by the Mission Planning Software. Realtime data collection is controlled in-flight via an Automatic Radar Controller (ARC) that sets data collection windows, performs Built-In Test (BIT's) before and after each datatake, and automatically turns the radar on and off during a data acquisition. Raw radar data is recorded on high-density digital tape recorders for subsequent, post-flight processing. The onboard data collection via the Automatic Radar Controller also records navigation data from the aircraft's GPS/INU system, the laser-based antenna-baseline measurement system, and raw signal data from X- and P-band radars. Table I gives a summary of the main system parameters.

## EXPERIMENTAL SETUP

### Site Description

Latour is a 9000 acre forest owned and operated by the California Department of Forestry and Fire Protection. About half of Latour forest is true fir, meaning

**Table 1.** GeoSAR System Parameters

| Parameter | P-Band Value | X-Band Value |
|---|---|---|
| Peak Transmit Power | 4 kW | 8 kW |
| Bandwidth | 80/160 MHz | 80/160 MHz |
| Pulse Length | 40 μs | 40 μs |
| Antenna Gain at Boresight | 11 dBi | 26.5 dBi |
| Look Angle Range | 22° to 60° | 22° to 60° |
| Center Frequency | 350 MHz | 9.755 MHz |
| Baseline Length | 20 m and 40 m | 2.6 m or 5.2 m |
| Baseline Tilt Angle | 0° | 0° |
| Platform Altitude | 5,000 m to 10,000 m | 5,000 m to 10,000 m |

80% of the trees in those stands are red fir or white fir. The remainder is sierra mixed conifer. Of particular interest are several single age stands where all of the trees are of approximately the same age and size. Trees on site are second growth with heights less than 50 m. Figure 2 shows a stand of trees in the study area.


**Figure 2**. Latour is a California State Demonstration Forest with 80% of the trees being red or white fur. Trees on the site are second growth with heights in the study area approximately 25-35 m. A perspective of the tree height can be made by comparing the trees to the people in the foreground.

## Ground Truth

In order to make quantitative assessments of the GeoSAR interferometric X-band and P-band height measurements extensive ground truth was collected at Latour. Ground truth consisted of five corner reflectors deployed in open areas surrounding the main study area that were used for precise subpixel geolocation of the radar data. Vegetation measurements and true ground or bare surface elevation measurements were made by LIDAR and a ground survey team. LIDAR data were collected at several altitudes by the Earthdata LIDAR mapping system and covered an area approximately 30 km by 16 km.

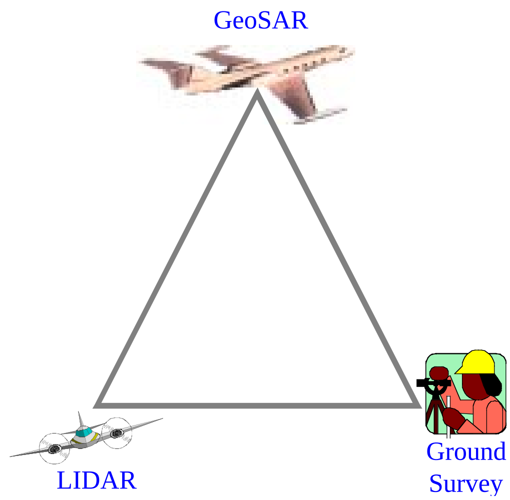


**Figure 3.** The objectives of the Latour experiment are to cross compare GeoSAR P-band and X-band DEMs, LIDAR DEMs, and ground survey of data.

Ground survey measurements of the bare surface elevations of a relatively flat and heavily vegetated portion of Latour approximately 1 $km^2$ in area were made at 5 m posts. A vegetation survey of tree species, tree height, crown thickness, tree diameter, soil moisture, and ground cover type for a dense set of cells within the 1 $km^2$ study area was also conducted. The vegetation survey and LIDAR data were tied to the same set of geodetic control to insure proper co-registration of the data sets.

## Experiment Objectives

The primary goals of the Latour experiment were to:

1. Determine how well the P-band radar system penetrates foliage.
2. Conduct phenomenology studies of X-band and P-band interferometry in a coniferous forest canopy and study the use of correlation measurements to correct to the true ground surface height.
3. Cross compare the radar, LIDAR, and ground survey measurements of bare surface elevations and canopy parameters as illustrated in Figure 3.
4. Determine if LIDAR measurements over a sparse set of points can be used to refine the radar bare surface elevation estimates.

## Radar Data Collected

Radar data at Latour were collected on four consecutive flight days in November, 2000. Each mission collected 12-15 flight lines approximately 60 km in length from a flying altitude of 9750 m. GeoSAR can collect data using either 80 MHz or 160 MHz waveforms. Using the Arbitrary Waveform generator (AWG) P-band waveforms were notched at several frequencies to avoid interfering with other critical users in the band.

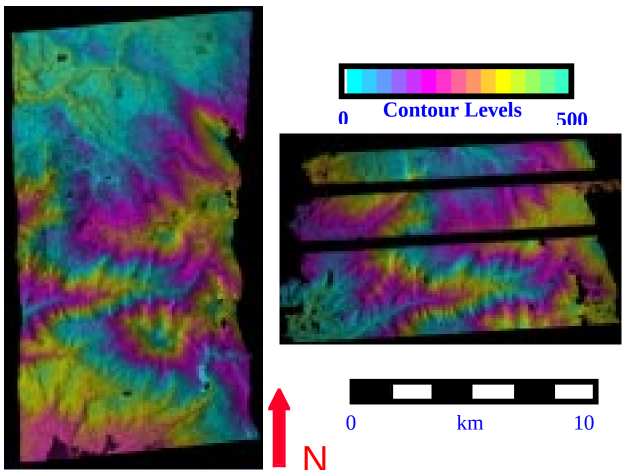


**Figure 4.** GeoSAR P-band (left) and X-band (right) collected at Latour. The data were processed with a 5 m posting and co-registered with the LIDAR and ground truth data for analysis.

## PROCESSING RESULTS

Processing of the X-band and P-band data uses a processing system specifically designed for the GeoSAR system [1]. The first step in processing is a Kalman filter blending of INU, DGPS, and the LBMS data to obtain accurate position and baseline data. Because the P-band portion of the spectrum is heavily used, the P-band data are "cleaned" of radio frequency interference (RFI) using a least mean square (LMS) filtering algorithm [2]. X-band data are processed using a standard Range-Doppler processing algorithm whereas P-band uses a wave-domain processing algorithm coupled with a novel two stage motion compensation algorithm needed for proper focusing of UWB radar data [2]. Strip map DEMs posted at five meters along with orthorectified imagery and correlation maps were produced for X and P-band over the study area as shown in Figure 4. Unfortunately, problems with the X-band TWT caused data dropouts in the X-band imagery.

Subsequent to processing the X-band and P-band data they were co-registered with the LIDAR data. Using the multiple returns from the Earthdata LIDAR we estimated the tree height as well as the elevation of the bare surface. After subtracting the LIDAR true ground surface data from the X-band and P-band heights, we compared the resulting difference maps to the LIDAR tree heights. A transect through each data layer shown in Figure 5 indicates that P-band penetrates approximately 10-15 m deeper into a coniferous forest canopy than X-band and that P-band HH interferometric height measurements do not directly measure the true ground surface.

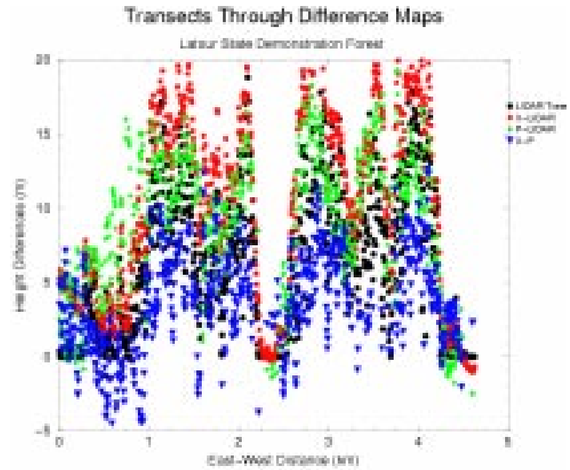


**Figure 5.** Plot of transects through LIDAR determined tree heights, differences of X-band/P-band and the LIDAR true ground surface, and the difference of X-band and P-band heights

## CONCLUSIONS

The Latour data collection provided the first opportunity to test the GeoSAR P-band radar in a vegetated region. GeoSAR's ability to transmit notched waveforms and algorithms for removing RFI were key elements for successfully collecting and processing P-band data. Comparison of P-band and X-band height measurements with the extensive ground truth measurements has shown that P-band penetrates approximately 10-15 m deeper into a coniferous forest canopy than X-band and that P-band HH interferometric height measurements do not directly measure the true ground surface. Initial studies using the correlation data from the dual P-band baselines and the X-band show promise for correcting the height measurements to the true ground surface.

## ACKNOWLEDGMENTS

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