Repeat Pass Radar Observations of Venus From the Magellan Radar System. S. Hensley[1], S. Shaffer[1]. [1]Jet Propulsion Laboratory, Mail Stop 183-601, 4800 Oak Grove Dr., Pasadena, CA 91101 (Scott.Hensley@jpl.nasa.gov).

Introduction: The Magellan mission to Venus was launched in May of 1989 and arrived at Venus in August of 1990 to begin unprecedented radar observations of the Venusian surface. Radar observations were made using a SAR imaging mode, an altimeter mode and a radiometer mode all of which operated at S-band (12 cm). The radar operated till 1992 and mapped 98% of the surface of Venus.

The Magellan spacecraft had an elliptical orbit with an apoapsis of approximately 8000 km and a periapsis of 257 km and an orbital inclination of 86°. In this way the radar was able to collect long strips of data approximately 10000 km in length running north to south with altitudes varying from 3000 km to 257 km. During the remainder of the orbit the collected data was down linked to earth. The SAR mode operated in burst mode fashion whereby it transmitted a small string of pulses up to a couple of hundred pulses in length followed by a quiescent period when the radar ceased transmission and allowed interleaved operation of the altimeter and radiometer modes. This mode of operation allowed for a significant reduction in downlinked SAR imaging data at the expense of azimuth (i.e. along-track) resolution.

By combining information from the SAR imagery with altimeter measurements of elevation with 10 km spatial scales detailed analysis of the surface geology were possible. However, in many instances it was highly desired to have elevation measurements with finer spatial scales, down to a couple hundred-meter scale, to aid determining the proper geologic history and composition of the surface. Such measurements were made possible by the using radar stereo techniques over regions of the planet that were mapped at multiple incidence angles. Magellan radar stereo maps can be made with spatial resolution on the order of 5-8 times in the intrinsic radar resolution or about 0.5-1 km scale with elevation accuracy of about 50 -100 m provided there is sufficient scene contrast.

Topography and surface changes measurements can also be made using radar interferometric techniques whereby phase data from multiple observations are used to infer topography or change. Due to the burst mode operation of the Magellan radar routine interferometric observation were not possible, however, it was possible to obtain radar interferometric observations for few SAR bursts, that we demonstrated during the mission. Unfortunately, these results were never formally published at the time but only communicated to the project internally. Because of repeated

requests from the community we now describe these interferometric observations.

Magellan Interferometry: Radar interferometric observations are possible only when certain constraints on the radar imaging geometry are met. The first constraint is on the interferometric baseline, which is the distance between the radar antennas for the two observations forming the interferometric pair. The maximal length of the perpendicular component of the baseline, i.e. the component perpendicular to the radar line-of-sight, called the critical baseline, is a function of the range, the radar wavelength and the range resolution of the radar. For repeat pass radar observations, that is for observations in an interferometric pair which are separated in time (which can be from minutes to years), this means that the repeat orbit for the second observation must pass within this distance to make interferometric observation possible. The critical baseline is proportional to the wavelength and range and inversely proportional to the range resolution so the critical baseline is at its minimum at periapsis.

The second major constraint concerns the pointing of the radar. In order to have viable interferometric observations the radar must be pointing in identical directions for the observations within a fraction of a beamwidth. Magellan adjusted its pointing profile as a function of latitude, however this pointing profile was highly repeatable and controlled to a fraction of beamwidth thus allowing for the possibility of interferometric observations.

The burst mode operation of the Magellan radar imposed a final constraint on the spatial overlap of pulses in the bursts on the two observations forming the interferometric pair. Basically, the two bursts must be aligned in space such that a large fraction of the pulses overlap in order for interferometry to be possible. Because along-track position knowledge at the time of radar acquisitions was several kilometers whereas the burst duration was a fraction of a kilometer meeting this condition was highly problematical.

In addition to the above observation constraints, the thick Venusian atmosphere can not have differential path length delays between observations that vary from pixel-to-pixel by more than a small fraction of a wavelength. the surface must remain sufficiently undisturbed at the wavelength scale with a resolution element in order that a meaningful interferogram can be formed.

Example Interferogram:

Two experiments were conducted on generating interferograms using Magellan radar interferometry. The first used observations separated by 2 orbits (about six hours) in the North polar region and the second used data from observations separated by one Venusian rotation period of 243 days (Magellan mapped the surface in narrow strips whose swath widths were matched to the amount of Venus rotation during one orbit period. After one Venus rotation period the spacecraft trajectories relative to the surface Venus are nearly repeating and thereby meeting the critical baseline constraint.).

The limited ephemeris and time tagging accuracy was the main difficulty in finding two bursts meeting all the observational constraints discussed to forming an interferogram. To overcome this problem we used an automated matching algorithm to find tie points between image data in orbits 380 and 2171 (243 day temporal separation) disturbed along the entire 10000 km image strips. These tiepoints were use to estimate relative orbital corrections (estimated parameters included relative inclination, true anomaly, etc.) which when used to correct the ephemeris data provided us with good baseline and burst alignment data which were used to search for suitable interferometric pairs. The search algorithm looked for bursts that were within the critical baseline and had at least 70% alignment between the burst. Only a few bursts met the criteria for making suitable interferograms. Figure 1 shows an interferogram made from one burst on orbit 380 and it's corresponding burst on orbit 2171.
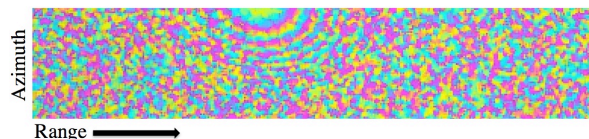

Fig. 1. Repeat pass interferogram of the surface of Venus obtained using the Magellan S-band radar obtained from orbits 380 and 2171 which were separated by one Venus rotation period of 243 days.

The bulls-eye fringe pattern matched the predicted baseline pattern computed directly from the baseline data confirming the accuracy of the relative ephemeris correction and burst alignment.

Conclusions: Although the Magellan was not operated in an optimal mode for radar interferometry we have shown that at least in a few limited cases repeat pass observation through the thick atmosphere are possible and the surface, at least in this location, did not have significant changes at the wavelength scale within a resolution element. It was not possible with the small sample of interferograms we were able to generate to estimate how much changes in the atmosphere between observations would affect topographic map generation from interferometric radar data. That is to say we could not quantify how much small fluctuations of the atmospheric path delay from pixel-to-pixel between observations would translate into elevation errors.