USGS Magellan Stereomapping of Venus

E. Howington-Kraus, R. L. Kirk, D. Galuszka, B. L. Redding

U.S. Geological Survey, Flagstaff, Arizona 86001 (ahowington@usgs.gov)

Introduction: The Magellan spacecraft went into Venus orbit in 1990 and by 1992 had made three complete cycles of polar orbits, each cycle covering the full range of longitudes. During this time the spacecraft obtained synthetic aperture radar (SAR) images of >96% of the planet at a resolution of 75 m/pixel [1]. Images taken with a decreased look angle from vertical, primarily during Cycle 3, provide stereo coverage of 17% of the planet when combined with images with same-side illumination from earlier in the mission. The stereo geometry of these images is extremely favorable, allowing elevation measurements with an estimated vertical precision (EP) of ~10 m [2]. Magellan also obtained radar altimetry data at a horizontal resolution of 10x25 km, but photogrammetric analysis of the stereoimagery can yield topographic maps with a horizontal resolution more than an order of magnitude superior to that of the altimeter. We therefore developed software needed to utilize Magellan stereomagery on our photogrammetric workstation running commercial (SOCET SET® BAE) software [3,4]. The special hardware and SOCET SET software of this system provide many useful capabilities for stereomapping which can be extended by programming with the SOCET SET Developer's Toolkit (DEVKIT). The unique properties of the Magellan SAR data made it necessary to develop both translation software (of image data and supporting geometric information) and a sensor model [5].

Sensor Model: A sensor model is a function that specifies the transformation between image space (lines, samples) and object or ground coordinates (latitude, longitude, elevation). Our Magellan SAR sensor model includes all the physics of the Magellan imaging process, and accounts for the fact that during the Magellan imaging process, the images have been partially orthorectified as part of the correlation process: distortions attributable to topography were removed (but only those accounted for in the very low resolution pre-Magellan topo model) and must be put back in for the images to be matched correctly. The sensor model is designed to work with any combination of unmosaicked (F-BIDR), Mission-mosaicked (F- and C-MIDR), and USGS-mosaicked (FMAP) images. Information about the spacecraft position and velocity can be taken either from the F-BIDR headers or from separate NAIF SPICE kernels, letting us take advantage of post-mission improvements to the spacecraft ephemerides. In addition, the SOCET SET bundle-adjustment software can be used to estimate corrections to the ephemeris of each orbit. The form of the corrections, offsets in three orthogonal directions (along-track, across-track, and radial) suffices to correct the orbits over short arcs and reconcile SAR and altimetry observations.

Validation: We rigorously tested and accounted for potential error sources in our mapping process. We first addressed the well-known "cliffs," artifacts in the stereo data caused by discrepancies between the mission ephemeris solutions for successive blocks of orbits. Alex Konopliv of JPL reprocessed the entire set of orbital tracking and navigation data based on the detailed gravity observations from the end of the mission and claimed that errors in the new orbit solutions were decreased 1.5 orders of magnitude (to 50-200 m) in all 3 axes [6]. To produce seamless elevation data, we found it necessary to collect image-to-image tie point measurements and use these to estimate local position/velocity corrections to the orbits. We concluded that both the improved orbit/tracking solution and corrections based on the images themselves are necessary for successful stereomapping. Secondly, because we constrain elevations of control points based on the Magellan altimetry, the question arose of how sensitive our bundle adjustment process is to artifacts in the Magellan altimetry. (Elevations of individual altimeter footprints can be in error by several kilometers at high-contrast boundaries in the surface scattering function.) We demonstrated that the adjustable parameters allow each image to be translated and rotated as a whole, but not to be "warped" to fit erroneous altimetry data. Furthermore, control points with bad altimetric elevations have large residuals as well, and is possible to identify them as outliers or "blunders" and exclude them from the solution. Finally, we found that the north-south coordinates of burst centerpoints computed in our software differed from the values stored in the F-BIDR headers. We traced this coordinate discrepancy, which is negligible at low latitudes and up to <2 pixels (0.15 km) at high latitudes, to the difference between implementations of the atmospheric refraction correction in our software and in the Magellan SAR processor that produced the F-BIDRs. Both software packages use a simple empirical function fit to numerical calculations of atmospheric refraction. It seems likely that our calculation, which uses a rational function of ground point elevation, spacecraft elevation, and their horizontal separation, is slightly more accurate than the SAR processor code, which uses a polynomial in spacecraft elevation and horizontal separation only.

Procedures: Starting with the improved ephemerides computed by Konopliv plus control points constrained to reliable Magellan altimetry measurements, we further adjust individual orbits to minimize the image-to-image and control-to-altimetric-elevation discrepancies. Once the adjustment process is complete, the FMAP mosaics are imported with Konopliv ephemerides plus our adjustments. Automatic DEM extraction is then done primarily from FMAP mosaics, at a resolution of 675 m/post (or every 9 image pixels), but we resort to the single-orbit BIDRs where there are problems at mosaic seams so that mismatches in mosaicked products are not propagated into the DEM. We found that first "seeding" the DEMs with manually collected points on ridge and valley lines, or with reliable altimetry data, greatly improves the success rate of the automatic matching step. After automatic extraction, the DEMs are interactively edited for blunders, and are then used to make orthoimages and topographic maps.

Conclusion: The results of our stereomapping process are high-resolution stereo DEMs that agree well with the Magellan altimetry, where the altimetry is reliable, yet are not distorted by altimetry artifacts. The horizontal resolution of these products improves dramatically on the altimetry as well. To date we have generated maps of the 12°x12° FMAP quads Joliot-Curie and

Greenaway (in publication), and a test area in Ovda Regio. Although NASA is not currently funding the systematic collection of additional DEMs of FMAP quads, the capabilities described here remain available for potential special area mapping.

References: [1] Saunders, R. et al., (1992) *JGR, 97,* 13067-13090. [2] Leberl, F. et al. (1997) *JGR, 97,* 13675-13689. [3] Miller, S.B. and Walker, A. S. (1993) *ACSM/ASPRS Annual Convention and Exposition Technical Papers, 3, 256-263.* [4] Miller, S.B. and Walker, A.S. (1995) *Z. Photogramm. Fernerkundung, 1/95,* 4-16. [5] Howington-Kraus, E., et al. (2000) *LPS XXXI*, 2061. [6] Rappaport, N.J. et al. (1999) *Icarus, 139,* 19-31.