Radar Performance Modeling for Venus

Scott Heredy, Ian Martin, Shahi Oveisgahrami, Xuyang Duan and Bruce Campbell
Jet Propulsion Laboratory, California Institute of Technology

Overview
The next generation of radar missions to Venus will employ more sophisticated radar instruments and operate in modes not previously used at Venus. We have developed a family of performance models for assessing how radar scattering, interferometry and stereo modes will perform on Venus. The performance models are comprised of several elements that capture the instrument configuration and mode, atmospheric propagation model and a Venus backscatter model. A brief overview of the performance model is described here.

Model Elements
The radar performance tool is comprised of several elements that specify the observing geometry and scenario, the instrument configuration and product specification parameters, propagation and backscatter parameters that are used to determine radar performance depending on models and scene and location of measurement.

Orbit Model
The orbit model provides the key parameters needed to compute radar modes: performance. Instrument parameters include radar center frequency (S-band), transmitted power, pulse length, antenna size, range bin width, system noise temperature, ADC sampling rate, look angle and receive looser.

Atmospheric Model
The Venus atmosphere effects radar observations in two ways: 1) it attenuates the signal with loss proportional to the frequency squared in dB; 2) it shapes and blends radar waves resulting in range measurements being increased relative to the geometric range given by

\[ r_{\text{geom}} = \frac{c}{2f} \]  

where the complex permittivity uses the atmospheric model [2]. The topographic contribution in dB is well approximated by quadratic polynomial with coefficients depending on radar wavelength. Since the Venus has a neutral atmosphere the impact on delay is: frequency independent. For SM it the atmosphere only impacts the range measurement whereas for RFI it impacts the phase measurements due to its interference to SOI, variability (see Table).

SOI variability of the 200 km spatial scale is conservatively estimated from Figure 21 [1] in which the neutral gradient is estimated from latitudes 45°-55° at the lower and upper ends of the Venus surface respectively. Atmospheric distortion at smaller spatial scales is extraneous assuming a Kolmogorov power spectrum [16].

Product Specifications
Product specifications are the values that impact model performance. For example spatial resolution of SAR images or DEM products.

Performance Model Block Diagram
Performance Model and Metrics
- Radar Image Quality Assessment
  - Single Pass Radar Interferometry for Topography
  - Repeat Pass Radar Interferometry for Topography
  - Radar Stereo for Topography
  - Repeat Pass Radar Interferometry for Deformation

Radar Backscatter Model
- The backscatter model is based on a physical scattering model to convert S-band radar data to the geocentric range measurement being increased relative to the geometric range given by

\[ r_{\text{meas}} = \frac{c}{2f} + \frac{c}{2f} \frac{\Delta f}{f^2} \]  

where the error bars respectively. Atmospheric gradient is estimated from latitudes 45°-55° at the lower and upper ends of the Venus surface respectively. Atmospheric distortion at smaller spatial scales is extraneous assuming a Kolmogorov power spectrum [16].

Radar Image Quality Assessment
SAR image quality is measured by two metrics. Two metrics are particularly important in the context of SAR imagery, namely range and azimuth image resolution and radiometric resolution that measures the ability of the radar to determine and discriminate backscatter features respectively.

Radar Stereo for Topography
Radar stereos data collected from two distant viewpoints to measure range and azimuth differences from the reference surface that will appear shifted in the radar image called radar parallax or disparity. Disparity can be measured directly from interferograms using the decorrelation algorithm. Merging and phasing algorithms are the major source of elevation error and can be modeled from a rigorous sensor model [2]. An empirical model of the merging algorithm based on Magellan stereo data and general radar theory is used to characterize merging performance.

Radar Interferometry for Topography
Single pass interferometry is used for topographic measurement and repeat pass interferometry can be used topography and surface deformation measurement [6].

Sample Mode Outputs
Example model outputs of an X-band single pass radar interferometry mission to measure the topography of Venus. The simulated mission spanned three Venus Cycles and operated from a nearly circular orbit with altitudes ranging from 190 km to 240 km. Topographic mapping was assessed using phase noise based on S/N only which is a function of surface backscatter and atmospheric attenuation that is dependent position and topographic dependency. This represents the best possible interferometric map results assuming no other source errors. Topographic accuracy is then assessed incorporating factors for all other error sources including platform position, velocity, and attitude errors, baseline errors and range calibration and atmospheric errors and without handle adjustments that use overlapping strips to remove orbital drift.

References

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