THEORY AND DESIGN OF TIME-SERIES SAR (TSAR) SYSTEMS

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1. INTRODUCTION

InSAR has proven to be a very versatile for the measurement of Earth surface topography, displacement, and volume structure. In the past 20 years since InSAR has become useful, the community has developed many capabilities to exploit single interferograms for the above and other applications. Current research is moving towards the next logical step in InSAR capability—extending the measurement modality from three dimensions to four, and present the temporal variability of surface change. Most current spaceborne SAR systems are designed with repeat orbits to image terrain repeatedly and consistently, and NASA's studies to develop DESDynI and other radars are aimed at enabling time-sensitivity. Two common techniques, persistent scattering (PS) and small baseline subset analysis (SBAS), provide the needed time series data. Here we model these and other temporal techniques with the goal of accurately describing their performance based on system parameters, and orbital and imaging geometries. This allows us to properly choose between the several radar systems now in use for a given application, and perhaps more importantly, design new spaceborne systems to enable specific studies and uses. We process several data sets collected by the various instruments in orbit today, and find that the accuracy of the radar image time series varies from cm to several mm radar line-of-sight measurements. Finally, we examine several possible designs for the NASA DESDynI mission and tabulate the expected level of performance for various surface conditions.

2. APPROACH

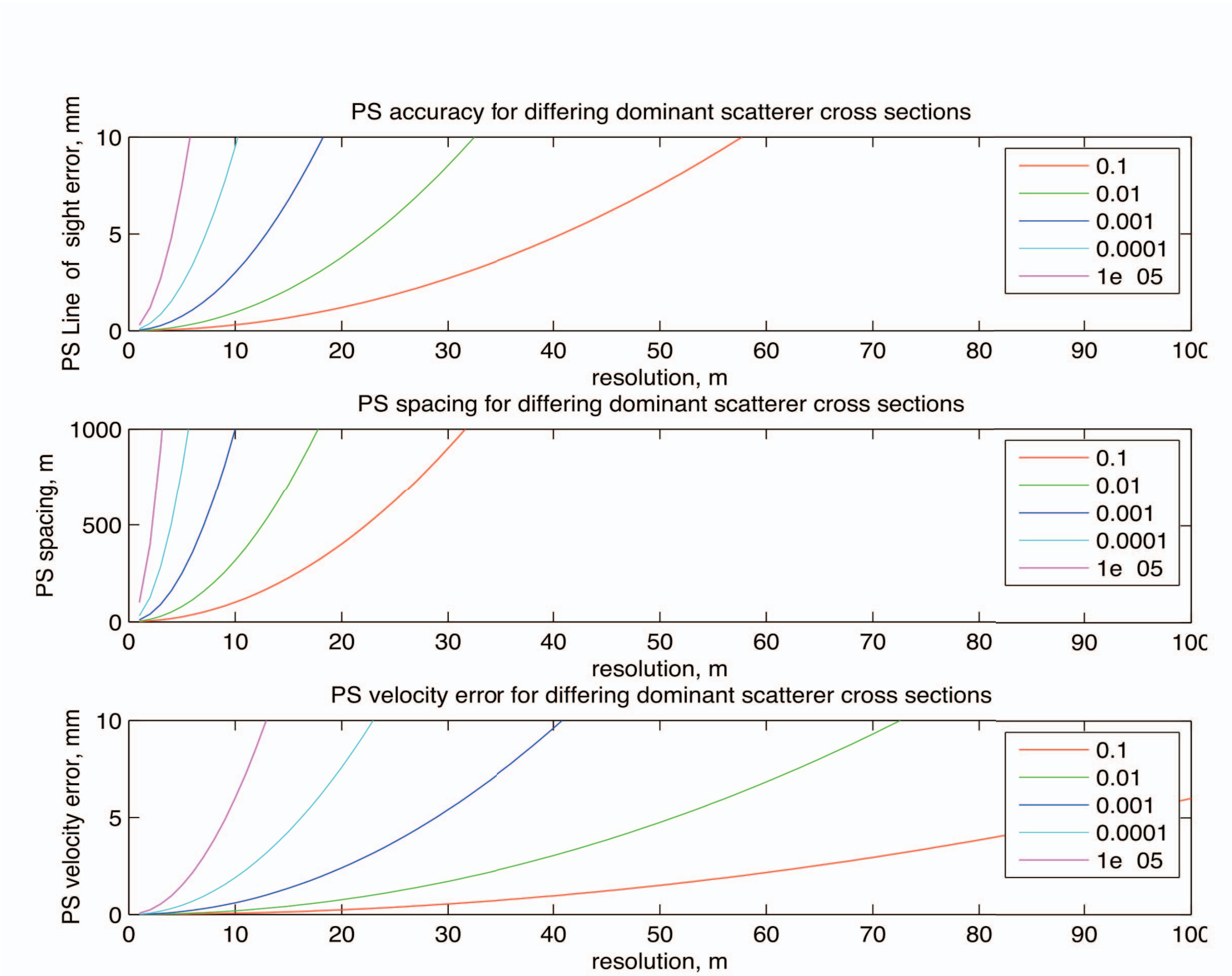
We begin with a model for the probability that a given pixel is persistent, which gives us the PS spatial density, and this is compared to the spatial sampling needed to represent geophysical processes. The multiple persistent scatter and SBAS implementations in use today all use different algorithms to identify and connect the stable scattering pixels and areas over time, so each must be modeled by a slightly different system architecture. Yet the basic phase density functions are common to each, so we derive a generic system model that can be suitably altered to accommodate the given specific algorithm and implementation. The phase probability functions give the expected errors for each phase measurement conditioned on the set of system parameters, including hardware performance, orbit characteristics, and imaging mode. Random signals described by these pdfs are processed into time series dependent on atmospheric propagation variations, system resolution, and other filters to remove the effects of topography, thermal noise, and the many decorrelation sources present in InSAR imaging. We model each of these and estimate the final time series location and velocity errors for different geophysical models. The model dependence account for, as an example, block fault motion appropriate for assessing interseismic creep rates when spatial resolution is not critical, and for post seismic slip distributions when resolution is paramount. Similar disparities apply for volcanic steady state and episodic events, or for more complex cycles associated with hydrologic applications.

3. SAMPLE RESULTS

For each candidate radar design, we determine the line of sight position accuracy, the spatial density of the PS or SBAS points, and the accuracy for average velocity measurements along the time series. These three quantities all affect how the system could be applied to measurement problems. For example, the spatial density gives sampling available to represent a geophysical process. The velocity estimates are useful for long term studies when extreme precision (<1 mm/yr) is important, such as for the study of interseismic strain accumulation that affects the earthquake cycle or for slow volcanic inflation that may presage eruptions. The line of sight accuracies depict how well we can track episodic changes in position for processes with important time scales if weeks or less. Other quantities can be calculated as well, but we find these three to be a useful representation of the capabilities of a design.

We present in Figure 1 below a theoretical assessment of the use of ERS data for tracking creep along the San Andreas fault in California. The actual performance of the system follows roughly that of the cyan curves, with ~4 mm line of sight accuracy, velocity accuracy about 1 mm/yr, and a sample spacing of about 1 km. This is what we observe in a PS analysis; expected DESDynI performance may vary as the actual system is not fully designed.

Figure 1. Expected performance of ERS radar for measuring fault creep in California



4. REFERENCES

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