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High-resolution rainfall signatures on X-band Synthetic Aperture Radar imagery: model analysis and experimental validation

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Climate modelers need global precipitation measurements because the released latent heat distribution has a profound effect on the performance of such models. Precipitation measurements are also required to facilitate water management strategies by hydrologists, and managers of transportation, agricultural and flood relief agencies. Although precipitation measurements are widely available in technologically advanced countries, the measurement of precipitation over oceans, mountainous terrain and less developed regions leaves much to be desired.

Since the 1980s much of our understanding of global precipitation has been provided by space-borne passive microwave radiometers and a combination of microwave and infrared passive measurements. Unfortunately space-borne microwave radiometers, even in combination with infrared sensors, have had limited success in retrieving precipitation over land because they rely heavily on the scattering properties of ice in the upper regions of precipitating clouds. Those scattering properties may be poorly related to surface rainfall rates. This limitation can be overcome over land by space-based radars operating at X or Ku band. The Ku band Precipitation Radar (PR) aboard the Tropical Rainfall Measurement Mission (TRMM) program has provided unique precipitation measurements over land. Mountainous terrain has presented challenges to both ground and space-based radars. Radar reflectivity measurements from PR are routinely removed within about 1 to 2 kilometers from mountainous surfaces to avoid ground clutter. If significant shallow precipitation or rain cells smaller than the 4 km horizontal resolution occur along mountain slopes, then such precipitation may be missed by PR. The measurement of light, small rain cells may also be impaired by the signal-to-noise ratio floor of the PR.

A new opportunity to measure precipitation from space may be afforded by the forthcoming availability of several X-band Synthetic Aperture Radars (X-SARs). The TerraSAR-X (TSX) was launched on June 15, 2007 by the Deutsches Zentrum f. Luft u. Raumfahrt (DLR) and another X-SAR will be launched by 2009. The Constellation of Small Satellites for Mediterranean basin Observations (COSMO-SkyMed, CSK) will be launched by the Agenzia Spaziale Italiana (ASI) within 2009. The first of four of these satellites was launched by ASI on June 7, 2007. The Israeli Defense Ministry plans to launch yet another X-band SAR, the TecSAR SAR Technology Demonstration Satellite, later in 2009.

Space-borne X-SARs are generally not designed for atmospheric observation. SARs are often considered "all weather" sensors. However, there is relevant theoretical and experimental evidence that X-band radar may be significantly affected by precipitation occurrence within the synthetically scanned area [9]-[13]. As a matter of fact, PR was designed at Ku band which is only 4 GHz away from X band. Several authors showed that X-SARs are more sensitive to rainfall effects than SARs operating at longer wavelengths, such as L and C bands [10]-[13]. For example, this was demonstrated by the Shuttle Missions STS-59 and 68 of 1994 and the STS-99 Shuttle Radar Topography Mission (SRTM) of 2000 carrying the first X-SAR along with L and C band SARs. Rainfall reflectivity at X-band may be enhanced by about 12 dB and the attenuation increased by about 4 dB when compared to C-band reflectivity and attenuation.

The potential of X-SAR for precipitation retrieval is intriguing. They will probably be able to measure rainfall over land with greater sensitivity than from radiometers. The high spatial resolution (less than 100 m) of X-SARs can provide new insights into the structure of precipitating clouds with respect to PR and its future upgrades. X-SAR platforms could also significantly enhance the planned constellation of satellites carrying microwave radiometers and radars that will be part of the foreseen Global Precipitation Measurements (GPM) mission. These X-SAR satellites, then, may make a valuable contribution to our understanding of the hydrological cycle.

This work is devoted to the exploration of the potential of space-borne microwave SAR to estimate rainfall over land from both a model and inversion point of view. The main objective is to provide a framework for a physically-based inversion of SARs measurements at X band over land. The X-SARs potentials for rainfall retrievals will be investigated to design quantitative inversion algorithms. We will concentrate on SAR inversion over land in order to avoid the ambiguities of X-SAR response over ocean in the presence of rainfall. A forward model of SAR response will be illustrated not only the X band, but also at Ku and Ka band where some SAR technology is already available. The inversion methodologies will be extensively illustrated and quantitative applications to X-SAR data will be discussed, dealing with several case studies gathered during overpasses of TerraSAR-X over America and Europe. The latter will be also discussed in terms of rain-field validation using available ground-based weather radar data.