STUDY OF TROPOSPHERIC PROPAGATION EFFECTS IN SPACE-BORNE SAR REMOTE SENSING: LATEST RESULTS FROM TERRASAR-X

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ABSTRACT

TerraSAR-X, the first civil German space-borne synthetic aperture radar (SAR) satellite, has been successfully launched on 15th of June, 2007. The main purpose of Synthetic aperture radar systems is to map the Earth-surface in high resolution with numerous applications. Synthetic aperture radars are often considered as day/night and all-weather imaging systems. Whereas the first argument is true, since it is an active system, the second does not hold in every case depending on the operating frequencies for the applied system. Indeed, recent examples of typical rain-induced signature modification have been recorded with the X-band TerraSAR-X system. It is well known that the specific attenuation of the signals may be approx. 1 dB/km assuming a rain-rate of 40 mm/hr and such an occurrence may frequently take place for tropical areas over rain forest. Attenuation up to 20 dB and beyond may occur through the precipitation volumes in the cases of heavy precipitation, such as the Brazilian rainforest. However, as will be shown, even the northern latitudes are sometimes vulnerable to precipitation induced distortions.

During the commissioning phase, a total of 12000 SAR-images (scenes) have been investigated for potential "propagation effects" and some scenes have been selected that revealed visible atmospheric effects. In this contribution, we will present a particularly interesting example acquired over New York, where the SAR image will be compared with weather-radar data acquired nearly simultaneously (within the same minute). The comparison of the images show a good overall agreement and it can be clearly shown that reflectivities in the weather radar image of 50 dBz may cause visible artefacts in the SAR images.

INTRODUCTION

Amongst the many propagation effects capable of influencing space–borne synthetic aperture radar (SAR) are delays, attenuation, noise and scintillation, which are caused by atmospheric gases, rain (precipitation), clouds, fog and others. In this contribution we focus primarily on the tropospheric effects which are caused by precipitation.

TROPOSPHERIC EFFECTS

The troposphere, as the lowest part of the Earth's atmosphere, reaches from the surface to approximately 12 km above ground and causes, amongst other effects, attenuation of traversing signals due to hydrometeors (rain, snow, hail), atmospheric gases, fog and clouds [1]–[4]. Except at low elevation angles, the attenuation of frequencies below 1 GHz is negligible. Insignificant contributions to the attenuation will be obtained for frequencies up to 10 GHz due to fog and non-precipitating clouds. However the transmission spectrum exhibits peaks for frequencies around 22 GHz and 60 GHz due to molecular resonances from gases i.e. water vapour and oxygen. Whereas absorption effects due to atmospheric gases are present constantly and everywhere, attenuation due to condensed water in the form of precipitation, clouds and fog is infrequent and is limited to certain areas. Attenuation consists of two physical processes: the reduction of the wave's energy due to the heating of the water particles and, the scattering of energy away from the main direction of propagation.

Attenuation through Rain

One of the major problems affecting microwave and millimetre wave bands for terrestrial and space-borne radars is the attenuation through rain [5], [6]. Rain is the most important cause, not only due to the strong attenuation effect but also due to the fact that rain occurs most frequently. A convenient way to describe the rain intensity is the so called rainfall-

rate or rain-rate given in millimetres per hour. This quantity refers to a certain flux of rain towards the surface of the Earth and may be measured by gauges or weather radars. A rain rate of 4 mm/hr is a typical value for the specification of moderate rain [5].
Typical values for the specific attenuation (attenuation for 1 km propagation path) of different frequency bands according to a given rain-rate are provided in [1]. In many publication an empirical relation of the form

$$\gamma(x,t) = a \cdot R^b \qquad (1)$$

between specific attenuation γ (x, t) and rain rate R are provided [5], [7], [8]. The parameters a and b are dependent on the radio frequency, the raindrop size distribution, the polarization and other factors [7]. After [5], the total attenuation for a given instant of time can be obtained by integrating the specific attenuation along the path of propagation using the following expression

$$A(t) = \int_0^{2h} \gamma(x,t)dx \qquad (2)$$

where

$A(t)$ . . . total attenuation for given time instant t
t . . . time
h . . . path length
$\gamma (x, t)$ . . . specific attenuation
x . . . position along the path of propagation

The specific attenuation along the slant path of propagation has to be known. However, detailed knowledge of the medium through which the signal propagates is rather limited and the temporal and spatial variation of the medium requires assumptions and some modelling [3]. In the case of precipitation we may have some idea about the thermodynamic phase (ice, water, melting band) but no precise information. Using the tabulated values for the attenuation in X-band for a 5 km long path through a heavy tropical convective rain (50mm/hr and more) suggests a 20 – 30 dB attenuation. In Fig. 1 an example of a rain cell affected SAR image is given. It is a zoom into the first image which was acquired with TerraSAR-X.

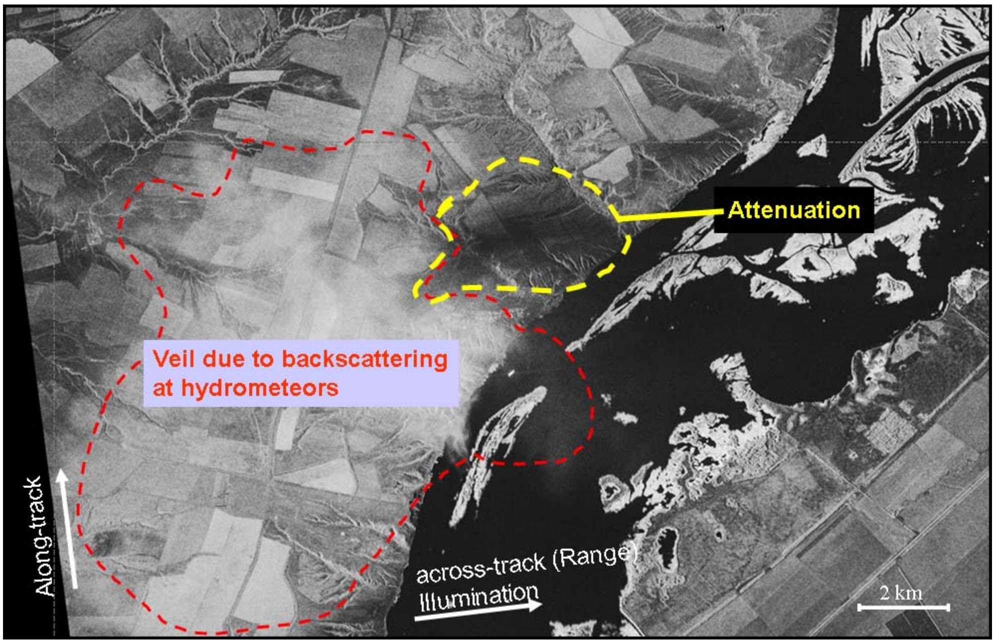

Fig. 1. An example of a rain-cell-affected SAR image recorded with TerraSAR–X. The white shading is due to direct reflections from the rain region (shown as volume ’A’ in Fig. 2). The darkly shaded areas are due to rain attenuated (blocked) signals from the ground; this effect is shown as region ’B’ in Fig. 2. The parameters of acquisition are given in Table 1.

Table 1. The main acquisition parameters of the first image acquired by TerraSAR–X

Parameter	Value
Frequency band	X–band / 9.65 GHz
Image dimensions	Original image: Azimuth: 60 km, Range: 30 km Reduced size: ~ 20 x 15 km
Location	50 km to the west of Volgograd (Russia)
Scene center	Lat: 48.4504; Lon: 43.5542
Imaging Mode	Strip map / HH Polarization

ANALYSIS OF DATASETS AND PHYSICAL INTERPRETATION OF ARTEFACTS IN SAR–IMAGES DUE TO PRECIPITATION

A physical interpretation of how rain cells affect SAR images is given in Fig. 2. The image shows an imaging scenario, where the transmitted waves interact with a precipitation cell. The red rays correspond to the signals transmitted through the clouds, the black rays to the reflected ones. It can be observed, that at area 'A' which corresponds to time instant τ_A in the amplitude/time diagram, is due to strong backscattering from large hydrometeors. Time instant τ_B, which corresponds to the region 'B' proves that signals have been heavily attenuated. By comparing the encircled area in Fig. 1 and the amplitude/time diagram in Fig. 2, the veil in Fig. 1 corresponds to area 'A' (τ_A) and the shadow like black areas close to these veil in Fig. 1 corresponds to the region 'B' (τ_B) in Fig. 2. As diagrammatically shown, the backscattering is accompanied with higher amplitude values and the weak signals behind the first maxima belongs to the black shadows behind to the right hand side of the bright spots, where up to 20 dB difference in the dB level may be observed.

In Fig. 3 we provide a comparison between weather radar data and SAR-data acquired almost simultaneously (within the same minute) over New York. Reflectivities of up to 50 dBZ were observed for the precipitation cells in the weather radar image. Rain events with such an intensity are entirely capable to introduce visible signature in SAR images.

CONCLUSIONS AND OUTLOOK

The conclusions in this contribution are manifold. First of all, propagation effects can be very important and they need to be considered in interpreting radar images. Attenuation caused by heavy rain events, has been identified as the main potential reason for image degradation and artefacts. The underlying analysis comprised more than 12000 data takes of TerraSAR-X. Maximum attenuation up to 25 dB through the precipitation volumes may occur in the cases of heavy precipitation, for instance, for data takes acquired over the Brazilian rainforest. Clouds with low liquid-water content or low rain rates and homogenous distribution will cause no or negligible distortions (visible artefacts). The TerraSAR-X satellite offers new possibilities for investigation of propagation effects in the troposphere.

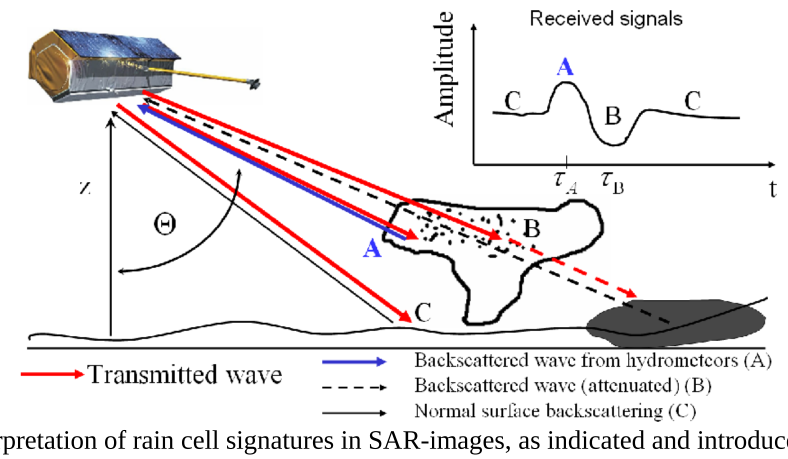

Fig. 2. A physical interpretation of rain cell signatures in SAR-images, as indicated and introduced previously in Fig. 1.

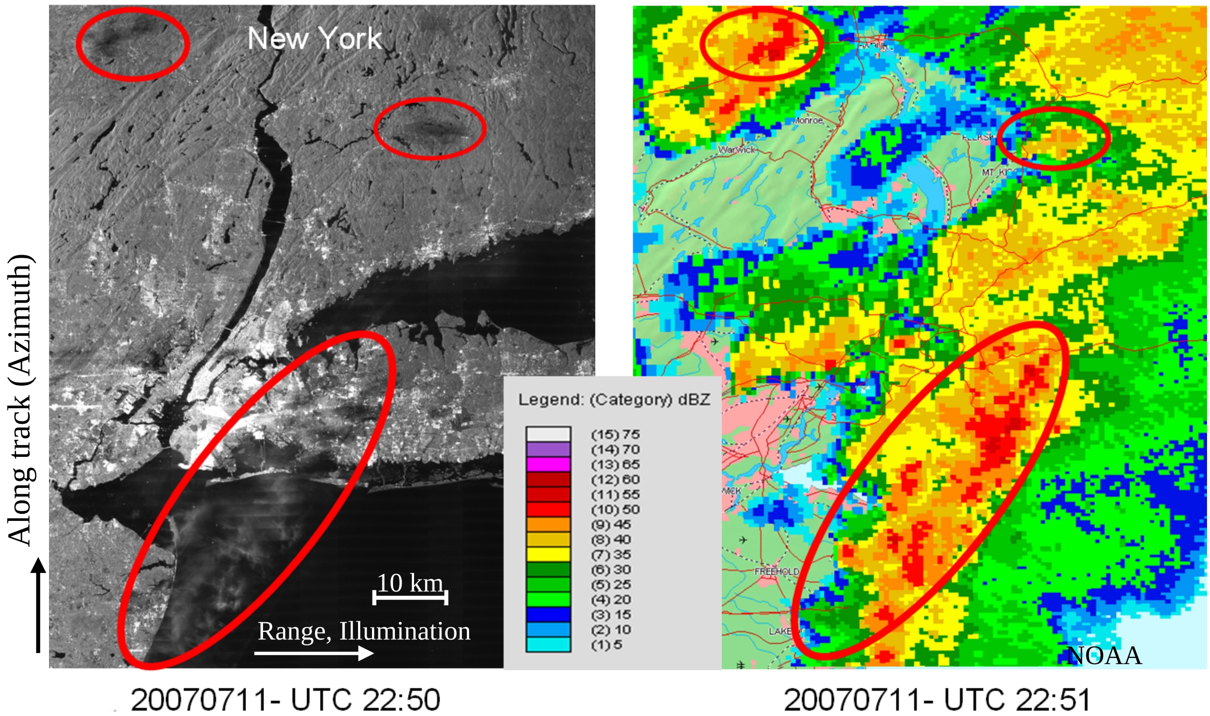

Fig. 3. A test–case showing a comparison of SAR and weather radar data acquired nearly simultaneously (within the same minute) over New York, US. A good agreement between the rain-cell signatures in the SAR–image (left hand side) and the weatherradar image (right hand side) can be observed. The effects are most pronounced for reflectivieties of up to 50 dBZ.

The results presented herein may be also important for future SAR systems operating with higher nominal frequencies, e.g. the Ka-band (35 GHz) where propagation effects due to precipitation will become even more severe. For such cases the results presented in this contribution may act as a reference. In a test-case, it was shown that simultaneous precipitation measurements with weather radars are in good agreement with the observed rain-cell signature observed in the SAR-images. Such measurements are now available for further in-depth study and for further investigations of attenuation effects and their quantification.

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