# MONITORING TIANJIN SUBSIDENCE WITH THE PERMANENT SCATTERERS TECHNIQUE

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## 1. ABSTRACT

Many urban areas in China are affected by land subsidence. The Permanent Scatterers (PS) technique [1], [2] is a powerful tool for monitoring terrain motions by means of space-born radar data on a large number of coherent targets. Core idea of the PS technique is the exploitation of a high density of measure points (usually but not necessarily corresponding to man-made objects) in order to estimate and remove atmospheric artifacts that normally prevent a correct displacement analysis. Aim of this paper is the description of the results obtained by means of the PS technique over the area around Tianjin city in the Popular Republic of China, where a subsidence at the present time is active. Furthermore, the dispersion of acquisition parameters like normal baseline and Doppler centroid (DC) frequency has been used for characterizing the physical nature of PS's, thus providing the first basis for the identification of targets visible by different satellites [4], [5], [6].

## 2. INTRODUCTION

The area of P.R. of China situated between the capital Beijing and the Yellow Sea is known being affected by geological instability. The Tangshan earthquake of July 28, 1976 is one of the largest earthquakes in loss of life to hit the modern world. The epicenter of the earthquake was near the industrial city of Tangshan in Hebei, which housed around one million inhabitants. Seismic events are not the only problems affecting the ground stability of this area. With the rapid growth of the local economy, the ground subsidence caused by water withdrawal has begun to concern a lot of towns [3]. Tianjin City is one of the four greatest municipalities in China, with a very large population and an old history. In the 1960s due to the development of local industry and the consequent increase of inhabitants, water supply became a major issue. Under such conditions, the ground water was over-withdrawn causing a progressive subsidence that till now has reached up to 3 meters of displacement. According to local surveys, in the recent years the subsidence rate in Tianjin downtown is decreased to 10mm/year.

The present work has been carried out within the Dragon Project by Politecnico di Milano in order to evaluate the possibility of a ground subsidence control by means of space-born radar data over the area of Tianjin. To this aim, the recently developed PS technique [1], [2] has been adopted for processing the data. Main advantage of such a study is supplying a high density of measure points at very low costs exploiting archived SAR data.

## 3. PS ANALYSIS

The data available for monitoring the Tianjin subsidence have been acquired by the satellites ERS1 and ERS2 of the European Space Agency (ESA) in an 8 years time span, from 18/06/1992 to 25/06/2000. The data-set is formed by 23 images with normal baseline ranging from –1500 to 1000 m and Doppler centroid (DC) variations limited between –0.4 and 0.4 PRF (pulse repetition frequency) replicas with respect to the master acquisition acquired on 19/10/1997. The processed area is 3200x5000 pixels (range interpolation factor 4), equivalent to about 16x20 $km^2$. In Figure 1 the main parameters of the dataset are shown. In the lower part of the figure on the left, dots are plotted in correspondence of the acquisition date, highlighting lack of data in years 1994 and 1999. Moreover, only about between 1995 and 1996 images have been acquired regularly. As further shown, such a lack of data prevents from observing fast and non-linear motions.

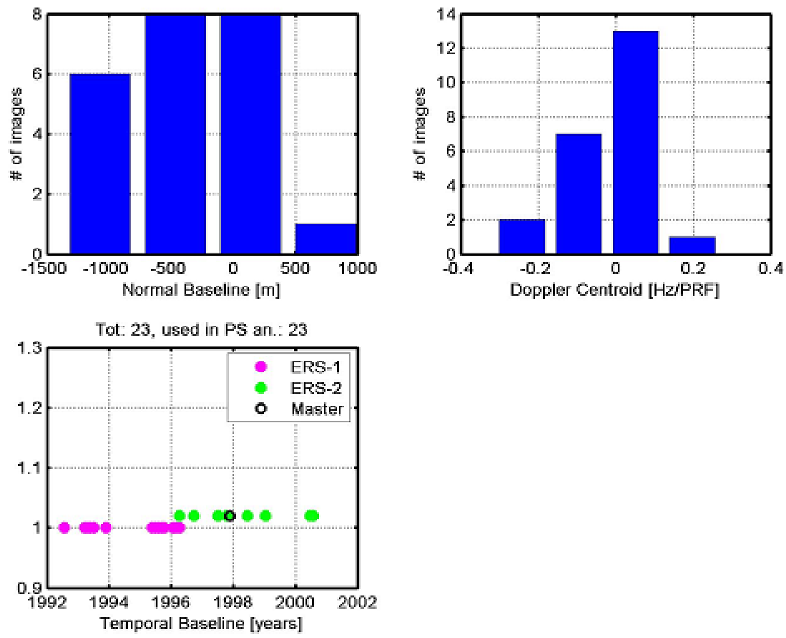


*Fig. 1. Data-set parameters: normal baseline, Doppler centroid and acquisition date.*

First step of the PS analysis is the selection of PS candidates (PSC) [1], [2]. To this aim the reflectivity map of the analyzed area, visible in Figure 2, is obtained as the incoherent time-average of the amplitudes of the radar images. Then local maxima are extracted and side lobes eliminated. For the selected points birth and death dates are estimated analyzing the amplitudes as a function of the acquisition time. Exploiting the acquisitions in the lifetime the amplitudes stability index is calculated and

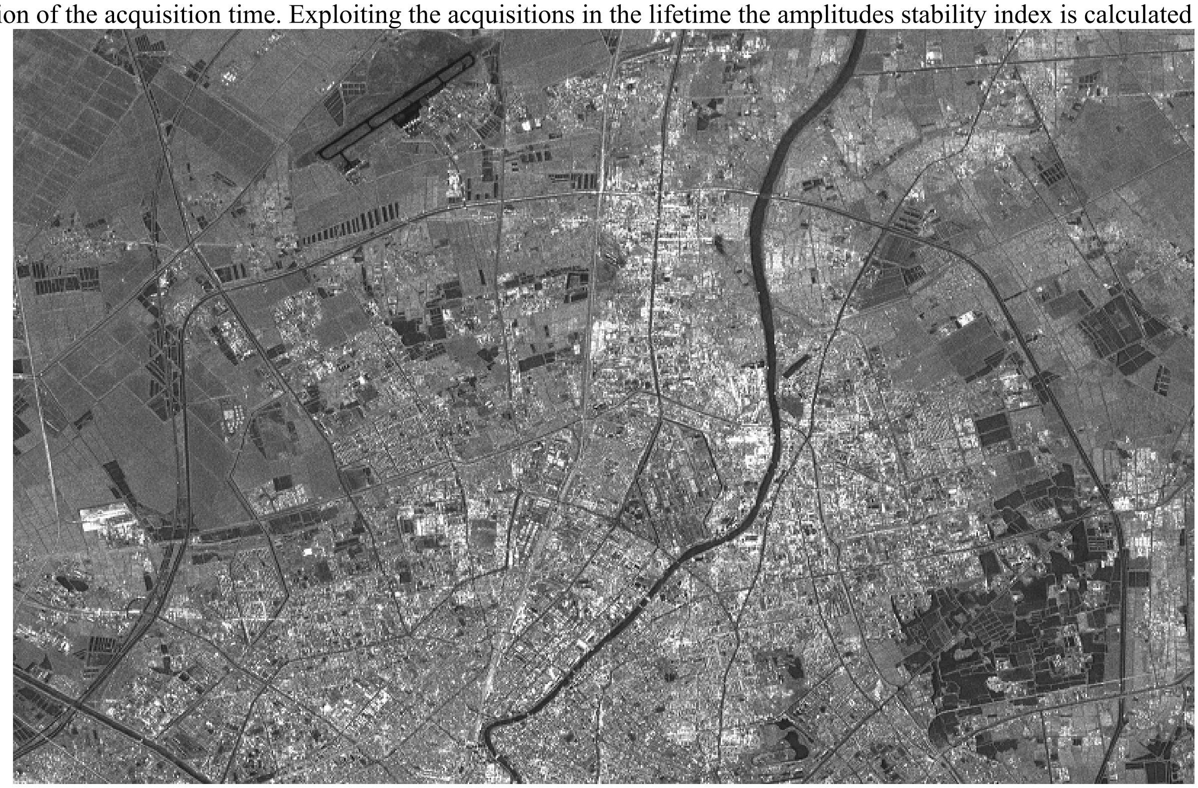

*Fig. 2. Reflectivity map of the processed area.*

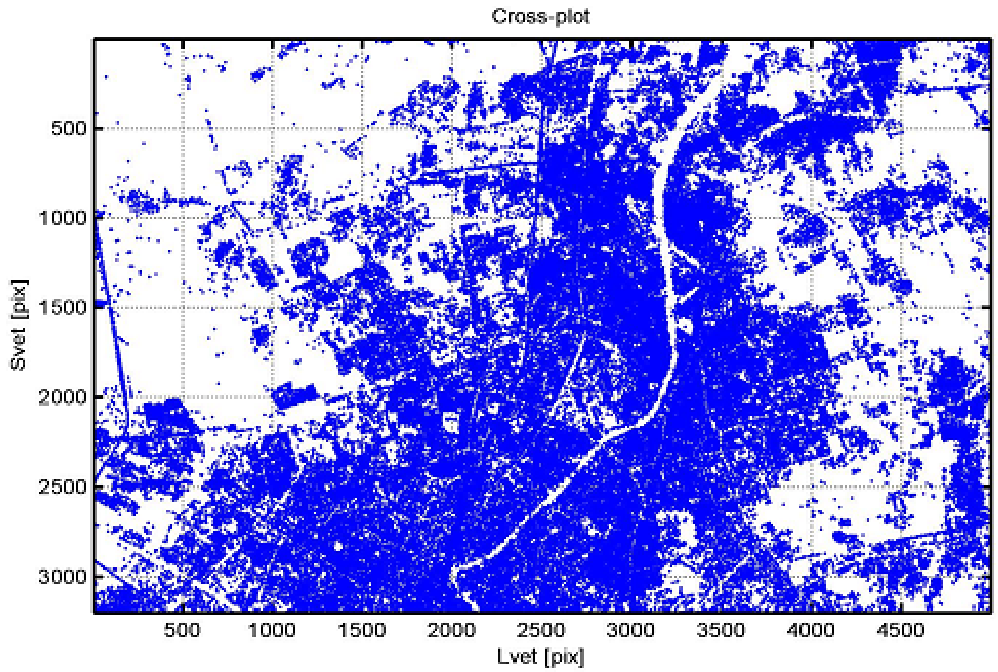


*Fig. 3. 100,000 PSC selected in the area of interest.*

PSC are individuated posing a threshold on its value. In Figure 3 the ensemble of the obtained PSC (more than 100,000 points) is plotted as a function of their SAR coordinates (samples and lines). From Figures 2 and 3 the city profile and the surrounding rural areas can be easily recognized. The Hai He River crosses the radar image in the middle from the top to the bottom, many streets are visible and on the left a railway appears evident. In Figure 4 on the left the birth dates are shown for a subset of PSC with a colored scale. As clear from Figure 4, the city is increasing its size as years go. On the right of the image the histogram of birth dates is reported.

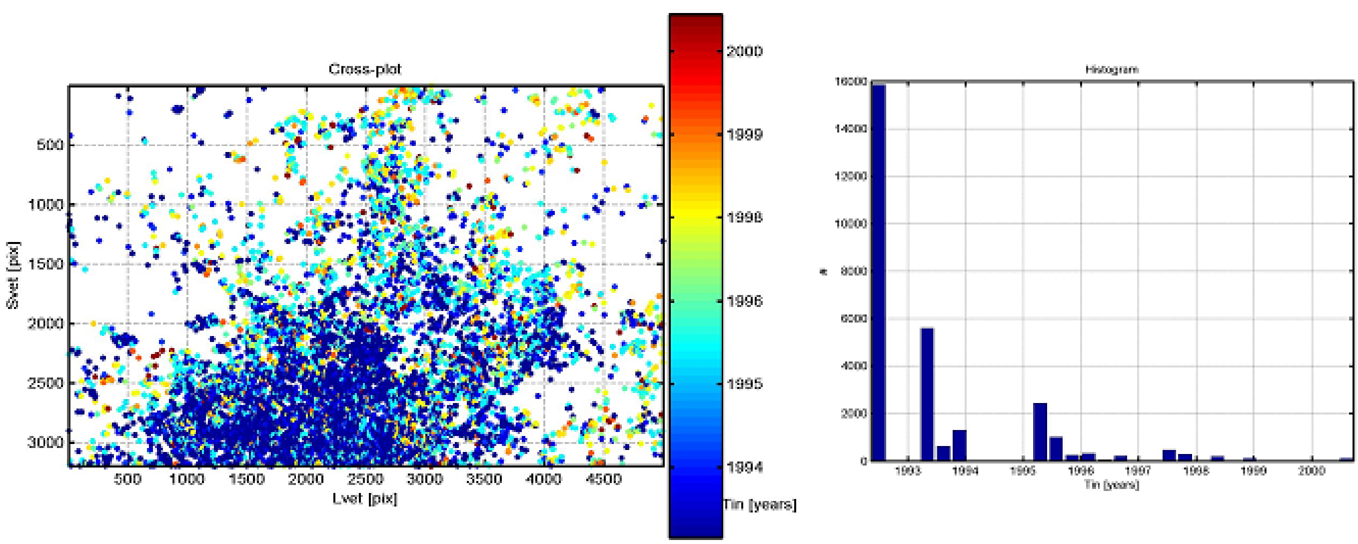


Fig. 4. Birth dates for a subset of PSC (left) and birth dates histogram (right).

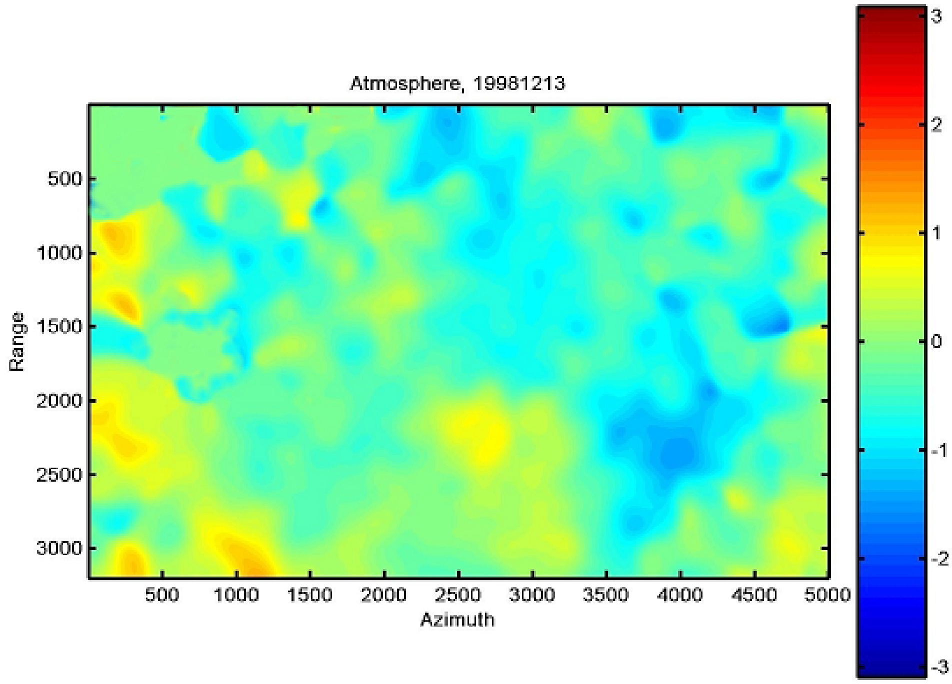


*Fig. 5. APS of acquisition 19981213 in radians.*

Once PSC are identified, a subset of them equally distributed in space is exploited to retrieve the atmospheric phase screen (APS) through the interferometric phase processing [1], [2]. In Figure 5 an example of APS is reported. Note that far away from the city center the APS is estimated with less accuracy due to the lack of PS's. After removal of the APS for each image, height and average deformation trend are estimated with respect to a reference point. At the end of the processing chain about 10,000 PS's are detected with multi-interferogram coherence $\gamma \geq 0.8$.

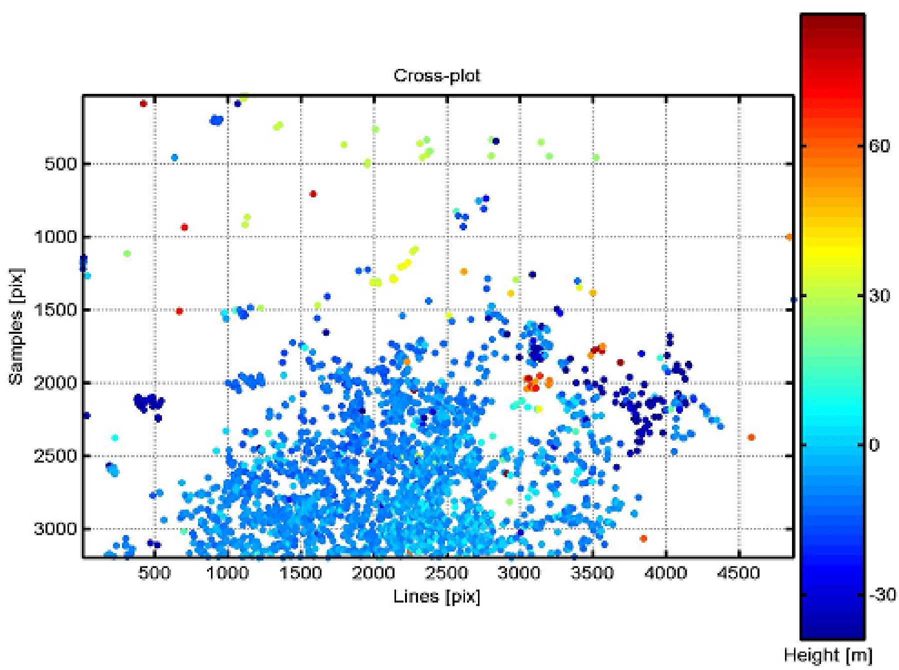


*Fig. 6. PS's estimated height.*

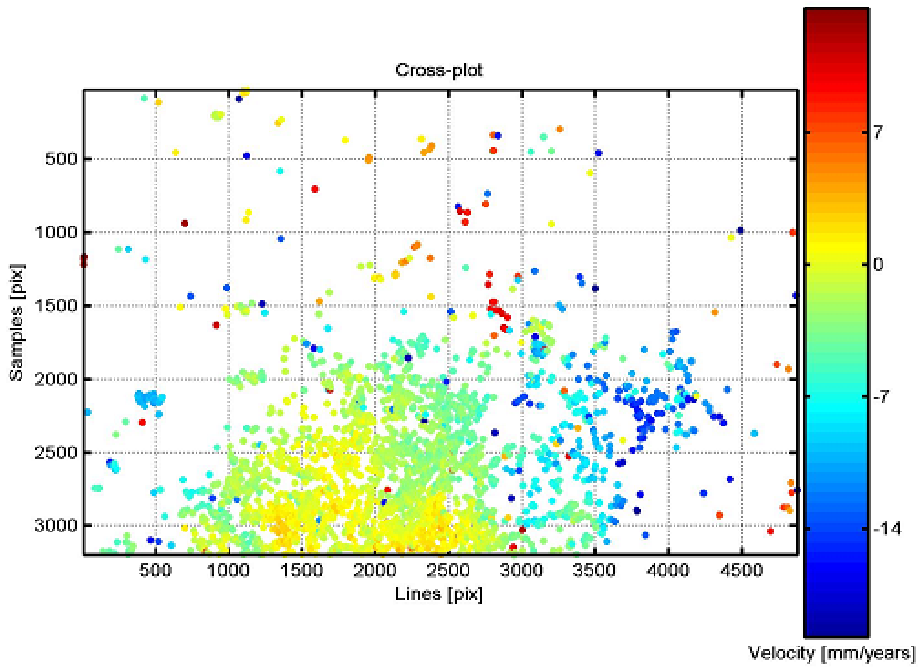


*Fig. 7. PS's average deformation trend.*

In Figure 6 and 7 the estimated height and average deformation trend are plotted as a function of SAR coordinates. As visible from Figure 7, the city center is almost unaffected by terrain motion, whereas the surrounding areas, in particular on the right of the Hai He River, show an active subsidence with a rate up to about –15mm/year, in good agreement with the local surveys conclusions. In Figure 8 an example of displacement time series is reported for a PS with coherence $\gamma$=0.91 and subsiding rate –11mm/year. The lack of data in years 1994 and 1999 in Figure 8 makes evident the impossibility in this case to reconstruct a possible non-linear motion.

The last result we show is a preliminary study on the physical nature of PS's in Tianjin, aimed to the identification of targets visible by other satellites. In this way, possible further work can foresee the exploitation of more satellites or more acquisition geometries for the subsidence monitoring [4], [5], [6]. The adopted strategy is based on the analysis of the amplitudes of each PS as a function of the acquisition geometry, characterized by different values of normal baseline and DC frequency [6]. The variation of the amplitudes is connected to the PS dimensions and orientation in range and azimuth, thus identifying the point-wise targets not affected by geometrical decorrelation. In Figure 9 and 10 the histograms of the obtained parameters are reported respectively for the range and azimuth dimensions.

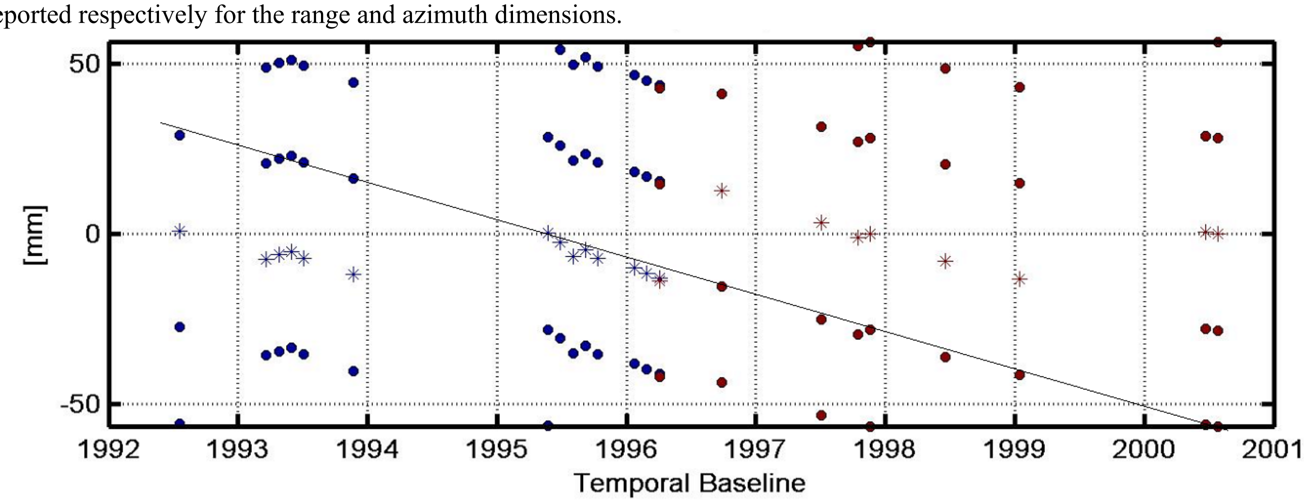


*Fig. 8. Example of displacement time series of a PS with coherence $\gamma$=0.91 and subsiding rate –11mm/year.*

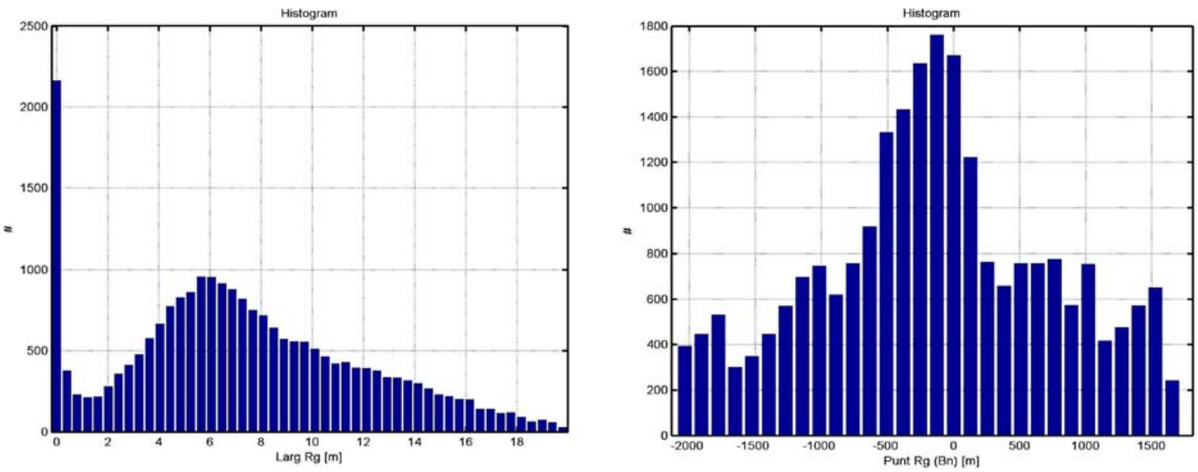


Fig. 9. Histograms of PS's width (left) and orientation (right) in cross-slant range. The peak on zero width identifies possible point-wise targets in cross-slant range (like dihedrals).

**References**


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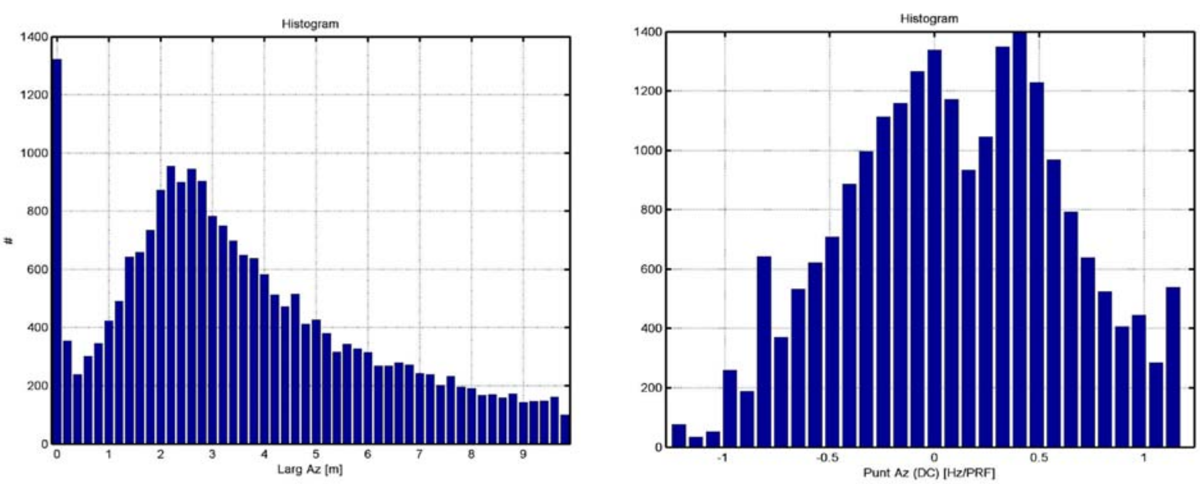


Fig. 10. Histograms of PS's width (left) and orientation (right) in azimuth. The peak on zero width identifies possible point-wise targets in azimuth (like dihedrals and trihedrals).