An Approach to Align Subarray Channels in PPAR Using Weather Returns

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1. ABSTRACT

Because phased array radar (PAR) technology supports more flexible scanning strategies than radars using mechanically steered antennas (resulting in reduced data update times), this technology has been proposed as a foundation for the development of the next generation weather surveillance systems in the USA. Furthermore, the Spectrum Efficient National Surveillance Radar (SENSR) program is exploring the feasibility of combining the functions of multiple national aircraft and weather surveillance radar networks into a single network of polarimetric phased array radar (PPAR) systems. While the use of PAR technology for point target detection and tracking is well established, the use of PPAR for polarimetric weather observations is still in the research stage and has been identified as particularly challenging. This is because weather measurements impose strict requirements on the beam shape matching of the copolar horizontal (H) and vertical (V) antenna patterns, the levels of cross-polar patterns as well as the entire hardware in terms of signal purity and minimal cross coupling. Consequently, this significantly increases the PPAR calibration requirements. At the same time, many modern phased array radars are multi-channel systems which include multiple receiver channels for data acquisition. Each channel provides signal received from a group of T/R elements comprising a section of the antenna. Channels typically consists of a full receive path, often with an independent Local Oscillator Clock (LO) source. Such arrangement provides for beamforming flexibility on receive which can be applied in a digital domain. Consequently, channel-to-channel phase and amplitude alignment is critical to maximize the performance of the digital beamforming process and accuracy of the resulting detections and measurements. But due to the hardware imperfections and temperature variations, the time series produced by the analog-to-digital converters (ADCs) in each channel intrinsically vary in amplitude and phase with respect to each other (thus, requiring alignment prior to summation). Herein, an approach to improve channel-to-channel alignment using weather signals from individual channels is described.

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2. THEORY

It is assumed that the main beams of two-way patterns of all subarrays encompass the same volume of space.

The cross-correlations between the subarray channels i_0 and i_1 in horizontal (h) as well as vertical (v) are computed as

$$\hat{R}_{sc}\left(i_0,i_1\right)=\frac{1}{M}\sum_{m=0}^{M-1}V_c\left(m,i_0\right)V_c^*\left(m,i_1\right) \qquad (1)$$

where c is h or v, $V_c(m,i_0)$ as well as $V_c(m,i_1)$ are subarray time series, and M is the number of samples in sample-time. The ensemble averages of cross-correlation arguments represent the phase differences induced by the system.

The ratios of returned powers from subarrays of the same polarization (h or v) are

$$\hat{P}_{sc}\left(\vec{r},i_0,i_1\right)=\frac{\frac{1}{M}\sum_{m=0}^{M-1}\left|V_c\left(\vec{r},m,i_0\right)\right|^2-N_c\left(i_0\right)}{\frac{1}{M}\sum_{m=0}^{M-1}\left|V_c\left(\vec{r},m,i_1\right)\right|^2-N_c\left(i_1\right)} \qquad (2)$$

where $N_c(i_0)$ and $N_c(i_1)$ are the noise powers in subarray channels. By combining the measurements in (1) and (2), subarray amplitude and phase (SAP) alignment is achieved.

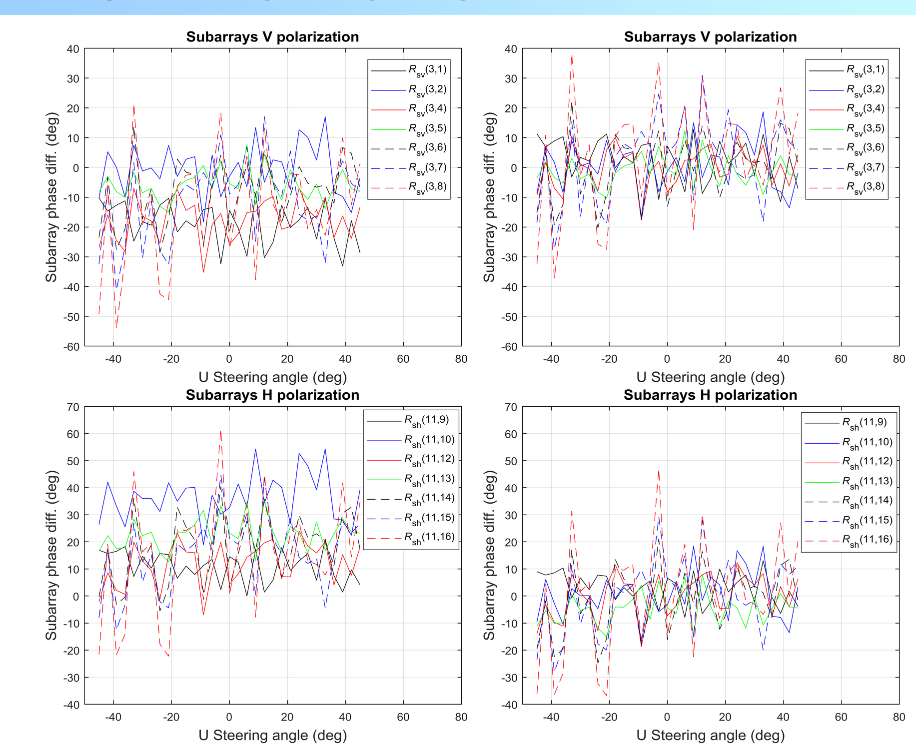

Fig. 1. Subarray phase difference before (left panels), and after (right panels) alignment.

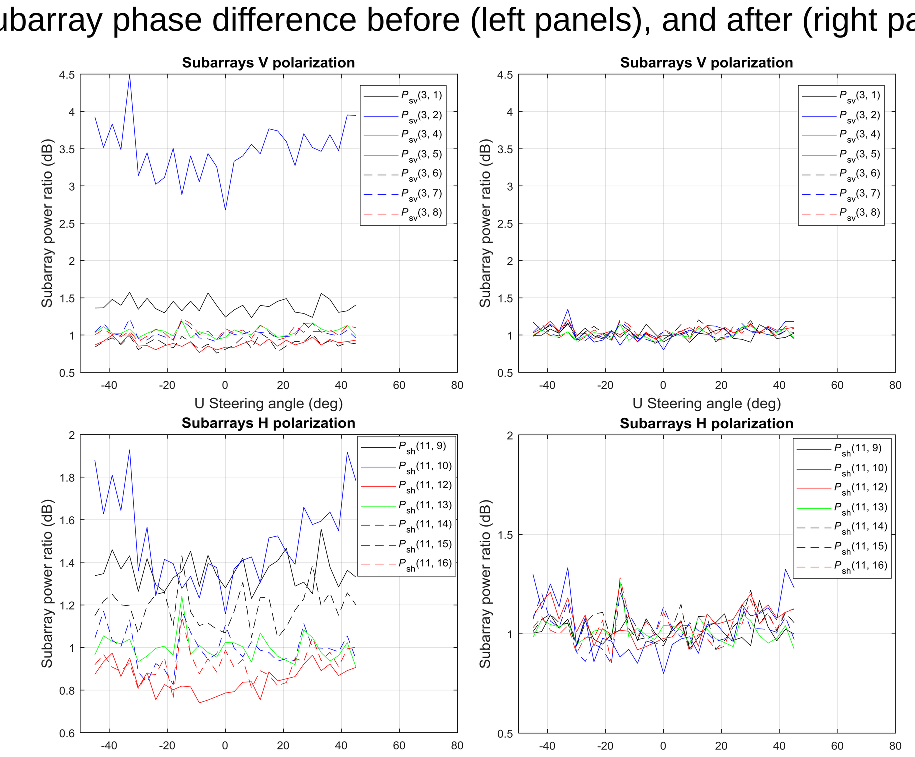

Fig. 2. Subarray power ratio before (left panels), and after (right panels) alignment..

3. BEAM STEERING -3.5º OFF PRINCIPAL PLANE AT VERTICAL INCIDENCE (BIRDBATH)

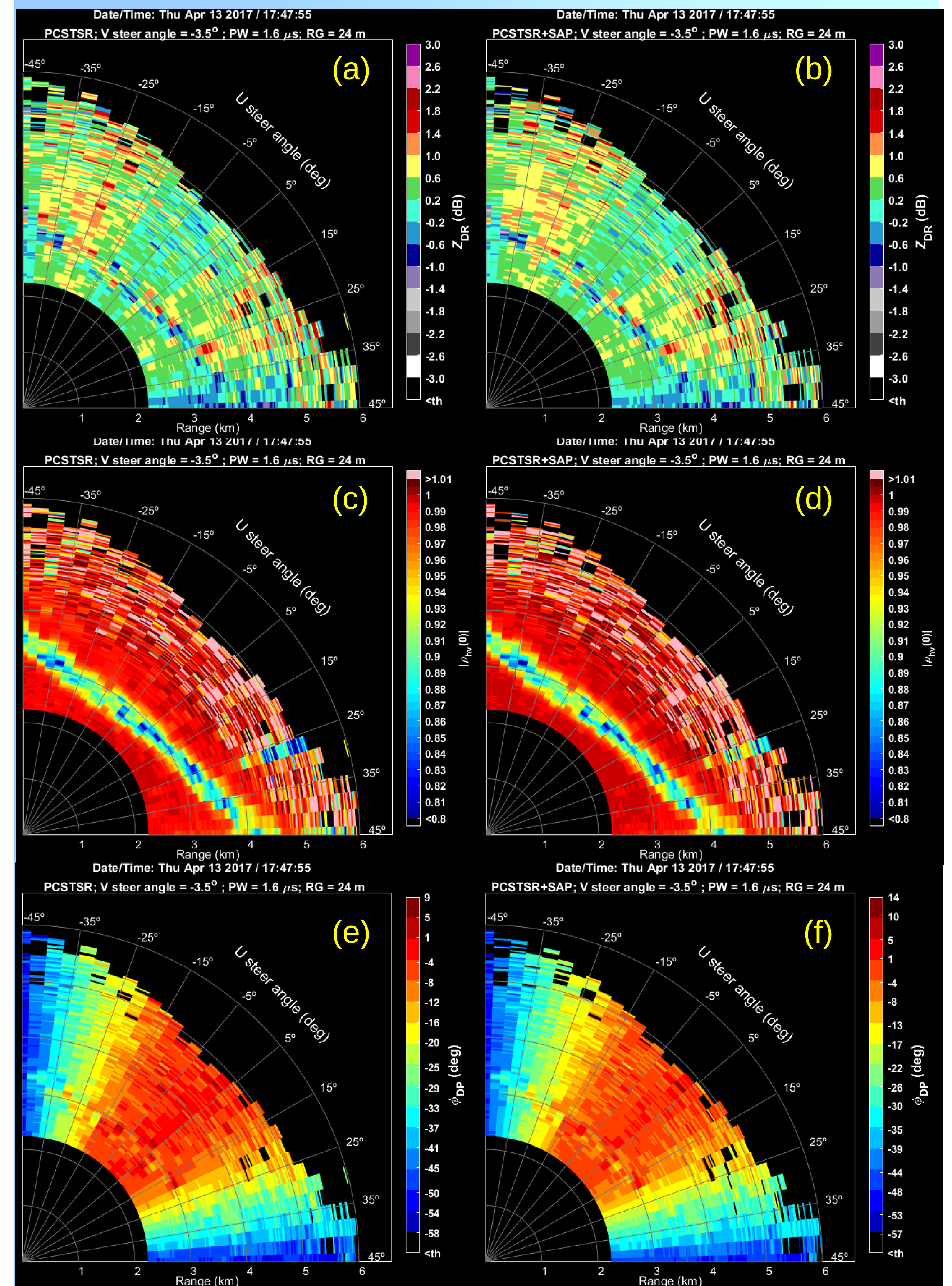

Fig. 3. Differential reflectivity without (a), and with SAP (b). Copolar correlation coefficient without (c), and with SAP (d). Differential phase without (e), and with SAP (f).

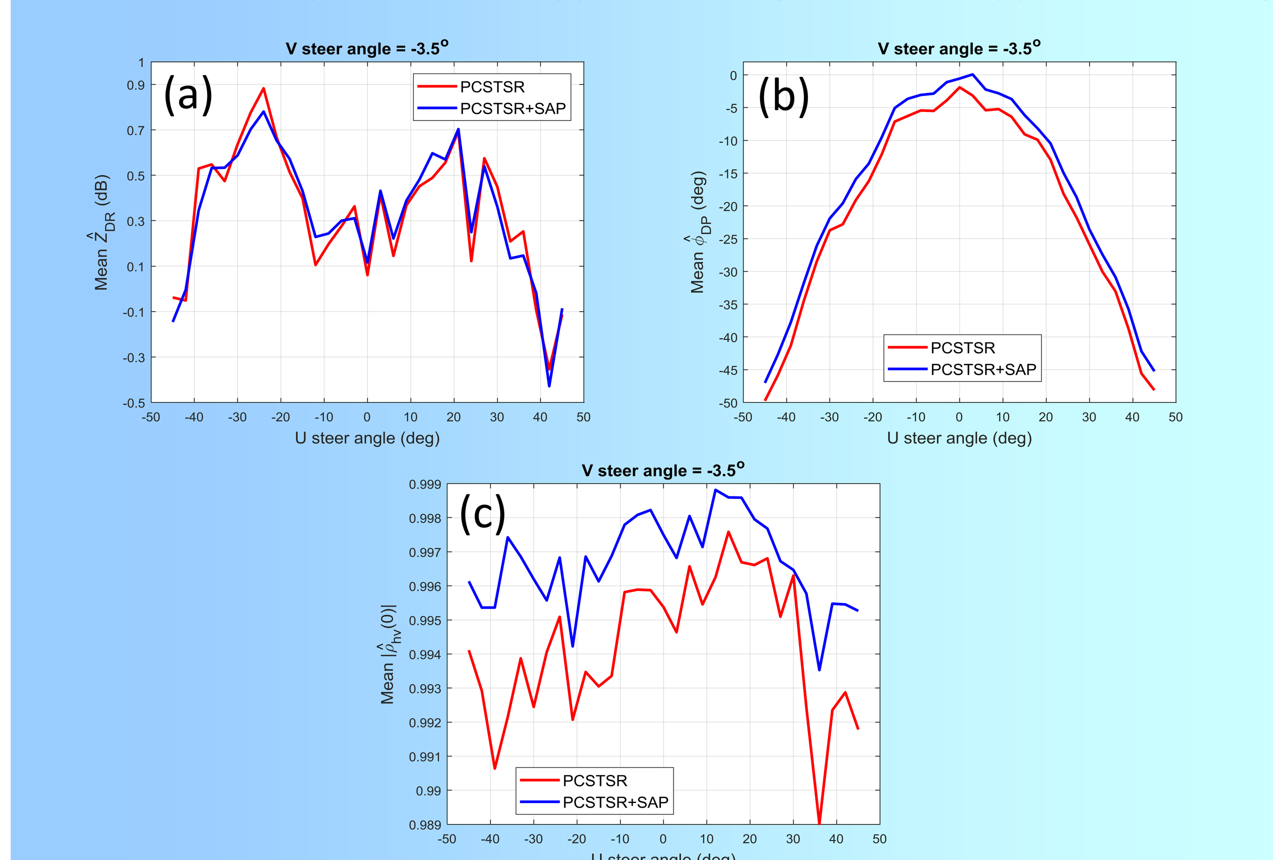

Fig. 4. Spatial mean (a) differential reflectivity, (c) differential phase, (c) copolar correlation coefficient.

4. BEAM STEERING 15º OFF PRINCIPAL PLANE AT VERTICAL INCIDENCE (BIRDBATH)

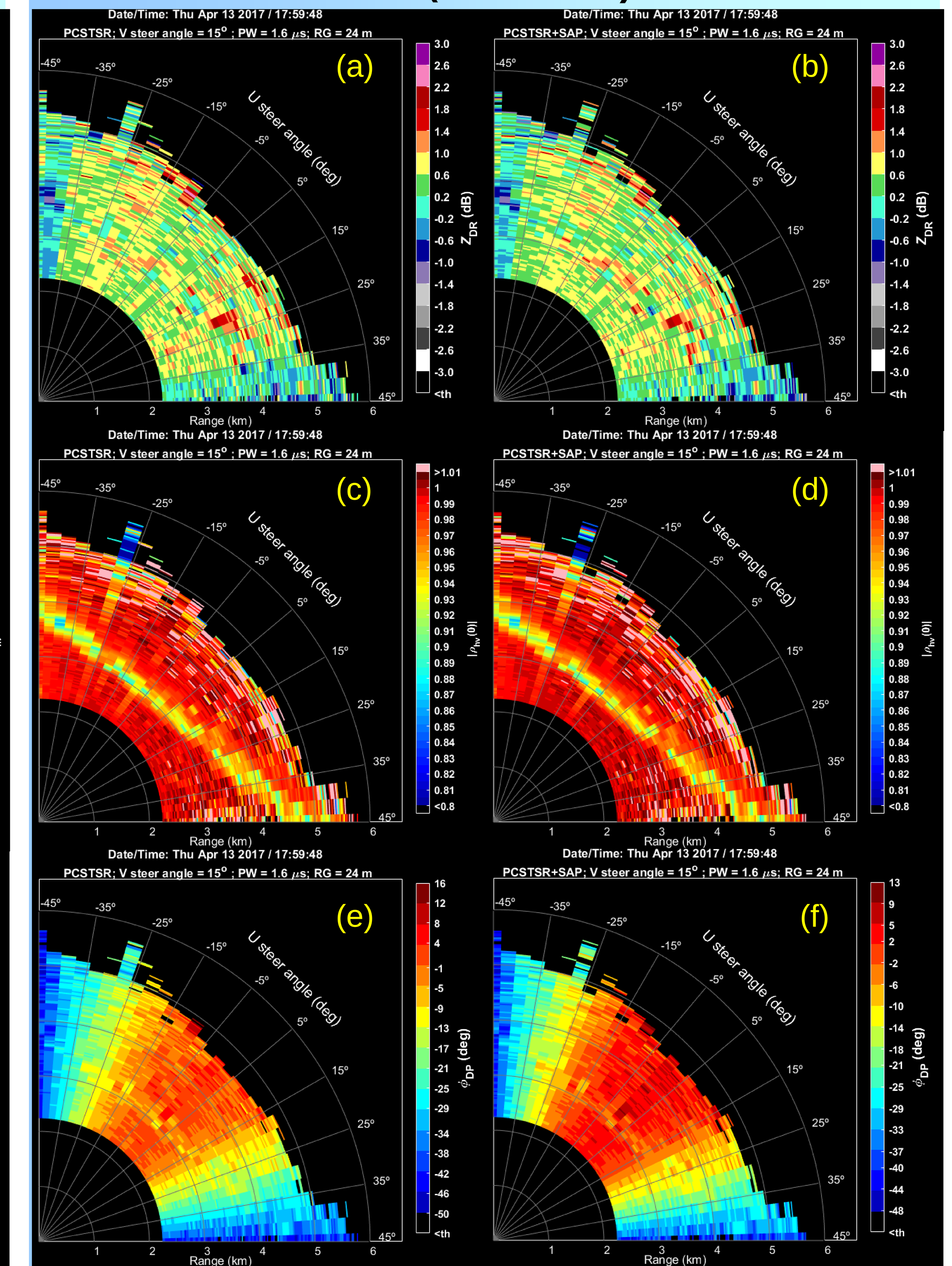

Fig. 5. Differential reflectivity without (a), and with SAP (b). Copolar correlation coefficient without (c), and with SAP (d). Differential phase without (e), and with SAP (f).

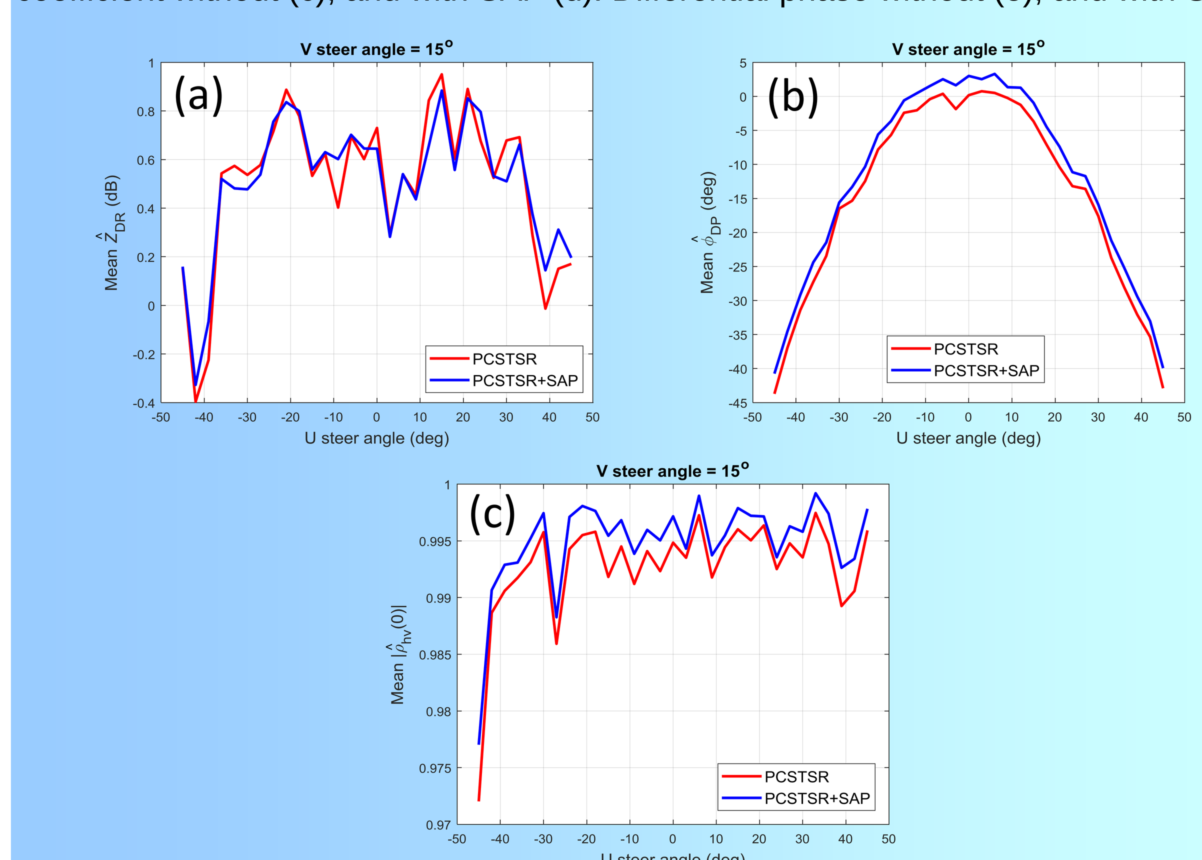

Fig. 6. Spatial mean (a) differential reflectivity, (c) differential phase, (c) copolar correlation coefficient.