DISCRIMINATION BETWEEN WEATHER AND SEA CLUTTER USING DOPPLER AND DUAL-POLARIZATION WEATHER RADARS

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ABSTRACT

The results of automatic discrimination between weather and sea clutter using S-band dual-polarization Doppler weather radar are presented. The data were collected with the NCAR SPOL radar located in the Pacific shoreline near Seattle, USA. The multiparameter dataset includes backscattered power P (or radar reflectivity Z), Doppler velocity V, spectrum width σ_v, differential reflectivity Z_{DR} (polarization ratio), differential phase Φ_{DP}, linear depolarization ratio LDR, and cross-correlation coefficient ρ_{hv}. Two versions of classification algorithm based on fuzzy logic are explored. One of them utilizes only Doppler radar variables (P and V), whereas the other makes use of both Doppler and polarimetric measurands.

INTRODUCTION

Algorithms for automatic classification of different meteorological and non-meteorological scatterers based on the use of multiparameter data from Doppler polarimetric weather radars have been developed during recent years. These classification schemes utilize ideas of fuzzy logic and prove to be very efficient for hail detection, rain/snow discrimination, identification of ground clutter (including anomalous propagation), birds, and insects [1]. In this study, we apply this methodology to distinguish between sea clutter, precipitation, and marine boundary layer clouds observed with coastal or shipborne S-band radars.

We have examined Doppler polarimetric radar data obtained from the IMPROVE I Field Experiment: Offshore Frontal Precipitation Study conducted by the University of Washington west of the Seattle, WA, area during the period 4 January – 14 February 2001. The data were collected with the NCAR SPOL 10-cm dual-polarization radar located on the Pacific shoreline at the height of 10m above sea level. The multiparameter dataset includes backscattered power P (or radar reflectivity Z), Doppler velocity V, spectrum width σ_v, differential reflectivity Z_{DR}, differential phase Φ_{DP}, linear depolarization ratio LDR, and cross-correlation coefficient ρ_{hv}.

NCAR SPOL is a very sensitive radar capable detecting $Z = -15$ dBZ at ranges up to 50 km [2]. The radar has a pencil beam of 0.93°. Raw data are sampled every 0.15 km along a range up to 180 km with an azimuthal resolution of 1°. Five days of observations have been examined so far. The multiparameter data from three elevation tilts: 0.0°, 0.5°, and 1.5°, have been thoroughly analyzed with the major focus on the PPIs at the lowest tilt where the problem of discrimination between weather and sea clutter is the most challenging.

OBSERVATIONS

Four types of radar echo in the sea sector of PPI are easily distinguished. The first of them is "normal" sea clutter with a range extension determined by the height and strength of evaporation duct [3]. The second is "anomalous" sea clutter likely caused by multipath propagation attributed either to reflections from elevated layers or to strong local non-uniformities of the evaporation duct. The third is the weather echo associated with the marine boundary layer stratiform clouds (MBLSC) that exist almost all the time in the US Pacific coast area and cover about 25% of the World Ocean. These are shallow clouds consisting of cloud-size or drizzle-size droplets. The height of the cloud top is usually between 0.5 and 1.5 km, and radar reflectivity Z is usually less than –5 to 0 dBZ. Most often these clouds do not produce precipitation, or produce very light drizzle-type rain near sea surface. These clouds are important objects of climatological studies because of their omnipresence and strong effect on radiative transfer. The fourth type of radar echo is caused by precipitating clouds that are most often associated with atmospheric fronts.

Figure 1 illustrates a case where at least three types of echo coexist: (1) "normal" sea clutter, (2) MBLSC, and (3) convective precipitation. The PPI fields of returned power and mean Doppler velocity at the 0.0º elevation angle are displayed in Fig. 1a,b. The radar is located at the point (0,0). Simple visual analysis of the P and V images points to convective precipitation as the most likely origin of isolated echoes that are immersed in a uniform background of extended echoes that can be attributed either to weather or sea scatterers. Only detailed examination of multiparameter data provides a clue about the possible origin of the extended radar echo. Example of such data along the azimuthal direction 273.7º (depicted as a solid line in Fig. 2a) is shown in Fig. 2. There are three range intervals that are characterized by distinct Doppler and polarimetric signatures. The echo from convective precipitation in the 140-160 km range is recognized by low LDR, high ρ_{hv}, large negative values of V, and very small spatial variations of Z_{DR} and Φ_{DP}. The high reflectivity region close to the radar (0 – 30 km) has much higher LDR, lower ρ_{hv}, smaller values of V, and large spatial variations of Z_{DR} and Φ_{DP} that are likely associated with echoes from the sea surface. The low reflectivity zone between 30 and 60 km has properties that are somewhere in between convective rain and sea clutter. These echoes are likely to be from shallow marine boundary layer stratiform clouds (MBLSC). In this particular case, the echoes are confined within the 0 – 500 m height interval. Because the echoes from these clouds are relatively weak and signal-to-noise ratio (SNR) is low, such polarimetric variables as Z_{DR}, LDR, and ρ_{hv} are significantly biased by noise. Therefore, the contrast between sea clutter and MBLSC is not as clear as between sea clutter and precipitation from convective clouds. Measurements of differential phase and Doppler velocity are not affected by noise (at least for SNR > -5 dB) and are particularly useful for distinguishing MBLSC from the sea clutter. Differential phase provides amazingly sharp delineation between sea and weather echoes at the distance of 30 km (Fig. 2). The sea – weather transition is also marked by a pronounced change in the magnitude of Doppler velocity. Our analysis of the Doppler

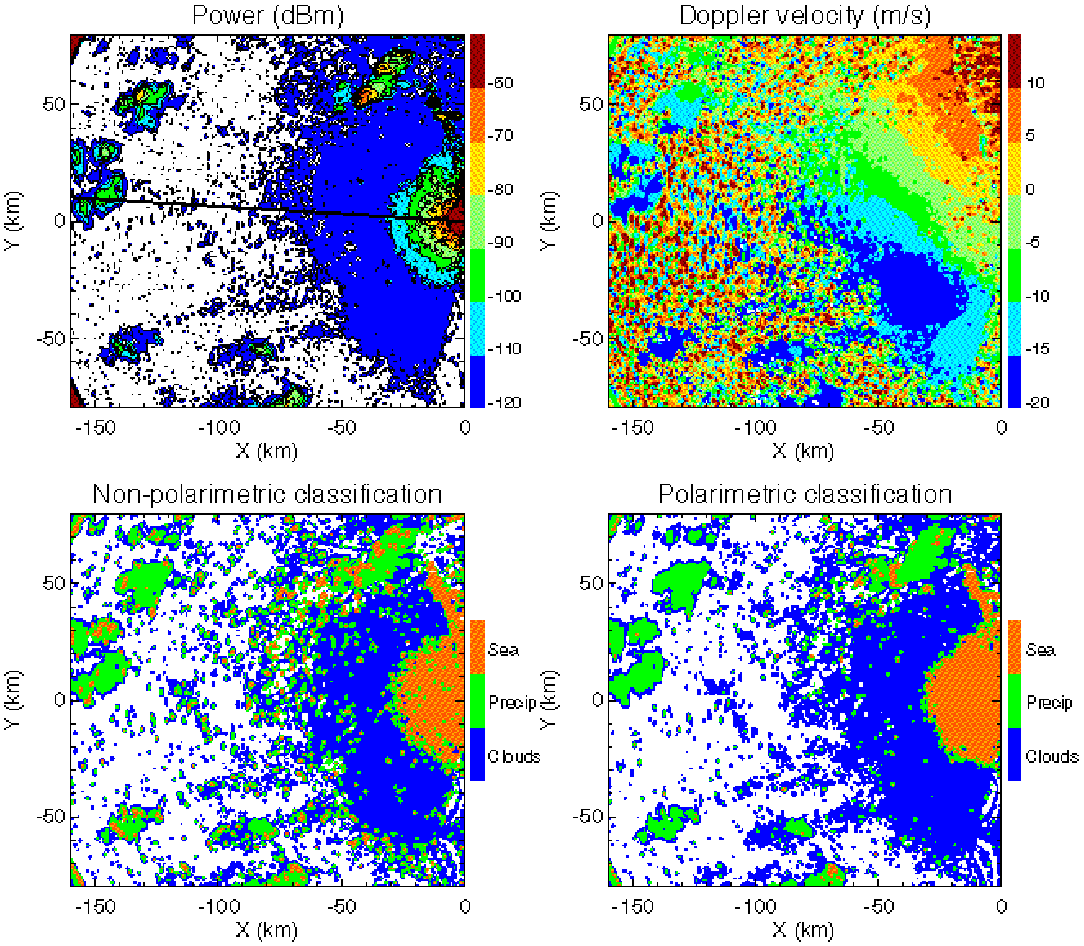

Fig. 1 Combined plot of the fields of returned power P, mean Doppler velocity V, and results of non-polarimetric and polarimetric classification for data at 0.0º elevation on 2 February 2002 (16:10 UTC). The NCAR SPOL radar is located at (0,0). Solid line corresponds to the direction for which raw multiparameter data are displayed in Fig. 2.

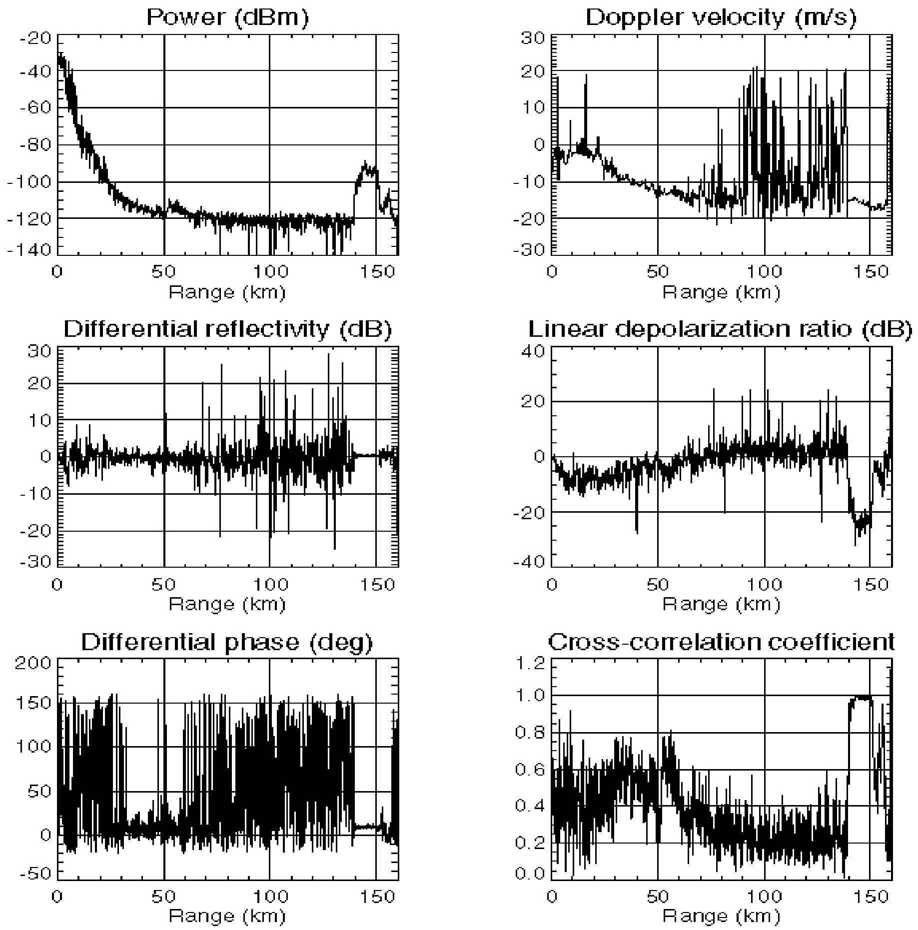

Fig. 2 Radial dependencies of P, V, Z_{DR}, LDR, Φ_{DP}, and ρ_{hv} at the azimuthal direction shown in Fig. 1a.

velocity data for all 5 days of observations shows that the magnitude of V for sea echoes is usually less than 5 m s^{-1}, whereas any Doppler velocities within the unambiguous range ±22 m s^{-1} are possible for meteorological echoes.

FUZZY LOGIC CLASSIFICATION

Fuzzy logic classification method requires knowledge of membership functions for different variables and classes. In order to determine membership functions, we analyzed scattergrams of measured radar variables versus mean power of returned signal (or signal-to-noise ratio) separately for weather and sea clutter. We examined such scattergrams for different days of observations and found that they do not differ much from case to case. In Fig.3, some of these scatterplots for the 2 February 2001case are represented. Black and grey dots correspond to sea clutter and weather clutter respectively. In addition to the ρ_{hv} – SNR, LDR – SNR, and Z_{DR} –SNR scattergrams, we display the $SD(P)$ – SNR scattergram, where $SD(P)$ is the standard deviation of P that characterizes the texture of the P field.

To obtain $SD(P)$, we average raw P data (sampled every 0.15 km) along the radial using 1-km-width running average window and subtract the smoothed values of P from their original raw values. A similar procedure was used to estimate $SD(\Phi_{DP})$ that characterizes the texture of the Φ_{DP} field.

It is evident from Fig. 3, that despite overlapping for SNR < 10 dB, sea and weather clutter are very well separated in terms of ρ_{hv}, LDR, and $SD(P)$. The separation is even better for $SD(\Phi_{DP})$ (Fig. 1). As in the case of Doppler velocity, the two classes of echo are well overlapped in the Z_{DR} - SNR plane although the corresponding scattergrams have very different widths. Noticeably larger values of $SD(P)$ for sea clutter reflect the fundamental fact that an amplitude distribution of the echoes from the sea surface is much wider than the one from hydrometeors.

We consider two versions of classification scheme: polarimetric and non-polarimetric ones. The polarimetric classification algorithm utilizes $SD(\Phi_{DP})$, ρ_{hv}, LDR, Z_{DR}, V, and $SD(P)$, whereas only $SD(P)$ and V are used in the non-polarimetric version. Once discrimination between sea and weather clutter is made, a simple threshold of Z = -5 dBZ is

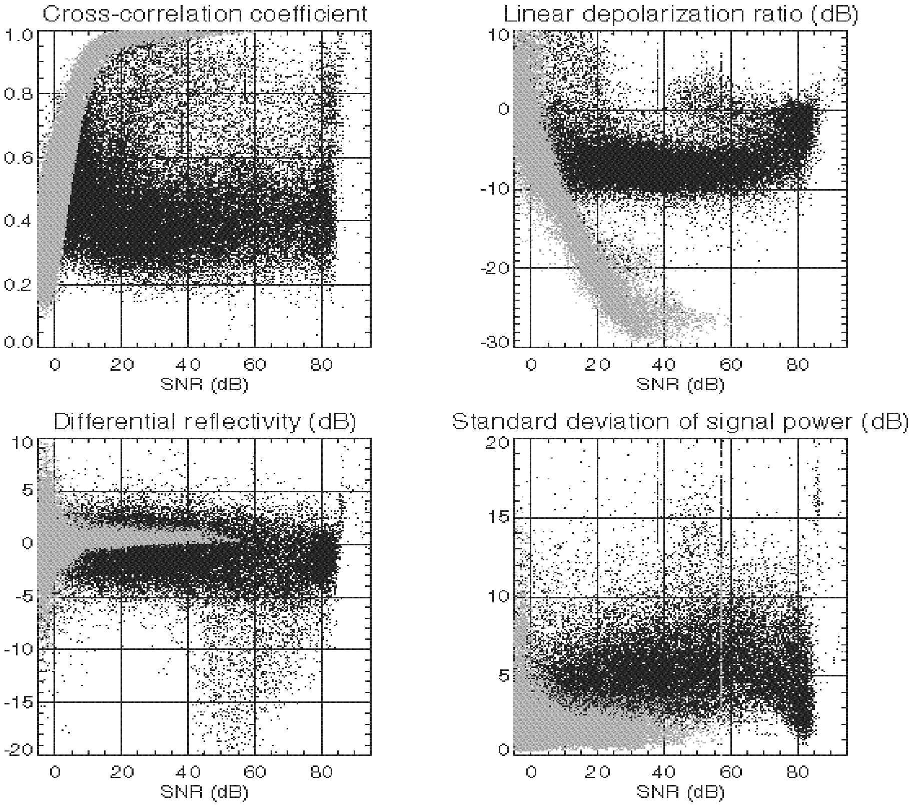

Fig. 3 Scattergrams of ρ_{hv}, LDR, Z_{DR}, and $SD(P)$ versus SNR for (a) sea echoes (black dots) and (b) weather echoes (grey dots). The data are taken at the elevation angle of 0.0º on 2 February 2001.

used to distinguish between MBLSC (denoted as "clouds" in Fig. 1c,d) and convective precipitation (marked as "precip"). Results of automatic classification are displayed in Fig. 1 c,d. As expected, polarimetrric algorithm exhibits superior performance. Although non-polarimetric version produces more speckles, it delineates quite well sea clutter and both types of weather echoes.

POSSIBLE PRACTICAL APPLICATIONS

The need for partitioning the near-surface radar echo leads to very important practical implications regarding the technique for estimating evaporation duct heights from sea echoes [3]. Discrimination between sea and weather echoes has to be performed prior to application of the mentioned technique.

There are many National Weather Service WSR-88D S-band radars operating in the coastal regions of US. The standard technique for ground clutter rejection based on filtering around zero Doppler frequency doesn't work for sea clutter because the latter has essentially non-zero mean Doppler velocity. This study provides an alternate approach for sea clutter detection and rejection.

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