NOTES AND CORRESPONDENCE

Software-based Cancellation of Clutter in the Doppler Spectrum Measured by a Wind Profiler

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Abstract

The wind profiler developed by the Communications Research Laboratory and operating at the Okinawa Radio Observatory is a Doppler radar for measuring the vertical profile of the three-dimensional wind vectors from the echo signal scattered by clear air turbulence. Vegetation motion caused by wind, however, will produce signals cluttering the Doppler spectrum and making it difficult to identify the echo signal in the spectrum. A software-based clutter cancellation method was therefore developed, and its effectiveness has been confirmed by comparing the horizontal wind vectors estimated from the clutter-cancelled wind profiler data with those measured from radiosonde.

1. Introduction

Measuring the profile of the wind vector is quite important in several research fields as well as weather forecasting. This profile is conventionally measured by using radiosondes, but the routine use of radiosondes is both expensive and laborious. A recently developed wind profiler, however, can measure the vertical profile of the three-dimensional wind vector from the echo signal scattered by clear air turbulence (CAT) (Woodman, 1980). Initial studies with such a wind profiler used VHF (about 50 MHz) radar (Woodman and Guillen, 1973), but such low-frequency radars can not observe winds at low altitudes (less than 1.5 km) and can not provide high spatial resolution. These limitations are unacceptable in many meteorological applications, so a UHF (about 1 GHz) wind profiler has been developed to observe the boundary-layer with good spatial resolution (Ecklund *et al.* 1988). The Com-

munications Research Laboratory (CRL) also has developed a boundary-layer wind profiler (Masuda *et al.*, 1992). The characteristics of this wind profiler which is at the Okinawa Radio Observatory of CRL are listed in Table 1.

Vegetation motion caused by wind produce signals cluttering the Doppler spectrum measured by the wind profiler. Since the Okinawa Radio Observatory is located in a wooded area, such clutter makes it difficult to identify the CAT signal in the Doppler spectrum. This paper describes our implementation of a software-based clutter-cancellation method based on the concept proposed by Kalmus (1967).

Sato and Woodman (1982) treated the ground clutter problem that occurs when the desired signals scattered from CAT are extracted from the measured Doppler spectrum. They proposed a non-linear parameter estimation technique for identifying the CAT signal in a measured Doppler spectrum with a very strong fading clutter. But because this

Table 1. Characteristics of the CRL's wind profiler.

Frequency	1327.5 MHz
Mean transmitter power	40 W
Antenna diameter	4 m (Parabola)
Height resolution	75/150/300 m (Selective)
Min. range	75 m
Typical max. range	3 or 4 km in clear air

technique is somewhat complicated, the work described in the present paper used a simple clutter-cancellation method proposed by Kalmus.

Authors know that some form of Kalmus's method is already applied to almost all wind profiler data. However, there is no paper focussing on this method as far as authors know. Carter *et al.* (1995) is a paper reporting this method briefly. Therefore, this paper investigates the potential of Kalmus's method.

2. Clutter cancellation

Kalmus pointed out that because vegetation motion due to the wind will be back-and-forth motion, the Doppler spectrum of the clutter due to this motion will be distributed on both sides of the zero Doppler frequency. The peak power of such clutter is sometimes larger than that of CAT signal, and it is difficult to distinguish the CAT signal from the clutter. But because the Doppler spectrum of clutter is generally symmetrical about the zero Doppler frequency, it can be canceled by subtracting the side of the Doppler spectrum without the CAT signal (the target signal) from the side with the target signal, yielding the asymmetrical target spectrum. Our wind profiler provides the Doppler spectrum on-line, and the resultant set of spectra is recorded on a removable disk for off-line data analysis.

Figure 1a shows an example of the Doppler spectrum. The Doppler frequency here is transformed to wind speed along the antenna radial direction, and such a figure is called a wind spectrum. Positive and negative wind speeds respectively refer to wind blowing toward the antenna and wind blowing away from it. The clutter spectrum around zero wind speed is clearly evident, and the target spectrum is to the left of the clutter spectrum. The dot in this figure shows the mean wind speed estimated from a first-moment calculation without the clutter cancellation, and it is because of the clutter spectrum that the mean wind speed is not estimated correctly. If the left part of the sum of the spectrum power (P_L) is larger than the right part of the sum of the spectrum power (P_R), the symmetrical clutter spectrum is canceled by subtracting the right part of the spectrum (without the target) from the left part of the spectrum (with the target). If P_R is larger than P_L , on the other hand, the symmetrical clutter spectrum

is canceled by subtracting the left part of the spectrum from the right part of the spectrum. Figure 1b shows a clutter-cancelled wind spectrum generated from Fig. 1a. Five-point running averaging is done to enhance the symmetry of the clutter spectrum and to reduce ripples in the spectrum. As shown by the dot in Fig. 1b, the mean wind speed is estimated almost correctly.

The target spectrum exists separately from the clutter spectrum in Fig. 1a. However, when the wind speed is low, the target spectrum overlaps with the clutter spectrum. Authors guess that the mean wind speed is estimated correctly by a software-based clutter-cancellation method, even at the above case when the clutter spectrum is symmetrical. To investigate the potential of this clutter-cancellation method, the horizontal wind vector estimated from the wind-profiler data was compared with the corresponding vector measured by the radiosonde.

3. Results and discussion

The wind profiler measured from heights of 0.3 km to 2.4 km with 150-m resolution and at 5-minute intervals. Radiosondes were launched from the Okinawa Meteorological Observatory of the Japan Meteorological Agency at 3, 9, 15, and 21 hours (Japan Standard Time). Hourly means of the horizontal wind vector at these times were calculated from the wind-profiler data and were compared with the radiosonde data. However, the horizontal wind vector calculated from the wind-profiler data does not correspond well to that from the radiosonde data at lower heights (less than about 1 km) even using a clutter cancellation. It is checked that the clutter spectrum is sometimes asymmetrical, but there is no clear dependence of the asymmetrical characteristic on height. Thus, this asymmetrical characteristic will not cause a bad correspondence between two horizontal wind vectors, especially at lower heights.

The distance between the Okinawa Radio Observatory and Okinawa Meteorological Observatory is about 15 km. The Okinawa Radio Observatory is located at 170-m altitude, and one side of this observatory steeply slopes down to the Pacific Ocean. On the other hand, the Okinawa Meteorological Observatory is located at downtown Naha which is the largest city in Okinawa, thus the situations around both observatories are quite different from each other. Since, the characteristic of wind will be depend on the surface condition at lower heights, wind will blow independently on each observatory at lower heights, but at greater heights the wind will blow uniformly over a wide area. It is found that a closer correspondence existed between the wind-profiler and radiosonde-derived horizontal wind vectors at higher heights (about over than 1 km).

Clutter is generally much stronger at lower heights. From the above fact, unfortunately, the po-

Fig. 1. (a) A wind spectrum measured at 0937 LT on December 4, 1992. Azimuth and zenith angles are respectively 225 and 10 degrees and the measurement range is 1.5 km. The dot shows the mean wind speed estimated from a first-moment calculation. (b) Like Fig. 1a but with the clutter cancellation and with 5-point running averaging.

Fig. 2. (a) A scatter-diagram of wind speeds derived from radiosonde data (S_{RS}) and from wind-profiler data (S_{WP}) without the clutter cancellation for the north-south component. Positive and negative here respectively mean north-to-south and south-to-north. r and $S.D.$ are the correlation coefficient and standard deviation of wind speed derived from wind profiler. The equation for the least-square-fitted line is also shown. (b) Like Fig. 2a, but for the west-east component. Positive and negative respectively mean west-to-east and east-to-west.

tential of a clutter-cancellation method can not be investigated separately, by using data with strong clutter at lower heights, from the effect of the surface condition. Thus, wind profiler data at greater heights only is used. Wind vectors estimated from wind-profiler data at heights of 1.5, 1.95, and 2.4 km can be compared directly (with no interpolation in the vertical direction) with vectors estimated from the radiosonde data. These heights were chosen

to avoid errors due to interpolation. Wind vector data for comparison were obtained from December 1992 to November 1993, and the following four scatter diagrams, showing relations between wind speed derived from radiosonde data (S_{RS}) and wind speed derived from wind profiler data (S_{WP}), contain about 4000 data points.

Figure 2a is a scatter-diagram between S_{RS} and S_{WP} for the north-south component without clut-

Fig. 3. (a) As for Fig. 2a, but with the clutter cancellation. (b) As for Fig. 2b, but with the clutter cancellation.

ter cancellation. Positive and negative respectively mean north-to-south and south-to-north. Figure 2b is similar to Fig. 2a, but for the west-east component, and in Fig. 2b positive and negative respectively mean west-to-east and east-to-west. As shown in Fig. 2, when the absolute value of S_{RS} becomes large, that of S_{WP} is sometimes less than that of S_{RS} . This difference is due to the clutter effect. Figures 3a and 3b are analogous to Figs. 2a and 2b but with clutter cancellation, and they show closer correspondence between S_{RS} and S_{WP} . The slope and intercept of the equation for the least-square-fitted line in Fig. 3 are close to unity and zero, respectively. Thus it is believed that a clutter cancellation does not cause bias error.

Figures 3a and 3b show good correspondence between S_{RS} and S_{WP} in S_{WP} ranging from about -2 to $+2 \text{ ms}^{-1}$. However, outside this range, scattering between S_{RS} and S_{WP} is enhanced. These results suggest that when the absolute value of S_{WP} is less than 2 ms^{-1} (low wind speed) the clutter spectrum is symmetrical, and when S_{WP} is greater than this (high wind speed) the asymmetry of the clutter spectrum is enhanced. Thus, a clutter cancellation works well when the wind speed is low, and it does not work perfectly when the wind speed is high. The wind speed at ground level of the Okinawa Radio Observatory will correlate partially to that at greater heights (about 1 or 2 km). From the above postulations, it seems that vegetation moves back and forth symmetrically when the wind speed is low and moves asymmetrically when the wind speed is

high. When the wind speed is low, the target spectrum overlaps with the clutter spectrum. Since a clutter cancellation works well in the case of low wind speed, as shown in Figs. 3, the author's expectation of Section 2 will be correct.

Data points at heights of 1.5, 1.95, and 2.4 km are plotted in Figs. 3. When the measurement height becomes appreciable, the signal-to-noise ratio (SNR) becomes low. The scattering properties between S_{RS} and S_{WP} at the three heights are slightly different from each other. These differences will be caused by the dependence of the SNR on height. Since the aim of this study is to investigate the potential of a clutter-cancellation method, this dependence is not treated here.

4. Concluding remarks

When the clutter spectrum was canceled by software-based clutter cancellation, the horizontal wind vector estimated from the wind-profiler data corresponded well to that estimated from the radiosonde data. This clutter cancellation method is thus effective in cancelling the clutter in the estimation of the horizontal wind vector.

This clutter cancellation method will also be used in estimating the vertical wind speed. The vertical wind speed is generally less than $\pm 1 \text{ ms}^{-1}$, so that it will be quite close to the clutter spectrum around zero wind speed. The authors believe that a clutter-cancellation method always works well when the clutter spectrum is symmetrical.

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ウィンドプロファイラにより観測されたドップラースペクトラム中の クラッタ成分のソフトウェアによる除去

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通信総合研究所沖縄電波観測所では、ウィンドプロファイラを用いて低層大気の観測に関する研究を行っている。ウィンドプロファイラは、大気乱流からの散乱波を受信することにより、風の三次元ベクトルの高度分布を観測することができるドップラーレーダである。沖縄電波観測所の周囲には小さな森が点在しているために、アンテナサイドローブを通して木の葉等からの散乱信号がドップラースペクトラム中に混入し、風向・風速の推定精度を劣化させることが分かった。そこで、ウィンドプロファイラにより観測されたドップラースペクトラム中のクラッタ成分をソフトウェアにより除去することを試み、この手法の有効性をラジオゾンデのデータと比較することにより確認した。