2.4A INTERPRETATION OF RADAR RETURNS FROM CLEAR AIR - DISCRIMINATION AGAINST CLUTTER

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Generally, different kinds of interference may cause problems to the proper detection and analysis of the atmospheric signals, when using VHF and UHF radars. We may separate these into passive and active contributions.

Passive contributions are existent in the receiving system without the radar transmitter switched on. There are: P1) noise from the receiver/antenna system, P2) noise from cosmic sources, the sun and planets, P3) noise from the earth's surface, P4) noise from the earth's atmosphere, P5) interference from man-made sources (signals from communication and broadcast transmitter, ignition and machinery noise etc.).

Active contributions are due to scatter and reflection of the own transmitted radar signal from unwanted targets, which are called clutter. These active contributions are due to clutter from: A1) fixed and stationary targets on the earth's surface, e.g., power lines, transmitter towers, mountains, buildings and any kinds of erased structures, A2) surface waves of rivers, lakes and oceans, A3) ships, A4) motor cars, A5) aircrafts (and rockets, during special experiments), A6) satellites, A7) moon, planets (and sun), A8) atmospheric turbulence, A9) ionospheric irregularities.

The passive contributions have different effects depending on the operation frequency. P1 normally has to be regarded only at UHF, P2 is the main noise source at VHF, P3 has to be regarded only at UHF with low elevation antenna angles, P4 is negligible at UHF and VHF. P5, interference from man-made sources depends strongly on location and can be minimized by good suppression of low elevation antenna sidelobes, although strong nearby transmitters still may cause crucial interference. Also tropospheric ducting will increase the interference level from distant transmitters. A critical problem may arise in the low VHF band if transhorizon propagation via ionospheric reflection becomes possible.

In any case, care must be taken that the unavoidable interference signals do not saturate any stages of the receiver or move these into the nonlinear regime. Cross modulation effects then would prohibit proper suppression of the interference during the data analysis.

Of major importance to radar systems are active interference contributions. Different methods can be applied for elimination or at least suppressing unwanted effects. These are:

(1) Directional filtering, i.e., applying optimum suppression of antenna sidelobes,

(2) Range filtering, i.e., suppressing unwanted signals only in affected range gates,

(3) Selection by amplitude distributions,

(4) Temporal filtering, i.e., recognizing typical temporal variations of the clutter signals, viz, spectral characteristics, and applying matched filters.

Application 1, obviously needs a fairly good optimization of the antenna pattern and may need additional shielding or screening of the antenna. Since the cross sections of all the clutter targets A1-A9 may often be substantially larger than the cross sections of wanted atmospheric targets and the clutter signal still may be strong, applications 2, 3 and 4 should always be considered.

Applications 2, 3 and 4 mostly go together, since clutter targets with different characteristics will occur in different range gates. The simplest application of 2 is just for the case of stationary clutter targets (A1), yielding constant echo amplitudes in specified range gates. The easiest way then is to measure an average stationary clutter profile as a function of range and antenna position and subtract it during each following measurement. This of course has to be done according to amplitude and phase. However, all other clutter echoes A2-A9 are not stationary, and even echoes from fixed targets (A1) can fade due to tropospheric propagation effects.

Application 3, i.e., determining the amplitude distributions of signals, may help in some cases to detect an unwanted signal. The amplitude distribution of an echo from a very slowly varying target can be described by a Rice distribution, whereas atmospheric scatter has a Rayleigh distribution. Deciding which kind of distribution the echoes belong to then may allow to detect a false signal, but will not eliminate it.

One also can use a method of maximum likelihood to determine if wanted or unwanted signals are observed. One for instance does not expect clutter from ionospheric irregularities (A9) at ranges shorter than 100 km, if care is taken to avoid range ambiguities. Echoes from targets on the earth's surface (A1) and clutter from sea surface waves (A2), ships (A3), and motor cars (A4) will not occur at distances greater than the radio horizon of the antenna, if edge effects on mountain ridges, multiple scattering, ionospheric reflection or tropospheric ducting can be excluded. Echoes from moving targets are normally characterized by a U-shape variation of clutter power with range.

The most efficient way to detect and eliminate clutter echoes is by application 4, namely applying matched filters. This essentially works for slowly moving targets, since the fast moving targets, such as aircrafts, satellites, moon etc. (A5-A7) cause fast frequency changes which cannot be resolved with typical interpulse-period sampling rates of MST radars. This aliasing effect results in an increase of the noise power, since the clutter returns are non-coherent. The power due to scatter of these point sources decreases inversely with $(\text{distance})^4$, as compared to the $(\text{distance})^2$ variation of volume scatter from atmospheric turbulence. Thus, problems will not be too severe if the clutter target is at a far distance. However, it can be very critical at too close distances, since the effective cross section, or aircrafts for instance, is fairly large yielding very strong clutter signals even in the antenna sidelobes. A solution would be to set up MST radar systems far away from any aircraft flight routes.

Matched filters can be applied to eliminate clutter which exhibit "well-behaved" frequency characteristics, such as ground clutter, sea clutter and partly also the clutter from atmospheric turbulence (and ionospheric irregularities). In case of slowly varying processes, such as clutter from ships, cars, and sea clutter with frequency changing due to tides, adaptive filters can be applied.

In Figure 1 we have shown a selection of spectra-height-intensity plots to demonstrate some of these effects. The experiments to obtain these spectra were carried out at the Arecibo Observatory with a 46.8-MHz radar using the 305-m dish as antenna (ROTTGER et al., 1981). The antenna beam with 1.7° half-power width was pointed at a fixed azimuth to different zenith angles (ZE) of 1.7°,

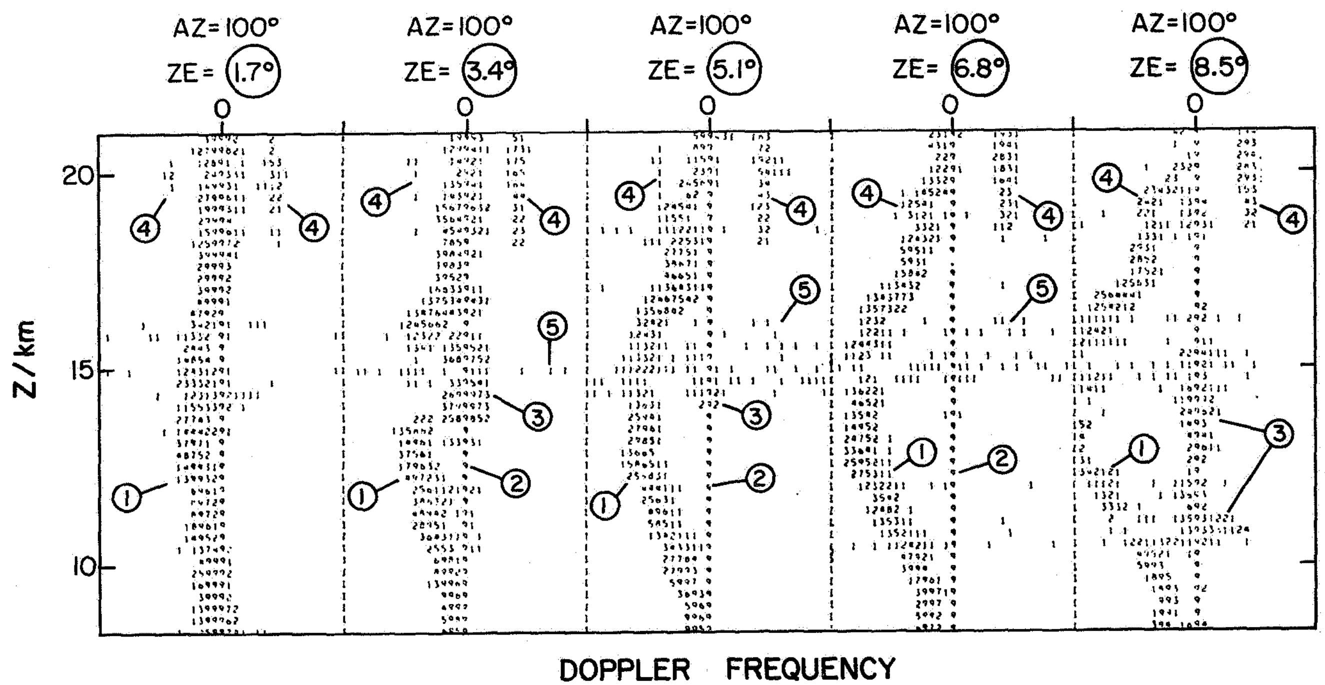

Figure 1. Spectra-height-intensity plots of VHF radar signals. (1) = atmospheric echo, (2) = nonfading ground clutter, (3) = atmospheric clutter due to sidelobe into zenith direction, (4) = sea clutter, (5) = noise.

3.4°, 5.1°, 6.8° and 8.5°. For each range gate (of 300 m increment) the amplitude of the Doppler spectra was normalized to its maximum value. The numbers 9 in the plots correspond to the maxima. The range covered by these radar experiments was from about 8 km to 21 km. Echoes from atmospheric turbulence, (1), carried with the wind, cause a Doppler shift which fairly continuously varies with range. The Doppler shift increases with zenith angle because the radial velocity component (in direction of the beam) of the horizontal wind increases with zenith angle. This effect can be used as a straightforward criterion to discriminate atmospheric echoes from clutter.

Strong ground clutter (2), having zero Doppler shift, is observed at all ranges. However, at ZE = 3.4° and some other angles this clutter widens (3). It became obvious during our experiments that this effect is due to atmospheric clutter received through sidelobes pointing towards the zenith. This kind of clutter can be strong because of the aspect sensitivity of the tropospheric and stratospheric VHF radar echoes. To reduce (or eliminate) this effect, a zenith angle of the antenna main lobe (e.g., ZE = 6.8° in these VHF radar experiments at A.O) should be chosen where sidelobes pointing close to the zenith are sufficiently suppressed.

Clutter from ocean waves (4) occur in Figure 2 at ranges larger than 18 km, which is due to sidelobes close to the horizon. This clutter occurs at positive and negative Doppler frequencies due to approaching and departing ocean waves (having different amplitudes). The phase velocity of the ocean surface waves is directly depended on their wavelength, such that the frequency offset ±fs of the scattered radar waves is fixed. It may be shifted, however, due to (tidal) currents. To eliminate the sea clutter a notch filter could be applied, which on the other hand also would affect a wanted signal. Also a low-pass filter could be used, if the atmospheric signal has lower Doppler shift than fs (e.g., at ZE = 1.7°). Too small zenith angles would yield too low accuracy and problems with separating the atmospheric scatter from ground clutter.

An optimum approach to select or separate the atmospheric signal from different types of clutter is by applying a non-linear curve fitting procedure as it was done by SATO and WOODMAN (1980). They had to apply this procedure to data taken with the 430 MHz radar at A.O., where they found that even the ground clutter faded slowly (causing a line broadening) and could not be eliminated by high-pass filtering (viz. dc-subtraction). They assumed a theoretical function shape of the power spectral components of clutter and the desired echo. They also considered some a priori knowledge of clutter/signal signatures, e.g., the ground clutter has almost a symmetrical spectrum, whereas this is not the case for almost every atmospheric signal (ZE>0°). The sea clutter also in a first approach can be expected to be in well defined frequency channels symmetrical to zero, but having different amplitudes and a small common offset due to ocean currents. The fitting procedure of Sato and Woodman allowed to detect even signals having -50 dB signal-to-clutter radio. An example of a fitting result is shown in Figure 2 (by courtesy of T. Sato), where the spectra of the atmospheric signals found by this technique are inserted. From these fitted spectra, the essential parameters signal power, Doppler shift and spectra width can be directly deduced.

In summary, we find that several methods exist and are applied to eliminate or suppress clutter effects in the data analysis. It must be regarded, however, that clutter influences should be suppressed as early as possible, i.e., by properly selecting antenna location, antenna and receiver design.

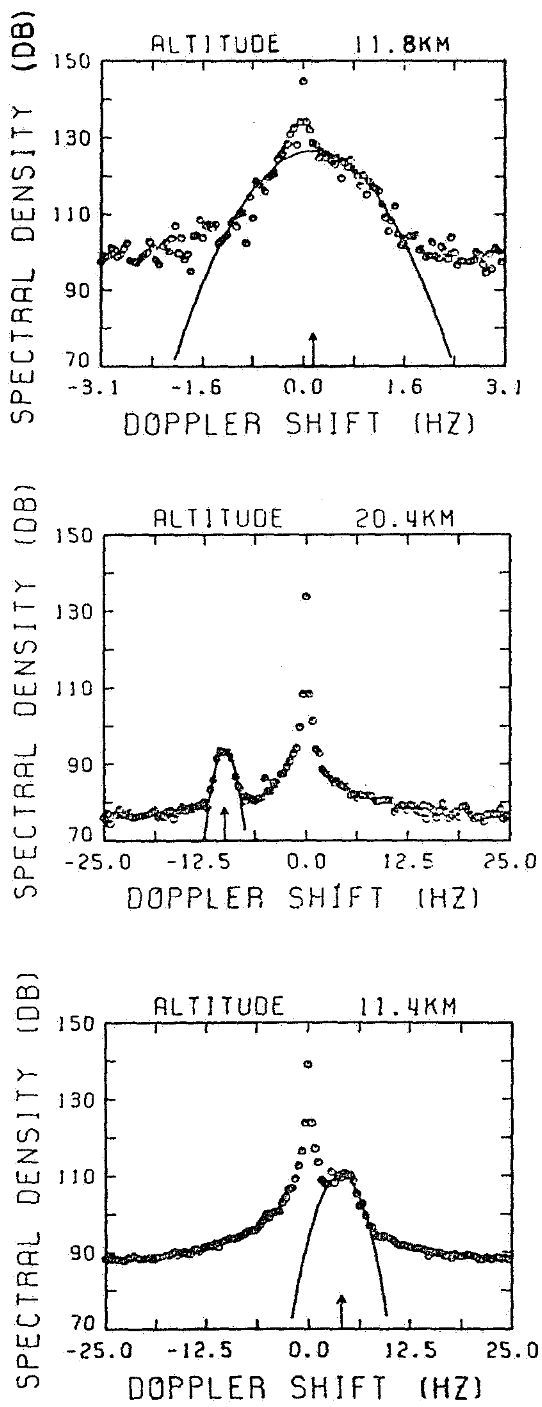

Figure 2. Optimum fitting of model signal spectra to signal + clutter data.

REFERENCES

Rottger, J., P. Czechowsky and G. Schmidt (1981), First low-power VHF radar observations of tropospheric, stratospheric and mesospheric winds and turbulence at the Arecibo Observatory, J. Atmos. Terr. Phys., 43, 789-800.

Sato, T. and R. F. Woodman (1980), Spectral parameter estimation of CAT radar echoes in the presence of fading clutter, Proc. 19th Conf. on Radar Meteorology, Miami, FL.