IMPLEMENTATION OF REFRACTIVITY RETRIEVAL FROM GROUND CLUTTER USING THE S-BAND KOUN RADAR

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1. INTRODUCTION

Phase variations of ground clutter radar returns are related to changes in the index of refraction of the atmosphere between the radar and the target [Fabry et al., 1997]. The index of refraction varies with pressure, temperature and relative humidity, so any phase change in returns from ground targets acts as an atmospheric record of these variables. Refractivity extraction can provide low-level moisture information useful for thunderstorm initiation forecasts, boundary-layer research and data assimilation in models. Therefore, this relatively new technique will become increasingly important over the coming years. Using the KOUN dual-polarization radar, we will show that the time-varying phase of ground clutter returns can be used to generate a field of near-surface index of refraction, usually limited to a 30-40 km range from the radar. With the ultimate goal of implementation of this technique on shorter wavelength radars, such as 3-cm gap-filling radars, we will present results from the S-band KOUN radar in Norman, Oklahoma, operated by the National Severe Storms Laboratory.

2. PHASE AND REFRACTIVITY RELATIONSHIP

The propagation speed of an electromagnetic wave depends on the material through which it travels. Waves traveling through the atmosphere propagate slightly slower than in a vacuum. The ratio of the speed of light in a vacuum to the speed of light in a medium is called the refractive index, n, which is more easily expressed as refractivity [Bean and Dutton, 1968]:

$$N = (n-1) \times 10^6 \tag{1}$$

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Refractivity is related to atmospheric variables by

$$N = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \tag{2}$$

where T is temperature in kelvins, and P and e are atmospheric and water vapor pressure, respectively, in millibars. Changes in refractivity along a path from the radar to a target are linearly related to phase changes of the target by

$$\Delta\phi = \frac{4\pi f r}{c}\Delta n \tag{3}$$

where f is the radar frequency and c is the speed of light. In addition to this dependence on the refractive index, the phase of a target is also a function of the distance from the radar, as well as the physical properties of the target itself.

3. GROUND CLUTTER ECHO QUALITY

Refractivity extraction requires a selection of high quality ground clutter targets to be used exclusively. High quality clutter points have a large phase-time coherence, while clear air and clutter points with ”sway” have low coherence. Coherence is estimated here as the ratio of lag-1 to lag-0 autocorrelation for phase, over a period of roughly 90 minutes. Figures 1 and 2 show the signal-to-noise ratio (SNR) and phase coherence, respectively, for the KOUN research radar in Norman, Oklahoma. Areas to the south and west of the radar show high SNR but have weak phase coherence, a signature of vegetation, while targets such as power lines and gridded city roads, which have moderate SNR, show strong phase coherence. The distribution of phase coherence is bimodal, consisting of either very weak or very strong target phase coherence, which allows for easy discrimination between static ground targets and those with noticeable sway. For this experiment, ground clutter with a phase-time coherence greater than 0.5 were selected as quality targets, since this value is the mid-point between the two coherence distribution modes. It should

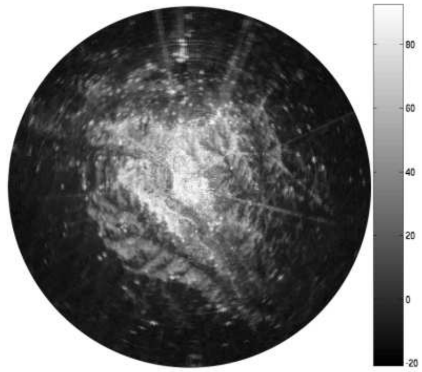

Figure 1: Average SNR, in dB. Map encompasses a 50 km radius around the KOUN research radar in Norman, Oklahoma.

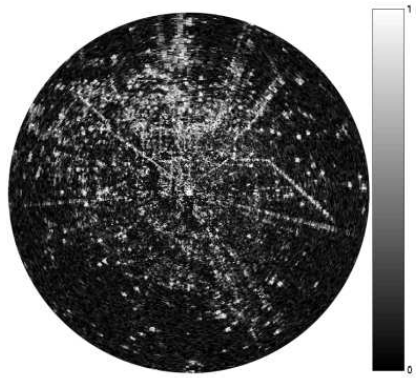

Figure 2: Coherence, defined as the ratio of lag-1 to lag-0 autocorrelation of phase over 90 minutes. Map encompasses a 50 km radius around the KOUN research radar in Norman, Oklahoma.

be noted that the results were not highly depedent on the threshold of coherene.

4. REFRACTIVITY MEASUREMENTS

Extraction of refractivity can be achieved as described by [Fabry et al., 1997; Fabry, 2004]. A phase reference is determined from a ten-scan average, ideally collected during a period when moisture conditions are spatially homogeneous. The difference between the measured phase and the reference phase is calculated for the selected ground clutter targets (Fig 4a), and the slope of this phase difference is estimated using a line-fitting algorithm (Fig 3). The slope estimate is removed from the phase difference, and the remainder is smoothed using a Gaussian filter with a 4 km window. The estimated slope is then added back into the smoothed field, producing a field of phase difference that encompasses the radar scanning area out to a distance of approximately 40 km (Fig 4). From the phase difference field (Fig 4e), the change in refractive index can be determined from the slope of the phase difference by modifying (3), such that:

$$n(r,t) - n_{ref} = \frac{c}{4\pi f}\frac{d}{dr}\left[\phi(r,t) - \phi_{ref}(r)\right] \qquad (4)$$

The refractive index difference is calculated over short path lengths, and the refractive index reference, n_{ref}, is removed to produce a field for the given radar scan. This refractive index reference map is determined from Oklahoma Mesonet surface weather stations located within and near the radar scanning region.

5. CONCLUSIONS AND POTENTIAL

The ultimate goal of this research is to implement refractivity extraction on a mesoscale network of 3-cm radars currently being installed in southwest Oklahoma. This radar network, created as part of the Engineering Research Center for Collaborative Adapting Sensing of

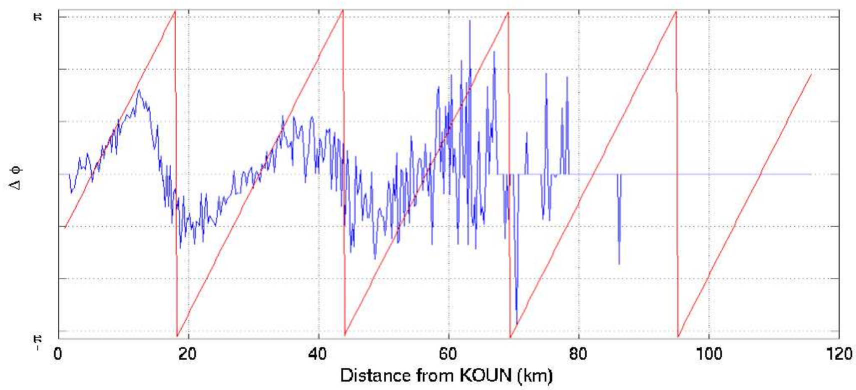

Figure 3: Phase difference averaged over all azimuths (blue), plotted with estimated slope (red).

the Atmosphere (CASA), aims to provide high resolution sensing of the atmospheric boundary layer below 3 km, areas in which the NEXRAD 10-cm radar network has limited reach. Implementing refractivity extraction on the CASA radar network poses a few challenges, namely more rapid phase wrapping due to a shorter wavelength, and possible phase stability limitations due to radar design. In additon to the implementation of this technique on 3-cm radars, further work will likely focus on case studies, using radar-generated refractivity fields to investigate such possible topics as frontal passages, thunderstorm initiation along drylines and boundary layer moisture transport.

References

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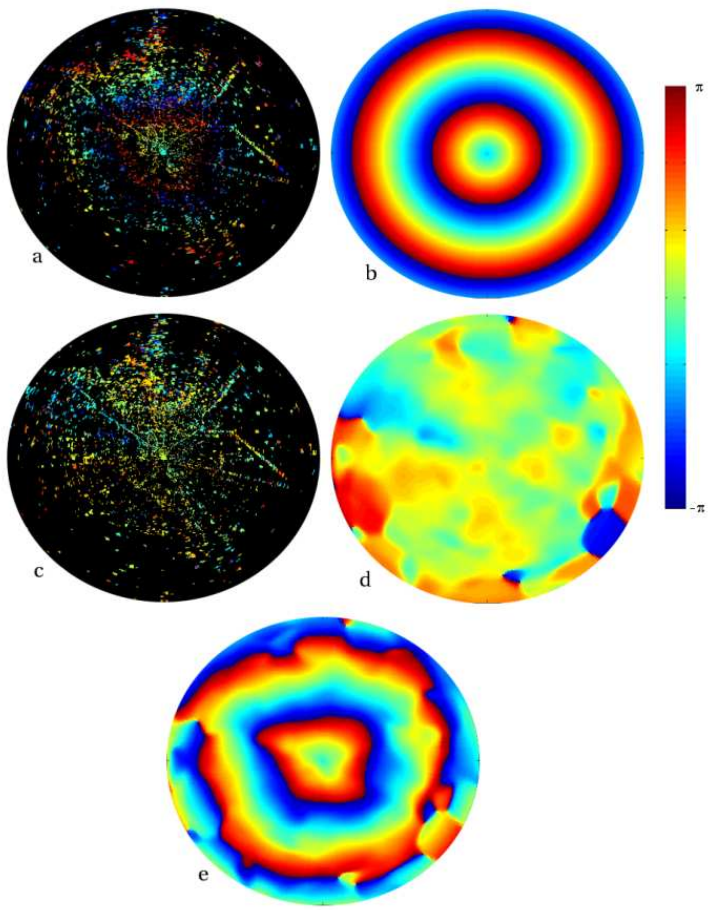

Figure 4: Phase difference estimation process: (a) phase difference between two times, (b) estimated average slope, (c) phase difference after removal of average slope, (d) smoothed phase difference, (e) phase difference field after average slope is returned.