Detection of Phantom Drones
(with WiPPR FMCW radar)

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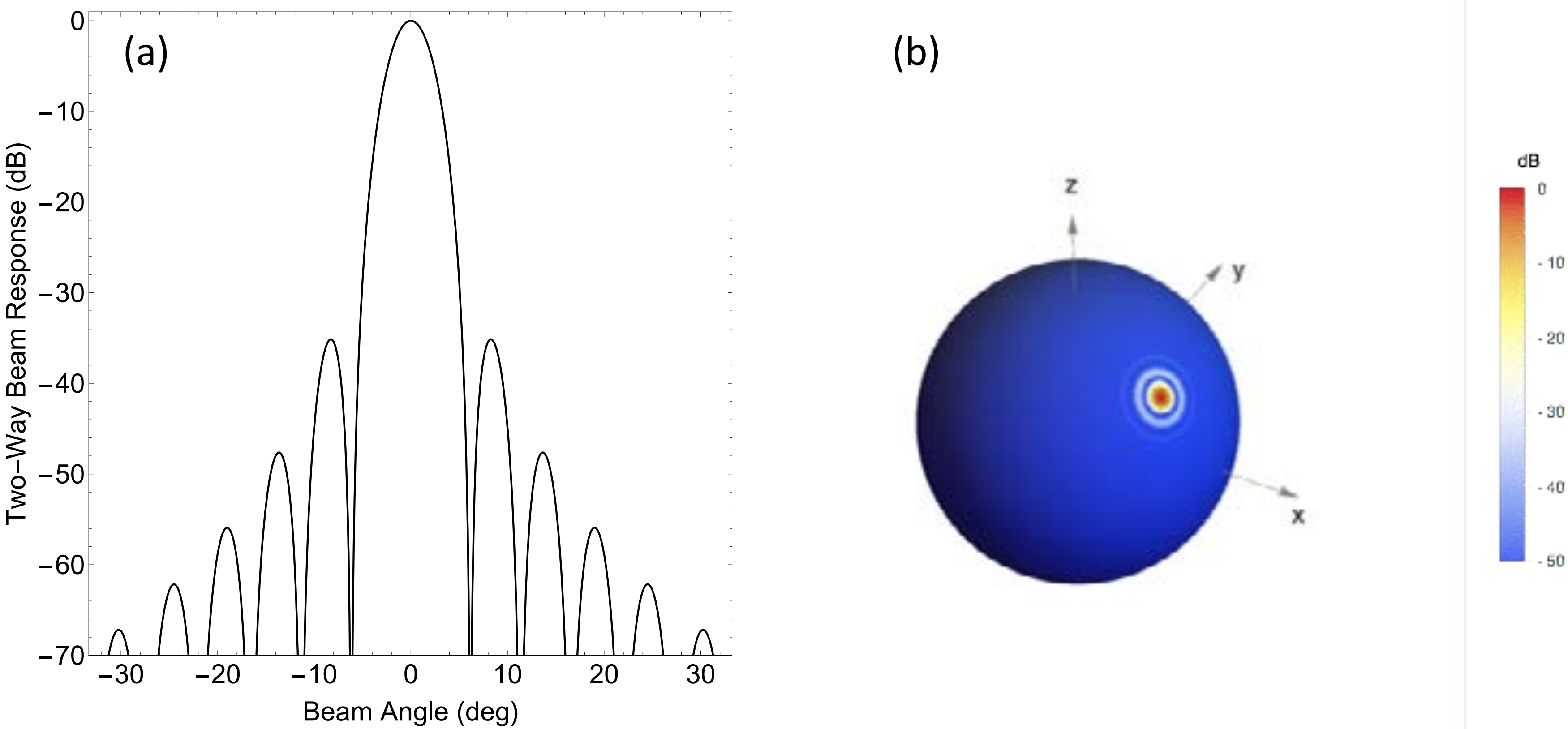
1 June 2016

Detection of Phantom Drone with WiPPR

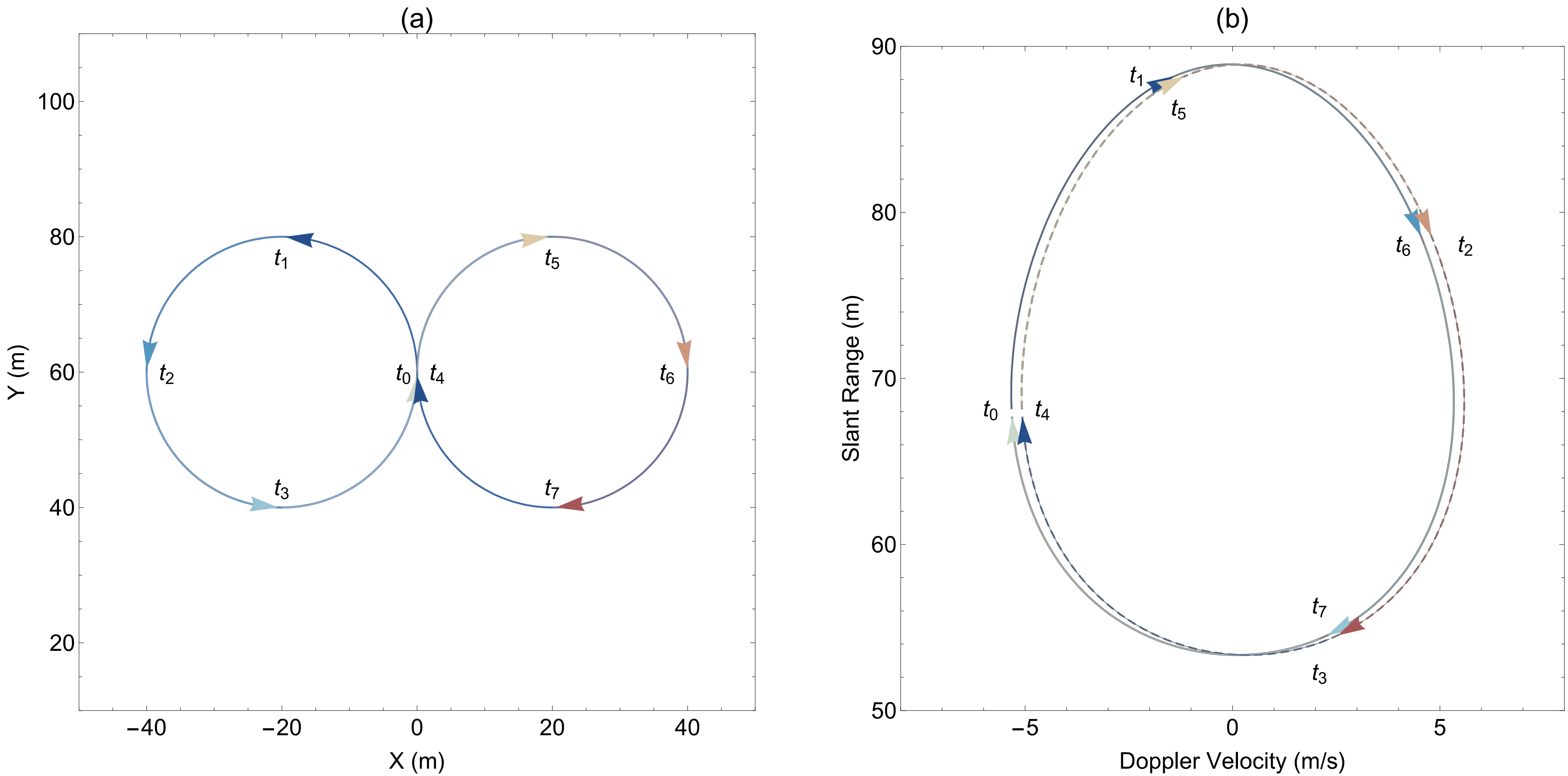
- Experiment conducted 9 March 2016
- Drone is readily detectable by the WiPPR radar
- Unique feature of drone signature documented

WiPPR beam patterns with 31 dB gain antennas



Discussion. (a) Line plot of the WiPPR beam pattern response. (b) 3D response of the WiPPR beam pattern. Graphics (a) and (b) were computed with 31 dB gain antennas. Beyond about 9 deg from the beam center, the detection of a drone will be difficult because of large two-way losses. Near the beam center the radar will detect the drone at ranges of at least several kilometers but the echo signal will be so large that clipping will occur in the electronics and it will be impossible to make detailed inference about the nature of the drone echo. Examples of WiPPR performance against the drone in this brief will be based upon radar-drone angles in the 3-9 deg range on either side of the main beam response axis. It is important to remember that in its present configuration, the WiPPR system has a pencil beam and is optimized for detection of very small targets (radar cross section on the order of 10^{-5} to 10^{-4} dB re m^2) at ranges on the order of a kilometer or more. This detection capability against small targets is made possible by virtue of the WiPPR systems 70 dB dynamic range and the use of high gain antennas. Said another way, the current WiPPR system is currently not optimized for the detection of small drones. Figure produced by Mathematica notebook *"WiPPR 3D Beam Pattern Visualization.nb"*.

Doppler kinematics of a drone figure 8 track

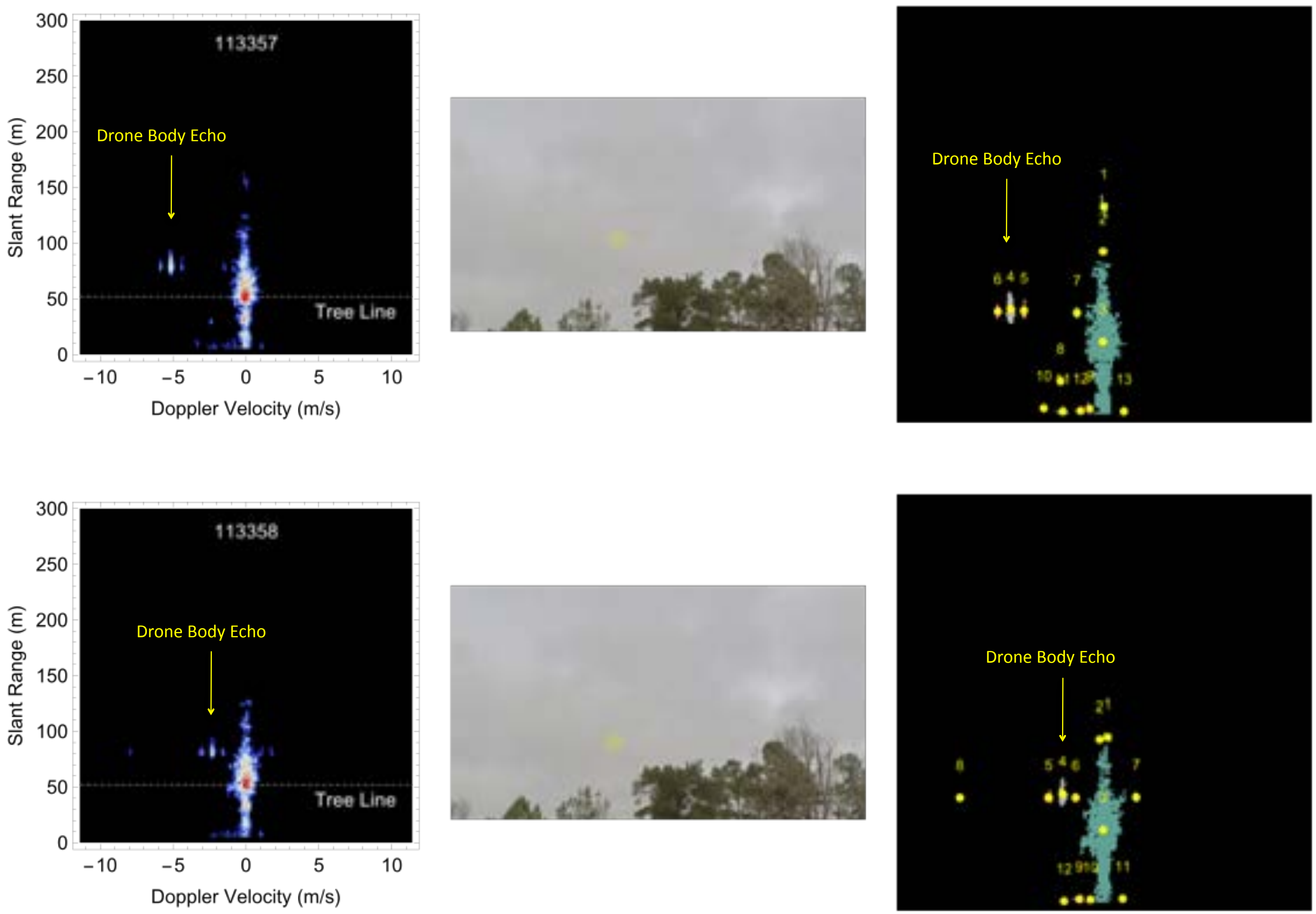


Discussion. (a) During the data- recording time period addressed in this brief the drone was moving in figure 8 track. (b) The radar sees figure 8 motion as two identical cycles in Doppler velocity- slant range space. As the drone moves from t_0 to t_1 the radar sees an increase in slant range and a decrease in Doppler velocity. As the drone moves form t_1 to t_2 the radar sees a decrease in slant range and an increase in Doppler velocity. The Doppler velocity-slant range track observed by the radar is not symmetric because the actual drone motion takes place out in front of the radar and not over it. The radar cannot tell a right turn from a left turn but it can tell if the drone is moving on a straight track or is turning into or away from the radar. The numerical values shown in this figure are based upon tracking the drone as described later in this brief. Tracks shown in (b) are slightly offset to aid in viewing. Figure produced by Mathematica notebook "*Drone Figure 8.nb*."

Drone signature at successive track points t_{30} and t_{31}

t_{30}

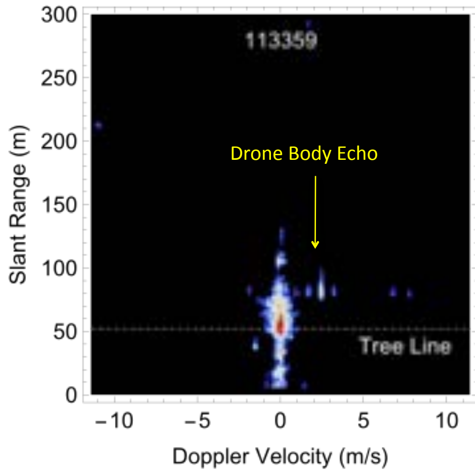
t_{31}

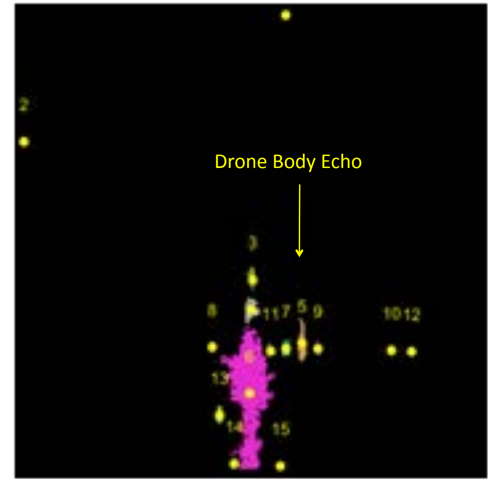


Discussion. (Left) radar range velocity matrix on SNR scale extending from 8 to 58 dB. Black indicates SNR<8 dB. (Center) GoPro photograph. (Right) Morphological processing of radar RVM to identify the Doppler velocity slant range of the drone body echo. Yellow points in the morphological images are centroids of features. Time of data is indicated by white numbers in left hand figures. The shift towards zero Doppler velocity from t_{30} to t_{31} indicates the drone is beginning a turn back towards the radar. Figure generated by Mathematica notebook "*Drone Detection Experiment 9 March 2016*.nb".

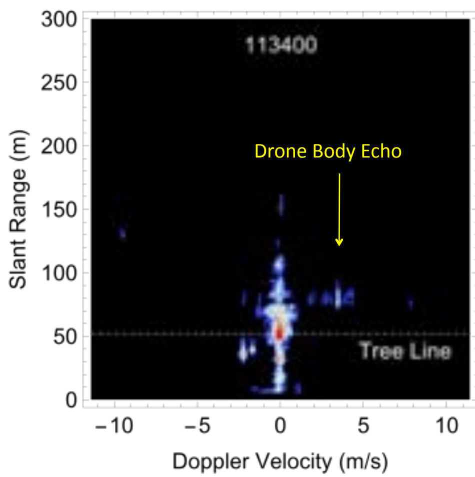
Drone signature at successive track points t_{32} and t_{33}

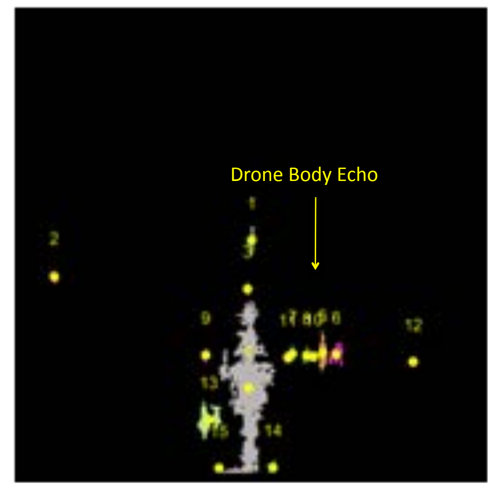
t_{32}





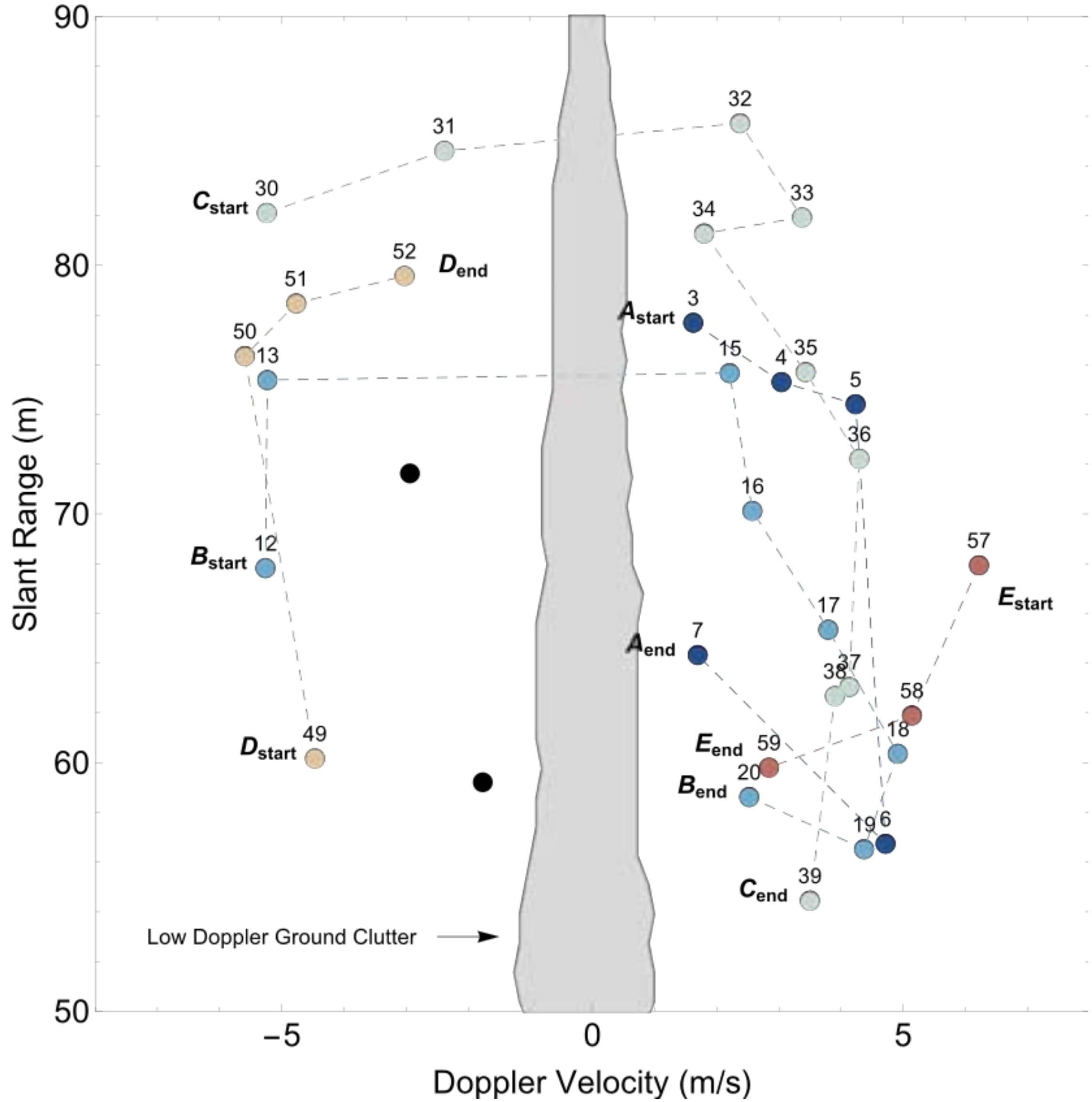
t_{33}





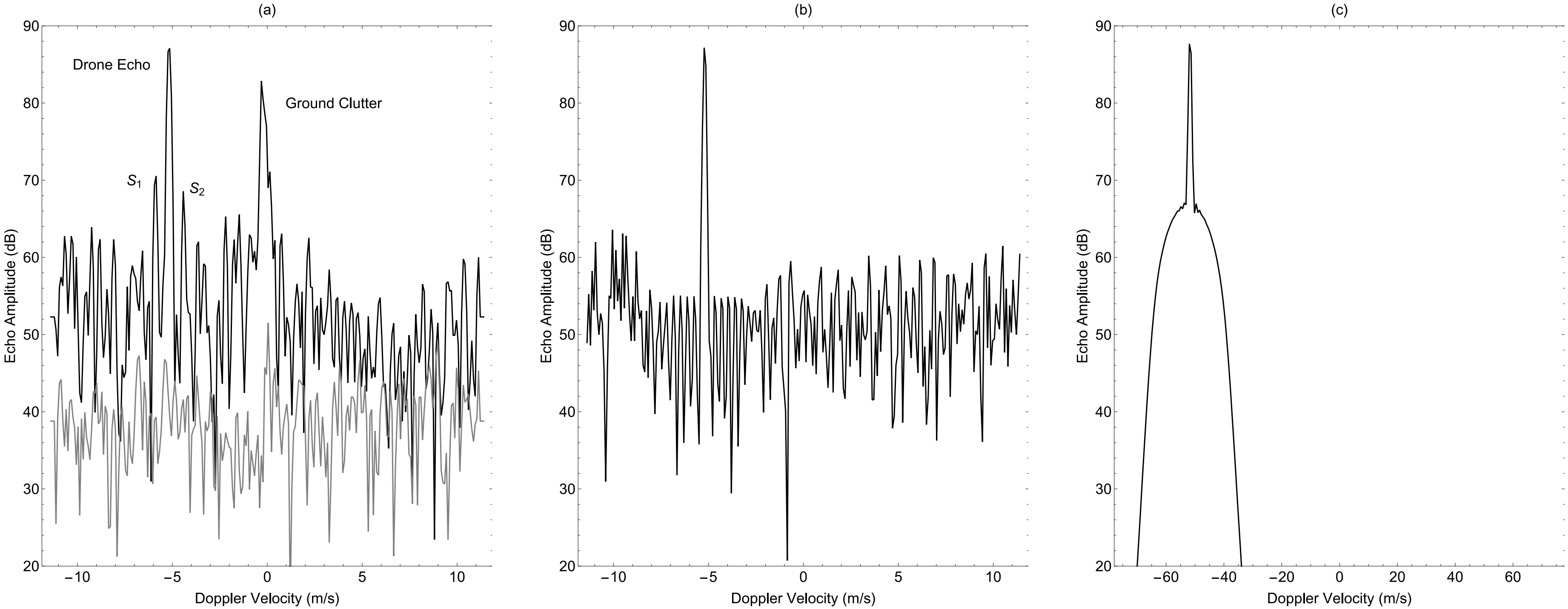
Discussion. (Left) radar range velocity matrix on SNR scale extending from 8 to 58 dB. Black indicates SNR<8 dB. (Center) GoPro photograph. (Right) Morphological processing of radar RVM to identify the Doppler velocity slant range of the drone body echo. Yellow points in the morphological images are centroids of features. Time of data is indicated by white numbers in left hand figures. The slight increase in positive Doppler velocity from t_{32} to t_{33} indicates the drone is in the later phases of a turn back towards the radar. Figure generated by Mathematica notebook "*Drone Detection Experiment 9 March 2016*.nb".

Drone tracks using data observed at time epochs t_1 to t_{59}



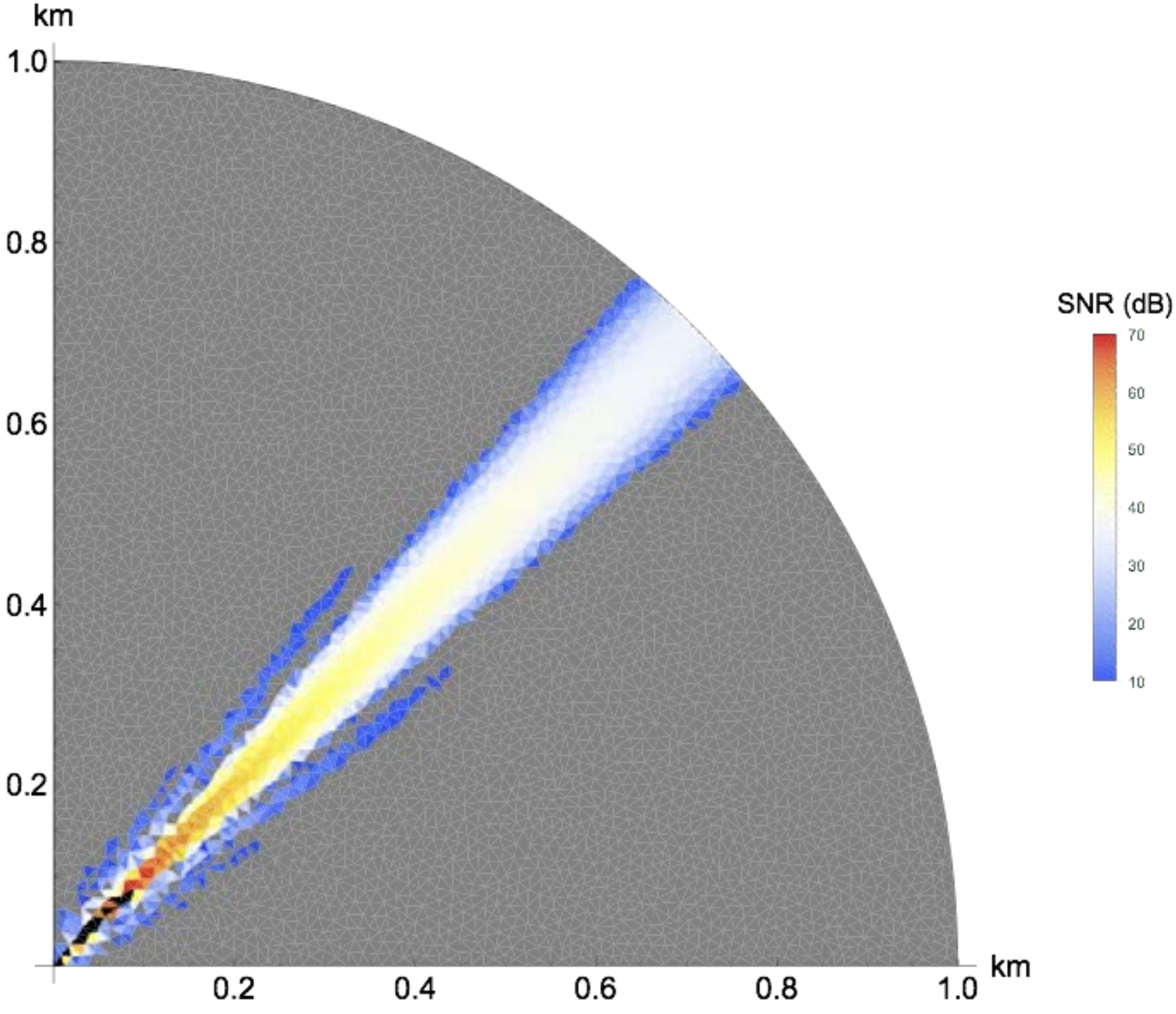
Discussion. Drone tracks obtained from data recorded at time epochs t_1 to t_{59}. Five tracks were found (*A*, *B*, *C*, *D* and *E*). Detection of the drone body at sequential times defines a track. Color is used here to link data points on a track. The two black points are detections that were not consistent with a track. Track *C* corresponds to data presented in previous slides. Track *B* actually has one time period missing but it is consistent with a drone figure 8 track so it has been included in its full length. The region near zero Doppler in the center of the figure corresponds to ground clutter returns. Only tracks *B* and *C* cross the this region. In general the tracks are consistent with the theoretical description track description presented earlier in this brief. Figure produced using Mathematica notebook "*Drone Detection Experiment 9 March 2016.nb*"

Details of the drone signature at time epoch t_{30}



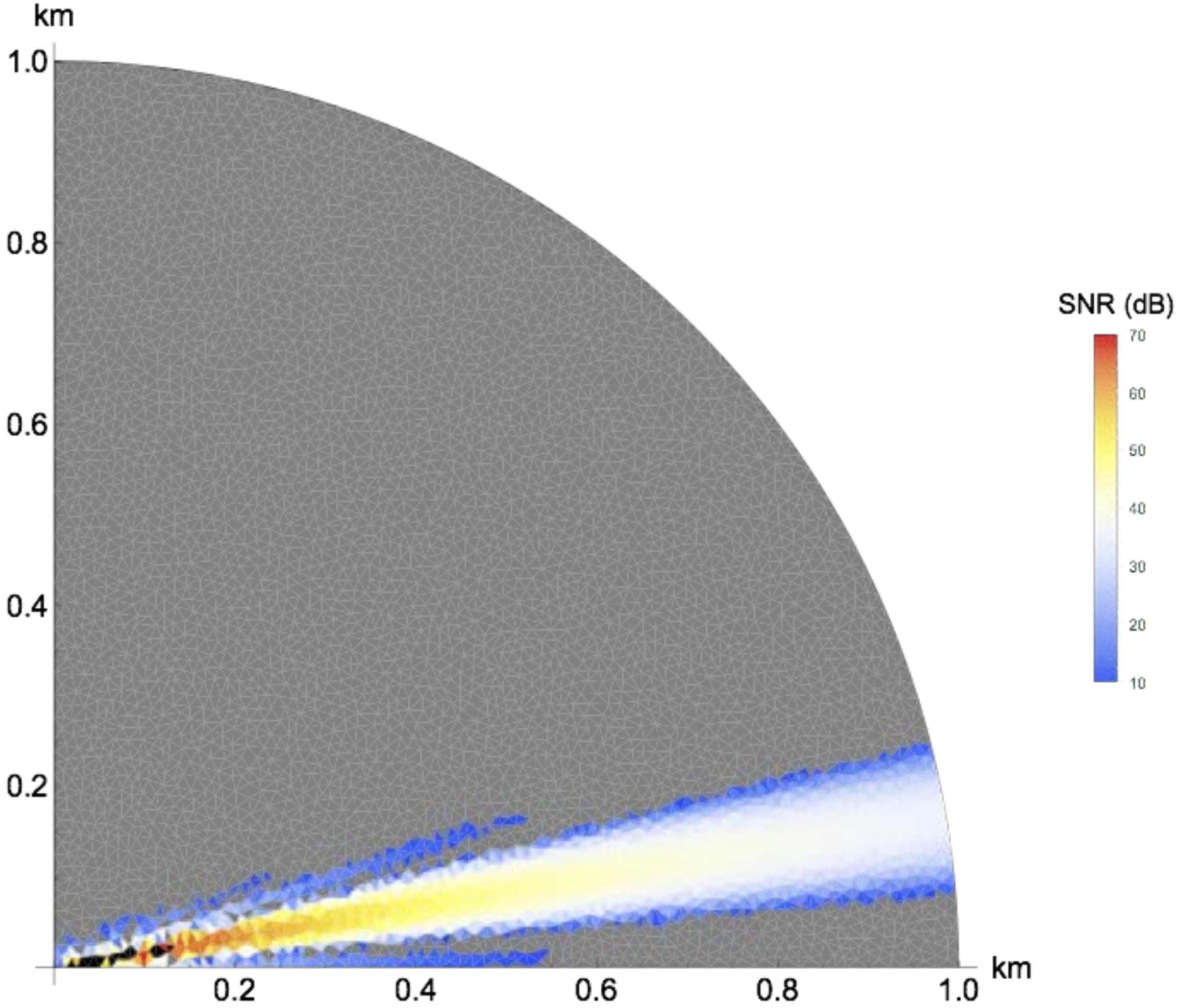
Discussion. (a) Measured drone echo (black) and background noise level (gray) for time epoch t_{30}. The drone echo is much higher than the background noise observed at a slightly greater range. (b) Model simulation using an analytic model with a 197 microsec pulse as was used by the WiPPR system. (c) Model simulation for 30 microsec pulse. Amplitudes of the model simulation have been matched to peak echo from the drone. There is no noise in the two model simulations. The structure in (b) on either side of the peak is caused by velocity wrap and constructive and destructive interference. The blade tip speed for the drone is approximately 41 m/s. This far exceeds the unambiguous -11.4 to 11.4 m/s Doppler bandwidth of the 197 microsec pulse. Reducing the pulse to 30 microsec increases Doppler bandwidth and completely resolves the drone echo. The structure in the measured drone signal in (a) is very similar to the simulation shown in (b) apart from the two strong side lobes S_1 and S_2 in the measured echo. These side lobes could be caused by a variety of factors including the fact that the drone had 4 sets of propellers. Figure produced using Mathematica notebook "*Drone Signature Simulation.nb*".

Spatial coverage provided by GWiPPR at 45 deg azimuth



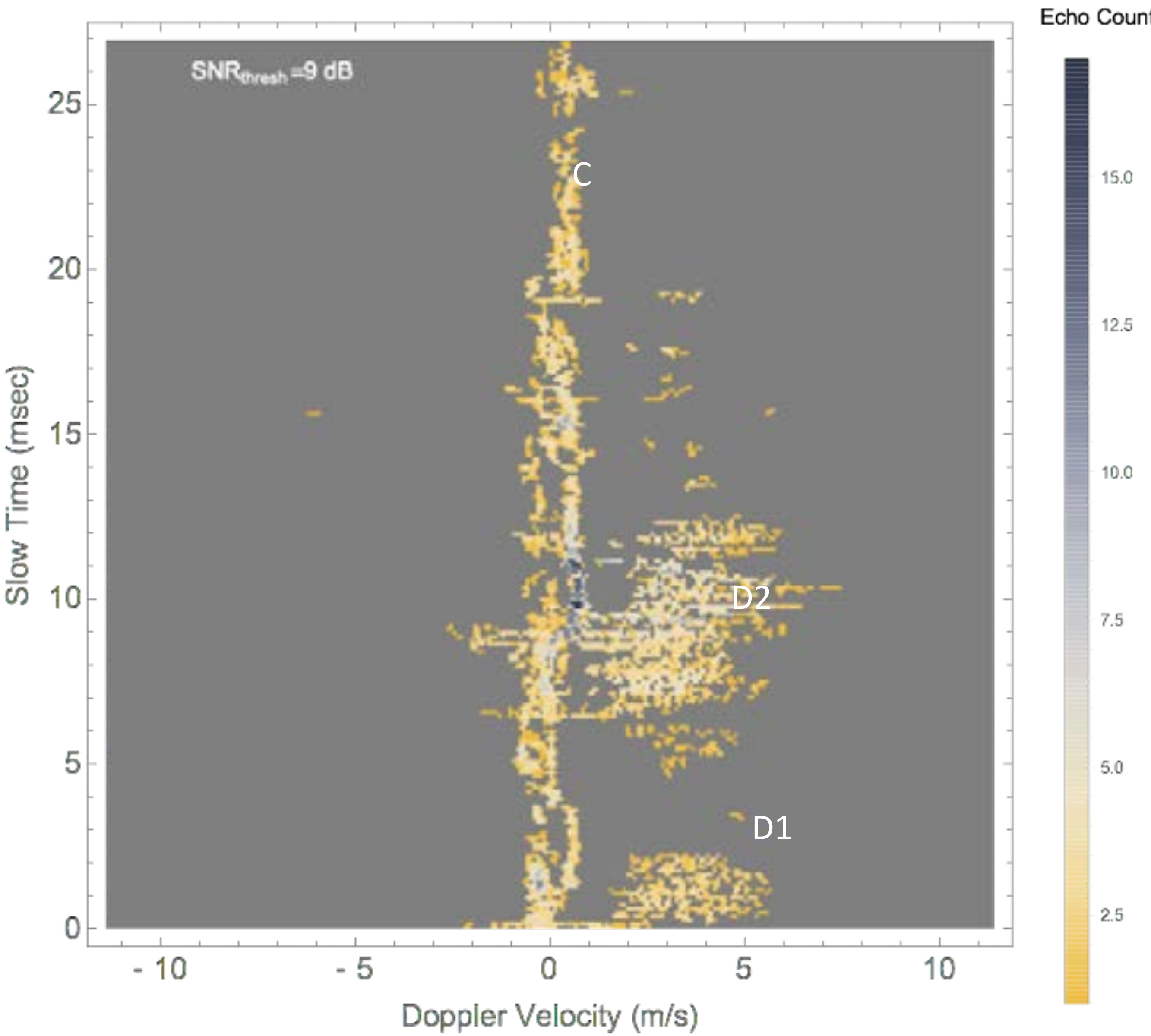
Discussion. The figure illustrates the spatial coverage provided by a single fixed, unmoving beam of the GWiPPR system against a drone with a -30 dB re m^2 RCS. The drone is assumed to approach the radar from an azimuth of 45 deg re north. The figure can also be interpreted as a drone approaching the radar along a vertical track with a grazing angle of 45 deg with respect to the horizontal. The radar system transmit power, system noise temperature, pulse length, bandwidth, stack size and antenna gain are respectively 4 W, 300 K, 190 µsec, 48 MHz, 256 and 31 dB. The coherent pulse length of the radar is $T_c = N_{stack} T_m = 0.0486$ sec where T_m is the length of a single radar pulse. Figure generated by "*Drone Detection Range.nb*".

Spatial coverage provided by GWiPPR at 80 deg azimuth



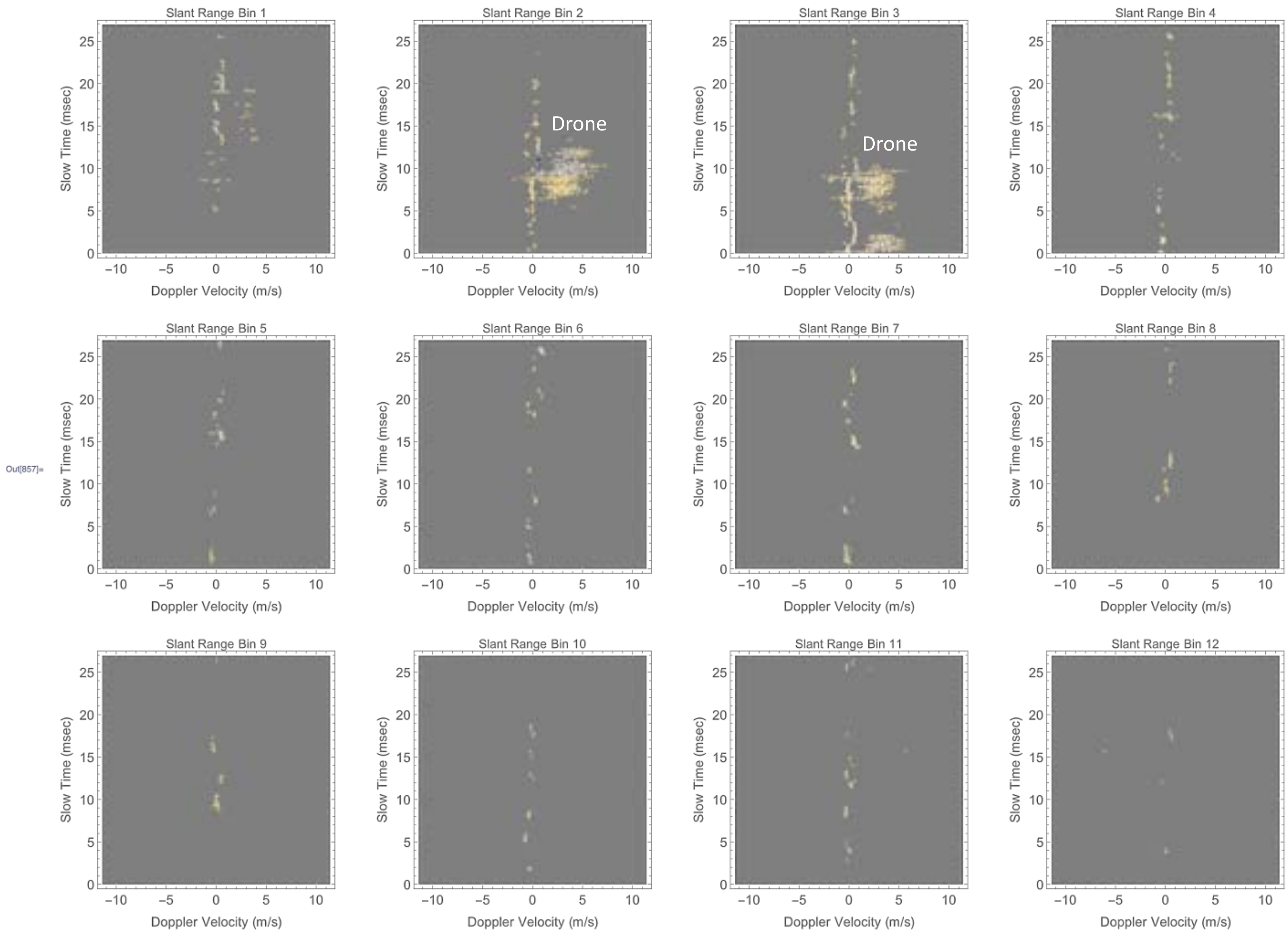
Discussion. The figure illustrates the spatial coverage provided by a single fixed, unmoving beam of the GWiPPR system against a drone with a -30 dB re m^2 RCS. The drone is assumed to approach the radar from an azimuth of 80 deg re north. The figure can also be interpreted as a drone approaching the radar along a vertical track with a grazing angle of 10 deg with respect to the horizontal. The radar system transmit power, system noise temperature, pulse length, bandwidth, stack size and antenna gain are respectively 4 W, 300 K, 190 µsec, 48 MHz, 256 and 31 dB. The coherent pulse length of the radar is $T_c = N_{stack} T_m = 0.0486$ sec where T_m is the length of a single radar pulse. Figure generated by "*Drone Detection Range.nb*".

Figure 1: Drone Measured by MilWiPPR 11 July 2016



Discussion. The figure to the left shows the signature of a Phantom drone as observed by the MilWiPPR radar system on 11 July 2016. The Doppler velocity signature of the drone is located near times D1 and D2. Zero Doppler clutter is indicated by the vertical bar of contacts labelled C. The figure has been produced by thresholding MilWiPPR range-velocity matrices at an SNR threshold of 9 dB, forming binary range-velocity matrices(called occupancy matrices) for altitude bins 11-128. The final stage in the processing is to sum across these 118 occupancy matrices. The result is an altitude marginal distribution of the MilWiPPR data cube. Notes: 1) Altitude bin 11 begins at slant range 11*3.125 m and is 3.125 m in range extent. 2) The figure was formed using files 2155-2389. During this time period the drone was descending. 3) The dark gray background color in the image indicates zero count, i.e. no detection. Figure produced by Mathematica notebook "*WiPPR Drone Images 11 July 2016.nb*".

Figure 2: Altitude partitioned radar data cube



Discussion. Similar to figure 1 but with the data cube partitioned into 12 slant range bins each of width 31.25 m. The first slant range bin begins at 32.5 m.