Detection of Biological Scatter Using Spaceborne Precipitation Radar: A Feasibility Study

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Motivation

Weather radar is increasingly being used to monitor the location and movements of airborne animals, including insects, bats, and birds (Chilson et al., 2012a). Although it is difficult (and in most cases impossible) to determine the individual species being observed, radar data do provide valuable biological information on the bulk behavioral patterns of many volant animals, which is otherwise unavailable to researchers. Unfortunately, even networked radars do not provide adequate spatial coverage to fully explore large-scale biological patterns, such as long-distance migration. Large extents of the atmosphere over the Earth's landmasses and the vast majority of its oceans go unobserved by radar. This presentation explores the potential of using spaceborne radar to study birds and bats. Observations from both the Precipitation Radar (PR) onboard the Tropical Rainfall Measuring Mission (TRMM) satellite CloudSat's Cloud Profiling Radar (CPR) were considered in this study; however, here we only present findings related to CloudSat.

CloudSat

CPR operates at 94 GHz, has a nadir footprint with a resolution of about 1.4 km, and a minimum detectability of about -28 dBZ. Taking sampling time (0.16 s) and the forward satellite velocity (7 km s^{-1}) into consideration, the observation footprint is about 1.4km x 1.8km. Non-quality controlled composite reflectivity data collected using the network or S-band weather radars in the US (NEXRAD) during periods of nocturnal migration can reach values up to 25-30 dBZ (see Figure 1). Therefore, it seems reasonable to assume that the migration signature could be detectable using CPR.

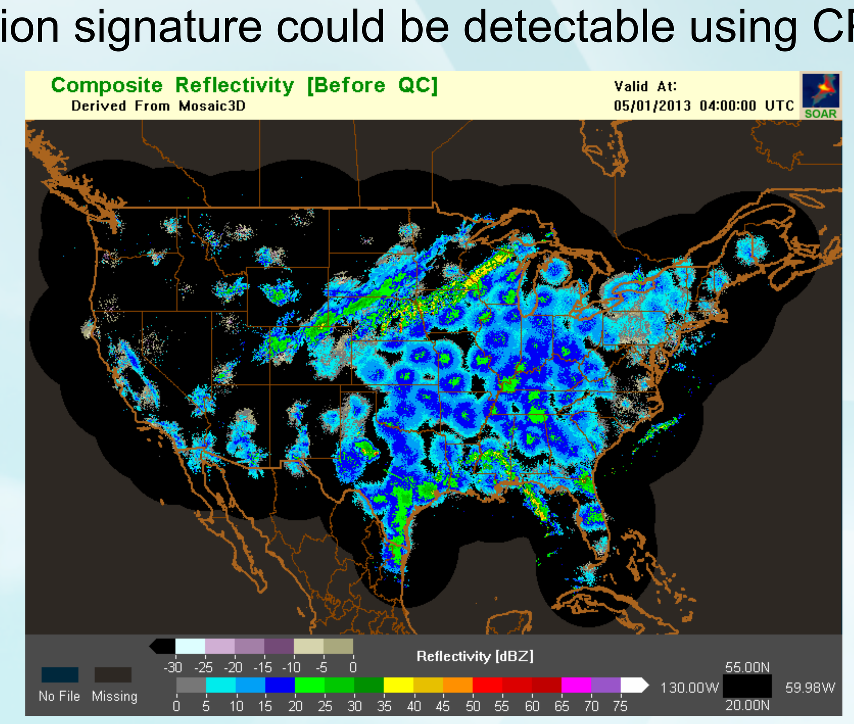

Figure 1: Example of weather patterns mixed with nocturnal migration of birds as seen by NEXRAD

Sample Observations

Since the strongest, wide-spread biological signal observed in NEXRAD data corresponds to nocturnal migration, we selected satellite tracks for CloudSat that positioned CPR over the continental US during the evening hours. One such track is shown in Figure 2.

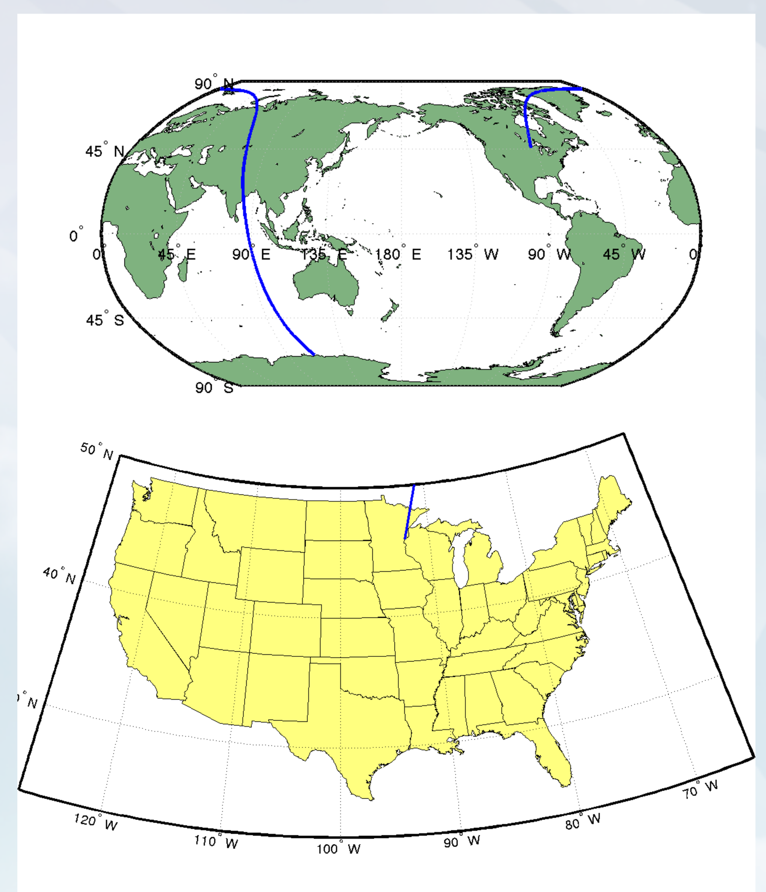

Figure 2: CloudSat track for 27 April, 2013. The track is shown as a blue line.

The corresponding equivalent radar reflectivity factor (Z_e) data collected by CPR for the portion of the track over the US is shown in Figure 3. The radar does not appear to be detecting any echoes that could be caused by migrating birds.

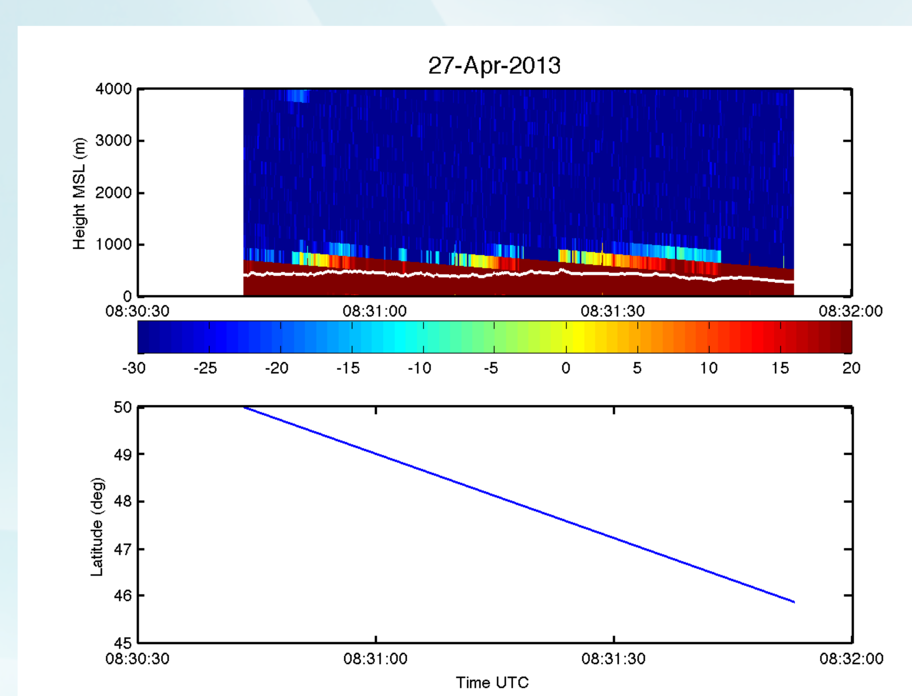

Figure 3: Upper panel – values of Z_e (dBZ) collected using CPR as a function of time and height. The echoes near the surface are from ground clutter. The white line shows the surface elevation. Lower panel - plot showing the latitude of CloudSat as a function of time.

Figure 4 shows radar data from NEXRAD for the time corresponding to the CPR observations depicted in Figure 3. Although not a wide-spread migration, there are clearly signs of biological echoes in the northern US in the area along the CloudSat track.

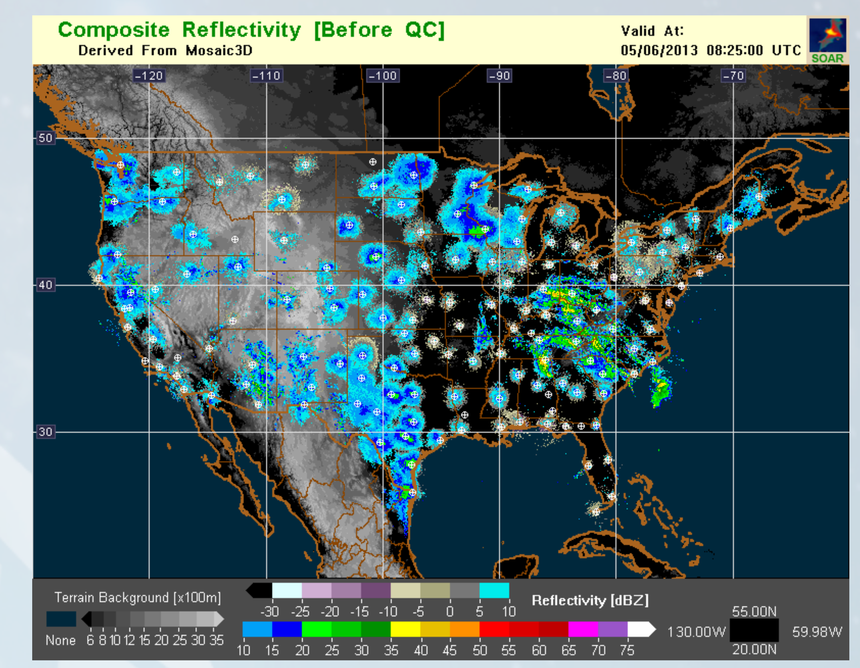

Figure 4: Non-quality controlled composite reflectivity data from NEXRAD.

Comparisons of Observations

Why are birds being detected by NEXRAD (S-band) but not with CPR (W-band)? One possible explanation could be that the birds are flying to low to be detected by CPR. However, nocturnally migrating birds can fly at heights of 2-4 km (see Figure 5) and should be above the clutter region of the satellite radar data

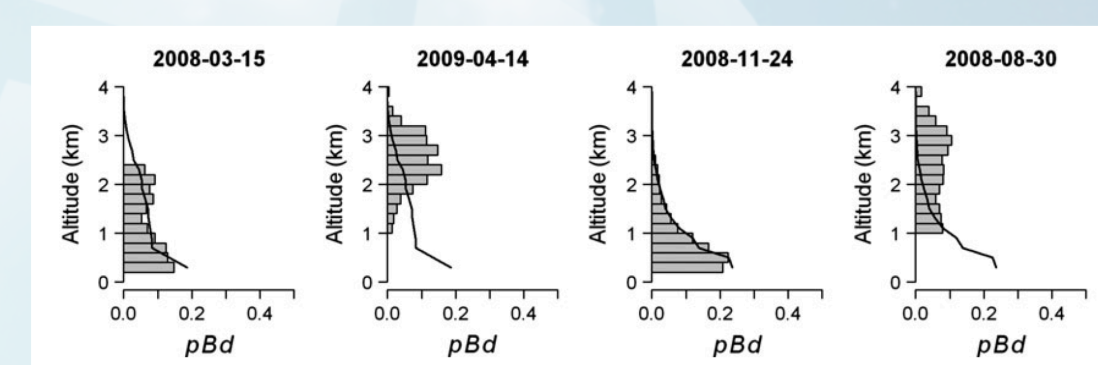

Figure 5: Height distributions of nocturnal migrants as reported by Kemp et al, 2013. Here, pbd = probability of bird detection.

This finding lead us to revisit the fundamentals of radio-wave backscatter at S- and W-bands. As discussed in Chilson et al. 2012b, when investigating biological scatter from radar, the radar reflectivity (η) is a more meaningful unit than the equivalent radar reflectivity factor (Z_e). Converting from Z_e to η is achieved through the equation:

$$\eta = Z_e + \beta,$$

where η is given as dBη (using 1 $cm^2\ km^{-3}$) as a reference, Z is given in dBZ, and

$$\beta = 10 \cdot \log_{10}(10^3\ \pi^5\ |K_m^2|\ \lambda^{-4}),$$

with $|K_m^2| = 0.93$ and λ given in cm.

In earlier studies, estimates of the number densities of migrating birds have been obtained by multiplying η (units of $cm^2\ km^{-3}$) by a representative radar cross section (RCS) expressed as σ_b for the birds (units of cm^2). Diehl et al.2003 found a value of 17.5 cm^2 for σ_b for S-band data. Here we adopt an approach of simply approximating a bird as a mass equivalent sphere of water with a temperature of 35°C and then using Mie scattering theory to find σ_b. See results in Figure 6.

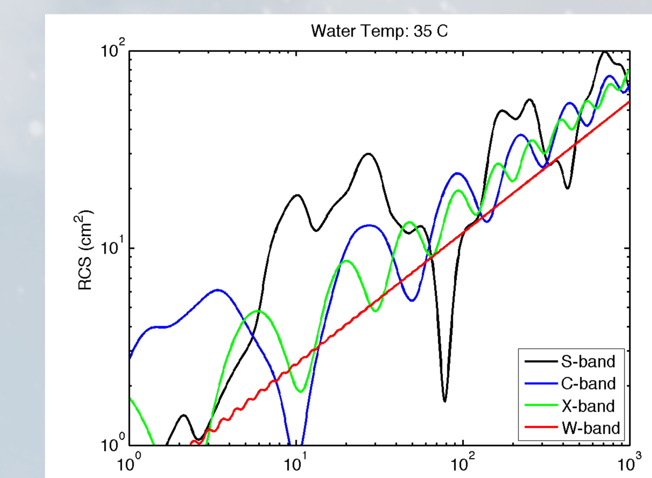

Figure 6: RCS values versus equivalent mass of water spheres at different frequency bands calculated using Mie theory.

For a bird having a mass of 15 g, the corresponding RCS values at S- and W- band are 14 and 3.3 cm^2, respectively. Using these values, we have calculated what the equivalent values of Z_e at W-band would be for a specified range of Z_e values at S-band. The results are shown in Figure 7.

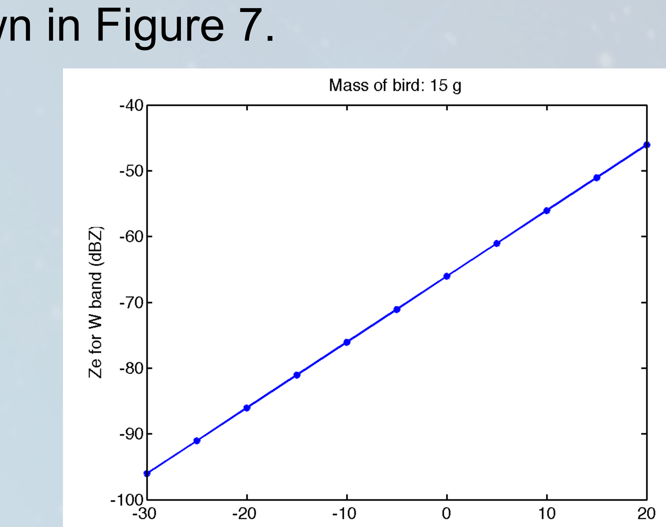

Figure 7: Equivalent values of Ze at W-band for given values at S-band for a collection of birds having individual masses of 15 g.

Conclusion

The CloudSat CPR does not seem to have adequate sensitivity to detect echoes from nocturnal migrants. Although not discussed here, the TRMM PR also does not have sufficient sensitivity.

References:

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Diehl et al, 2003: Radar observations of bird migration over the Great Lakes, *Auk*

Kemp et al., 2013: The influence of weather on the flight altitude of nocturnal migrants in mid-latitudes, *IBIS*

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