In this study we explore ways to more accurately geolocate backscatter: 

1. We show how using elevation angle of arrival measurements improves geolocation 

2. We verify the accuracy of our elevation angles, by measuring a known source of backscatter above the HAARP facility in Gakona, AK 

3. We propose a hybrid geolocation technique (standard model + mode) for cases where elevation angles are not reliable or nonexistent 

4. We compare four different geolocation techniques using HAARP-induced backscatter: standard model, Chisham model, elevation angle method, and standard model + mode

In the middle row, we can see that three of the techniques (CHM, EAM, HYB) place the 1½-hop backscatter to nearly within a 45 km range gate. However, HYB incorrectly maps this backscatter, having an error of 262 km. Chisham et al., recognized the limitation of the standard model in this case, and developed his empirical model to correct for this offset. Our data here agrees with Chisham’s results, showing that his model correctly maps 1½-hop backscatter. As a consequence of Chisham’s ½-hop assumption, however, the virtual heights for CHM are artificially high (right column).

Finally, the top row shows that EAM and HYB both correctly place the 2½-hop backscatter to within a 45 km range gate, while CHM and STI have large offsets of 245 km and 503 km, respectively. Again, the artificially high virtual heights for CHM can be seen to the right. The occurrence of natural 2½-hop backscatter will be the subject of another study.

While correctly geolocating the backscatter is important, doing so with reasonable virtual heights is also highly desirable. The measured virtual heights provides a measure of the refractive index along the signal’s path. This information can be used for velocity corrections, since the speed of our transmitted signal varies according to refractive index. It is clear that the EAM technique provides the best combination of ground range accuracy and virtual height information.

**Summary**

- We have verified the accuracy of our elevation angle of arrival measurements at cw, using HAARP-induced backscatter
- Having compared four different methods of geolocation using HAARP-induced backscatter, the EAM technique most significantly improves geolocation, especially for multi-hop paths, while also providing accurate virtual height information.
- Our standard model + propagation mode (HYB technique) also provides significant geolocation improvement, for cases where elevation angles are not available