HF Beacons and Ionospheric Specification – Sensitivity Analysis and Automatic Differentiation

D. L. Hysell[(1)]
(1) Earth and Atmospheric Sciences, Cornell University, Ithaca, NY, USA; e-mail: david.hysell@cornell.edu

HF beacon networks have been deployed in Peru and in Alaska for regional ionospheric electron density specification. The beacons are dual frequency and employ pseudorandom noise coding (PRN). The observables derived from the received signals include pseudorange, Doppler shift, and amplitude. Electron densities are specified parametrically across the region where the beacons are deployed. The forward model connecting the observables to the electron densities involves ray tracing. The data are inverted, and the regional electron densities estimated, through the use of a regularized gradient descent method. Data from GNSS, incoherent scatter radars, and/or sounders can be seamlessly incorporated in the inversion. The experimental cadence is typically once per minute.

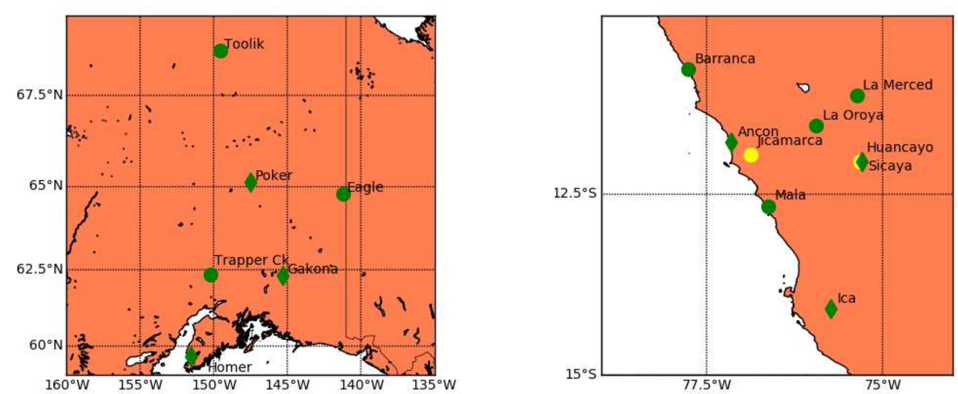

Figure 1. HF beacon networks deployed in Alaska (left) and Peru (right). Diamonds are transmitters, and circles are receivers. The beacons operate at two HF frequencies and employ PRN coding.

Sensitivity analysis occurs twice in the estimation method: once to impose the raytracing terminal condition, and once to guide the overall gradient descent. Sensitivity analysis is also required to interpret the signal amplitudes since it describes focusing and defocusing. Traditionally, sensitivity analysis has been done using one of three methods: brute-force finite differences, variational analysis, and adjoint analysis. Whereas the first option suffers from poor accuracy, the second and third options require the computation of Hessian matrices which is also undesirable.

In this presentation, an alternative method involving automatic differentiation (AD) is discussed. Automatic differentiation decomposes expressions into elementary steps and then combines the steps known derivatives through the chain rule. The computational cost of the method is algebraically related to that of the original problem, and the coding difficulty is minimal. Libraries for AD underlie much of machine learning and so already exist. Applications of AD to the raytracing problem and the overall HF estimation problem will be discussed.