amisrsynthdata: A Python package for generating synthetic data for the Advanced Modular Incoherent Scatter Radars

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Software

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Summary

Advanced Modular Incoherent Scatter Radars (AMISR) are a class of ground-based radars that are used to study plasma dynamics in the ionosphere (Kelly & Heinselman, 2009). Ionospheric plasma is highly structured and varies on a wide range of scales, both spatially and temporally. There are large and often abrupt variations in the plasma state parameters depending on geomagnetic conditions and local or global events. AMISR remotely measures the electron density, N_e, ion temperature, T_i, electron temperature, T_e, and line-of-sight component of the drift velocity, V_{los}, of the plasma in the ionosphere. These ionospheric state parameters are measured in profiles over different look directions over time.

AMISR utilizes phased-array technology to steer the radar beam electronically, which allows it to change look directions rapidly with a sub-second timescale. This allows the radar to both effectively collect data from different look directions nearly simultaneously and have a great degree of flexibility in terms of beam positions and observational mode designs. Most standard modes use between 4 and 50 beams, roughly evenly spread across the radar field-of-view. Some specialized modes use tight clusters of beams, or other unusual configurations to observe specific phenomena. This flexibility, as well as the radars' locations in regions that are key for magnetosphere-ionosphere coupling, make them a heavily utilized and invaluable resource for space physics research.

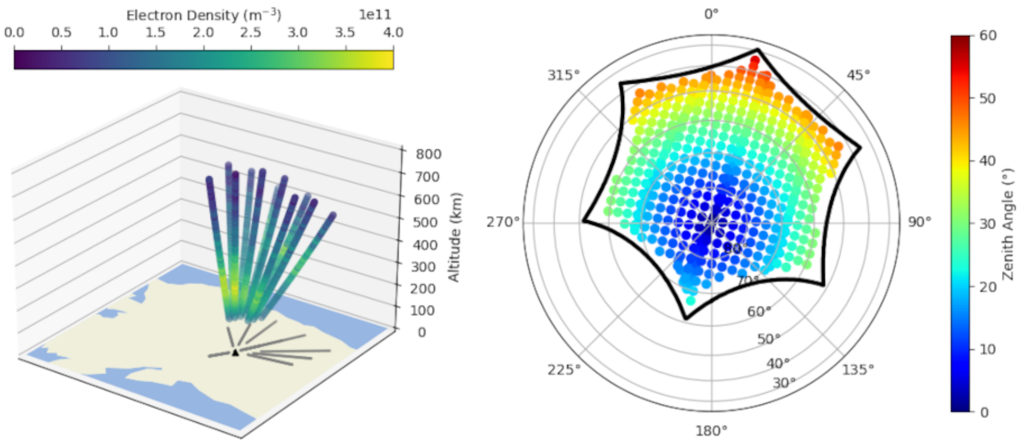

Figure 1: Left: A 3D visualization of beam positions with synthetic density measurements from a commonly run 11 beam AMISR mode. Right: All possible beam positions within the AMISR field-of-view.

The `amisrsynthdata` package produces synthetic data for AMISR. It is written purely in

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Python, with use of common numeric, array manipulation, and plotting libraries (Collette et al., 2023; Harris et al., 2020; Hirsch, 2018; Hunter, 2007; Met Office, 2010 - 2015). Users create a configuration file containing information both about the radar observational mode and the ionospheric states, which the package then uses to create a synthetic data file showing what the data would be expected to look like if the radar were to measure the specified ionospheric phenomena in the given mode.

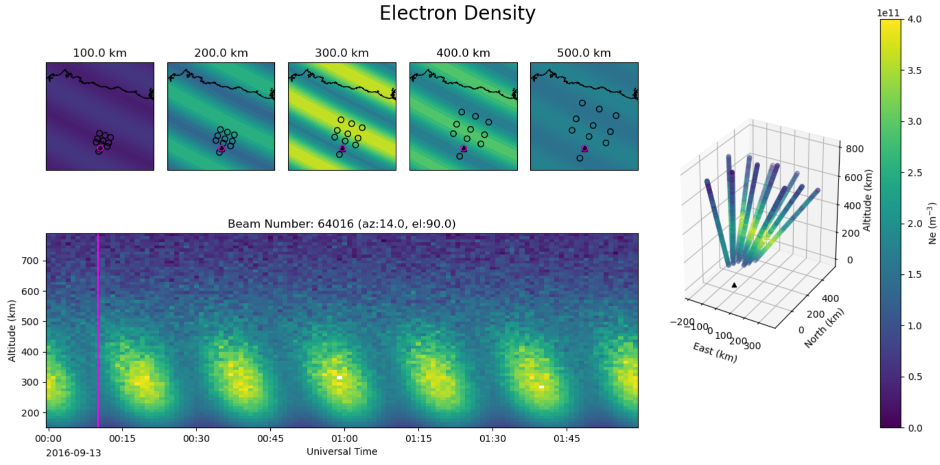

Figure 2: Example of summary figure output of `amisrsynthdata`. This shows electron density for a traveling ionospheric disturbance or large-scale wave propagating in the ionospheric F-region. The top row of panels show the "truth" density at different altitude slices as well as the beam locations in each. The bottom panel shows a "range-time-intensity" plot of synthetic measured electron density over time in a specific beam. The right panel shows a 3D view of synthetic measurements in all beams at a particular time. The beam used in the bottom panel is indicated in pink in the top panels and the time used in the top and right panels is indicated by the pink line in the bottom panel.

The package provides a variety of options for specifying the background ionosphere, from extremely simple uniform parameter fields to more complex combinations, including sampling the output of numerical models. The source code was also designed so it is relatively simple to add new ionospheric state functions as needed.

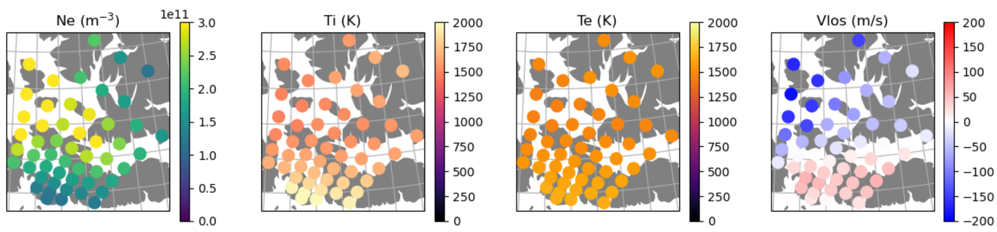

Figure 3: Horizontal slices of synthetic AMISR data in all four standard incoherent scatter radar parameters. The ionosphere used in this case comes from output of the GEMINI numerical model of local ionospheric dynamics (Zettergren & Snively, 2015)

Statement of Need

The `amisrsynthdata` package is useful for several items related to ensuring efficient and effective use of the AMISR radars and accurate subsequent data analysis.

1. **Validation of higher-level data products:** AMISR data are often used in sophisticated inversion and interpolation procedures to generate high level data products. These include things such as generating vector velocities from the line-of-sight measurements (Heinselman & Nicolls, 2008; Nicolls et al., 2014), 3D volumetric interpolations (Lamarche et al., 2020), and inversion of the precipitating energetic particle spectra (Semeter & Kamalabadi, 2005). When developing these algorithms, it is important to have "truth" data to validate against. Because there are rarely datasets available that directly measure these higher-level parameters, using synthetic data where the ionospheric state is known unambiguously independent of sampling or instrument effects can be convenient.
2. **Designing and optimizing observational modes:** The `amisrsynthdata` package lets users experiment with different beam positions and modes, which allows you to determine the optimal configuration for observing particular structures or phenomena. This is particularly useful when coordinating with rare events such as rocket or satellite observational conjunctions with the radar and there will not be the opportunity to iterate over the mode through normal observations.
3. **Determining if a particular phenomena is observable:** Sometime it is unclear if an ionospheric structure can be seen in the radar data, or what it is expected to look like. This is relevant to determine if a radar mode under-resolves a structure, which can lead to aliasing and bias interpretation if not accounted for. This is also useful if you are looking for a particular kind of event in the collected database, but need to understand the expected signatures of it in the radar data.

Although there are only a small number of people who routinely design and optimize radar operation modes, this work is done in service to the broader ionospheric science research community. Furthermore, the user community routinely experiments with new ways to utilize the radar data and extract more information from it. AMISR is a widely utilized facility that continues to contribute significantly to space physics research (National Research Council, 2013).

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