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Data Products from the Deployable Low-band Ionosphere and Transient Experiment (DLITE)

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Introduction

The Deployable Low-band Ionosphere and Transient Experiment (DLITE) is an NRL-developed telescope array optimized for remote sensing of density irregularities within Earth's ionosphere (~100-1,000 km altitude). A DLITE system consists of four inverted vee dipole antennas that were developed and patented by NRL Code 7210 for the Long Wavelength Array (LWA) project (https://lwa.unm.edu). These four antennas are used as an interferometer with a digital processing backend comprised of software defined radios (SDRs) and a control computer. Separating the antennas from one another by 200-500 meters and using a relatively large bandwidth (~8-10 MHz) enables time difference of arrival (TDOA) and frequency difference of arrival (FDOA) methods for resolving 2-4 extremely bright cosmic radio sources that are visible on the sky at any given time. By operating in a 35-40 MHz band where the impact of the ionosphere is relatively large, the array can be used to measure fluctuations in the cosmic radio sources' sky positions and intensities due to ionospheric irregularities on scales of ~1 km or more. These measurements can then be used to characterize the irregularities. Helmboldt et al. (2021) provide a detailed description of the system and analysis methods along with examples using two prototype arrays located at NRL-Pomonkey (DLITE-POM) and in central/western New Mexico (DLITE-NM).

Data Products

DLITE analysis can be separated into two categories: gradiometry and scintillometry. The gradiometry mode uses a specialized algorithm to measure the apparent position shifts of bright cosmic radio sources and to convert these to gradients in the total electron content (TEC), or the line-of-sight integrated electron density. For each 24-hour data collection, these gradients are recorded in comma separated variable (CSV) text files, with a separate file for each cosmic source. In practice, only the three brightest sources in the sky, Cassiopeia A, Cygnus A, and Virgo A (or, Cas A, Cyg A, and Vir A) reliably generate high-precision TEC gradient measurements.

Within each CSV file, the gradients are recorded as differential TEC measurements between a reference antenna (defined as antenna 1) and the other three antennas. Each CSV file follows the naming convention DLITE-AAA-yyyy-mm-ddTHHMMSS_nnnn.csv, where AAA is the array name, yyyy-mm-dd is the date, HHMMSS is the start time of the data collection, and nnnn is the source name (CasA, CygA, or VirA). Within each file, there is a header with the geographic coordinates of the antennas listed. This is followed by the data time series with each row having the following comma-separated columns:

1. Date/time in the yyyy-dd-mmTHH:MM:SS format (universal time).
2. Elevation angle of the source above the horizon (degrees).

3. Azimuth angle of the source, clockwise from north (degrees).
4. The difference in TEC between antennas 1 and 2 (TECU; 1 TECU = 10^{16} m^{-2}).
5. The difference in TEC between antennas 1 and 3 (TECU).
6. The difference in TEC between antennas 1 and 4 (TECU).
7. The 1-sigma uncertainty for column 4 (TECU).
8. The 1-sigma uncertainty for column 5 (TECU).
9. The 1-sigma uncertainty for column 6 (TECU).
10. The covariance for quantities in columns 4 and 5 ($TECU^2$).
11. The covariance for quantities in columns 4 and 6 ($TECU^2$).
12. The covariance for quantities in columns 5 and 6 ($TECU^2$).

CSV gradiometry files are located at https://lda10g.alliance.unm.edu/~dlite/csvdata/.

The scintillometry mode uses TDOA/FDOA images generated with ~1 hour of data from each unique pair of antennas, or "baseline," to measure the impact of km-scale irregularities on the intensity of the cosmic radio sources. Within these images, scintillations due to these irregularities produce artifacts along the FDOA direction, which can be used to measure the commonly used irregularity strength parameter, C_kL (see, e.g., Rino 1979). Due to the weighting scheme used, the temporal resolution of these images is ~30 minutes, and they are typically spaced ~20 minutes apart within a 24-hour collection to ensure adequate temporal sampling of irregularity behavior.

These images for the longest baseline in the array and the source/scintillation properties derived from them for each 24-hour collection are stored in a Flexible Image Transport System (FITS) binary file. These files have the naming convention DLITE-AAA-yyyy-mm-ddTHHMMSS.fits. Each file has two Header/Data Units (HDUs), each of which consists of an ASCII header and a binary data block. The first/primary HDU contains the images as an N_t x N_p x N_{FDOA} x N_{TDOA} four-dimensional array, where N_t is the number of time steps (typically = 69), N_p is the number of polarizations (=2), and N_{FDOA} and N_{TDOA} are the number of FDOA and TDOA pixels, respectively (usually = 59 and 64, respectively). The header contains the standard FITS keywords CTYPE, CRPIX, CDELT, and CRVAL for each of these four axes that together specify the full 4-D grid. Additional header keywords are:

- YEAR: Year of the data collection.
- DOY: Day of the year for the data collection.
- SOURECES: A string list of the sources whose properties were measured.
- ALAT1: Latitude of the first antenna of the longest baseline.
- ALON1: Longitude of the first antenna of the longest baseline.
- ALAT2: Latitude of the second antenna of the longest baseline.
- ALON2: Longitude of the second antenna of the longest baseline.
- ALT: Altitude (above sea level) of the array (meters).
- BUNIT: Intensity units for the image ($\log_{10}$ Jy; 1 Jy = 10^{-26} W m^{-2} Hz^{-1}).
- DMAX: Maximum possible TDOA (seconds).
- FMAX : Maximum possible FDOA (Hz).

The Second HDU is a FITS binary table with the following columns:

- tstamp: UNIX time stamp (seconds since January 1, 1970).
- ut: Universal time (hours).
- lst: Local sidereal time (hours).
- el_ateam: Elevation of bright “A-Team” sources as a six-element array per row (degrees).
- az_ateam: Azimuth (clockwise from north) of bright “A-Team” sources as a six-element array per row (degrees).
- x_ateam: TDOA pixel number within the corresponding TDOA/FDOA image for each A-Team source as a six-element array per row.
- y_ateam: FDOA pixel number within the corresponding TDOA/FDOA image for each A-Team source as a six-element array per row.
- el_sun: Elevation of the Sun (degrees).
- az_sun: Azimuth (clockwise from north) of the Sun (degrees).
- x_sun: TDOA pixel number within the corresponding TDOA/FDOA image for the Sun.
- y_sun: FDOA pixel number within the corresponding TDOA/FDOA image for the Sun.
- flux_ateam_x: Intensity of each A-Team source from the X (north/south) linear polarization feed as a six-element array per row (Jy).
- flux_ateam_y: Intensity of each A-Team source from the Y (east/west) linear polarization feed as a six-element array per row (Jy).
- sigma_ateam_x: 1-sigma intensity variation of each A-Team source from the X-polarization feed as a six-element array per row (Jy).
- sigma_ateam_y: 1-sigma intensity variation of each A-Team source from the Y-polarization feed as a six-element array per row (Jy).
- plat_ateam: The latitude of the location where the line of sight intersects the ionosphere at an altitude of 300 km for each A-Team source as a six-element array per row.
- plon_ateam: The longitude of the location where the line of sight intersects the ionosphere at an altitude of 300 km for each A-Team source as a six-element array per row.
- nsys_x: System noise for an integration time of one minute from the X-polarization feed (Jy).
- nsys_y: System noise for an integration time of one minute from the Y-polarization feed (Jy).
- ckl_x: C_kL irregularity strength parameter from the X-polarization feed (MKS units).
- ckl_y: C_kL irregularity strength parameter from the Y-polarization feed (MKS units).
- ckl_ateam_x: C_kL irregularity strength parameter per A-Team source from the X-polarization feed as a six-element array per row (MKS units).
- ckl_ateam_y: C_kL irregularity strength parameter per A-Team source from the Y-polarization feed as a six-element array per row (MKS units).

Both HDUs are readable by standard packages/modules/libraries available for use with many programing languages/analysis packages including FORTRAN, C, C++, Python, MATLAB, and

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IDL. FITS scintillometry files are located at https://lda10g.alliance.unm.edu/~dlite/fitsdata/.

Measurements extracted from TDOA/FDOA images using all baselines and all available data collections for a particular array are made available within a single FITS file named DLITE-AAA_yyyy-mm-dd_yy-mm-dd.fits, where the two dates are the first and last dates within the dataset. This FITS file has an empty primary HDU with a header that has the keywords LAT, LON, and ALT that give the latitude, longitude, and altitude above sea level of the array, respectively. The measurements and other relevant data are stored in a second HDU as a binary table with the following columns:

- tstamp: UNIX time stamp (seconds).
- year: Year of the measurement.
- doy: Day of the year.
- ut: Universal time (hours).
- lst: Local sidereal time (hours).
- el_ateam: Elevation of bright "A-Team" sources as a six-element array per row (degrees).
- az_ateam: Azimuth (clockwise from north) of bright "A-Team" sources as a six-element array per row (degrees).
- flux_ateam_x: Intensity of each A-Team source from the X (north/south) linear polarization feed as a six-element array per row (Jy).
- flux_ateam_y: Intensity of each A-Team source from the Y (east/west) linear polarization feed as a six-element array per row (Jy).
- sigma_ateam_x: 1-sigma intensity variation of each A-Team source from the X-polarization feed as a six-element array per row (Jy).
- sigma_ateam_y: 1-sigma intensity variation of each A-Team source from the Y-polarization feed as a six-element array per row (Jy).
- plat_ateam: The latitude of the location where the line of sight intersects the ionosphere at an altitude of 300 km for each A-Team source as a six-element array per row.
- plon_ateam: The longitude of the location where the line of sight intersects the ionosphere at an altitude of 300 km for each A-Team source as a six-element array per row.
- el_sun: Elevation of the Sun (degrees).
- az_sun: Azimuth (clockwise from north) of the Sun (degrees).
- flux_sun_x: Intensity of the Sun from the X-polarization feed (Jy).
- flux_sun_y: Intensity of the Sun from the Y-polarization feed (Jy).
- sigma_sun_x: 1-sigma intensity variation of the Sun from the X-polarization feed (Jy).
- sigma_sun_y: 1-sigma intensity variation of the Sun from the Y-polarization feed (Jy).
- nsys_x: System noise for an integration time of one minute from the X-polarization feed (Jy).
- nsys_y: System noise for an integration time of one minute from the Y-polarization feed (Jy).

- ckl_x: $C_k L$ irregularity strength parameter from the X-polarization feed (MKS units).
- ckl_y: $C_k L$ irregularity strength parameter from the Y-polarization feed (MKS units).
- ckl_ateam_x: $C_k L$ irregularity strength parameter per A-Team source from the X-polarization feed as a six-element array per row (MKS units).
- ckl_ateam_y: $C_k L$ irregularity strength parameter per A-Team source from the Y-polarization feed as a six-element array per row (MKS units).

FITS scintillometry measurement files are located at https://lda10g.alliance.unm.edu/~dlite/.

Data Access

As DLITE was developed to facilitate basic research in ionospheric structure and dynamics and, to a lesser degree, astrophysics, the data are being submitted for approval for unlimited release (Distribution A). To make the data available to the scientific community while protecting its integrity, the data will be submitted to the Defense Technical Information Center (DTIC; https://discover.dtic.mil) upon approval of a Distribution A release by NRL.

References

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