

Improving Weather Radar Data Processing for Biological Research Applications: Final Report

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Jeffrey J. Buler^{1*}, Valliappa Lakshmanan², and David La Puma¹



¹ Department of Entomology and Wildlife Ecology, University of Delaware, Newark, DE 19716



² Cooperative Institute of Mesoscale Meteorological Studies, University of Oklahoma, Norman OK 73069; valliappa.lakshmanan@noaa.gov

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* jbuler@udel.edu

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EXECUTIVE SUMMARY

The current national network of more than 160 weather surveillance radars (WSR-88D) routinely detects a variety of biological targets (e.g., birds, bats, and insects) across the United States and offers exciting opportunities for investigating the ecology of aerofauna at broad spatial and temporal scales. Despite the vast potential, current radar products and tools have limited the application of radar for advancing biological research due, in part, to a lack of collaboration among radar scientists, atmospheric scientists, and ecologists. In particular, the technical and logistical challenges of screening and processing WSR-88D data have limited the ability of ecologists to use radar for biological research.

Recently, ecologists and atmospheric scientists at the University of Delaware (UD) developed radar data processing methods and software to facilitate the mapping of bird distributions. Additionally, the National Oceanic and Atmospheric Administration's National Severe Storms Laboratory and the Cooperative Institute for Mesoscale Meteorological Studies at the University of Oklahoma (OU) jointly developed the Warning Decision Support System -- Integrated Information (WDSS-II), a suite of algorithms and software tools for the analysis, diagnosis, and visualization of WSR-88D data. The purpose of this project is to integrate these two existing software systems and develop new and improved software (**w2birddensity**) to automate the detection and quantification of biological targets from WSR-88D data.

The **w2birddensity** tool is now part of the WDSS-II software package. It is currently freely available for download at <http://www.wdssii.org/>. The software processes radar data to correct reflectivity measures for several sources of measurement bias with the purpose of mapping relative densities of biological targets (e.g., birds) at the onset of synchronized flights (e.g., evening migratory flight). This software will facilitate the ability of biologists to conduct cost-effective comprehensive monitoring of the spatial and temporal distribution and movements of aerofauna across the United States, simplify the analysis of radar data in general, and enable the use of radar by a wider group of non-technical users.

INTRODUCTION

The current national network of more than 160 weather surveillance radars (WSR-88D) routinely detects a variety of biological targets (e.g., birds, bats, and insects) across the United States and offers exciting opportunities for investigating the ecology of aerofauna at broad spatial and temporal scales (Diehl and Larkin 2005, Gauthreaux et al. 2008, Kunz et al. 2008). WSR data are collected continuously, and the data archive that dates back to the mid-1990's is freely accessible via the National Climatic Data Center (NCDC). WSR-88D data have been used to map the spatial and temporal pattern of bird densities “on the ground” by sampling birds as they leave their terrestrial habitats when they initiate large-scale movements *en masse* synchronized with the position of the sun (Bonter et al. 2009, Buler and Diehl 2009, Buler and Moore 2011, Buler and Dawson 2012, Buler et al. 2012). The density of birds in the airspace is linearly related to radar reflectivity (Gauthreaux and Belser 1998, Black and Donaldson 1999, Diehl et al. 2003), a measure of total reflected energy from targets distributed within the sampled volume of air space. Thus, WSR-88D data are particularly useful for analysis of habitat use patterns of birds, and for elucidating bird movements during migration.

Despite the vast potential, current radar products and tools have limited the application of radar for advancing biological research due, in part, to a lack of collaboration among radar scientists, atmospheric scientists, and ecologists. There is an absence of radar product outputs focused on aerofauna. In fact, biological data are routinely filtered out by radar and atmospheric scientists (e.g., Lakshmanan et al. 2007a, 2010). Furthermore, the technical and logistical challenges of screening and processing WSR data have limited the ability of ecologists to use WSR for biological research.

Recently, ecologists and atmospheric scientists at the University of Delaware (UD) have developed radar data processing methods and software (Bias Improvement of Radar Data System, a.k.a. BIRDS) to facilitate the mapping of bird distributions (Buler et al. 2012). BIRDS interpolates radar data to specific times in reference to the position of the sun and reduces biases in radar measures caused by the vertical distribution of biological targets in the airspace and radar beam geometry as described in Buler and Diehl (2009). More specifically, the software is a system of Java scripts, Python scripts, and Fortran 95 code

operating in a UNIX environment and optimized for relatively fast processing time. Provided uncompressed raw radar data from the NCDC archive, BIRDS converts batched data (i.e., samples from multiple days) from a single radar station to ASCII data, performs an interpolation (temporally and spatially) to a given sun angle, derives a vertical profile of reflectivity (VPR), adjusts reflectivity measures using the VPR and modeled beam height limits, and provides summary statistics for every radar sample volume. The end result is that BIRDS provides processed radar reflectivity measures from archived data that are comparable throughout the radar sampling area, allowing for comprehensive quantitative mapping of bird distributions over large regions. BIRDS can also provide measures of bird density in the airspace as a function of altitude, allowing for monitoring of altitudinal profiles of bird density over time during migration.

The Warning Decision Support System -- Integrated Information (WDSS-II) is a suite of algorithms and software tools for the analysis, diagnosis, and visualization of WSR developed jointly by NOAA's National Severe Storms Laboratory and the Cooperative Institute for Mesoscale Meteorological Studies at the University of Oklahoma (OU) (Lakshmanan et al. 2007b). Included in the suite of WDSS-II algorithms is an automated quality control algorithm that identifies non-meteorological radar returns (e.g., "bloom" of migrating birds) and anomalous radar beam propagation that can be adapted to automatically identify radar data suitable for biological analyses. This would significantly reduce the time needed to visually screen radar data for biological applications.

The purpose of this project is to integrate these existing software systems of UD and OU and develop new and improved software to automate the detection and quantification of biological targets from WSR data. The production of software to process and analyze weather surveillance radar data for biological applications will facilitate cost-effective comprehensive monitoring of the spatial distribution and movements of aerofauna across the United States, simplify the analysis of radar data in general, and enable the use of radar by a wider group of non-technical users (e.g., ecologists, land managers, wind energy developers). Ensuing radar research using this software could provide fundamental insight into the movement patterns and habitat associations of migratory birds and other wildlife. Additionally, land

managers and industry may use the knowledge and tools developed to optimize the siting of migratory bird habitat and energy projects.

Incorporating the fully automated algorithms into the WDSS-II infrastructure could yield real-time mapping and monitoring of bird migration from the network of weather radars, useful for biological research. Furthermore, the software analysis tools and data products are freely available online for biological research and education. The public dissemination of these radar tools and products will promote new studies from the greater research community and interest from citizen science activities.

OBJECTIVES

Our objective was to develop new and improved weather surveillance radar data processing algorithms and a software tool to help automate data screening, identify biological targets, and quantify target densities. This work is important to enable the use of WSR data by a wider group of non-technical users, reduce considerably the time to process radar data, and refine the resulting products.

W2BIRDDENSITY – SOFTWARE DESCRIPTION

The **w2birddensity** tool is part of the Warning Decision Support System — Integrated Information (WDSS-II) software package. It is currently freely available for download at <http://www.wdssii.org/>. The software processes radar data to correct reflectivity measures for several sources of measurement bias with the purpose of mapping relative densities of biological targets (e.g., birds) at the onset of synchronized flights (e.g., evening migratory flight). It runs on a UNIX platform.

We developed **w2birddensity** with the following features:

1. Analyzes all data formats (e.g., Legacy, Super Resolution) of unfiltered WSR-88D Level II and Terminal Doppler Weather Radar (TDWR) data.
2. Identifies the presence of meteorological radar returns within 100 km range from the radar.
3. Identifies the presence of ground clutter.
4. Preserves the following algorithms from UD's BIRDS software code that are described in more detail in Buler and Diehl (2009) and Buler et al. (2012):

- a) Creates an interpolated radar volume scan to a user-specified sun elevation angle. The default sun elevation angle is 95.5° , which corresponds to approximately five minutes before civil twilight. Note that a given sun angle occurs twice a day (e.g., the sun is at an angle of 96° at both morning and evening civil twilight). The algorithm does not distinguish between the two time points and will produce interpolated data for either or both occurrences based on the volume scans provided.
 - b) Derives high-resolution (10-m interval) vertical profiles of reflectivity (VPR) from volume scan data in close proximity to the radar.
 - c) Ingests radiosonde data to determine the vertical refractive-index gradient of the atmosphere.
 - d) Models radar beam propagation using standard or observed refractive index.
 - e) Adjusts reflectivity measures for individual sample volumes by accounting for the VPR and radar beam limits of the sampling volume.
 - f) Avoids processing of areas over water.
5. Employs model analysis fields to compute refractivity at radar locations or times without radiosonde data.
 6. Computes VPRs routinely, i.e., at times other than sunrise/sunset.
 7. Produces a product that represents the effective bird density at the surface. This product is produced by applying the VPR to correct the radar reflectivity for height effects.
 8. Allows most parameters of the bird-density algorithm (thresholds for the presence of meteorological echo, sun angle, effective beamwidth, beam profile, etc.) to be set by the user, making the software more flexible.
 9. Outputs processed data products in NetCDF and/or ascii data formats.

Instructions for using the software are included in Appendix A and B of this report.

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Appendix A. Quick reference usage information for **w2birddensity** tool of WDSS-II software.

Usage: **w2birddensity** [i:I:S:o:l:rs:E:H:UV:OC:Zab:]

Command-line options:

-i InputIndexes (required) Please see Appendix B for an explanation of how to create this index file.

Provide the full path to the index file here.

-I Reflectivity (default=Reflectivity). You will not change this.

-S SoundingTable (default=SoundingTable). You will not change this, but you should have the SoundingTable products along with the radar data because they are used to compute refractivity. If this is not available, we'll assume standard atmosphere. The SoundingTable can be created in one of two ways:

(1) The program that comes with WDSS-II can create this from the output of a numerical weather model

such as the RUC. (2) The ingest_sounding.pl script that comes with WDSS-II reads and converts

sounding data from the U. Wyoming website (<http://weather.uwyo.edu/upperair/sounding.html>) into

WDSS-II's XML format. (3) You can write your own XML table file. Regardless, these are the columns

that need to be present in the file (the column names are case-sensitive): We use the Height column in the

table. We also look for a Refractivity column in the table. If no Refractivity column is present, we look

for Temperature, DewPoint and Pressure and use them to compute Refractivity. Typically, we use method

2 i.e. the method that uses the U. Wyoming data.

-o outputDir (required)

-l outputLBName (optional). Ignore this as you will not change it.

-r realtime (default=false). The alternative, which is the default, is to process archival data.

-s sourceRadar (required). This is the 4-letter radar name such as KEWX

Make sure that the identifier you provide is part of w2config/misc/radarinfo.xml

-E terrainDir (required). Please see the explanation below of how to get these files.

Provide the netcdf terrain file (e.g., Digital Elevation Model), or a directory here. If a directory is provided, we'll look for dir/RADARNAME.nc and use it as the terrain file.

-H horizonAngleOfSun (default=95.5)

A special time-interpolated VPR is written out when the sun reaches this angle. Use -1 if you don't want it. 90.833 corresponds to sunrise/sunset.

-U useUniformBeam (default=false)

By default, we use a Bessel-function (near-Gaussian) beam profile. Set -U to use a uniform beam.

-V vilThreshold (default=20)

BirdDensity products will not be produced if there is weather in the domain. Specify the threshold for the VIL value in kg/m^3 here. Specify -1 if you don't want a weather screen.

-O useOverOceanData (default=false)

By default, we ignore data over ocean when computing the vpr. Set -O to use data over oceans also.

-C clutterThreshold (default=-20)

Specify -C 10 to remove pixels where the difference between the lowest tilt and the next tilt at least 1-degree above it is greater than 10 dBZ. Clutter pixels are not vpr-corrected and are, instead, replaced by MissingData. A negative clutter threshold turns this feature off.

-Z turnOffZCorrection (default=false)

By default, we use the vertical profile of Z to correct the Z values and write them out as BirdReflectivity. Supplying -Z turns this off, so that the BirdReflectivity values are uncorrected for the vertical profile. Essentially, this program becomes a QC program that applies a weather screen and removes speckle and clutter.

-a asciiOutput (default=false)

Enable this if you want an ascii output file at the time of sunset. The information in this file is present in the netcdf files, but the ascii output may be more convenient to use since it is all in one place.

-b beamSize (default=0.5)

By default, the beamSize is assumed to range from -0.5β to 0.5β where β is the half-power beamwidth. Change the 0.5 to 1 if you want a 6dB beam, for example.

Example: `w2birddensity -i /scratch2/lakshman/udbirds/nc/code_index.xml -o /tmp/birds -s KAKQ -E ~/WDSS2/gtopo30/radars -verbose`

Appendix B. Detailed instructions on preparing radar data for use with **w2birddensity**. A current version of these instructions is maintained at <http://sites.udel.edu/aeroecologyprogram/research/radar-processing-software/>

Getting Started

Before you begin you will need to have installed the WDSS-II program and gone through the Getting Started procedure explained here:

<http://www.cimms.ou.edu/~lakshman/WDSSII/installation.shtml>

You can request a copy of the program by filling out the form at the bottom of this page:

<http://www.cimms.ou.edu/~lakshman/WDSSII/download.shtml>

Setting up your directories for processing

For this example the radar data has been downloaded to a folder called **example** and inside that folder is another folder called **radiosonde**. In the same directory as **example**, is a folder called **topo** which contains a Digital Elevation Model (DEM) for each radar station. Existing DEMs for individual radars are available upon request from Buler or Lakshmanan. Alternatively, users may create their own topographic data given a DEM file (see Lakshmanan for details).

Processing Radar Data Through the w2birddensity Module

Step 1: Convert radar to netcdf format

w2birddensity does all of the processing on NetCDF versions of your radar data. Therefore the first step is to convert your radar data to NetCDF. WDSS-II includes the `ldm2netcdf` module that will do the work for you. Here is the syntax:

```
ldm2netcdf -i <INPUT DIRECTORY> -a -l -s <RADAR NAME> -p K -o <OUTPUT  
DIRECTORY>
```

reads: convert all of the LDM radar data in my

(-i) input directory

(-s) for the following station to NetCDF format.

(-a) Read old LDM data (archive) and...

(-l) execute the command only once (not real-time).

(-o) Save the new NetCDF data to the output directory.

(-p) States that all files with the particular pattern should be processed.

Code Example:

```
ldm2netcdf -i ~/Dlinuxshare/example -a -l -s KDOX -p K -o ~/Dlinuxshare/example/netcdf --  
verbose
```

Notice that the order in which you enter the parameters doesn't matter. Here I also added the `-p` (pattern) flag as well as the `--verbose` command so that WDSS-II will output more of what's going on as it processes the data. To see the entire list of options, simply type "`ldm2netcdf`" into your terminal window. Please also note that you should always provide absolute paths like `/home/lapuma/example/data` (not relative paths like `../example/data`) to WDSS-II.

After running `ldm2netcdf` you'll see the following directories in your netcdf folder `../example/netcdf`:

```
AliasedVelocity  
code_index.fam  
Reflectivity  
SpectrumWidth
```

WDSS-II has interpreted all of your radar data and created NetCDF files for the three product moments (Velocity, Reflectivity and Spectrum Width). Note that if you are processing data collected after 2012, you might also see polarimetric radar moments such as Zdr and RhoHV. You may ignore those as **w2birddensity** does not use them. The **code_index.fam** folder is simply a directory containing a listing of all the files just created. This directory is used in the Real-Time version of WDSS-II but not in the research version (you are using the research version), so you need to create a **code_index.xml** file from this .fam directory in order for **w2birddensity** to know what data to process. If you are planning to use radiosonde data instead of assuming standard atmospheric refractivity, then you need to include your Sounding Tables in this index file as well. Therefore you'll need to ingest those radiosonde data before you make your final code_index.xml file. Don't worry, this becomes apparent shortly. If you opt to assume standard refractive index, rather than to use radiosonde data, you can skip Steps 2 and 3 and go right to creating the index file (Step 4).

Step 2. Download Radiosonde Data

WDSS-II comes with a script to ingest radiosonde data from multiple sources, including data downloaded from the University of Wyoming soundings page. (<http://weather.uwyo.edu/upperair/sounding.html>) In order to use this data, you will need to download the individual 00Z sounding files for each date of radar you wish to process. The 00Z file corresponds to the day following the night of migration, so if the migration event occurs, for example, on the night of 05012012, then the 00Z file should be for 05022012. WDSS-II will read the radiosonde data and determine the appropriate file to use, so you can download more than you need and not worry about having extra radiosonde dates (e.g., you could include both the 05012012 and 05022012 00Z files and it will ignore the 0501 file and use the 0502 file to correctly process data from 05012012).

To download the individual sounding files:

1. Navigate to <http://weather.uwyo.edu/upperair/sounding.html>

2. Use the following parameters:

Region: **North America**

Type of Plot: **Text List**

Year: **<user defined>**

Month: **<user defined>**

From: **<user defined>**: first two digits are the date and last two are the time of the sounding. You only want 00Z soundings, so for April 26 2012 you'd choose 26/00Z>

To: **SAME AS FROM** (this way you're only getting a single 00Z sounding for the date specified above)

Station Number: **<user defined>**; can be selected by clicking on the station on the map or by manual entry>

Note that the URL for the radiosonde data contains all of the information for a request, so you can modify the URL to request new data more quickly:

Here is a request for the Charleston Observation center (Station Number: 72207; Alpha Code: CHS) for the 00Z radiosonde reading on April 26, 2012

[http://weather.uwyo.edu/cgi-](http://weather.uwyo.edu/cgi-bin/sounding?region=naconf&TYPE=TEXT%3ALIST&YEAR=2012&MONTH=04&FROM=2600&TO=2600&STNM=72208)

[bin/sounding?region=naconf&TYPE=TEXT%3ALIST&YEAR=2012&MONTH=04&FROM=2600&TO=2600&STNM=72208](http://weather.uwyo.edu/cgi-bin/sounding?region=naconf&TYPE=TEXT%3ALIST&YEAR=2012&MONTH=04&FROM=2600&TO=2600&STNM=72208)

Once you have the request displaying in your webpage, right click on it and select **Save Page As...** and from the Save As window, select **Web Page, HTML Only**. The name of the file doesn't matter, so name it something that works best for you. Save it to the radiosonde folder somewhere near your radar data (for

convenience). Once you have all of the individual radiosonde files saved, you can use WDSS-II to ingest them and create the sounding table files.

Step 3. Ingest Radiosonde data using ingest radiosonde.pl

Running **ingest_radiosonde.pl** is straightforward, just provide the input directory, output directory and the pattern (i.e., extension of your files. You want the output directory to be the same as when you ran **ldm2netcdf** because **w2birddensity** will look here for the SoundingTable files. Here's an example where I'm processing all of the radiosonde data with the extension htm in the...**example/radiosonde** directory, and outputting the SoundingTable files to the **.../netcdf** directory.

```
ingest_radiosonde.pl ~/Dlinuxshare/example/radiosonde ~/Dlinuxshare/example/netcdf -p htm  
-p = pattern (htm, txt, etc.)
```

Once you run it you'll have the new directory **SoundingTable** and an updated **code_index.fam** file that includes the paths to the **SoundingTable** files (this updating automatically happens, you don't need to specify anything).

Now that the **SoundingTable** directory is in the same directory as your netcdf files, you are now ready to create the master **code_index.xml** file needed to run **w2birddensity**.

Step 4. Create the Index File

Creating this file is easy- run the following code:

```
makeIndex.pl ~/Dlinuxshare/example/netcdf code_index.xml
```

Step 5. Run w2birddensity

Here we'll run through an example of **w2birddensity** using the data we've just created and/or converted... the code:

```
w2birddensity -i ~/Dlinuxshare/example/netcdf/code_index.xml -s KDOX -E ~/Dlinuxshare/topo -S  
SoundingTable -a -o ~/Dlinuxshare/example/birddensity --verbose
```

Let's break it down...

-i: path to the code_index.xml file. By default **w2birddensity** is going to operate only on the reflectivity data so you don't need to specify that.

-a: turn ON ascii output in the form of comma separated value (csv) files (this option is OFF by default)

-S: signifies that sounding data is present and located in a directory called **SoundingTable**

-s: station ID

-E: path to the elevation data directory that contains netcdf files of topographic data.

-o: output directory (if it doesn't exist, WDSS-II will create it)

--verbose: as it sounds, gives you the most output during processing

Assuming this runs, you'll now have the following directories within your output directory (in my case, **.../birddensity**):

BirdCorrectionFactor

BirdReflectivity

BirdVprTable

code_index.fam

InterpolatedBirdReflectivity

MeanVprTable

Within the **InterpolatedBirdReflectivity** directory are netcdf files for each interpolated night of migration, as well as a separate csv folder (assuming you turned on ascii output when you ran **w2birddensity** as in the example above) containing csv files for each night of migration (beam elevation angle, azimuth, range, z_raw, correction factor, z_corrected, and interpolation time). This data can now be read into statistical packages or attached to GIS layers for further analysis.

The BirdReflectivity, BirdCorrectionFactor and BirdVprTable are produced routinely at the end of every volume scan. Ignore these products if you are interested only in the data at/around the time of migration.