Z-R Relationships

Weather Radar Applications
ECE / METR 5683
Spring 2008
Prof. Chilson

1   Learning Objectives

The following are the learning objectives for this assignment:

- Learn how NEXRAD data stored in the NIDS format can be converted to the popular netCDF data format.

- Familiarize yourself with the netCDF data format and how it is manipulated.

- Discover how netCDF data can be imported into MATLAB

- Explore and understand the errors and benefits associated with single-parameter rainfall estimation.

2   Introduction

Remote measurement of the rainfall rate R is of considerable practical interest. For many years meteorologists have attempted to find a useful relation between the radar reflectivity factor Z and the rainfall rate R. Unfortunately, there is no single relation that can satisfy all meteorological phenomena - Battan (1973) lists no fewer than 69 separate $Z - R$ relationships that have been proposed by various investigators. More importantly, observed drop size distributions, of which both Z and R are functions, can be expressed in an indefinite number of parameters. Single-parameter measurement of rainfall constrains the DSD to one free parameter, which may vary strongly in both space and time, and as a result most $Z - R$ relationships are expressed as a power law:

$$Z = aR^b \tag{1}$$

in which Z is expressed in linear units (mm^6 m^{-3}) and R is in mm hr^{-1}.

Your task is to investigate the appropriateness (or lack thereof) of various $Z - R$ relations which are implemented for the WSR-88D network. You will also begin to familiarize yourself with the netCDF data format, which is widely used in scientific applications because of its ability to embed metadata into the file itself, and its ease of integration with MATLAB. Finally, the WeatherScope

software package will be used to visualize remotely-estimated rainfall rates and compare them to Oklahoma Mesonet measurements.

A list of $Z - R$ recommended by the Radar Operations Center for use in the US is shown below

Z-R Recommendations (see `http://www.roc.noaa.gov/ops/z2r_osf5.asp`)

Relationship	Optimum for:	Also recommended for:
Marshall-Palmer $(Z = 200R^{1.6})$	General stratiform precipitation	
East-Cool Stratiform $(Z = 130R^{2.0})$	Winter stratiform precipitation - east of continental divide	Orographic rain - East
West-Cool Stratiform $(Z = 75R^{2.0})$	Winter stratiform precipitation - west of continental divide	Orographic rain - West
WSR-88D Convective $(Z = 300R^{1.4})$	Summer deep convection	Other non-tropical convection
Rosenfeld Tropical $(Z = 250R^{1.2})$	Tropical convective systems	

2.1   Acquiring Necessary Software

If you have not already downloaded the NCDC Java NEXRAD Viewer, refer to the previous assignment for instructions on how to acquire and operate the program. It will be needed for its export capability to the netCDF format.

1. Visit `http://mexcdf.sourceforge.net/downloads/` to install MEXNC, a software package that allows for the reading of netCDF files into MATLAB. Select the version of MATLAB you have installed on your computer (most likely R2007b or R2007a) and on the next screen, select the most recent version of the file. See Figure 1. When you have downloaded the file, uncompress it and place it into a directory of your choosing. You will later tell MATLAB how to point to this directory.

2. Open the file named `INSTALL` and follow the instructions for setting up your system path. See Figure 2.

3. Visit `http://sourceforge.net/project/showfiles.php?group_id=119464&package_id=130914` to download the SNCtools package, which is a group of MATLAB script files that have functionality similar to the standard routines that come with the netCDF package. Most likely, you will be able to get away with the most recent version posted (Figure 3).

4. Uncompress the downloaded file into a directory of your choosing (i.e., the same place where you put MEXNC).

5. Visit `ftp://ftp.unidata.ucar.edu/pub/netcdf-java/v2.2.22` and download the file `toolsUI-2.2.22.jar`. See Figure 4. This file acts as a backend for the MEXNC and SNC-

tools packages, so it needs to be co-located with the two directories you created earlier. See the `netcdf_init.m` file which you will be downloading in the next step.

6. Download the scripts contained in `kyodai.metr.ou.edu/~mmorris/module_3_mfiles` and place them in a directory of your choosing. Modify the directory paths found in `netcdf_init.m` and `netcdf_done.m` so they point to where your MEXNC, SNCtools, and `toolsUI-2.2.22.jar` live. These two small scripts will modify your MATLAB path to allow the execution of the various netCDF access scripts in SNCtools. The other files are used to read in and process radar data in netCDF format and read in Oklahoma Mesonet data in MDF format.

2.2   Acquiring Data

The easiest way to evaluate the accuracy of $Z - R$ relationships is to compare the estimated rainfall accumulations with those observed by the Oklahoma Mesonet. The data are distributed in the `MDF` format, which lists data at all 117 Mesonet sites every 5 minutes. We will use these data to calculate 1-hour and 3-hour accumulations and instantaneous rainfall rates and compare them to the NIDS products that are available from NCDC. Additonally, you will need to use the NCDC Java NEXRAD Viewer to export the NIDS data into netCDF format.

1. Data for this assignment are stored at `kyodai.metr.ou.edu/~mmorris/erin_data.zip` (Figure 5). Download the file and uncompress its contents.

2. The `mdf` folder contains Oklahoma Mesonet observations, and will be used to calculate rainfall parameters. These files should be stored in the directory you created for the MEXNC and SNCtools utilities.

3. The NIDS folder contains data for use in WeatherScope (`KTLX`) and the Java NEXRAD Viewer/Exporter (`Viewer`) The WeatherScope data should be placed in the proper location in your `WeatherScope Data/edu.ou.ocs.nids` directory.

4. The data in `Viewer` are for exporting into netCDF using the Java NEXRAD Exporter utility.

3   netCDF Data

The netCDF data format (`http://www.unidata.ucar.edu/packages/netcdf/`) is a set of software libraries and machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data. The Java NEXRAD Viewer allows users to export Level II or Level III radar data into netCDF format for later manipulation using programs such as MATLAB.

The zip archive you downloaded contains a Base Reflectivity dataset from 0915 UTC 19 August 2007. Load the data into the Java NEXRAD Viewer and you will see what looks like an "eye" developing over west-central Oklahoma (Figure 6), and banded precipitation structures radiating outward from it. Exporting the data requires only a few quick steps.

1. Select `Data>NEXRAD Exporter` from the menu bar or press `Ctrl-E` to open the Java NEXRAD Data Exporter. A dialog box will appear on your screen, presenting you with a list of files (in this case, there should only be one).

2. Below the "Select Output Directory" option, click the "Browse" button and navigate to your MATLAB `work` directory where you saved the SNCtools, MEXNC, and toolsUI software. The created netCDF file will be stored in this directory so you may immediately begin to manipulate it in MATLAB.

3. Select `Format>Gridded NetCDF` from the menu bar (see Figure 7). The option also exists to export as a raw netCDF, but the gridded data are much friendlier to MATLAB.

4. Click the "Export" button, and the processing will begin. It takes about 10 seconds to process the example file, at which time it will appear in the directory you selected under the same filename, but with a `.nc` extension.

When you have finished converting your data, visit the tutorial at `http://mexcdf.sourceforge.net/tutorial/index.html` to get a feel for the various capabilities of the MEXNC package, and the functions that are available. This will help you to understand the code that is in the `rainrate_cmp.m` script, and enable you to modify it to complete the assignment.

4 Hands-On Activities

During the afternoon and evening hours of 18 August 2007, an extraordinary event unfolded in western and central Oklahoma as the remnants of Tropical Storm Erin, downgraded to depression status after moving inland 48 hours earlier, reintensified to produce tropical storm-like conditions over much of the state. Two brief tornadoes were reported in western Oklahoma, near Cordell. As the evening progressed, the storm continued to wrap up, bringing torrential rainfall across southwestern Oklahoma and slowly spreading eastward and northward across the state. Sustained wind gusts of 40 knots were recorded by the Oklahoma Mesonet site in Watonga, northwest of Oklahoma City. For more information see
`http://w1.spc.woc.noaa.gov/exper/archive/events/searchindex.html.`
Immense rainfall totals were recorded due to the very high precipitation efficiency and warm-cloud processes that are attendant to tropical systems. However, because of the unusual nature of the event, the traditional NEXRAD $Z - R$ relationships were not appropriate.

We will look at this system in more detail using WeatherScope and the NCDC Java Data Viewer. To that end, you should complete the following tasks.

1. Display the data using WeatherScope. For the time 5:18 am CDT (10:18 UT) create a plot with the zoom set such that all or most of Oklahoma is visible.

   - Show the Oklahoma county borders.
   - Show the wind data at 10 m above the surface from the Mesonet (m/s) as wind vectors. Use the gridded option when showing these vectors.
   - Show the KTLX Base Reflectivity 1 data with the opacity set at 100%.
   - Air pressure from the Mesonet at 1.5 m as a gradient with an opacity of 50%.

   For this particular image, it is recommended that data feeds be listed in the order shown above. The last listed is the lowest layer in the display.

2. Save the plot as a PNG file.

3. Create a plot similar to the one above, but with 1 hour rainfall accumulation instead of Base Reflectivity. Save it as a PNG file.

4. Create another plot displaying the 3 hour rainfall accumulation and save it as a PNG file.

5. Next open MATLAB and run the `rainrate_cmp.m` routine. You will need to change the data directory paths in `rainrate_cmp.m` to have it read one of the netCDF formatted reflectivity data files that you created.

   - Create a plot of Z and save it as a PNG file. The `rainrate_cmp.m` files is already set up to do this.

- Calculate R from Z using the Marshall-Palmer and the Rosenfeld Tropical $Z - R$ relationships given above and produce plot of the distribution of rainfall rates. Save them as a PNG files.

- Calculate the instantaneous rainfall rate using two `MDF` files separated by 5 minutes (see `rainrate_cmp.m` for an example).

- The `rainrate_cmp.m` produces comparisons of the rainfall rates estimated from the radar and those from the Mesonet for several stations. See Figure 8

- For any two of the radar data files (two distinct times) create tables in which you show for each of the stations shown in Figure 8 the rainfall rates calculated from the Mesonet, Marshall-Palmer $Z - R$ relation, and the Rosenfeld Tropical $Z - R$ relation. That is, you will have one table for one time and one table for the other time.

- Compare the results and decide which $Z - R$ relationship appears to give better results.

6. Using `rainrate_cmp.m` as a template, write a MATLAB script which will allow you to compare the 1-hour accumulations as measured using the Mesonet and with the radar.

  - Create a plot using MATLAB of the 1-hour rainfall accumulation for one of the radar data files that you downloaded and converted to netCDF. Save it as a PNG file.

  - Calculate the 1-hour rainfall accumulations for the Mesonet sites.

  - For any two of the radar data files (two distinct times) create tables in which you show for each of the stations shown in Figure 8 the rainfall accumulations calculated from the Mesonet and from the radar. That is, you will have one table for one time and one table for the other time.

  - Compare the results

7. Repeat the process in (6) for the 3-hour accumulations.

Figure 1: Downloading the MEXNC package.
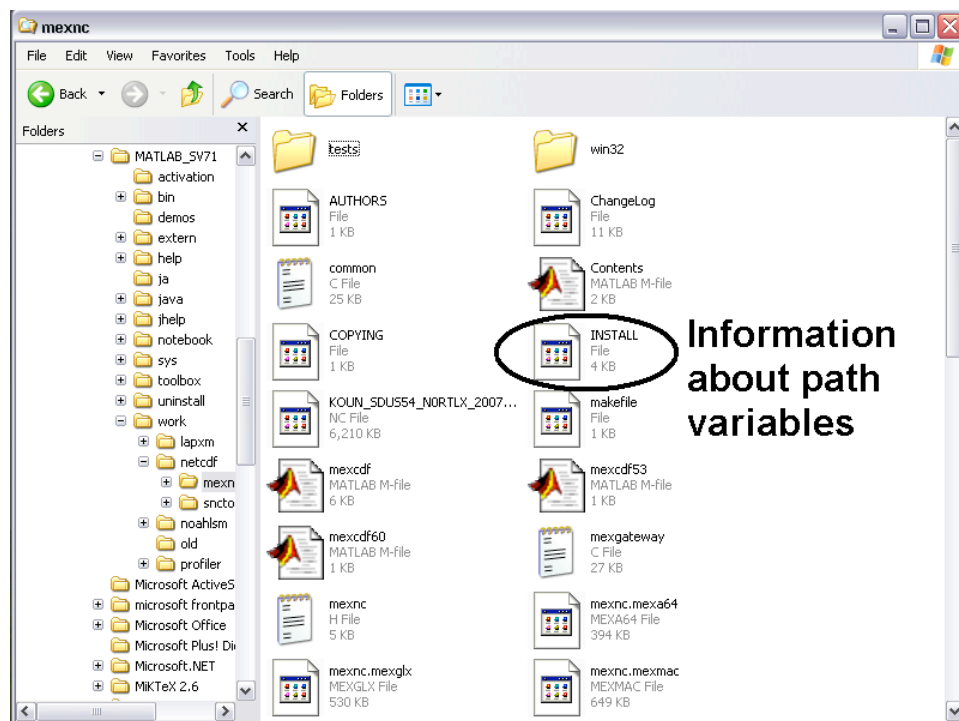
Figure 2: File describing how to configure your system path.

Figure 3: Downloading the SNCtools package.

Index of ftp://ftp.unidata.ucar.edu/pub/netcdf-java/v2.2.22

```
Up to higher level directory
  cdmSrc-2.2.22.jar           52131 KB  8/5/2007 12:00:00 AM
  cdmSrc-2.2.22.jar.MD5           1 KB  9/9/2007  9:27:00 PM
  nc2.2.jar                    4384 KB 2/28/2008  6:20:00 PM
  nc2.2.jar.MD5                   1 KB 2/28/2008  6:20:00 PM
  ncCore-2.2.22.jar             403 KB 2/28/2008  6:20:00 PM
  ncCore-2.2.22.jar.MD5           1 KB 2/28/2008  6:20:00 PM
  ncSrc-2.2.22.zip            13326 KB 2/28/2008  6:20:00 PM
  ncSrc-2.2.22.zip.MD5            1 KB 2/28/2008  6:20:00 PM
  netcdf-2.2.22.jar            2270 KB 2/28/2008  6:20:00 PM
  netcdf-2.2.22.jar.MD5           1 KB 2/28/2008  6:20:00 PM
  netcdfAll-2.2.22.zip        14073 KB 2/28/2008  6:20:00 PM
  netcdfAll-2.2.22.zip.MD5        1 KB 2/28/2008  6:20:00 PM
  netcdfUI-2.2.22.jar          3427 KB 2/28/2008  6:20:00 PM
  netcdfUI-2.2.22.jar.MD5         1 KB 2/28/2008  6:20:00 PM
  toolsUI-2.2.22.jar          14833 KB 2/28/2008  6:20:00 PM
  toolsUI-2.2.22.jar.MD5          1 KB 2/28/2008  6:20:00 PM
```

Figure 4: Public repository containing the Java backend for the MEXNC and SNCtools packages.

Index of /~mmorris

Name	Last modified	Size	Description
Parent Directory		-	
500mb.wxscript	01-Feb-2008 10:28	1.9K	
KOUN_SDUS54_N0RTLX_200707130841	26-Feb-2008 14:21	31K	
ccli_latex.zip	26-Feb-2008 15:00	10M	
dsd_images/	28-Jun-2007 12:16	-	
edu.ou.arrc.test/	04-Feb-2008 14:54	-	
erin_data.zip	03-Mar-2008 14:05	67K	
ncdc_to_nids.zip	03-Mar-2008 11:20	2.0K	
ncdc_to_nids/	07-Feb-2008 12:28	-	
oklahoma.wxscript	06-Dec-2007 13:38	2.5K	
radar.cgi	18-Dec-2007 13:05	1.5K	

This file contains the data

Figure 5: Public repository containing the radar and Mesonet data needed for the assignment.
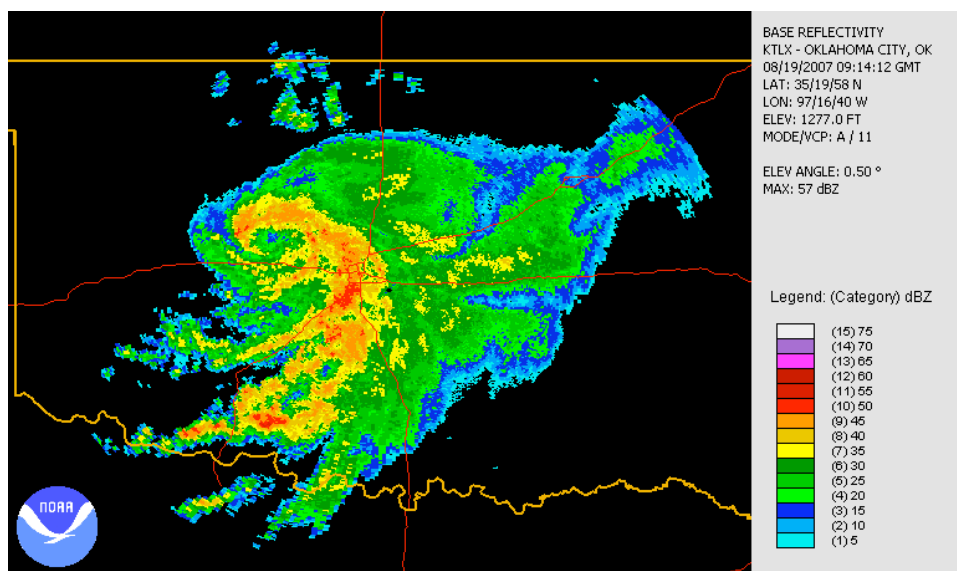
Figure 6: Visualizing the example radar data with the Java NEXRAD Viewer. Note the "eye" feature northwest of Oklahoma City.
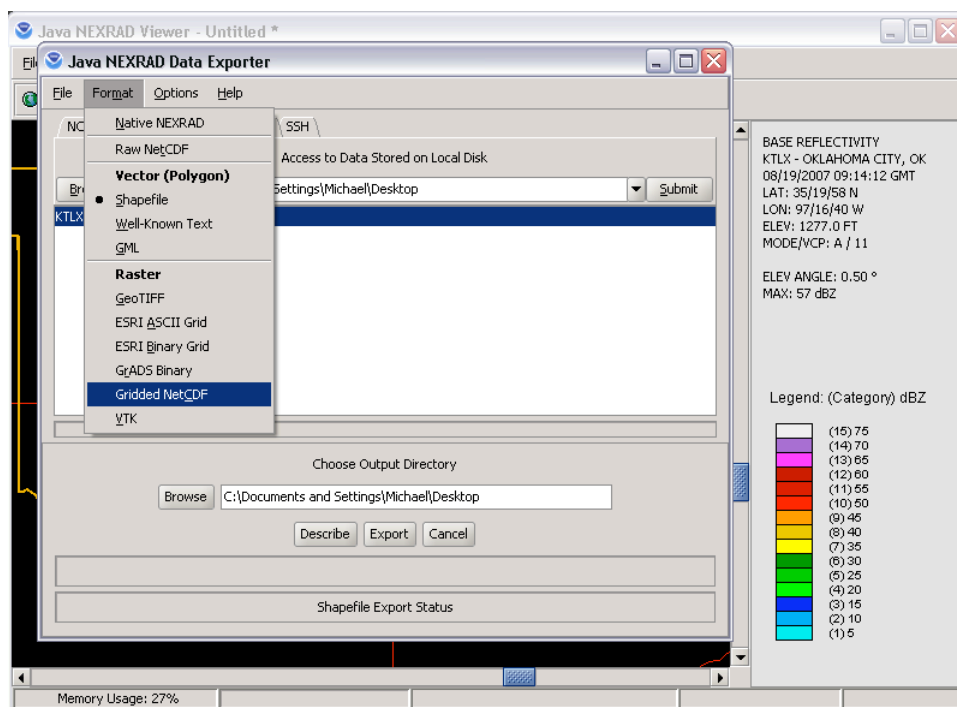

Figure 7: Selecting the "Gridded NetCDF" export option from the Java NEXRAD Exporter.
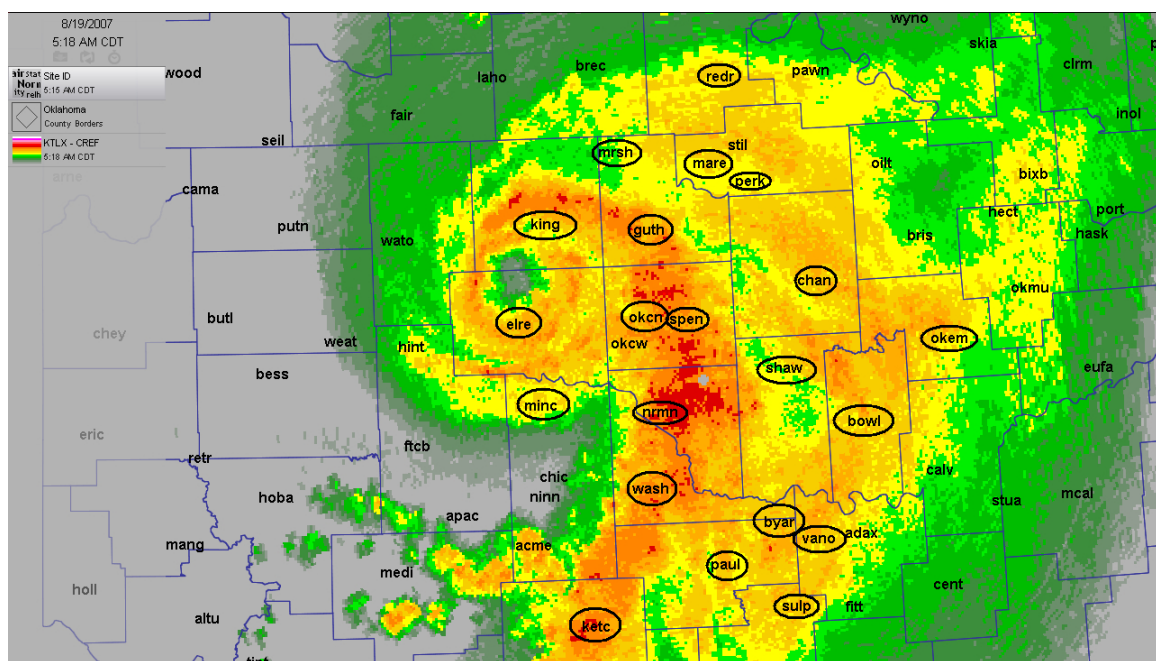
Figure 8: KTLX 0.5 degree Reflectivity 1018 UTC 19 August 2007, with Mesonet station identifiers. Annotated to indicate stations that recieved significant rainfall accumulations for this event.