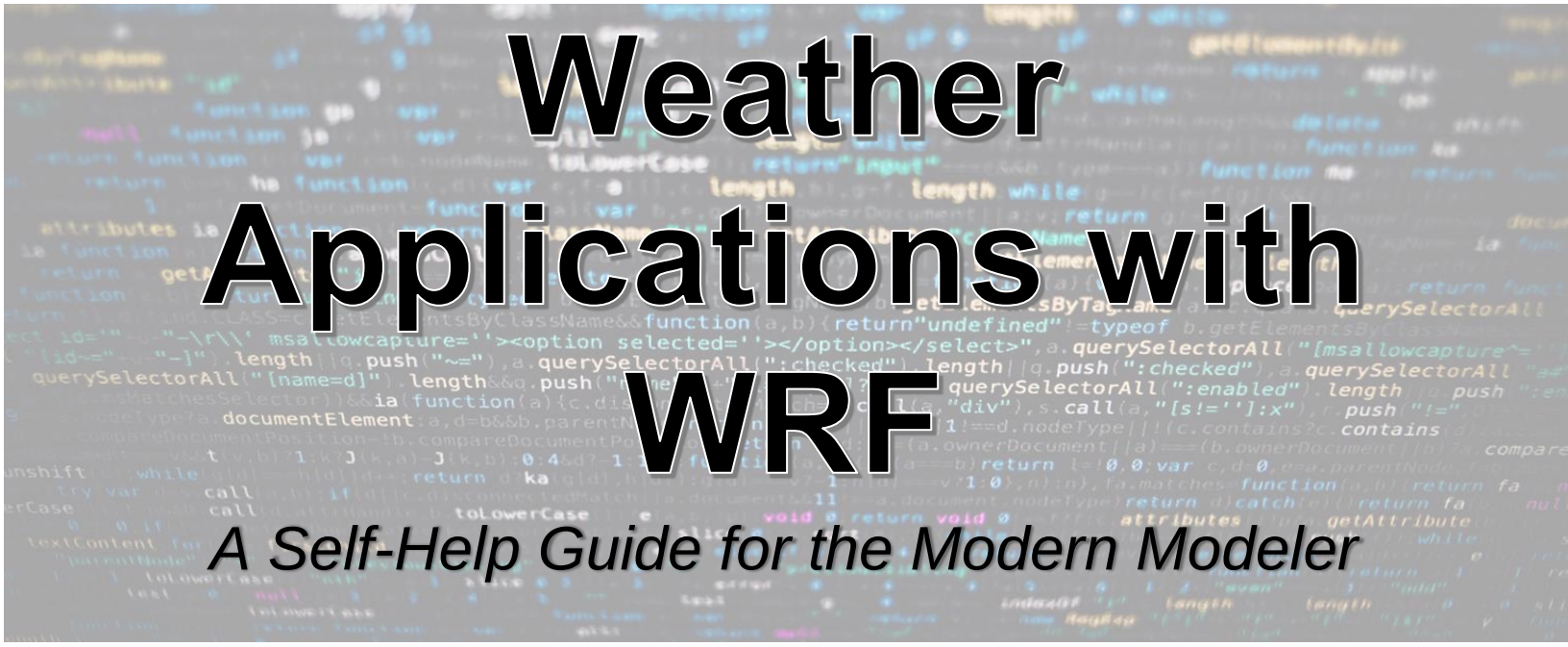

Weather Applications with WRF

A Self-Help Guide for the Modern Modeler

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Chapter 1: Getting Started

Congratulations on starting your journey to become an experienced modeler! There are many different types of weather and climate models available for use in practice as well as in research, so our goal with this book is to cover the broad concept of running a dynamic computer simulation. We will do so using a version of the Weather Research and Forecasting (WRF) model. While the step-by-step procedures covered in the upcoming chapters will be specific to this model, we will also be challenging you to reflect on the big picture. Some examples include:

- What is the purpose of this action, and what is the syntax for this model?
- What is the role of the input data?
- How do we know which parameterizations to use?
- Does the output make sense?

If you follow along with the activities we provide in this book, you will eventually set up and run a WRF simulation. However, you will also finish this book with a deeper understanding of weather and climate modeling in general, so that you can apply your understanding to a new situation when needed. However you use models throughout the course of your career, this book is an excellent place to get you started on this journey!

What to Expect and What You Will Learn

This course was created with the modeler's needs in mind: What would you like to know if you started to learn about limited-area modeling today? But the course goes beyond that, and it gives you hands-on modeling activities to prepare you to tackle a range of realistic scenarios.

The purpose of this book is to give you a practical understanding of limited-area modeling theory. You will be able to run your own simulations and will build the necessary skills to develop a career in this area even further. With that in mind, by the end of this book you can expect to:

- Understand the weather and climate system in the context of modeling
- Set up an experiment for a region of interest
- Make decisions concerning model resolution and parameters
- Plot and critically assess your simulation

If you have taken an introductory class on atmospheric sciences (or weather in general), oceanography, climatology, physics or thermodynamics, you should be good to go. However, if you have never taken such courses before, we provide some reading and videos that will help you along the way. You can find more about this on our resources webpage: https://yarkerconsulting.com/wrfresources/.

Resources Webpage

There are plenty of supplemental resources that can enhance your learning as you work through this book. Along the way, we will point you towards additional learning opportunities, research papers, books, and communities that we find to be extremely helpful when exploring the concept of modeling. However, none of these supplementary resources is required to complete the tasks we have outlined in the chapters to come.

These resources will also be available on our resources webpage. Some topics covered include meteorology, climate science, modeling, software, coding, and industry applications.

Online Community

We have a growing community on the resources webpage where you can post and discuss questions you may have. These can be related to WRF specifically or modeling in general. Or, they could be related to the content of this book, including activity or troubleshooting questions.

Checking Your Understanding

In this book, there will be opportunities for you to contemplate how you might apply the contained modeling concepts to your own work and for you to actually synthesize concepts. Where appropriate, there will also be opportunities to learn new concepts in a straightforward way.

- At the beginning of each chapter:
  - Self reflection to consider a new topic that will be explored in that chapter and relevant to you or your specific work.
- Throughout each chapter:
  - Follow step-by-step guides in learning and applying new concepts.
- At the end of each chapter:
  - Self reflection to apply information presented in that chapter to a comprehensive activity and consider how that information might be built upon in the next chapter.

What is e-WRF and why use it?

In this tutorial, we will be studying how to prepare our computer to use WRF. We have created a version of the model called e-WRF: WRF for Educational Purposes (Mesquita, 2013). This version allows you to run WRF without having to install it, and working with e-WRF is just like working with the regular model. The only thing you will need is to use a program called VirtualBox, which we will learn more about later on.

The goal of this book is to help professionals conceptually understand how dynamic computer models work. It is critical that users understand the input data and how the data is processed through the various parameterizations so that they understand the output. If the model is conceptually a black box for the model user, it is impossible to evaluate whether or not the

results make sense (Mesquita et al., 2011). In fact, it not only makes you a more knowledgeable modeler, but it also makes you a better scientist and improves your understanding of the nature of science (Warner, 2011). This is why you have chosen to develop yourself professionally by taking the first steps to understand how to set up and run a weather model, and you will be a better scientist because of it. Kudos to you!

With that said, we will *not* take the time to take you through the process of installing the model. We have circumvented this task altogether through the use of e-WRF, developed by Mesquita (2013) and described in Walton et al. (2015) and Yarker, Kelsey, and Mesquita (2015). e-WRF is the same, open-source WRF model, but packed as one file, or a virtual hard disk, which participants can open and read on any computer platform.

Why do we avoid the process of installing the model for the sake of learning? The process of running the model is complex, but it requires making decisions and understanding the impact of those decisions in the long run. This is imperative and is what makes your knowledge as an atmospheric scientist unique. Not just anyone can use the model appropriately; that is something that our specific content knowledge affords us. Installing the model, on the other hand, is something more like a recipe. It has to be done and it has to be done correctly, but any IT professional can accomplish this without much trouble. In fact, many research organizations now outsource installation of these models to IT professionals so that the scientists can focus on their work. Taking the time to go through the steps of installing the model does not actually help you understand the model itself; rather, it is really just a step-by-step process.

This is why we view e-WRF as an achievement in science education for weather and regional climate modelers. You get to focus on the learning process and skip the frustrations of installing a model or struggling to locate and pay for computational time from a supercomputer. Our goal is to minimize technical hurdles so that you can focus more on the framework that fosters a better understanding of the model itself (Warner, 2011). This will help you become an experienced, knowledgeable, and critical thinker of weather and regional climate models.

Self Reflection

Before continuing, consider the following questions to begin thinking about your specific modeling needs:

1. Is there any work you are doing that may benefit from the use of a regional climate model?
2. Would a limited-area model be a good option, or would another type of model be better?
3. If your work does not currently require the use of a model, how might you, hypothetically, modify your work to do so?

Citing e-WRF

It took a lot of time and effort to develop, prepare, and create e-WRF, so we would appreciate it if you acknowledge this software whenever you use it for a project, cite it, or share it with others. An example APA format of the reference would be:

Mesquita, M.d.S. (2013) e-WRF: WRF for Educational Purposes [Computer program]. Available at m2lab.org (Accessed <day> <month>, <year>).

So, for example, if you downloaded it on 10 June, 2013, then you would write:

Mesquita, M.d.S. (2013) e-WRF: WRF for Educational Purposes [Computer program]. Available at m2lab.org (Accessed 10 June, 2013).

Setting up e-WRF

Computer Requirements

The e-WRF software, and the virtual machine it runs through, are files you need to download and install on your personal machine. You will be able to use them on Windows, Macintosh, or Linux laptops or desktops, but please keep in mind that tablets and Chromebooks will not work.

e-WRF has been tested with low/high RAM laptops and desktops, as well as with old generation processors. The reason for all the testing is so e-WRF could be used by anyone around the world, no matter the computing resources they had at hand.

The virtual machine, VirtualBox, is a free program to download.

The e-WRF software is freely available to download as a zipped file from an FTP server. The zipped file size is 4.54 GB. The total size of the unzipped file is 12.52 GB. If you do not have enough space on your computer, you can also unzip it on an external hard disk.

If you are reading this book because you already have access to a version of WRF through your institution's resources, you may skip this section of the book. If you do not currently have access to WRF, you can find detailed e-WRF installation steps, troubleshooting tips, and additional information on the resources webpage. After following those steps, you will be ready to run e-WRF and continue with this chapter.

Visualization Tools

We should check that Ubuntu and e-WRF have been installed correctly before proceeding. To do that, we will run a program to visualize data and, eventually, the model output. In this book,

we will be using a powerful tool called ncview, which was developed by David Pierce at the Scripps Institute of Oceanography (http://meteora.ucsd.edu/~pierce/ncview_home_page.html). This program allows you to quickly plot NetCDF data, which is the primary file type used in most dynamic atmospheric models (https://www.unidata.ucar.edu/software/netcdf/). This is useful, for instance, when you want to quickly evaluate the output of your WRF files.

To make things easier, ncview has already been installed for you on e-WRF. If you are using another version of WRF instead of e-WRF, you can install ncview yourself by visiting its website from our resources webpage. Or, if your institution provides access to a different visualization tool that can process NetCDF data, feel free to use that instead.

Before moving on to our first activity, it is important to check the installation of your visualization tools. For ncview, open Terminal in your Ubuntu installation of e-WRF, then type:

$ ncview

and you will see some instructions on how to use it.

Figure 1.7 - Screenshot of typing "ncview" in the Terminal application.

Application Activity 1.1: Viewing Model Data

Now, we are going to practise using ncview. We will look at the output from a WRF simulation that we have run and prepared for you, which is included in the e-WRF package you download and installed into Ubuntu.

In your Ubuntu installation, open the Terminal application and type the following commands:

$ ls
$ cd WRF
$ cd TEST
$ cd WRF
$ ls
*$ ncview wrfout**

"wrfout*" represents all of the files starting with the text "wrfout," which, in this case, refers to the included WRF output. Then, ncview loads and you are able to select variables to view or animate.

Once you have the wrfout files, click on "3d vars" and select the variable "T2," which refers to the two-metre temperature variable. Now, think about the following questions:

1. What does the "ls" command do?
2. What does the "cd" command do?
3. Now that you can visualise the temperature variable, how do you make an animation?

If you followed the commands above, you should have obtained the following figure of the two-metre temperature variable:

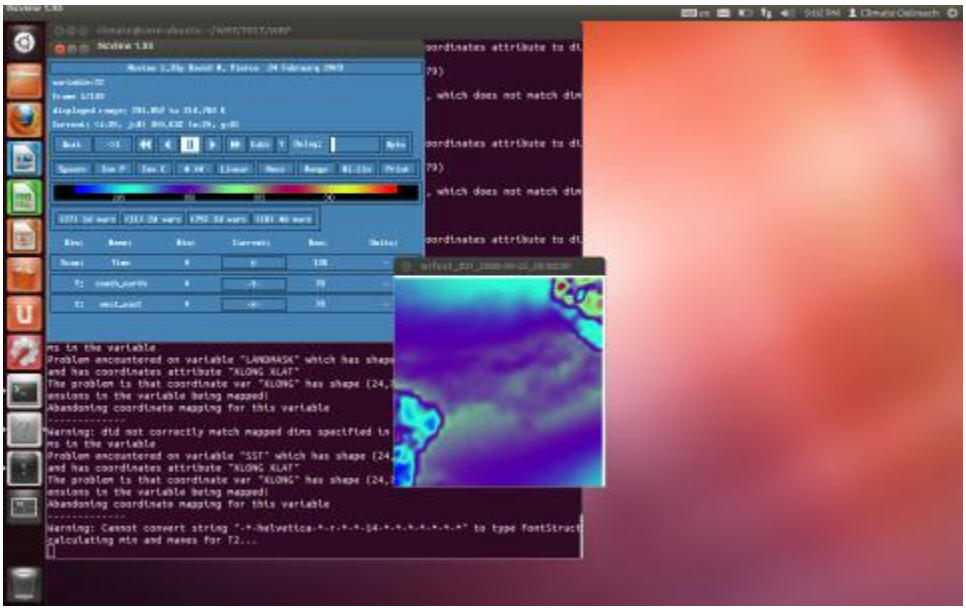

Figure 1.8 - Two-metre temperature variable plotted using ncview.

The figure above shows the two-metre temperature in the tropical Atlantic region for the first model output timestep. You can see, for instance, the coasts of Brazil to the left and Africa to the right. There you can find the value of the temperature for these two places.

Answers:

1. The "ls" command lists the files you have in a directory.
2. The "cd" command allows you to change directories.
3. You can produce an animation by pressing the "Play" button in ncview. This button looks like a triangle pointing to the right. You can control the speed of your animation by controlling the slider in the "Delay" box.

After you finish this exercise, you can close your Ubuntu/e-WRF program by using one of the following options:

1. Click on the top-right button in the Ubuntu screen to shut it down. Or,
2. You can click on the VirtualBox menu **Machine > Close > Save the machine state**. This will save the Ubuntu state where you stopped, so that the next time you use e-WRF again, it will be faster and easier for you to restart it.
    a. This option is available in full-screen mode. If you are not using this mode, you can just click on the "close" button located at the top right of your Ubuntu session. This is the same button you use when you want to close a program or window on your computer. Then the "save the machine state" option will appear there for you.

Tip: When it comes to preparing figures for publication, we do not recommend using ncview. The NCAR Command Language (NCL) is a much better tool for that, and we will introduce you to NCL in Chapter 3.

Self Reflection

Now that you have your tools in place, the next step is to decide how you would like to use the model. However, before moving on to the next chapter, a little self reflection is necessary to help you decide what you want to study and how you will go about it. Not only does it help solidify your understanding of the content covered in this chapter, but it will help you prepare for what you will do next. So before moving on to the next chapter, please take a few minutes to think about the following:

1. What are some other display options for visualizing data? Is ncview capable of all of those options? What about displaying data that is not in NetCDF format?
2. Are you more interested in designing your own model simulations and analyzing that data, or are you more interested in applying already-created simulation data for industry solutions?