Deep Learning Time Series Prediction Strategies for Efficiently Emulating Noah Land Surface Model Soil Moisture Dynamics

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A THESIS

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Atmospheric Science
in
The Department of Atmospheric and Earth Science
to
The Graduate School
of
The University of Alabama in Huntsville

May 2025

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Abstract

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This work examines the ability of deep learning time series generative models to accurately and efficiently emulate the hourly temporal dynamics of the Noah Land Surface Model (Noah-LSM) out to a 2 week forecast horizon, given atmospheric forcings and static parameterization provided by the second phase North American Land Data Assimilation System (NLDAS-2) framework. Results from multiple neural network architectures are compared alongside variations in prediction target, loss function characteristics, and model properties. The most performant model types are subsequently evaluated with respect to forecast distance, daily and annual seasonality, and against a variety of regional scenarios, including several extreme event case studies. Ultimately, we present a software system for developing and testing neural networks that use time-varying and static data to estimate temporal dynamics, with the goal of providing a foundation for similar data-driven modeling techniques to be implemented within the upcoming third phase of the NLDAS data record.

Acknowledgements

You must pay your scholarly debts by thanking those who have provided intellectual guidance, facilities, or financial support for your project; thus, you thank those who have been significantly involved in your work. You must acknowledge any agency providing funding or other resources, and any individual or institution who has granted you permission to reprint material.

If you wish, you may also thank family or friends. You may conclude your acknowledgments with a dedication rather than using a separate dedication page. Your acknowledgments should be brief and consistent in tone with a formal publication.

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Chapter 1. Introduction

Accurate characterization of the distribution of water content within the soil column by land surface models is critical for numerical weather prediction (NWP), operational decision making preceding and during drought and flood events, and for downstream datasets aiding assessment of vegetation health, crop yield prediction, and fire risk characterization [6][8][1]. Noah-LSM has helped to address these needs by serving as the land surface component coupled to NWP models including the Weather Research and Forecasting Model (WRF), the Global Forecast System (GFS) [5][7], and climate models including the NCEP Climate Forecast System (CFSv2) [9]. Noah-LSM also aids National Weather Service forecasts and US Drought Monitor designations within frameworks like the Short-Term Research, Prediction, and Transition high-resolution implementation of the Land Information System (SPoRT-LIS) [3][2], and supports research and derived product development by providing soil states for NLDAS datasets.

NLDAS has provided the community with reliable multi-model land surface states and associated forcings in a near real-time capacity since 1999 [4], with phase 2 of the project also contributing a retrospective climatology extending back to 1979 [10].

Data-driven modeling techniques like neural networks introduce the ability to approximate the highly nonlinear and conditional relationships between predictor and target datasets. This flexibility is accomplished by learning a sequence of transformations which are encoded as a composition of alternating high-dimensional matrix operations and element-wise nonlinear functions, and which serve as a mapping from the vector of predictors to a corresponding target vector. In the context of physical modeling, this

1.1 History of NLDAS and Noah-LSM

Chapter titles should begin with the word chapter and the appropriate number followed by a period. After typing the chapter heading, then type the chapter title. This template automatically formats your chapter titles. Just do not forget to include the chapter heading when you type the chapter name.

All paragraphs throughout your thesis should begin with an $\frac{1}{2}$ inch indentation. It should be double-spaced throughout. Since this is a formal document, do not use contractions. Remember that paragraphs should consist of at least two sentences. Figure 1.1 lists 11 common grammar mistakes. Please avoid these!

1.2 Deep Learning for Time Series Modeling

If your document includes many symbols or acronyms, you may include a List of Symbols, Abbreviations, *etc.* If you want a symbol/abbreviation included in the List of Symbols, be sure to create an entry for it first on the List of Symbols

Figure 1.1: 11 Most Common Grammar Mistakes Employees Make. When labeling your figures, single-space if captions extend to two lines

Glossaries.tex file. Once it is created, then you can insert it with a glossaries command. For example, the current temperature outside is 100°s.

You can capitalize your symbols or make them plural by using different commands included with the glossaries package. However, only those symbols that are actually referenced in the body of your thesis will be present in the List of Symbols. Below are a few more symbol examples.

1D

f

α

r_O

τ_e

Q_{10}

Chapter 2. Adding New Chapter, Creating Sections or Subsections, and Formatting Equations

2.1 Adding New Chapters

You may use the chapter.tex files already contained in this template for chapters 1, 2, and your concluding chapter. However, any additional chapters will need to be created in a separate .tex file and then inserted to your main.tex file with the include command. This template includes examples of how to properly format content, but feel free to delete all the content in these chapter.tex files in order to add your own content.

2.2 Creating Sections or Subsections

When adding sections or subsections, simply use the section or subsection command. LaTeX will format the title of the section and/or subsection correctly automatically. Also, if you use Overleaf as the editor, it automatically has a spelling check with is very convenient.

2.2.1 Formatting Equations

Latex automatically assigns equations numbers based on their location in the document. However, if you want to reference specific equations throughout your work, you will need to manually provide an internal label. Below is an example equation with a created label followed with a reference to this equation.

$$\begin{aligned} \nabla \cdot \nabla \psi &= \frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} \\ &= \frac{1}{r^2 \sin\theta} \left[\sin\theta \left(r^2 \frac{\partial \psi}{\partial r} \right) + \frac{\partial}{\partial \theta} \left(\sin\theta \frac{\partial \psi}{\partial r} \right) + \frac{1}{\sin\theta} \frac{\partial^2 \psi}{\partial \varphi^2} \right] \end{aligned} \tag{2.1}$$

Equation 2.1 will hopefully help you understand how to properly format and reference equations in your document.

2.2.2 Citations

When you make your citations, you will need to first add them to the ref.bib file. Then, use the citation command followed by the name of the citation.[**?**] LaTeX allows you to control the style of your citations.[**?**] On the main.tex file, set your bibliography style to the one you prefer.

Chapter 3. Conclusions and Future Work

While organization is flexible, all theses and dissertations, no matter the discipline, share certain scholarly elements. You must provide an introductory statement or overview of your project; identify the significance of your investigation; discuss relevant literature to position your work; describe your methodology; state findings or results and their implications; and present conclusions and, if appropriate, recommendations for future work. Your chapters might be organized by kinds of information (for example, a literature review, methodology, and results), or you may organize conceptually with these elements logically interwoven.

Below is just an example table. Notice that captions for tables are placed above the table while captions for figures are placed beneath the figure. LaTeX automatically formats this correctly

Table 3.1: Frequencies for equal-tempered scale, $A_4 = 440$ Hz. This table shows only the first five notes of a chromatic scale starting on C_0

Note	**Frequency (Hz)**	**Wavelength**
C_0	16.35	2109.89
$C_0^{\#}/D_0^b$	17.32	1991.47
D_0	18.35	1879.69
$D_0^{\#}/E_0^b$	19.45	1774.20
E_0	20.60	1674.62

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Appendix A: An Example Appendix

Appendices should appear at the very end of your thesis. Make sure to label each Appendix with a letter starting with "A". Any tables and/or figures located in the appendix should be labeled accordingly. For example, below is figure A.1 because it is the first figure that appears in Appendix A.

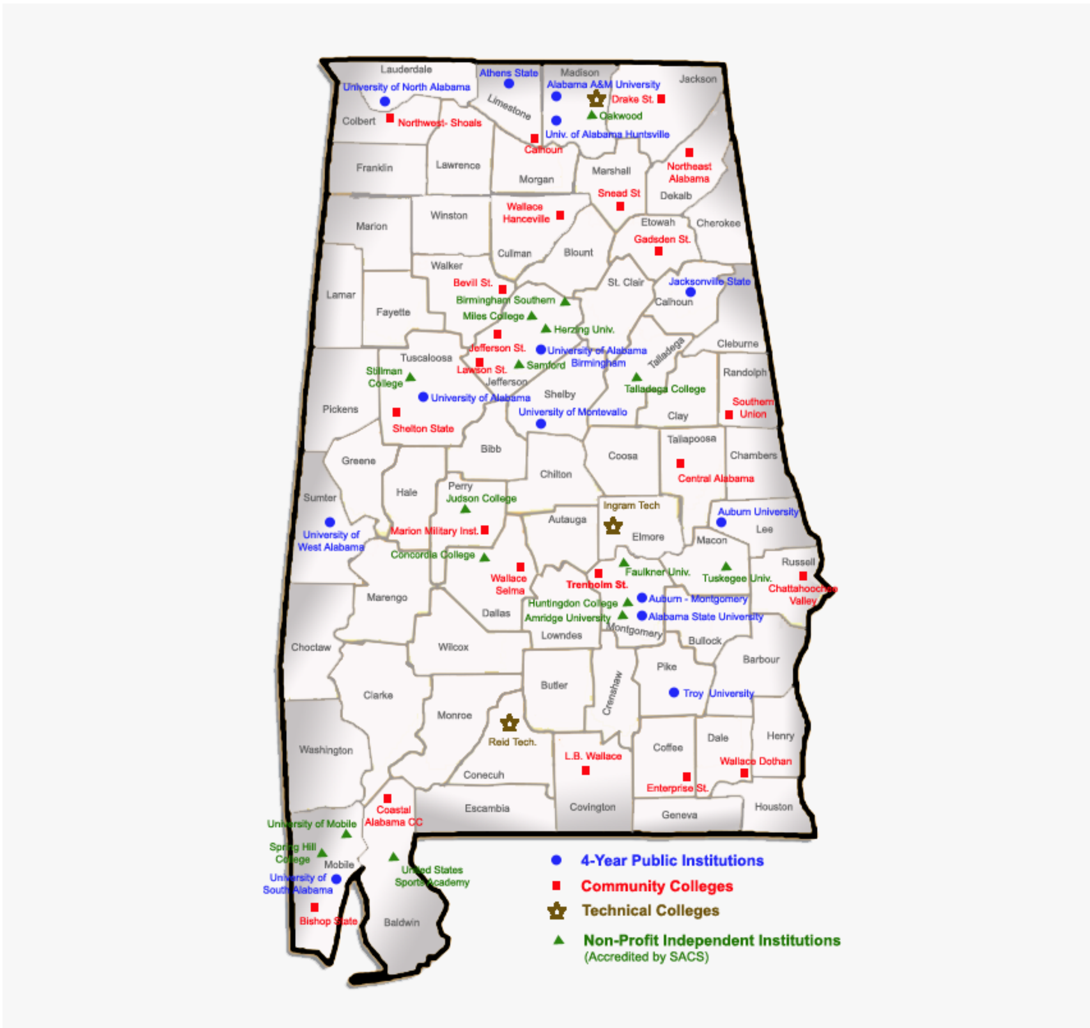

Figure A.1: Colleges and Universities in Alabama