Syllabus: STA 542 – Introduction to Time Series Analysis

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Fall 2026

Course Description

Time series data arrive in order along one observed path. Dependence changes what that path can reveal about a process, how uncertainty accumulates, and how a forecasting procedure should be evaluated. This course develops the probability models and statistical methods needed to answer those questions.

Topics include process specification, learning under dependence, forecasting, model criticism, multivariate series, and changing-state models, illustrated by examples from climate, finance, environmental science, and sensing.

Both frequentist and Bayesian reasoning are used. The Bayesian perspective enters through forecasting under parameter uncertainty and returns in latent-state models. Mathematical arguments establish what a method targets and when it can work; simulation and real-data analysis in R show how it behaves in practice.

Learning Objectives

By the end of the course, students should be able to:

- formulate time-series models through joint distributions, conditional distributions, or generating equations, and determine whether these specifications define coherent processes;
- identify which features of a dependent process can be learned from one observed path, and state conditions under which time averages estimate those features;
- describe temporal dependence using autocovariances, long-run variance, and spectral density, and explain what each description reveals about the information in a time series;
- construct point and probabilistic forecasts when a process law is known and after a model has been fitted, account for predictive uncertainty, and evaluate forecasts using information available at the forecast origin;
- fit and assess small ARMA and VAR models using moment, prediction-error, and likelihood methods, and diagnose important forms of model failure; and
- formulate simple models with evolving or hidden states, apply the Kalman filter in linear Gaussian state-space models, and distinguish gradual change from structural breaks.

Course Staff

Instructor	Lasse Vuursteen (lasse.vuursteen@duke.edu)
Teaching assistants	Arunsoumya Basu (arunsoumya.basu@duke.edu)
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Prerequisites

The formal prerequisite is Statistical Science 521L, 532 or 732, or an equivalent course in mathematical statistics. We assume familiarity with probability, conditional expectation, likelihood, regression, elementary asymptotics, linear algebra, and basic Bayesian analysis. In particular, students should be comfortable with prior, posterior, and posterior predictive distributions. Working familiarity with R is expected.

Course Information

Course	STA 542 – Introduction to Time Series Analysis
Section	01-LEC; class number 5453
Units	3
Class meetings	August 24 – November 23, 2026
Lectures	Mondays and Wednesdays, 10:05–11:20 a.m.
Location	Old Chemistry 001
Instruction mode	In person

Important Dates

Aug 24	First class
Sep 7	Labor Day; no class
Oct 7	**Midterm examination** in class
Oct 12	Fall break; no class
Nov 23	Last class
Nov 25–Dec 8	Graduate reading period
Dec 9	**Final examination**, 9:00 a.m.–12:00 p.m.

Workbooks and Course Materials

The workbooks and lecture slides are the primary course text. Each topic class is organized around one workbook. We will develop its central argument and selected examples in class. The weekly homework sheet identifies assigned exercises; the remaining exercises provide optional practice.

Outside class, plan approximately three to four hours per workbook for preparation, review, and assigned practice per lecture. This estimate includes the homework drawn from the workbook.

The workbooks are being written for this course and may contain mistakes. Please report errors. Canvas contains the current corrected version.

Quarto and R

Students are recommended for setting up Quarto on their own computers before beginning the workbooks; as it allows editing and running the R code in the workbooks without having to copy and paste the code into an R console. Follow the official Quarto Get Started guide. Workbooks are supplied as Quarto (`.qmd`) files. Open a workbook in RStudio, run individual R chunks while working through it, and use **Render** to build the complete document.

If you encounter any issues with the setup, such as a Quarto document does not render or an R chunk fails, asking your local LLM for help should fix most problems. Give it the smallest relevant code fragment and error message, request the smallest fix, and verify that the code runs. If you are still having issues, please reach out to the TAs.

Optional References

No textbook is required; the workbooks are the primary course materials. They draw most heavily on:

- Fan and Yao (2003), *Nonlinear Time Series: Nonparametric and Parametric Methods*, Springer;
- Shumway and Stoffer (2025), *Time Series Analysis and Its Applications: With R Examples*, 5th ed., Springer.

Particular units also draw on:

- van der Vaart (2010), *Time Series*, lecture notes, available from the author's website;
- Brockwell and Davis (1991), *Time Series: Theory and Methods*, 2nd ed., Springer;
- West and Harrison (1997), *Bayesian Forecasting and Dynamic Models*, 2nd ed., Springer;
- Prado, Ferreira, and West (2021), *Time Series: Modeling, Computation, and Inference*, 2nd ed., CRC Press;
- Lütkepohl (2005), *New Introduction to Multiple Time Series Analysis*, Springer; and
- Durbin and Koopman (2012), *Time Series Analysis by State Space Methods*, 2nd ed., Oxford University Press.

Each workbook ends with a source note giving the relevant chapters and any topic-specific articles.

Office Hours and Communication

Office hours will be posted on the course website Other meetings are available by request over email. All questions about homework, including requests for deadline extensions, should be directed to the TAs. The TAs decide whether to grant an extension.

Use the course discussion forum for content questions whose answers may help the class. Use email for private matters. Canvas is the source of record for course materials and deadlines.

Assessment

Let F, M, H, and Q denote the percentage scores for the final, midterm, homework, and pop quizzes. Starting from relative weights $5 : 3 : 1 : 1$, the course percentage is the maximum of:

Final	F
Final and midterm	$(5F + 3M)/8$
All four components	$(5F + 3M + H + Q)/10$
Final, homework, and pop quizzes	$(5F + H + Q)/7$

Each row is a complete grading scheme whose weights sum to one. Homework and pop quizzes can therefore help the course grade without lowering it.

Homework

There is no homework in the first week. There will then be ten short homework assignments. Each contains two or three selected tasks from the preceding week's workbooks: a conceptual question, a derivation or 'transfer to a nearby model', and occasionally a small R or data problem. A sheet should require about 60–90 minutes to complete, after having studied the relevant material.

The best eight of the ten homework scores determine H.

Homework is graded for effort rather than correctness:

- **2 – Substantive attempt:** every assigned part is addressed, reasoning is visible, and computational output is interpreted;
- **1 – Partial attempt:** meaningful work is present, but important parts are missing or perfunctory;
- **0 – No meaningful submission.**

A correct answer without supporting work does not constitute a substantive attempt. Complete solutions provide correctness feedback.

Mathematical and statistical reasoning must be written legibly by hand; tablet handwriting is welcome.

Submit one ordered PDF through Gradescope.

R code, numerical output, tables, and plots may be printed or inserted digitally and appended, or sketched when exact output is unnecessary. Label every computational exhibit, refer to it in the handwritten response, and explain what it shows. Approved accommodations may modify the handwriting requirement.

Homework is posted after Wednesday's class and is normally due the following Tuesday at 5:00 p.m. Homework 5 is due on October 4 so that its solutions are available for the October 5 clinic.

Solutions are released after each deadline.

Assignment	Material	Due at 5:00 p.m.
HW 1	Workbooks 3–4	Tue Sep 8
HW 2	Workbook 5	Tue Sep 15
HW 3	Workbooks 6–7	Tue Sep 22
HW 4	Workbooks 8–9	Tue Sep 29
HW 5	Workbook 10 and cumulative practice	Sun Oct 4
HW 6	Workbook 11	Tue Oct 20
HW 7	Workbooks 12–13	Tue Oct 27
HW 8	Workbooks 14–15	Tue Nov 3
HW 9	Workbooks 16–17	Tue Nov 10
HW 10	Workbooks 18–19	Tue Nov 17

The TAs administer homework deadlines. Late work is accepted only when a TA grants an extension; extension decisions are at the TAs' discretion. The two dropped scores cover ordinary missed deadlines.

Approved accommodations apply as specified in the Faculty Accommodation Letter.

Pop Quizzes

There will be eight unannounced pop quizzes. Each takes about five minutes and asks for a definition, short calculation, counterexample, or simple interpretation from previous meetings. Pop quizzes are graded for correctness and carry equal weight.

The best six quiz scores determine Q. There are no makeup quizzes for ordinary absences. Attendance is not otherwise graded. Approved accommodations apply independently of the drops.

Examinations

The midterm is a 75-minute in-class examination on October 7 and covers Workbooks 1–10. The cumulative final is December 9, 9:00 a.m.–12:00 p.m. It emphasizes Workbooks 11–21 and retains the concepts on which they depend.

Questions may ask for definitions, counterexamples, short derivations, estimation or forecasting arguments, and interpretations of supplied plots or R output. No live programming is required.

Each examination permits one student-prepared, double-sided letter-size sheet of notes and a nonprogrammable calculator. No other materials, electronic devices, collaboration, or AI tools are permitted.

Students who cannot take the midterm must contact the instructor promptly; a makeup requires an approved absence. Students who cannot take the final at its official time must contact their academic dean as soon as possible. Travel plans are not grounds for rescheduling the final examination.

Collaboration and AI Tools

Discussion is encouraged on homework. Students may compare approaches, explain ideas, and help one another debug code. They may not exchange or copy written solutions. Each student must prepare an independent handwritten response in their own words.

AI tools may be used on workbooks and homework as tutors, critics, and coding assistants. AI output may be incorrect; students remain responsible for every submitted statement. With each problem, list collaborators and material assistance, including the AI tool and type of help when applicable. Pop quizzes and examinations must be completed independently without AI tools.

Regrade Requests

If a grading error appears to have occurred, email a short written request within seven days after the work is returned. Identify the error and explain why the grading should be reconsidered. The entire problem may be reviewed, and its score may increase, decrease, or remain unchanged.

Tips for Success

1. **Read the core path before class.** Familiarity with the notation makes the derivations and examples in class useful even when the first reading leaves questions.

2. **Use homework as rehearsal.** An AI-assisted solution that is not understood will not transfer to a pop quiz or examination. Rework the argument independently after comparing it with the solution.

3. **Ask questions before gaps accumulate.** Later workbooks use the distinctions established early in the course. Use class, the forum, and office hours when one of those distinctions remains unclear.

4. **Interpret every computation.** A fitted coefficient, plot, or diagnostic should be accompanied by a statement of its target and limitations.

Accessibility

Students who need accommodations should register with the Student Disability Access Office (SDAO), which will determine appropriate accommodations. Accommodations are not retroactive and cannot be implemented until the instructor receives a Faculty Accommodation Letter. Once the letter is available, please share it with the instructor.

Religious Accommodations

Students may be absent to observe a religious holiday. Please notify the instructor near the beginning of the semester so that arrangements can be made in advance. Duke's policy and notification form are available through the Trinity College religious-holiday policy.

Schedule

The topic schedule may move in response to the pace of the class. Examination dates and university holidays are fixed. Current materials and any topic changes will be posted on Canvas.

Week	**Date**	**Topic**
1	Mon Aug 24	Workbook 1 – What Is a Time Series?
	Wed Aug 26	Workbook 2 – Solutions of Generating Equations
2	Mon Aug 31	Workbook 3 – Forecasting When the Process Law Is Known
	Wed Sep 2	Workbook 4 – Bayesian Forecasting Under Parameter Uncertainty
3	Mon Sep 7	*Labor Day – no class*
	Wed Sep 9	Workbook 5 – What Can One Path Reveal?
4	Mon Sep 14	Workbook 6 – When Does the Law Determine the Model?
	Wed Sep 16	Workbook 7 – How Much Information Is in a Dependent Sample?
5	Mon Sep 21	Workbook 8 – Transforming a Time Series
	Wed Sep 23	Workbook 9 – Flexible Prediction From One Path
6	Mon Sep 28	Workbook 10 – Dependence by Frequency
	Wed Sep 30	Integration and midterm review: Workbooks 1–10
7	Mon Oct 5	Midterm problem clinic and flex meeting
	Wed Oct 7	**Midterm examination: Workbooks 1–10**
8	Mon Oct 12	*Fall break – no class*
	Wed Oct 14	Workbook 11 – Fitting from Moment Restrictions
9	Mon Oct 19	Workbook 12 – Fitting by Prediction Errors
	Wed Oct 21	Workbook 13 – Likelihood and Misspecification
10	Mon Oct 26	Workbook 14 – Choosing and Checking a Fitted Model
	Wed Oct 28	Workbook 15 – Forecasting After Fitting
11	Mon Nov 2	Workbook 16 – Evaluating Forecasts in Time
	Wed Nov 4	Workbook 17 – When the Observation Is a Vector
12	Mon Nov 9	Workbook 18 – Does Another Series Improve the Forecast?
	Wed Nov 11	Workbook 19 – What If the Mechanism Changes Over Time?
13	Mon Nov 16	Workbook 20 – How Do We Learn a Changing State?
	Wed Nov 18	Workbook 21 – Did the System Change Abruptly?
14	Mon Nov 23	Course integration, final-exam preparation, and flex
–	Wed Dec 9	**Cumulative final examination, 9:00 a.m.–12:00 p.m.**