Think, Do, and Communicate Environmental Science

Many students find it daunting to move from studying environmental science to designing and implementing their own research proposals. This book provides a practical introduction to help develop scientific thinking, aimed at undergraduate and new graduate students in the earth and environmental sciences. Students are guided through the steps of scientific thinking using published scientific literature and real environmental data. The book starts with advice on how to effectively read scientific papers, before outlining how to articulate testable questions and answer them using basic data analysis. The Mauna Loa CO_2 dataset is used to demonstrate how to read metadata, prepare data, generate effective graphs, and identify dominant cycles on various timescales. Practical, question-driven examples are explored to explain running averages, anomalies, correlations, and simple linear models. The final two chapters and the epilogue provide a framework for writing, summarizing, and evaluating persuasive research proposals, making this an essential guide for students embarking on their first research project.

TARA IVANOCHKO is an associate professor of teaching and director of Environmental Science in the Department of Earth, Ocean and Atmospheric Sciences at the University of British Columbia. Her research focuses on marine palaeoclimatology and the reconstruction of environmental systems on timescales from 10,000 to 100,000 years. A passionate educator, she has also developed a multi-year curriculum to actively engage undergraduate students in authentic scientific experiences, and has incorporated learning portfolios and community-based learning into the Environmental Science degree.

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TARA IVANOCHKO
University of British Columbia

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Prologue

Large environmental changes are occurring all around us. As the human population has grown, the demand for food, energy, water, living space, and amenities has also grown, as has the production of industrial wastes, sewage, agricultural run-off, and carbon dioxide – the monster of all waste products. These changes are not always obvious to the naked eye, and the lack of a clear understanding is often a major barrier to taking appropriate action. This is where the environmental scientist is needed: to shed light on the what, where, when, why, and how of environmental change.

When I was barely one year old, my father Charles David Keeling started making measurements of atmospheric carbon dioxide at the Mauna Loa Observatory on the Big Island of Hawaii. The goals were to answer a couple of simple questions: Is atmospheric carbon dioxide increasing? If so, are humans responsible?

In those early days, he often was concerned that his instrument, which measured carbon dioxide around the clock, might break down or give erroneous readings. But within three years, he already had the answer to his first question: Yes, carbon dioxide levels were increasing. And within about six years, he could clearly demonstrate that the rate of increase was significantly slower than would be expected based on the amount of CO_2 emitted into the atmosphere each year by the burning of fossil fuel. This extra CO_2 was presumably being taken up by land plants or by the oceans. But this only raised new questions: How important were the land and ocean separately as sinks for CO_2? What processes controlled these sinks? How might they change in the future? And of course: would the continuing rise in CO_2 cause the planet to warm up?

He also found something totally unexpected. CO_2 was not only just rising year on year but it was also going up and down with the seasons. This reflected the annual cycle of plant growth dominated by photosynthesis in the summer and respiration in the winter: as plants grow, they consume carbon dioxide from the air around them, and as they decompose, they release carbon dioxide back to the air. He was effectively the first person to see the planet, as a whole, breathing.

Atmospheric carbon dioxide is now being measured at dozens of sites around the world. The Mauna Loa record is now more than 60 years long, and the records from the other sites also span many decades. We also have time series of data that track changes in the pH of the ocean, ozone concentrations in major cities, hurricane (drought and flood) frequency and intensity, the amount of human debris in space, and temperature and weather conditions from around the planet. These measurements further confirm that the increases in atmospheric carbon dioxide are caused by human activities: burning fossil fuels for energy, industry, transportation, and food production. They also tell us that land plants and the oceans are both important sinks for the CO_2, and yes, Earth's climate is warming. But again, there are new questions. How bad will things get if we continue on the same path? What needs to be done to get control of the climate problem? How can we demonstrate progress?

The Mauna Loa record continues to be relevant. For example, one of the best measures of progress is whether the curve itself starts to bend downwards. When do we expect to be able to see this happening? How will we know for sure?

When you first look at environmental data, and time series in particular, you can be overwhelmed. Environmental datasets can look messy, dense, and unpredictable. But hidden in the jumble of numbers are important stories. My father contributed more than just the numbers he was generating; he thought long and hard about what the data were telling him, how to graph the data, and how to make sense of the numbers.

Like other scientists of his day, my father's goal was purely to gain knowledge: to discover and report about the natural world. He certainly didn't consider himself to be an environmental scientist; this term didn't yet exist. But in his quest to understand the world around him in the context of human activities, he was actually an archetypal environmental scientist.

In the last few decades, environmental science has become a major field of interdisciplinary science studying the influences of humans on the environment and the influences of the environment on humans. Environmental datasets that extend over time, like the one my father started at Mauna Loa in the 1950s, now provide rich resources that expand our knowledge of Earth processes, and help us control our future.

Professor Ralph Keeling
Scripps Institution of Oceanography

Acknowledgements

This book was inspired by my students. I am always moved at the end of term when my students reflect on their accomplishments and express pride in their final research proposals. This book reflects what I have learned from students' interests, questions, frustrations, and achievements.

There is another, much earlier inspiration for the book – Charles David Keeling, or Dave, as I call him. At his dining room table, Dave consistently impressed me with his drive and passion for science and the importance of providing robust, unassailable data. I extend my deep appreciation to Ralph Keeling for sharing some of Dave's story in the foreword and showcasing how his father's Mauna Loa CO_2 record has shaped the new discipline of environmental science.

Many of the ideas and activities that I present in this book were developed over time working and teaching with colleagues at the University of British Columbia. I would particularly like to acknowledge Douw Steyn and Kai Chan who helped me develop approaches for reading scientific papers and writing scientific proposals that I have included in this book. Valentina Radic, Phil Austin, and three anonymous reviewers provided invaluable critiques and suggestions that improved the data analysis sections of the book. I also extend heartfelt thanks to Sara Harris, who provided me with daily writing support, and loving gratitude to Paul Keeling, my husband, who helped with copy-editing.

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Finally, I would like to dedicate this book to my parents, Liz and Bob Ivanochko, who taught me to value intellectual curiosity, creativity, initiative, and determination.