A Data-Intensive Approach to Studying Climate and Climate Change in Africa

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ABSTRACT

A data-intensive research project on the climate history of Africa has been made part of an introductory college-level earth-science course. The project introduces students to the challenge of working with real data as student teams analyze and interpret extended records of monthly rainfall and average temperature for stations across Africa with the goal of defining regional climate patterns and assessing evidence regarding climate change. The exercise emphasizes quantitative skills in data manipulation and statistical analysis within a framework of critical thinking, decision making, oral and written communication, and collaborative participation. The social context of the project is apparent immediately to the students, but the scientific context requires additional input from the instructor. The project has been carried out in classes with up to 100 non-science students and is a successful vehicle for engaging African-American students in the geosciences. It can also readily be adapted for use in high-school earth-science classes.

Keywords: Education – undergraduate; miscellaneous and mathematical geology; women and minorities.

INTRODUCTION

Many Americans lack the numeracy skills and scientific background to make informed decisions about environmental issues, resource allocation, or regional planning. Geoscience departments are well suited to introduce concepts of numerical and scientific literacy as they affect the important interface between science and human affairs. Unfortunately, many survey courses for non-majors cover many technical topics rather than helping students see the connections between geology and their lives. It is our experience that students learn best when they master information on topics that are relevant to their lives. By helping students to break through the compartmentalization that often separates science from daily life, we promote our own discipline and also help train future leaders in education, politics, medicine, law, and other fields.

The project described here introduces students to a data-rich environment. Students evaluate historical records of rainfall and temperature to describe the climate of a prescribed region. They then investigate evidence relevant to climate change over the 100-year period of record. For students with no prior science experience, the research project is both frightening and, ultimately, rewarding. Our conviction is that there is no substitute for real data and hard work. Students approach the project initially with a desire to "get the right answer" and must be guided to learn that they define the answer through their work. The most important aspect of the project is that students with little or no science background are empowered to examine natural data and reach defensible conclusions on a topic that truly interests them. This approach is strongly recommended by the AAAS (1989).

We focus on Africa for two reasons. First, the study of Africa can be attractive to African-American students, who represent an extremely small proportion of undergraduates enrolled in geoscience departments and courses (Tewksbury, 1995). Our experience supports this conclusion, as enrollment in this course at both the University of Virginia and Pennsylvania State University has been roughly 45% African-American, of whom over 75% are female. Second, the location and topography of the continent make it ideal for a regional survey approach. Africa is nearly centered on the equator, so rainfall patterns are affected by the subtropical anticyclonic belts of both hemispheres, and it lacks major orogenic mountain belts that serve as climatic divides in the Americas, Europe, and Asia (Goudie, 1996).

THE CLIMATE OF AFRICA: A 100-YEAR PERSPECTIVE

Overview

The project is a team-based exercise in which the class evaluates monthly precipitation and temperature data to reach a consensus on African climate patterns and climatic change over the past century. In the following sections, we outline the scientific context that we provide to students, the logistics of conducting and assessing the project, and the likely conclusions and learning outcomes for the students. We typically allow four to six weeks of instructional time to discuss the science, handle group logistics, conduct research, and present findings. The project is carried out by students working in teams, so prior group experience in the class is valuable. We conduct the exercise in the middle of the semester for two reasons: (1) we have sufficient graded material on each student to assign teams fairly and (2) this challenging project will not conflict with end-of-term assignments in other courses. Following this long-term project, we have observed improved student performance in a wide range of areas, including overall engagement with the course material, data manipulation, group interaction, oral discourse and presentation, and knowledge of basic geography.

Scientific Context

Students hear conflicting reports in the media regarding the consequences of greenhouse gas accumulation in Earth's atmosphere. Atmospheric levels of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are certainly higher today than in pre-industrial times. The presence of natural and anthropogenic greenhouse gases increases the amount of energy absorbed by the atmosphere, contributing to a warming of Earth's surface. Indeed, worldwide temperature measurements, screened for artifacts such as effects of urbanization, have been used to estimate that global mean surface temperatures have increased by 0.3 to 0.6°C during the last 150 years (for example, Hansen and Lebedeff, 1987; Nicholls and others, 1996). The increase, however, has not been monotonic, and large interannual fluctuations mean that no single explanation yet explains all of the patterns (see summary in Ledley and others, 1999). It is against this backdrop that we ask students to study patterns in rainfall and temperature with the goal of defining "climate" and distinguishing it from "climate change."

Post-industrial climatic changes are minor when considered in the context of geological time. This project is one of several exercises in the course designed to explore aspects of climate change over several million years. We find that students can integrate information much better over time scales measured in tens of thousands than in hundreds of millions or more. Still, most college students are unaware of the existence or effects of Pleistocene glaciation events. Rather than pursue all of Earth's history, we therefore focus on the human dimensions of settlement and industrialization that make 10,000 years of history more tangible. At the same time, it is worth describing to students some aspects of Earth's climate history over longer time scales during which there were no anthropogenic influences.

The project described here can be modified to emphasize connections to agriculture, hydrology, or ancient civilizations. It is important that students be given supplemental readings, lectures, or class activities that highlight these relationships. Suitable readings include a description of the effects of Nile fluctuations on ancient Egyptian civilization (Butzer, 1980), implications of Nile flood levels for understanding climate change (Hassan, 1981), and the significance of post-glacial delta formation to human settlement (Stanley and Warne, 1997). The effects of climate change on human evolution can also be explored through related readings and projects (for example, Feibel, 1997; Gore, 1997).

The atmospheric dynamics of African rainfall provide additional topics for discussion (for example, see Goudie, 1996). The annual movement of the Inter-Tropical Convergence Zone (ITCZ) between the equatorial regions and the Sahel is responsible for the rainy season(s) in sub-Saharan Africa. The timing and amount of rainfall in these areas document movement of the ITCZ. In contrast, Mediterranean weather patterns dominate the North African coast. Superposed on the long-term climatic patterns are shorter variations. For example, the influence of El Niño on rainfall in the Ethiopian highlands (the headwaters of the Blue Nile) is described clearly for non-technical audiences in MacKenzie (1987). Additional background information of this sort helps students see the global context of both weather and climate.

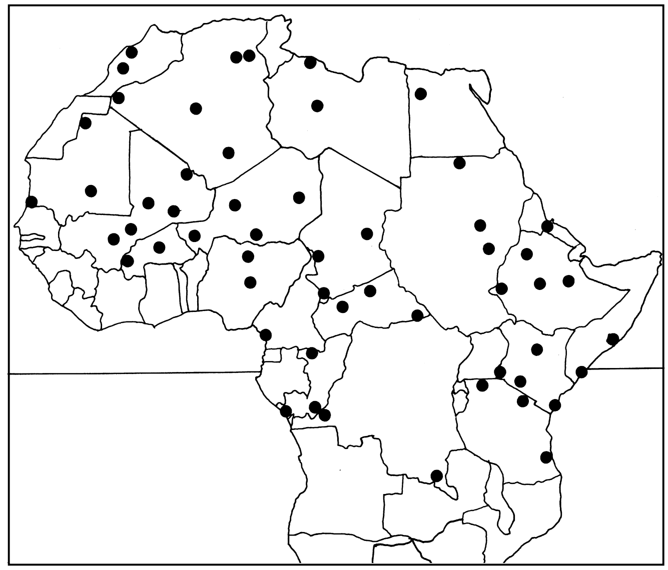

Figure 1. Selected stations for which monthly temperature and precipitation records are available for 50-120 years. *Algeria*: Adrar, El Oued, Tamanrasset, Tindouf, Touggourt; *Burkina Faso*: Ouagadougu, Bobo Djoulasso; *Cameroon*: Douala; *CAR*: Bossangoa, Ndele, Zemio; Chad: Abeche, Moundou, N'Djamena; *Congo*: Brazzaville, Pointe Noir, Souanke; *D.R. Congo*: Kinshasa, Lubumbashi; *Egypt*: Siwa; *Eritrea*: Asmara; *Ethiopia*: Addis Ababa, Dire Dawa, Gonder; *Kenya*: Kisumu, Marsabit, Mombasa, Narok; *Libya*: Sebha, Tripoli; *Mali*: Gao, Mopti, Segou, Tessalit, Tombouctou; *Mauritania*: Bir Moghren, Rosso, Tichit; *Morocco*: Casablanca, Marrakech; *Niger*: Zinder, Agadez, Bilma, Niamey; *Nigeria*: Jos, Kano; *Somalia*: Chisimaio, Gambela, Mogadishu; *Sudan*: Khartoum, Sennar, Wadi Halfa; *Tanzania*: Arusha, Dar es Salaam, Mwanza.

Logistics and Organization

Students are assigned to regional teams to examine temperature and precipitation records from stations spanning broad ranges in both geography and climate (Figure 1). Teams with three to four students are typically the most successful; each team is responsible for approximately eight stations. In many cases, monthly data are available for almost a century. Prior to working with the data or addressing the underlying scientific question, students must prepare maps of their regions and practice pronouncing the station names. This step is far from trivial, as it challenges students to confront their lack of geographic awareness and intercultural sensitivity. We have chosen to focus on supra-equatorial Africa, but a similar exercise could be designed for any region of interest to the students and instructors.

Obtaining climatological data for this project is remarkably easy. Rainfall records can be downloaded from the Africa Data Dissemination Service (ADDS) web site <http://edcintl.cr.usgs.gov/adds/adds.html>, which is maintained by the EROS Data Center (USGS) to support the United States Agency for International Development's (USAID) Famine Early Warning System (FEWS). FEWS is a multi-disciplinary project that provides information to decision-makers about potential famine situations, allowing them to authorize timely initiatives to prevent famine outbreaks. In addition to tabular data (such as precipitation and agricultural statistics) the ADDS web site provides satellite data and downloadable digital maps that make excellent additions to the project (for example, soils, cropland-use intensity, roads, hydrology, vegetation, population). Most stations with appropriately long records of precipitation have lengthy temperature records as well. Temperature data can be accessed from the National Climatic Data Center <http://www.ncdc.noaa.gov> or purchased from EarthInfo, Inc. in Boulder, Colorado in a user-friendly format. We prefer to hand each group a diskette with data files for each station rather than expecting them to obtain the data directly from the web.

Many high-school classes discuss global warming in very general terms, but rarely are students given the opportunity to take on the role of scientists and investigate global-climate trends. Any teacher with access to a computer lab can adapt this lesson for a high-school earth-science course. To help students understand the process, select one station and have each person make graphs from a common data set. Emphasize the importance of accuracy and completeness, allowing students to catch errors in this phase of the project before they receive team data sets. A class discussion about the implications of the single data set will help students understand the need to look at a larger region. Next, assign students to learning teams and follow the lesson plans suggested for the college course. Designing a grading scheme that tells students ahead of time how many points will be awarded for each phase of the project will help them stay focused and motivated.

This project has been used successfully in general-education classes with up to 100 students without a teaching assistant. In large classes it is essential to form groups on the basis of prior performance and expertise, and we recommend this approach regardless of class size. Group projects are inherently complicated because of the many external demands on each individual. A student on a varsity sport team or with a small child, for example, may be unable to attend meetings outside of class. The instructor helps most by making class time available for the students to work together and also by providing guidance immediately when needed. Procrastination is often a problem with projects that extend over many weeks, but by establishing a framework of many deadlines one can help combat this problem. Problems of personality and internal disharmony may arise as well, but within a structured setting, they can be minimized.

Quantitative-Skills Development

Three specific skills are addressed by this project: data assessment, spreadsheet manipulation, and statistical analysis of trends. The process of examining data provides opportunity for instruction in quantitative scientific methodology because we can introduce questions of sampling methodology, reproducibility, and natural variation within data sets. Students typically do not have prior experience working with large data sets where the quality of available data ultimately determines the reliability of conclusions drawn. As regional teams evaluate their stations, they find that the length and consistency of individual data sets varies considerably. We require students to investigate the factors that could be responsible for missing data, which include both climatic (for example, drought) and political (for example, change in government) considerations. By making explicit linkages to human events, the study of climate can take on personal meaning. In addition, this process enables students to evaluate the overall quality of their data record and its reliability for making interpretations.

Defining the climate of individual stations requires patient analysis of the available data. Each regional team prepares graphs that show the timing and duration of rainy seasons, monthly temperature variations, and long-term records of annual rainfall for each station (Figure 2). This phase of the project introduces students to the art of plotting data. Students, particularly those with limited computer experience, must learn to think critically about the graphs they generate. One month of missing data can render total annual rainfall inappropriate for trend analysis, so each datum must be plotted with caution. Monthly rainfall amounts may vary by up to three orders of magnitude between stations, raising questions of axis scaling. Most students overestimate their expertise with spreadsheet manipulation, making faculty guidance important. Common problem areas include calculating averages when individual data are missing, and customizing symbols, legends, and axes.

The statistical analysis of annual rainfall trends enables students to explore climate change. This phase of the project also introduces hypothesis testing, as students propose relationships between temperature and rainfall that they can evaluate graphically. For example, some students expect to see an inverse relationship between average annual temperature and rainfall, while others look for temperature variations during only the rainy or dry seasons. Two aspects of this phase may be particularly troubling to students. First, trend lines generated automatically by the computer may not be appropriate to the questions being addressed. We encourage students to calculate moving averages with twenty-year windows prior to – or in lieu of – calculating a linear regression for an entire data set. In this way we emphasize the need to think critically about the data as well as the computational scheme. Second, the temperature data rarely show consistent trends. Many students feel that they have "failed" if they do not discover long-term patterns. As noted by Shea (1999), the combination of an imperfect data set with a novice interpreter renders

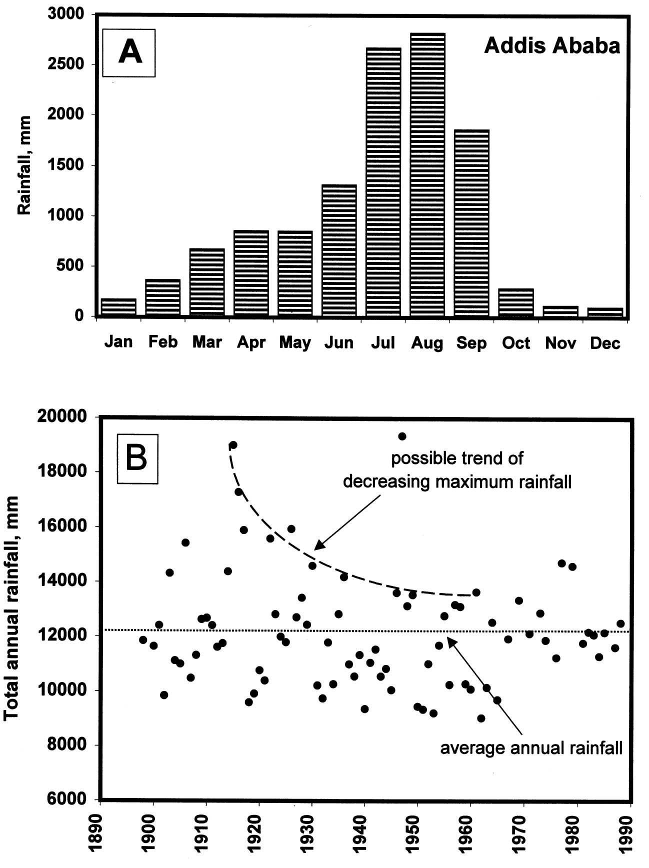

Figure 2. Examples of student work using data for Addis Ababa, Ethiopia (1896-1989). A. Magnitude and duration of the rainy season in the Blue Nile headwaters region. B. Average annual rainfall, showing a postulated multi-decade climate trend.

most temperature studies of this sort useless as indicators of climate change. This result is itself very important to student learning. Fortunately, annual rainfall values commonly fluctuate on a 20-50 year time scale, so the opportunity exists for students to demonstrate improved facility with data analysis. For example, decreasing maximum annual rainfall in the Ethiopian highlands between 1915 and 1960 (Figure 2) correlates inversely with rainfall in the equatorial lakes region, a pattern between 650 and 1960 on the basis of Nile flow levels described by Hassan and Stucki (1987).

Products and Grading

Each regional team must develop a case for or against climate change in its area. The findings are presented to the class orally and written up in a preliminary technical chapter. To integrate the project over a wider spatial scale, team members meet to compare findings across regional boundaries (in a small class, every student can be involved in this step). It is rewarding to listen to individual team members express ownership of their stations and their data. The outcome of these discussions is a synthesis that is incorporated into the final technical report, along with the revised regional chapters.

Grading any complex project is difficult, so we focus on the steps as well as the final product. The preliminary and final technical chapters are graded for style and content. The quality of writing is better if team writing assignments have been done throughout the term, and it is helpful to show the class a sample chapter outline to assist them in distinguishing between data and interpretation. Oral presentations are graded on completeness and clarity, including the figures. A peer evaluation of group participation is done as part of each student's final grade; we have found students to be quite forthright in their peer and self-evaluations.

Observed Learning Outcomes

We feel that the most important learning outcome is the ability to think critically about both data and its statistical interpretation. The scientific results of this project enable students to assess their preconceptions about global climate change and the ease with which it can be documented. This result is critically important to the students' views of both scientific and political aspects of the global-warming debate.

The written reports give students an opportunity to improve their technical writing skills, most significantly in the area of incorporating figures. Each group is required to provide the figures necessary to substantiate its conclusions. This step provides a context in which to discuss the need for clarity, brevity, and artistry in presenting figures and linking them to the written text. We observe that students commonly skip over figures in assigned readings or view them as optional accessories, rather than recognizing them as the vehicle for presenting primary data. As the students prepare their oral presentations, this perspective changes.

Students who have completed the project have been enthusiastic about developing posters showing their results. Their posters make excellent contributions to departmental recruiting efforts and also lend themselves to outreach efforts with local schools. Structured artwork opportunities also give students with a wide range of talents the opportunity to showcase their abilities, helping each person feel ownership of the project and its outcomes.

Final Comments

This style of teaching is very time consuming for the instructor. It is much more difficult to develop constructive and engaging group research activities than to pull together a 50-minute lecture on a familiar geological topic. Our experience shows that the end results, however, are rewarding for both the students and the faculty members. Students who engage in collaborative learning retain the material longer and have more interest in the subject than those who experience passive lecturing (see, for example, Johnson and Johnson, 1982). When they experience the power and relevance of research in the geosciences, they may elect to major in our field or to promote it in their daily lives.

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