

Texas A&M University's Laboratory for the Exploration of Atmospheric Processes—TAMU's LEAP*

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ABSTRACT

Improvements in computer technology, particularly the explosive growth of Internet applications, have created unprecedented educational opportunities, but with concomitantly little experience on how educators can best take advantage of them. The Laboratory for the Exploration of Atmospheric Processes (LEAP) is a new 15-workstation computer laboratory operated by the Department of Meteorology at Texas A&M University. The setup and use of LEAP in a variety of undergraduate and graduate courses are described. Particular emphasis is placed on applications that use the World Wide Web or specialized meteorological software, with the aims of fostering greater discussion of computer-based teaching methods in meteorology and sharing and improvement of Web-based teaching materials.

1. Introduction

Meteorology educators have for years been struggling with technological issues related to the teaching of meteorology (e.g., Smith et al. 1992, 1994, 1995). New observing systems have greatly enlarged the amount of material essential to an undergraduate meteorology education, including both the observing systems themselves and the atmospheric phenomena they detect (Ramamurthy et al. 1995). At the same time, improvements in computers, meteorological software, and data availability are expanding the possibilities for teaching techniques and classroom and laboratory activities, but with additional costs and difficulties to overcome (Wash et al. 1992; Ramamurthy et al. 1992; Byrd et al. 1994).

This article describes the physical aspects and educational use of the Texas A&M University's (TAMU) Laboratory for the Exploration of Atmospheric Processes (LEAP), a 15-workstation UNIX-based computer laboratory in the Department of Meteorology at Texas A&M University. The LEAP was funded through proposals to the National Science Foundation's Instrumentation and Laboratory Improvement (ILI) and Unidata Equipment Award programs, along with matching funds from Texas A&M University, the College of Geosciences and Maritime Studies, and the Department of Meteorology. Its installation in spring 1994 coincided with the explosive growth of the World Wide Web, the rapid utilization of Web browsers such as Mosaic and Netscape, and the use of Hypertext Markup Language (HTML) for constructing interactive, computer-based instruction modules.

The purpose of this article is to discuss trade-offs made in designing and using the LEAP and to show how this computer laboratory is used to enrich the undergraduate and graduate meteorology curricula. Given the recent rapid advances and usage of the Internet, emphasis is given to HTML and other World Wide Web-based teaching applications. Our goal is

*A hypertext version of this article, with active links, may be accessed at the following URL: <http://www.met.tamu.edu/class/LEAPPaper.html>.

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to promote the exchange of ideas, software, and learning materials among institutions. We hope to inspire others to explore ways of incorporating new computer-based teaching methods in the classroom and to share their experiences, in what is surely a learning experience for all of us.

2. Hardware

A schematic diagram of LEAP, along with other elements of the departmental computer facilities essential to its use, is shown in Fig. 1. The heart of LEAP is a set of 14 low-end Silicon Graphics, Inc. (SGI), workstations and a high-end SGI workstation/server named Nimbus. Nimbus is an SGI Indigo-2 workstation with 96 MB of memory, 18 GB of hard disk storage capacity, an 8-mm 5-GB tape drive, a CD-ROM drive, a 19 in. 1280 × 1024 24-bit color monitor, and a Galileo video board, and acts as a disk server for the other SGI machines. Another workstation handles data ingestion, receiving such National Weather Ser-

vice data streams as HDS (high-density data stream), DD+ (domestic data plus), the International data feed, the McIDAS data feed, and NIDS (NEXRAD Information Dissemination System) data over the Internet and processing the data using Unidata's Local Data Manager (LDM) software.

The 14 other SGI workstations are Indy SCs, each having 48 MB of memory, 535 MB hard disks, and video cameras. The monitors are 8-bit color, 1280 × 1024 resolution, and 16 in. diagonal in size. The high resolution and smaller size of these monitors is well suited for up-close use by one or two students per workstation, while the 24-bit graphics on Nimbus is needed for videotape production and projection.

The other essential piece of equipment needed to meet our teaching objectives is a high quality projection system, in this case, a Proxima 2800. The Proxima receives the composite video signal from Nimbus via the Galileo video board and projects it onto a white wall in the computer laboratory. (The Proxima can also receive output from Macintoshes and PCs and is often used in other classrooms when not in use in the LEAP.) The instructor can thus conduct interactive discussions with the class using Nimbus to display images that are easily viewed from any seat in the classroom. This aids the instructor in clarifying material being presented and in emphasizing important detail that may be difficult for the untrained eye to interpret.

The layout of the laboratory consists of parallel double-sided aisles, with a whiteboard at one end of the rows and a blank wall (for projecting images) at the other end (Fig. 2). The chairs swivel and roll, so that students can direct their attention to either end of the room. The design of the laboratory was constrained by size and by the requirement that the instructor had to be able to conduct interactive discussions, displaying imagery in a manner that provided easy viewing of the material from any seat in the classroom. A more traditional arrangement, with all chairs facing the same direction, was rejected because it did not allow the instructor quick and easy access to every computer in the room. Together, an instructor and a teaching assistant can monitor every student's progress and be at their side quickly to provide help should a problem be encountered.

At the time of purchase, the 15 LEAP computers retailed for approximately \$232,000. Through educational and other discounts negotiated with SGI, the actual purchase price was about \$151,500. With the additional equipment and furnishings, the total price paid for LEAP was near \$158,000. Recurring costs

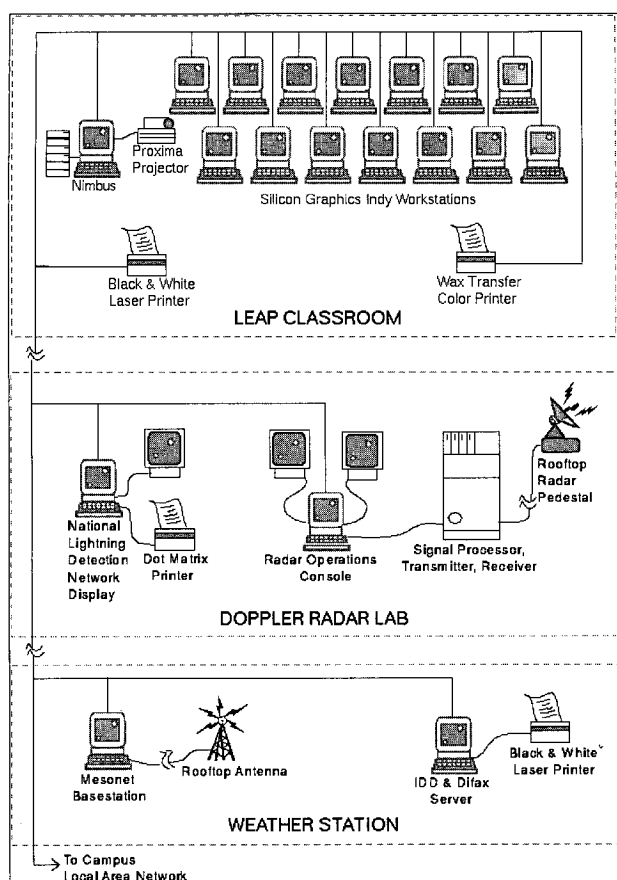


FIG. 1. Schematic diagram of Texas A&M Department of Meteorology educational and data collection computing facilities.

involve personnel for hardware and software maintenance [$\frac{1}{2}$ full-time employee (FTE)] and development ($\frac{1}{2}$ FTE), along with hardware and software maintenance contracts (\$7,350 per year).

3. Classroom applications

a. *Weather Forecasting (METR 151)*

Vincent and Smith (1995) have suggested several techniques for encouraging and maintaining students' interests in meteorology. Among them are "offer/require a freshman level course to be taken, ideally, in the first semester/quarter," "have some kind of computer-based instructional facility," and encourage participation in "a weather forecasting 'game'." Weather Forecasting (METR 151; Nielsen-Gammon), first taught in fall 1994, was designed to encourage and maintain interest in meteorology among freshman and transfer meteorology majors, and includes all three of the above approaches. An additional benefit of the course is the building of relationships and support structures among young students with common academic and professional interests.

The organizing and motivating agent for the course is the National Collegiate Weather Forecasting Contest (NCWFC), run by The Pennsylvania State University (Penn State) and cosponsored by Penn State, the American Meteorological Society, and Accu-Weather, Inc. In the NCWFC, which annually has about 600 participants from 30 institutions, forecasters compete



FIG. 2. The workstations in the LEAP are arranged in parallel rows, and computer graphics may be projected onto the walls at either end. Here a close-up of a surface map from Purdue University's WXP Web site is being used in the daily forecast discussion for METR 452 (Dynamics of Weather Processes).

against others of the same education level while making daily (Monday through Thursday) forecasts of the next day's maximum temperature, minimum temperature, and precipitation amount at a U.S. city. The forecast city changes at the end of each 2-week period, giving forecasters a taste of weather in a variety of locations. In the fall, METR 151 students forecast for five periods and part of a sixth, making 44 forecasts in all. In keeping with the format of the NCWFC, each section meets four times a week, in late afternoon.

METR 151 was inspired by a seminar taught for many years at the Massachusetts Institute of Technology by F. Sanders. Since there is no formal undergraduate seminar program at Texas A&M University, the course is worth one credit hour, and the liberal grading policy is based on attendance, two quizzes, and a forecast discussion, with extra credit available for forecasting performance. Unlike the MIT course, which featured a daily weather map hand analysis, METR 151 is taught almost entirely within LEAP, and relies fundamentally on the World Wide Web and computer graphics in its design and lesson content.

At the beginning of a typical class, students log in and bring up Netscape Navigator, a Web browser available free of charge to universities. The METR 151 home page (<http://www.met.tamu.edu/class/Metr151/151home.html>; an example from the last day of class, fall 1995, is shown in Fig. 3) includes a variety of current images (either generated locally or downloaded to a local disk), links to other TAMU weather resources, and a link to a listing of useful sources of Web meteorological data for weather analysis and forecasting. On Monday or Wednesday, the session starts with a 25-min lecture. The lecture content loosely follows a syllabus but is driven by current weather events or the day's forecasting problems. Maps and images that illustrate various points are projected onto the wall and discussed, and since links to the images appear on the home page, students can follow along on their own computers or review some of the images at a later time.

The lecture is followed by a forecast discussion, which during the latter half of the course is given by the students themselves on a rotating basis. The students follow a prescribed format in talking about the previous day's forecast, the current situation, and their ideas for the forecast for tomorrow. The students incorporate other maps on the home page into their discussion, and during the preparation of their discussion they may have downloaded images themselves from various Web sites for use in their presentations.

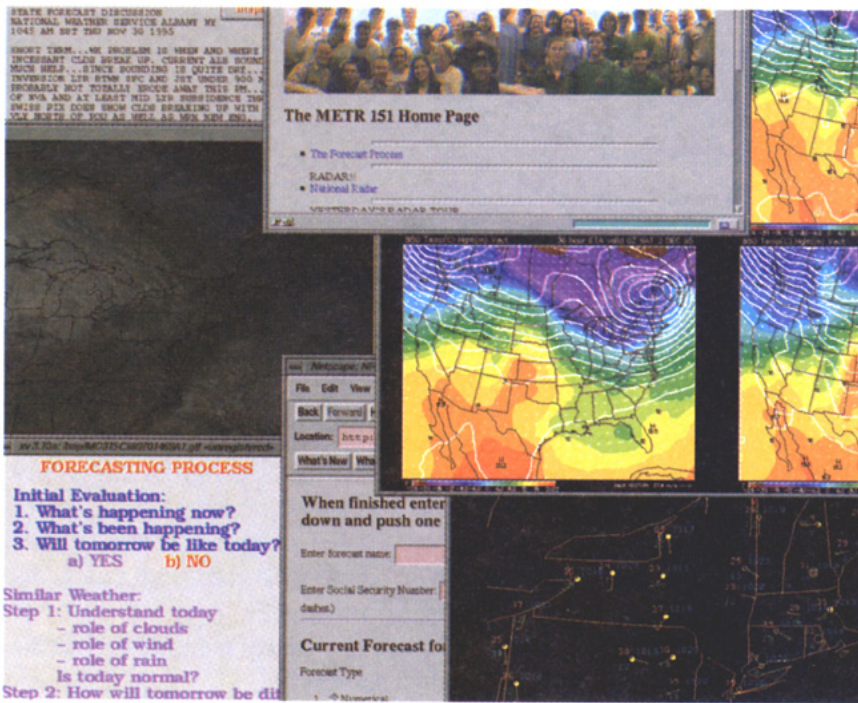


FIG. 3. Examples of images and forms accessed by students from the home page during a session of METR 151 (Weather Forecasting), with the objective of making a 24-h forecast for Albany, New York. Clockwise from top: the METR 151 home page; a four-panel 850-mb forecast downloaded from Purdue University's WXP Web site; a current surface weather map generated locally with GEMPAK; the Web form for entering forecasts; a forecasting flowchart; a visible satellite image, downloaded from the University of Wisconsin's Space Science and Engineering Center Web site; and the National Weather Service forecast discussion for Albany.

During the final few minutes of the class, students prepare and enter their own forecasts. Students have the entire Web at their disposal, including locally developed Web-based interfaces to the Weather program for obtaining alphanumeric data (http://www.met.tamu.edu:80/personnel/students/weather/weather_interface.html) and a set of locally generated maps and images (<http://www.met.tamu.edu/weather.shtml>). When they have settled on their forecast, they enter it by filling out an HTML form, part of TAMU's student-maintained unofficial NCWFC home page (<http://www.met.tamu.edu/forecast/scores.html>), which also contains scores and descriptions of cities and participants.

Using the Web as the foundation of a class such as this has several advantages:

- 1) Rather than spending several hours preparing graphics from current data for use during lecture, the professor or teaching assistant takes an hour or two to select from a wealth of maps and images that have already been prepared by dozens of in-

stitutions across the country and around the world. Lectures and discussions closely approach the normally competing goals of immediacy and comprehensiveness.

- 2) The wealth of information available, within the context of a forecasting contest, provides an excellent and appropriate environment for self-directed learning, an effective learning technique that is infrequently available to undergraduate students during their math and science courses.
- 3) Although forecasts are being made for specific cities, the variety of available information permits a global view of weather and the environment. For example, live weather cameras work very well for teaching students how to translate observations and numerical forecasts (<http://www.met.tamu.edu/bestrest.html#cams>) into a

sense of what the weather is actually like at a given place. Also, weather events around the globe are accessible for study: when a rare binary tropical cyclone system formed over the western Pacific (Lander 1995), the class followed its evolution day by day using satellite images from servers in Australia and Japan and requested and received souvenir printouts of a satellite image showing the merger of the two cyclones.

b. Other courses using HTML and the World Wide Web

1) RADAR AND MESOSCALE METEOROLOGY (METR 475)

METR 475 (Biggerstaff and Hristova-Veleva 1995; M. Biggerstaff et al. 1996, unpublished manuscript) has taken the lead at Texas A&M University in using LEAP and hypermedia for locally developed hypertext-based laboratory exercises appropriate to seniors and graduate students. Radar and Mesoscale Meteorology is a four-credit course that combines 3 h of lecture per week with about 2 h of weekly labora-

tory. The mesoscale meteorology component covers the kinematics and elementary dynamics of convective storm systems since these storms provide excellent opportunities to apply theoretical concepts discussed in radar meteorology.

The laboratory component of the course contains 12 HTML-based exercises (<http://www.met.tamu.edu/class/Metr475/Lab475.html>, Fig. 4), some of which are based on data collected using the Texas A&M University 10-cm Aggie Doppler Radar (ADRAD; Guynes et al. 1991). Students are also given an opportunity to manually operate the ADRAD, though the typical 30-person class size severely limits the amount of time each student has with the radar. Indeed, the motivating factor for developing the laboratory exercises was to expose each student to examples of storm observations that correspond to the topics presented in the classroom. Nature seldom produces useful radar echoes during scheduled class periods, so exercises were developed from previously collected data.

It would have taken a single investigator several years to assemble and analyze suitable datasets to cover the vast range of topics in the exercises. Fortunately, by taking advantage of HTML, it was possible to construct computer-based teaching modules from analyses freely available in the published literature. Much of the imagery used in the modules was created by electronically scanning color pictures using a Hewlett Packard ScanJet-IICX color scanner attached to a PowerPC Macintosh. Figures were edited using Adobe's Photoshop, converted to GIF format files, and transferred to the department Web server, where HTML documents were created with links to the GIF images.

The use of HTML simplified the development of the laboratory exercises in two ways. First, the instructor did not have to find and analyze a variety of raw datasets. Second, with the point-and-click interface of hypertext

and Web browsers, the students did not have to be trained on complicated scientific data analysis and display software such as the Research Data Support System (Oye and Carbone 1981), Zebra (Corbet et al. 1994), or SOLO (Oye et al. 1995). Third, while a single dataset might involve two volume scans and require 60 MB of disk space, the complete set of modules requires only 40 MB of disk space, so the images are always on-line and students have the ability to access the material whenever they desire, such as prior to exams.

Unlike printed exercises, the hypertext modules are easy to update and correct: old images can be replaced with new images and theories and references can be kept current, with no additional costs for printing or reproduction. This advantage is offset by a serious disadvantage of hypertext modules: preparation time. The radar modules required an average of 100 h to prepare, including generating or gathering images, generating text, processing images, designing and

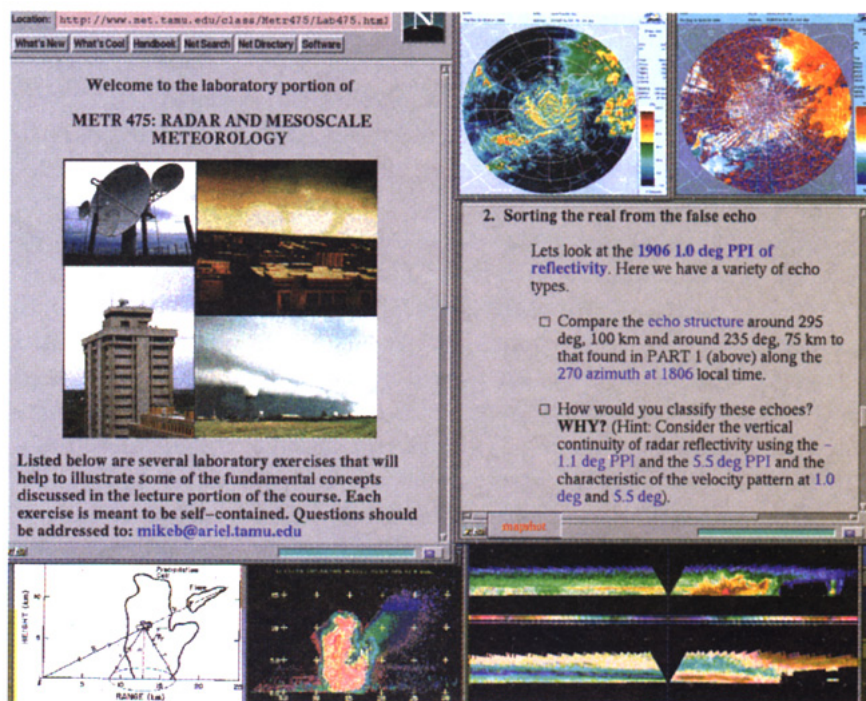


FIG. 4. Excerpts from the METR 475 (Radar and Mesoscale Meteorology) HTML tutorials. Upper left: the METR 475 home page, including images of the 10-cm Texas A&M University Aggie Doppler Radar (ADRAD) antenna atop the Eller Oceanography and Meteorology Building on the main campus in College Station, Texas. Upper right: low-level ADRAD scans from the ground clutter and anomalous propagation module, which is shown, in part, below the radar images. Lower right: reconstructed vertical cross section through a midlatitude squall line system illustrating a portion of the mesoscale component of the laboratory material. Lower left: Conceptual model and vertical cross section of radar reflectivity through an intense storm that is producing a reflectivity flare (from Wilson and Reum 1988).

implementing interactive exercises, and formatting the HTML document. The content and use of the modules will be described in greater detail in a forthcoming article (M. Biggerstaff et al. 1996, unpublished manuscript).

2) ATMOSPHERIC SCIENCE LABORATORY (METR 304)

New HTML-based laboratory exercises (<http://www.met.tamu.edu/class/Metr304/Metr304.html>) in Atmospheric Science Laboratory (METR 304; Alcorn), the one-credit laboratory companion to the introductory atmospheric science course, also took a tremendous amount of time to develop. Nonetheless, since this introductory course is often taken by nonmeteorology majors to fulfill university science requirements, and since a large portion of the science of meteorology is conducted with computers, it is important to include computer-based learning modules in this course.

Students are first taught how to read and interpret weather information plotted using the standard station model. From there the lessons proceed to analyzed fields using current weather observations available on the World Wide Web. Rules and examples for contouring are presented, and the students perform hand analyses of temperature and pressure from data they plotted earlier in the lab exercise.

Other HTML labs are designed to illustrate the mean vertical structure and chemical composition of the atmosphere and as well as the physical properties and characteristics of different cloud types. Since displaying temperature lapse rate involves plotting one variable against another, part of these lessons are devoted to general interpretation of graphs. The current day's time series of surface observations from a local station is used to further emphasize graphical interpretation in a manner that students can physically witness. Students experience firsthand the changes in temperature, and by comparing their sensations to a graph of temperature as a function of time they more easily grasp the physical interpretation of graphically plotted information. The use of computers reduces the time required for generation of graphs and increases the time available for the interpretation of graphs.

Like more conventional laboratory exercises, which allow students the opportunity to use simple equipment to measure elements of the atmosphere and to interpret their measurements, the HTML exercises are supplemented with short lectures and questions that guide students in understanding meteorological

phenomena. Eventually students will enter their answers using HTML forms that can be electronically mailed to the instructor.

c. Courses using specialized software

Many of the problem sets in the undergraduate dynamics sequence (METR 336 and METR 435; Bowman) are LEAP-based exercises involving simple programming in IDL (Interactive Data Language). The goal of the computer-based portion of the dynamics sequence is to give the students an understanding of the relationship between dynamical equations and weather phenomena by exposing them to the essential elements of numerical weather prediction models. IDL, with its built-in graphics libraries and recursive function-calling ability, greatly enhances the ease and speed at which students can complete their programming assignments.

After a 1-h tutorial session, students are assigned IDL-based homework sets and are encouraged to work in small groups to solve the problems. The simplest exercise involves integration of the hydrostatic equation from a sounding of temperature. More advanced exercises involve solution of ordinary differential equations to calculate two-dimensional trajectories using analytic flow fields. This allows the students to see firsthand the differences between trajectories and streamlines, a concept that is often difficult to visualize.

Later in the sequence, the students construct a nondivergent barotropic vorticity equation model using IDL and perform numerous calculations based on this model. One homework set involves initializing the model with a Rossby wave and watching the wave propagate through the model domain (Fig. 5). This allows the students to tie together the theoretical concept of wave dispersion with observations. Simulation of barotropic instability is another exercise that is based on the simple numerical model. Using the projection equipment in the LEAP, the model can be run in real time, and the resultant fields displayed and discussed during class.

The undergraduate synoptics sequence (METR 451; Djurić, and METR 452; Nielsen-Gammon) includes programming exercises in both IDL and FORTRAN. The exercises are directed toward giving students an appreciation for the technical aspects and nuts-and-bolts of numerical weather prediction. Among the topics studied are finite-difference calculations, staggered grids, map projections, numerical integration, numerical instability, and successive overrelaxation.

Students also give forecast discussions using maps and images from the weather map display wall and from the Web. As the sequence continues, the students are trained on various meteorological software packages such as GEMPAK, McIDAS, and VIS-5D. These software packages are used for case study analysis of synoptic-scale and mesoscale weather systems. Students are able to generate their own diagnostic quantities, such as Q-vectors and potential vorticity, and use VIS-5D to study parcel movement and air-flow in a cyclone as forecasted by NCEP (the National Centers for Environmental Prediction) models. By the end of the sequence, students are performing case study analyses by computer that would have taken months or years to execute prior to the installation of LEAP (Fig. 6).

While the elementary undergraduate courses teach students how to look at weather maps and forecast maps, the upper-division synoptic courses teach students how to generate weather maps and analyses, how numerical forecasts are produced, and how to use the available technology to generate forecasts of their own. Providing students experience with a variety of meteorological software packages is a secondary but real goal; we intend that our graduates be both meteorologically and technologically literate.

d. Using LEAP in graduate studies

LEAP is also used in graduate-level courses, primarily as a problem-solving tool but also occasionally for its access to current worldwide data and as a visualization laboratory. When not in use by a particular class, LEAP is heavily utilized by graduate students conducting thesis research, making weather forecasts, preparing storm-chasing expeditions, or just exploring the Internet.

Between 10% and 20% of the current homework assignments in the basic graduate-level dynamics

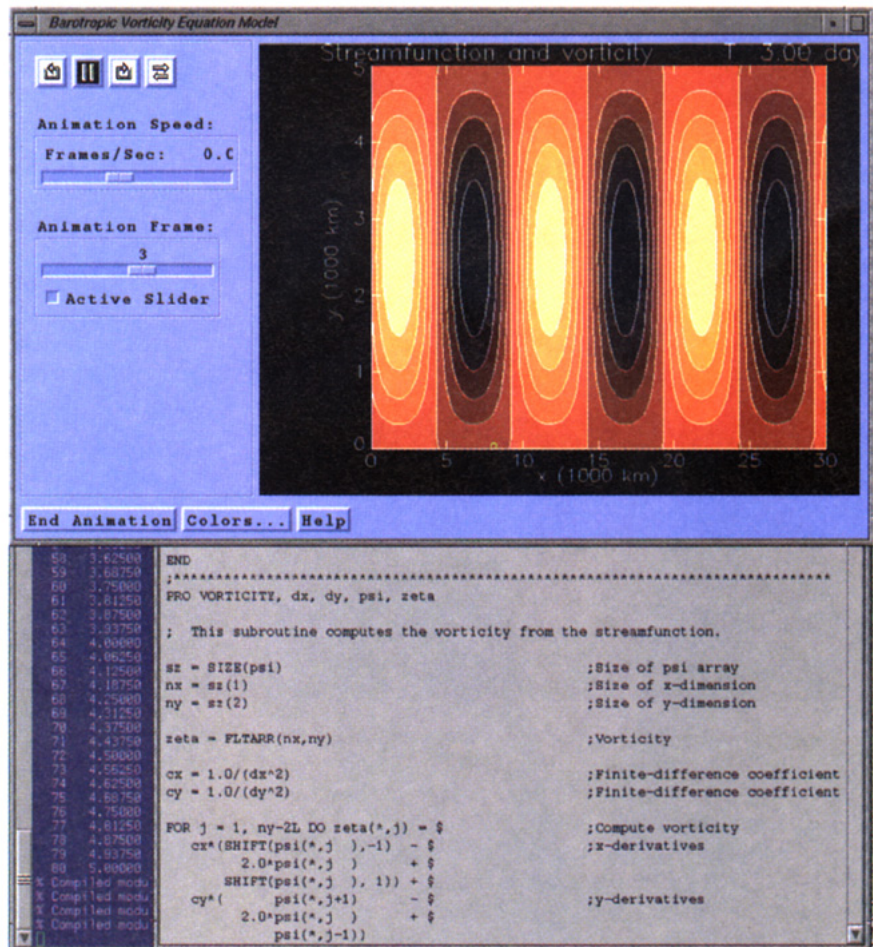


Fig. 5. A sample IDL session from METR 435 (Atmospheric Dynamics II). Shown are one frame in an animation of a barotropic Rossby wave simulation, an excerpt from the IDL source code that generated the simulation, and the window from which IDL commands are issued and status messages returned.

courses (METR 601 and 636; Panetta) and Turbulence (METR 661; Panetta) assume the easy access to computers provided by LEAP. As in the undergraduate dynamics courses, the visual representation of such basic phenomena as wave propagation, interference, and dispersion helps students understand both the phenomena and their analytical representations. Quite often we have found that students claim to understand a concept, such as the growth of an unstable mode, but cannot describe how a fluid would behave during this process.

LEAP has allowed students in these courses to develop a much richer understanding of the behavior of geophysical fluids. Solutions to simple problems with complicated closed-form solutions, or without closed-form solutions at all, can be easily examined. In addition, term projects now often include components requiring substantial numerical work, such as the de-

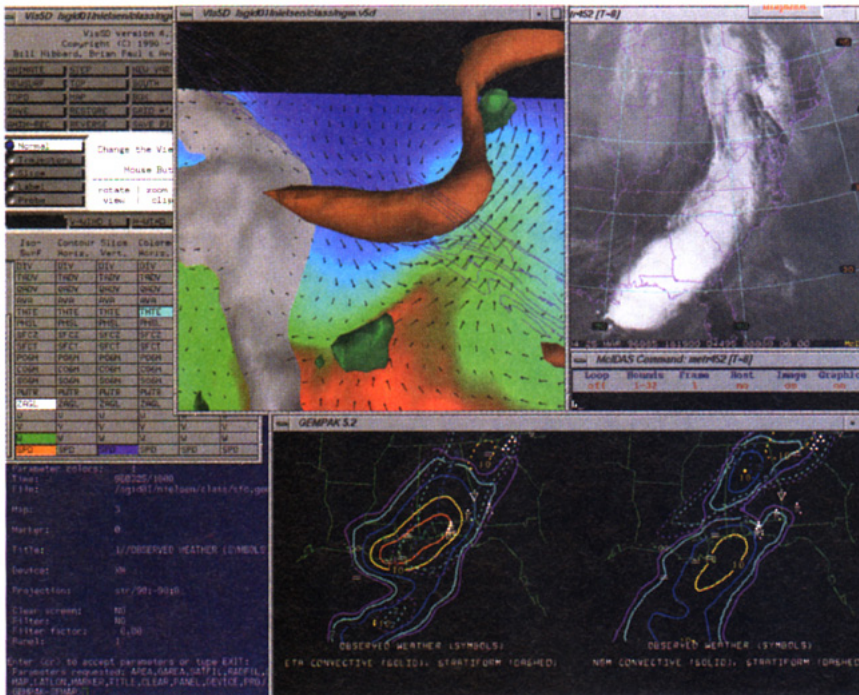


FIG. 6. Examples of software tools used in a case study analysis during METR 452 (Dynamics of Weather Processes). Upper left: the VIS-5D Graphical User Interface and the VIS-5D display window showing a frame from an NGM forecast. Shown are isosurfaces of topography (white), wind speed (orange), and upward motion (green), a contour slice of wind speed (purple), and horizontal slices of low-level winds (vectors), and equivalent potential temperature (color spectrum). The domain includes most of the continental United States and southern Canada. Upper right: a corresponding McIDAS infrared satellite image, remapped onto a stereographic projection, and the McIDAS command window beneath it. Lower left and right: the GEMPAK user interface and GEMPAK graphics window, showing convective (solid) and stratiform (dashed) precipitation forecasted for the 6-h period ending at the same time as the other two images, from the eta model (left) and NGM (right). Surface weather observations have been overlaid onto the contour plots. Except for the VIS-5D file, which was downloaded from the National Centers for Environmental Prediction, all the data used in constructing these images were obtained through Unidata's Internet Data Distribution system.

velopment of a pseudospectral two-dimensional beta-plane model in the turbulence course. By writing and using Fourier transforms, solving initial value problems, and developing numerical models that conserve appropriate quadratic quantities to machine precision, students gain an immediate appreciation of the central ideas. With access to the CPU speeds and large internal memory of the UNIX machines in LEAP, students can use such models to explore a much wider variety of nonlinear phenomena than was previously possible.

Other graduate classes, such as Quantitative Methods for the Atmospheric Sciences (METR 603; Wicker) and Synoptic Meteorology (METR 658; Nielsen-Gammon) use LEAP as a resource for students. Programming or other computer-based exercises can be assigned to students with the confidence

that ample computer facilities are available for all students to carry out their assignments. Prior to the installation of LEAP, student access to computers depended heavily on the resources of whatever research group with which the students were affiliated. With the availability in LEAP of computers that are not restricted to specific research projects, all students are on an equal footing.

4. Issues

The LEAP has allowed us to make many enhancements to our undergraduate and graduate curricula. Nonetheless, we have encountered several complications in our quest to modernize our teaching methods. By sharing experiences in computer-based education we hope to encourage dialogue with other institutions toward finding solutions to the disadvantages of using this medium.

a. Advantages and disadvantages of HTML-based teaching

1) CONTROL

In a Web-based class such as METR 151, the most dramatic change from a more conventional classroom setting is a loss of control. The instructor no longer guides his or her students through a fixed lesson plan; the students explore on their own. This is the classic dilemma of self-directed learning: students may learn more effectively, but what is it that they learn?

The Weather Forecasting class is well suited to self-directed learning for several reasons. First, although there are many facts and concepts that must be mastered, what is being taught is largely a skill or method. Individual forecasters normally examine considerably different sets of products in the course of making forecasts. Second, there is constant feedback in the form of daily forecast verification. Students quickly discover gaps in their knowledge and are motivated to

fill them. Third, students generally work in pairs, which allows them to share ideas and discuss possibilities in a nonjudgmental and nonevaluative setting. Finally, forecast discussions allow students to share their ideas and techniques with the rest of the class, thereby increasing the collective knowledge base of the entire group and evening out disparities generated by independent learning.

2) RAPPORT

The Radar and Mesoscale Meteorology course is not as well suited to self-directed learning. To counter student disparities, class discussions are conducted at several points during the lab exercise. Using the Proxima 2800, the instructor projects selected images to clarify the main points of the lesson and to emphasize crucial details. This also gives the students opportunities to ask questions regarding material in the HTML document that they found difficult or unclear.

The need to interrupt the class to be able to interact with the students illustrates a serious disadvantage of HTML-based education. There is a loss of professor-student contact and rapport. When a classroom of students begins a computer-based module, a hush falls over the room as students read the instructor's words rather than listening to them. The instructor can have difficulty monitoring students' progress during the laboratory session because the questions are being asked by the computer rather than by the students or the instructor.

3) TESTING

A related issue is the problem of testing. How do you design a quiz, when different students have learned different things? In the Weather Forecasting class, we have partly side-stepped this issue by testing primarily on instructor-directed material. Fortunately, most new meteorology majors want to learn about weather forecasting and possess strong internal motivation, so the threat of a test is not needed to enforce learning. When we do test on the remainder of the course, we have relied primarily on short-answer and essay-type forecasting questions. Since there may a priori be no right answer to a forecasting question, the answers are graded on the basis of logical consistency and thoroughness.

4) FLEXIBILITY

Another notable disadvantage in using computer-based laboratory exercises that rely on material gen-

erated by the instructor is some loss of flexibility. When students have access to complete datasets and have been trained on the tools to examine them, they are free to examine and explore the data in unusual ways, to ask themselves different questions, and to attempt to find answers for themselves. In the computer modules, students only have access to images that have been generated specifically in support of that module. A trade-off is involved: students have more time to look at real data, but because they are no longer trained on analysis tools, their ability to explore that data is more limited.

To counter the loss of flexibility, each HTML lab would need a robust set of imagery that was independent of the material used to introduce the concept being taught. Students could then be asked open-ended questions that required analyzing several images to answer. Moreover, by having a large library of images to choose from, students would have to exercise deductive reasoning in selecting the images needed to answer the questions in a reasonable amount of time.

5) TIME

A final disadvantage of computer modules is the time required to assemble them. The METR 475 modules required an average of 100 h to design and construct. Traditional laboratory exercises can often be assembled on the fly with minimal development time and can therefore take advantage of real-time events, although the instructional design may be crude. In many cases, there is little institutional reward or value placed on the time an instructor spends designing computer learning modules.

6) COLLABORATION

Given the time invested in developing hypertext teaching materials, it is important to note that the greatest advantage of using HTML and the World Wide Web is that this medium facilitates collaboration in the preparation of educational materials. It is not uncommon to receive materials from researchers at other institutions who see ways to improve the HTML modules. Moreover, instructors at other institutions can download the lab exercises, or even have students work through them remotely via the Internet. Since the HTML source code is freely available, it is possible for outside instructors to modify or add to the educational material and make the changes available to the original author and to the rest of the educational community. The sharing of teaching resources will enable us to better educate the next generation of at-

mospheric scientists by taking advantage of the strengths offered at each institution.

7) STRIKING A BALANCE

The biggest trade-off for HTML-based exercises involves all of the above issues. It is our experience that the most successful computer-based modules are the ones that are the most interactive, with frequent questions for the students and different threads to follow depending on the students' answers or desires. Interaction and flexibility are incorporated into the module, minimizing some of the disadvantages of this form of instruction. However, the instructor pays a heavy price, because the increased interactivity requires a great deal more time from the instructor for constructing the module.

b. Advantages and disadvantages of using specialized software

1) COMPARTMENTALIZATION

To promote development of scientific investigative skills, it is often necessary to provide upper-division undergraduate and graduate students with training in advanced software. This can lead to a tendency for only the instructor teaching the course to develop the expertise needed to lead the class. One way to counter this tendency is to hold a series of sessions in LEAP to train faculty, staff, and students on general usage of the software packages that are available in the department for teaching and scientific research. Already LEAP has been used to conduct UNIX training (by D. Austin and R. White) for faculty members and incoming graduate students. LEAP was also instrumental in providing UNIX, GEMPAK, and HTML training to the Science and Operations Officers of the Southern Region of the National Weather Service during a workshop in 1995. We plan to hold more short software workshops to ensure that our students are acquainted with the resources available to them for their coursework and thesis research. A reviewer of this paper has suggested that a series of workshops replace the traditional 15-week semester format for certain courses, better serving students and faculty alike.

2) LABORATORY ASSISTANCE

When training students on complex or advanced software, or walking them through an exercise, software may fail or students may mistype a command. If the instructor stops to fix such a problem, the rest of the class is left hanging, while if the instructor continues with the lesson plan, some students will not be able

to follow along. In computer-intensive classes with 10 or more students, we have found it essential to have at least one teaching assistant aid the instructor during the lesson. When the computers are behaving well, the assistant can wander through the laboratory and answer informal questions. When something goes wrong with a particular computer, the assistant is there to solve the problem (or solicit outside help, if necessary) and help the students catch up with the rest of the class.

3) SUPPORT

Installation and maintenance of software represents another major concern in using specialized data analysis and display tools. Seldom are institutional resources sufficient to provide instructors with the professional programming assistance required to install, debug, and maintain teaching software. Without an active research program to maintain the scientific infrastructure, specialized teaching tools would quickly become obsolete. While it may be personally rewarding to develop sophisticated teaching materials, again there is little institutional motivation to do so.

4) LEARNING

Another disadvantage in using complex software is that the students tend to spend too much time on programming and learning how to use the software. As the amount of material covered for an undergraduate meteorology degree increases, time "lost" learning about computer programs rather than the atmosphere is sorely missed. Greater effort is required to complete computer-based exercises than more traditional laboratory exercises. However, the advantage of being able to visualize a complex dataset or results from a numerical simulation often outweigh the disadvantage of the increase in time required to complete the project. Furthermore, employers increasingly look favorably on graduates with practice in computer skills. The instructor must carefully weigh the options and strike a balance between computer training that is beneficial for its own sake, computer work that permits a better grasp of the subject matter, and laboratory exercises that would be better conducted by hand.

c. Hardware configuration

1) NUMBER OF STUDENTS PER WORKSTATION

The number of workstations in LEAP was driven partly by funding availability, but it proved to be an ideal number. With a typical undergraduate class size of 20–30, students tend to sit two to a workstation, while for multiple-section lab classes such as

METR 475 there is a workstation for each student. Two students per workstation allows for cooperative learning and helps to keep the group focused on the topic of the day. Students ask questions of each other and share ideas, automatically learning one of the most important techniques of weather forecasting. The informal environment encourages class discussions. When students work individually with computers, they are not as likely to question their assumptions and opinions, because they are not directly exposed to alternatives. On the other hand, three or more students per workstation invariably leaves at least one student at a distance from the computer, unable to operate the mouse or closely inspect the imagery. Although it would be physically possible for 40–50 students to fit into LEAP, we regard 30 (2 students per workstation) as its effective capacity.

2) OPERATING SYSTEM

At the time that the equipment proposals were written, several of the planned laboratory exercises involved the use of scientific data analysis and display software that could only be executed on a UNIX-based platform. Also, although most of the intended uses involved generating graphics on a UNIX platform and displaying them on client terminals, the reviewers of the proposals were skeptical that less expensive personal computers, such as Macintoshes, would be adequate.

As it turned out, the acquisition of LEAP coincided with the explosive growth of the World Wide Web. Most of the teaching methods that have been employed using the LEAP have relied on software that could run equally well in a Windows or Macintosh environment. Certainly the HTML-based modules require little more than a low-end PowerPC Macintosh to run. Even the IDL exercises could be executed on a PowerPC Macintosh without much loss in performance.

If use of the LEAP were restricted to undergraduate education, the least expensive hardware configuration would consist of a UNIX platform serving a PowerPC-based Macintosh lab. The UNIX server would be able to ingest the appropriate data streams and run the software needed to generate imagery that could then be served to the Macs. This configuration would be more cost effective than a pure UNIX-based teaching lab. However, at institutions that seek to use computer-based learning at the graduate level, the UNIX platforms may be necessary to carry out more complicated numerical simulations. With the LEAP, students have ready access to hardware needed for

advanced model development and elementary numerical studies.

A compromise solution might be a set of moderately priced PCs running the LINUX operating system. They would be capable of performing most of the programming tasks of the workstations but at less than half the cost. The current advantage of a UNIX computer lab is that it can serve both the undergraduate and graduate curricula and, when not being used by a scheduled class, it forms a powerful facility for scientific research. Nevertheless, as computational speeds continue to increase on RISC- (Reduced Instruction Set Chip) based personal computers, it may be possible within a few years to conduct all the computer-based exercises discussed in this paper on non-UNIX platforms.

5. Future directions

At Texas A&M University, the use of LEAP will continue to expand. As classes that now use LEAP learn how to better incorporate it into the learning process, additional classes will begin to take advantage of the facility. Indeed, there have already been scheduling conflicts with lower-division and upper-division courses that wish to make use of the facility. This had led to an effort to construct a second computer laboratory of personal computers, which can be devoted to hypermedia-type instruction, leaving LEAP for more computationally intensive applications.

Specific plans for METR 151 include replacing many of the 25-min lecture segments with interactive hypermedia modules. The modules would be designed to be 20 min in length so that a 5-min discussion session can round out the lesson. We believe that the computer format will be more engaging to the students, serve the purpose of a textbook, and allow students to learn and retain material rather than simply attending its presentation. The modules in METR 475 will be made more interactive with on-line forms and compel students to think and make more decisions about what they are viewing. Image libraries will be constructed, so that students will regain the opportunity to explore datasets and answer open-ended questions. Also, the number of computer-based modules in METR 475 and METR 304 will increase, while maintaining a balance between computer-based learning and physical interpretation of hands-on measurements. At the graduate level, students in a new convective modeling course will run one- and two-

dimensional cloud models to learn about thunderstorm dynamics, parameterizations, and other numerical modeling techniques.

Eventually LEAP will impact nearly the entire undergraduate and graduate curriculum at Texas A&M. During the modernization of our curriculum we wish to foster the attitude that the materials that have been developed at Texas A&M, particularly the HTML-based instruction modules, are fully interactive in the sense that they may be used and improved by other instructors. All of our HTML modules are made freely available through our Web pages, and we encourage other instructors to use them in a spirit of cooperation. Persons interested in the non-HTML exercises should contact the appropriate coauthor for additional information.

While we do take pride in authorship, the large amount of time required to develop these teaching materials makes us eminently grateful if another instructor finds ways to modify or improve them and shares his or her ideas or material with us. We encourage other instructors involved in generating classroom materials to follow the same approach. By taking advantage of the strengths available at each institution, we can provide the best possible education to future scientists and engineers.

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