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ABSTRACT

A meteorological instruments course that provided undergraduate geography students the opportunity to use and/or observe meteorological equipment while also preparing for possible internships with the National Weather Service is evaluated and suggestions for improving it in the future are offered. The paper first provides a general course evaluation. More than three-quarters of the total class time was devoted to using and discussing instruments that make surface measurements. The bulk of the paper, therefore, evaluates instruction regarding radiometers, temperature, atmospheric pressure, wind direction and speed, atmometry, hygrometry, nephometry, and hyetometry. The next time the course is taught, emphasis will be placed on the following three areas: First, the greatest amount of time will be devoted to surface instruments, especially those devices for measuring temperature, pressure, humidity, and precipitation. Second, the addition of a laboratory session will provide more time for the hands-on experience that students want. The final area of improvement involves more effort to combine the theoretical with the practical during lectures. (RM)

TEACHING A COURSE ON METEOROLOGICAL INSTRUMENTS

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Introduction

The Geography Department at Western Illinois University offered an intermediate level course entitled Principles of Meteorological Instruments for the first time during the spring semester 1984. The course served the needs of students concentrating on meteorology by providing them with an opportunity to use and/or observe meteorological equipment while also preparing them for possible internships with the National Weather Service. The greatest amount of time in the course was spent on the principles of instrument operation, including a comparison of their advantages, as well as disadvantages and how to select the best instrument for a specific type of observation. A mininal amount of time was devoted to how to properly tabulate and present meteorological data.

The textbook chosen for the course was entitled Instruments for Physical Environmental Measurements, Volume One by Wang and Felton(second edition). This book was used because it considered a variety of instruments, was up to date and was reasonably priced. Most of the material in the book was self-explanatory except that on occasion sections had to be read very carefully to separate the sometimes detailed quantitative discussion from a general qualitative explanation of how a particular instrument functioned. A background in electronics would have been useful in understanding the operation of some of the more sophisticated instruments.

Several items were placed on library reserve for the class to complement the textbook. The books by Berry, Coulson, Middleton, Robinson, Sellers and Stringer cited at the end of the paper were particularly useful as supplementary readings.

The WeatherMeasure Weathertronics instrument catalog was also a valuable reference. It provided pictures of every conceivable weather instrument, a description of how they functioned, specifications and a price list. All of this was very useful, especially for discussions of instruments that you could not afford to purchase but yet felt students should have some knowledge of their operation. There was also a glossary of terms for each group of instruments and conversion tables for temperature, pressure, humidity and wind measurements. The best part about the catalog was that it was free. Prices for the more common instruments were competitive with prices quoted in other instrument catalogs.

Purpose

The purpose of the paper was to evaluate the meteorological instruments course and to offer suggestions for improving it in the future. This was done by using a combination of student evaluations and personal reflections after the course was concluded. The results of this evaluation could be used as a guide for someone anticipating the development of a similar course.

General Course Evaluation

The main concern of students was the lack time to adequately discuss all the material in the two hour class which met once a week. This will be remedied next time the course is taught by adding a two hour laboratory which will have exercises utilizing the more common weather instruments to collect data under a variety of conditions. The laboratory experience will add more time to the course and also provide a hands-on approach which students felt was very important.

A short paper and presentation were required of each student in the class. The topic dealt with a meteorological instrument which was not discussed but only referred to in the text. Unfortunately, students were not pleased with this assignment. Some felt it was too much work for a two hour course and others objected to speaking before the class. Regardless of what form it takes, some sort of short presentation would help to improve written and verbal communication skills. Perhaps, a discussion of the results from each laboratory exercise would be an appropriate substitute.

The course outline was divided into three main parts. Part one examined the operational characteristics and requirements of instruments in general including their range, accuracy, sensitivity, response time, stability, reliability, ruggedness, portability, simplicity, cost and maintenance. This background knowledge was then used in comparing specific instruments to determine which one was most appropriate for a particular set of circumstances.

The greatest amount of time was devoted to the second part of the course which examined the instruments which measured and recorded atmospheric phenomena at or near the earth's surface. This included solar radiation, temperature, atmospheric pressure, wind speed and direction, evaporation, atmospheric humidity, clouds and precipitation. The least expensive instruments to obtain and the easiest to use in the class for demonstrations were those which measured temperature, pressure, humidity and precipitation. These instruments were also the ones most commonly encountered by individuals collecting meteorological data for government or private agencies.

If you cannot afford to purchase inexpensive thermometers, barometers, sling psychrometers and rain gages you should probably not contemplate a course on meteorological instruments. You could build your own instruments to help defray costs, and the books by Laird, Trowbridge and Yates cited in the references provide the instructions for building the more common instruments. This option, however, results in a product which is less sophisticated and certainly less accurate than the catalog instrument which students are most likely to use. If you have the time and materials you may want to consider some exercises which involve building some of the simplier and less costly meteorological instruments, such as a hair hygrometer, wind vane, rain gage or nephoscope. The accuracy of these erstaz instruments could then be compared to an instrument purchased from a catalog.

The third section of the course provided a brief introduction to upper-air instrumentation including upper-air sounding systems, ground monitoring equipment and aircraft techniques. The costs of such equipment were much greater than for surface instruments and the chances of using them were more remote. The only type of upper-air sounding equipment available for class inspection was a radiosonde donated by the National Weather Service. If supplemented with catalog pictures and operating specifications this section can be meaningful even though students do not observe the free flight and actual recording of data sent back to earth. A trip to observe the launch of a radiosonde would be a worthwhile experience if you are close to a place which periodically conducts such launches. Copies of the soundings from radiosondes and rawinsondes launched by the National Weather Service are available for selected cities from the National Climatic Center in Asheville, North Carolina for a modest charge. The soundings were discussed in class and may be incorporated into an exercise on upper-air instruments in the future.

The discussion of aircraft techniques for sounding the upper atmosphere was restricted to the textbook. This is a very specialized area and, although students might eventually operate instruments on aircraft, they are more likely to use radiosondes and rawinsondes for upper-air soundings. If time permits output from actual aircraft soundings might be obtained for classroom examination.

More than three-quarters of the total class time was devoted to using and discussing meteorological instruments which made surface measurements. Therefore, the final section will evaluate each group of instruments and make recommendations for improving the course in the future.

Radiometers

A discussion of radiometers should be included in a course on meteorological instruments even if they are unavailable for classroom demonstrations because of increasing interest in solar research. Caution, however, should be exercised so that too much time is not spent on the operation of a lot of similar instruments. It is better to use a few examples of the more common and readily available instruments such as the pyranograph, net radiometer, sunshine recorder and pyrheliometer that students might encounter rather than risk boring students with details about instruments they may never use. The books by Coulson, Robinson, Sellers and Wang cited in the references were excellent sources of general information, as well as details on all types of radiometers including some no longer in use. The manuals that accompany radiometers, or any instrument, you may purchase are sources of valuable information. They can help you learn how to properly operate and maintain a costly instrument.

The Geography Department has several radiometers which students examined. The Robitzsch bimetallic mechanical pyranograph has been used for over ten years to record daily totals of direct and diffused short wave radiation with accuracies of plus or minus five to ten percent. Students had the opportunity to see the instrument in actual operation on the roof of a building. The recorded values on the strip chart were examined but more time could have been spent by each student using the digitizer to convert the area under the daily curve to a solar energy equivalent. The star pyranometer was useful for instantaneous read outs only and could be used to compare response times of the recording pyranograph the next time the course is taught. Net radiometers are useful in a variety of micrometeorological studies for measuring solar and terrestrial radiation and should be discussed regardless of availability. The WeatherMeasure Measuretronics catalog provides a picture, description and specifications of these instruments, as well as other radiometers. Sunshine recorders should be examined because they are useful in solar energy studies and since there are only a few major types they should not take too long to discuss.

Finally, if time permits after discussing the preceding instruments the general operating characteristics of pyrheliometers could be investigated. These instruments are much more sophisticated because they only measure direct solar radiation, and therefore are considerably more expensive than pyranometers. Pyrheliometers are found at only a few places in the United States and thus it is less likely that students would ever use them. Even so, a discussion of these instruments would be useful in emphasizing the differences in operation and the difficulties in recording direct solar radiation compared to the pyranometer.

Temperature

A number of devices are available for the instantaneous measurement of air temperature. The most common and least expensive thermometers are the mercury and alcohol maximum/minimum and bimetallic. Classroom exercises could be developed which compare and contrast the range, accuracy and response time of these different thermometers. Each student can make measurements under a variety of conditions and record them in a table. The different results can be discussed in class to better understand instrument accuracy and the role of human error in such measurements. Hopefully, this experience will inform students how the instruments function, their assests, their liabilities and which works best in a certain environment.

If you have access to the more expensive electrical-resistance, thermocouple or thermistor type thermometers they can also be incorporated into the experiments which compared the operating characteristics of the more common thermometers.

If you have a thermograph, which makes a continuous record of temperature, you might want to compare the results with a maximum/minimum thermometer placed nearby for several days. There will be discrepencies which students can be asked to explain and comment on how adjustments could be made to improve accuracy. Finally, if time allows you may want to discuss special uses of orchard, soil, floating and submersible thermometers.

Atmospheric Pressure

The science of atmospheric pressure measurement is one of the most important to the field of meteorology. Most instruments for measuring atmospheric pressure are more expensive than most thermometers. Aneroid barometers are usually the least expensive type of barometer and can be used to develop demonstrations for the class. Students can record the differences and rate of change that occurred when an aneroid barometer is carried up and down in an elevator. This can be done several times to compare results from each of the students in the class. Hysteresis, which is the condition of not returning to the correct value when the cause of the pressure change is removed, can be examined by noting whether or not the aneroid barometer returned to the original pressure on the ground level by itself or did it require a slight tap to respond. Students can speculate why a tap is sometimes needed to register a correct reading.

If mercurial barometers are available the less accurate aneroid barometer can be compared to it to determine the margin of error. Proper installation of mercurial barometers should be discussed in class as well as the correct way of reading the instrument, especially the use of the vernier scale. The corrections required for temperature, latitude, altitude and individual construction differences should be discussed in class. Each student can be given the tables to make the necessary adjustments for several different readings as part of a class exercise.

A barograph or microbarograph records the atmospheric pressure on a strip chart which if available can be examined and periodically compared to the instantaneous readings of the aneriod and mercurial barometers. Pressure jumps on the chart of a microbarograph can be compared for sensitivity to a barograph record kept during the same time period.

Wind Direction and Speed

There are many different types of instruments available to measure and record the direction and speed of the wind. Unfortunately, most of them are expensive and are unlikely to be available to departments with even a modest equipment budget. To be meaningful some sort of permanent recording device is also needed so short-term wind records can be evaluated in class. Devices which convert and then transfer wind direction and/or wind speed to a permanent strip chart are very expensive.

The Geography Department at Western Illinois University has a skyvane (similar to aerovane and stratovane) which is a heavy-duty wind speed and direction sensor which utilizes a four blade propellor on a horizontal axis which is mounted on a vertical shaft. The cost of this unit including a translator and some sort of strip recorder can exceed several thousand dollars depending on the model. Since the department's skyvane was not yet permanently mounted outside it was not possible to observe the instrument while operating. Instead the instrument was displayed in class and its components and functions were discussed. The skyvane was also compared to the 3-cup anemometer regarding ease of use, accuracy and the environmental circumstances which would favor its installation.

A light weight micro-cup anemometer was also examined in class. Students had the opportunity to observe how sensitive the cups were even with the slightest air movement. This instrument recorded the number of revolutions of the cups and registered that figure on a counter. A table was used to calculate the average wind speed by comparing the number of revolutions during a certain period of time. The micro-cup anemometer has potential for exercises the next time the course is taught. Teams of students could record wind speed at different heights outside noting the variations in wind speed as elevation and exposure are altered. They could even be asked to determine the ideal height and best exposure for an anemometer placed on the top of a building.

The only other wind instrument available in the department was a totalizing anemometer which is frequently mounted next to a class A pan to assist in checking evaporation amounts. Average wind speed can be estimated from the difference between successive counter readings in miles divided by the elapsed time between these readings. The totalizing anemometer is portable and could be mounted next to the micro-cup anemometer for comparisons of sensitivity, response time and overall accuracy for light, moderate and strong winds.

Hand held devices for measuring wind speeds are available and range in price from ten to 100 dollars depending on the model. The Geography Department recently purchased one of these instruments for ten dollars. Its accuracy will be checked against the other anemometers in the department the next time the course is taught.

If you have time a discussion of bivanes which measure wind in several directions, pressure tube, sonic and hot wire anemometers should provide a reasonably complete picture of the more common wind measuring devices. Consult the WeatherMeasure Weathertronics catalog for details.

Windvanes and anemometers can be made but require considerable knowledge of electricity, money for materials and mechanical ability. A trip to the National Weather Service to observe wind instruments and/or the use of weather instrument catalogs may compensate somewhat for a lack of equipment when discussing this group of instruments.

Atmometry

The measurement of evaporation from solid or liquid surfaces is called atmometry. The brief discussion of evaporation instruments in the course was restricted to liquid surfaces. The Geography Department has a Class A evaporation pan which measures free-water evaporation but unfortunately it can cost in excess of 1000 dollars with accessories. An alternative to this high cost is to make evaporation pans from a variety of containers which have a relatively large surface area. Students can keep daily records of evaporation losses both indoors and outdoors. Results from these experiments can be compared to a Piche evaporimeter (about $150) which measures rates of evaporation by means of a tube which is filled with water and closed at one end. Special filter paper is placed over the open end with evaporation occurring through the paper. The difference in successive readings equals the amount of water evaporated in a given time. Short-term and long-term evaporation can be recorded and compared to pan evaporation during the same time interval.

An evaporograph costs about $400 and provides a continuous record of evaporation from a water surface. If you are able to afford this instrument, results can be compared to the pan evaporation and the Piche evaporimeter. Consult a weather instrument catalog for details about these instruments in preparation for general class discussion.

Hygrometry

Hygrometry involves making measurements of the water vapor content of the free atmosphere near the earth's surface. The most common and least expensive instrument($30 to $45) for making humidity measurements is the sling psychrometer. This device can be easily constructed if price is a problem. A laboratory exercise can have several students use this instrument to reveal the considerable variations in relative humidity which result when different rotation speeds are employed to cool the wet-bulb thermometer. Most tables for computing relative humidity were developed for ventilation rates of approximately four revolutions per second(about 9 miles per hour) for a one foot long instrument. Pocket psychrometric slide rules are useful for quickly computing relative humidity and are inexpensive enough that they should be considered for the course. They can be compared to the sling psychrometer tables for accuracy and ease of use.

The Assmann psychrometer utilizes a fan which provides a nearly constant rate of cooling which results in more accurate readings(plus or minus 1%) compared to the sling psychrometer. However, they cost about $350 but are useful in providing a standard for evaluating the sling psychrometer which is less accurate. An alternative to the Assmann psychrometer is a battery operated psychrometer which also uses a fan to provide a more constant rate of cooling around the wet-bulb thermometer.. It is only slightly less accurate and costs about one-third as much as the Assmann psychrometer.

Mason's hygrometer uses two thermometers like a sling psychrometer except that the muslin on the wet-bulb thermometer is immersed continuously in a tube of distilled water. Relative humidity can be computed from tables developed specifically for this instrument. Its accuracy can be compared to the sling and Assmann psychrometers.

A hygrothermograph, which combines temperature and relative humidity on one chart, and costs about $400 is particularly useful in displaying the relation between temperature and relative humidity. If you cannot afford this instrument maybe you can obtain a copy of a weekly chart for laboratory discussions from the National Weather Service. Other devices which might be mentioned in class which are more sophisticated and more costly include humidity probes, sintered filters and dew point sensors.

Constructing a hair hygrometer to measure relative humidity could be a worthwhile project to be completed outside of class if time is limited. Yates and Trowbridge provide the details in their texts for making hair hygrometers. The finished product can be evaluated for accuracy against the other instruments mentioned previously.

Nephometry

The measurement of the height, velocity and amount of cloud cover is called nephometry. A lack of instruments only permitted a limited discussion in the course of the more common cloud measuring instruments such as the clinometer, ceilometer and nephoscope. Procedures which utilized photography and search lights for cloud measurements were examined in the text and in the WeatherMeasure Weathertronics catalog.

The one exercise that was conducted in class used the dry and wet-bulb temperatures from a sling psychrometer to obtain a dew point temperature from a table which was then used in the following relationship to compute the height of a cloud base in feet above the local ground surface:

$$H = 227(T-D)$$

Where:

H = height of the cloud base in feet

T = air temperature in °F at the surface

D = dew point temperature in °F at the surface

A nephoscope can be built at modest cost as part of a class project to measure the speed and direction of clouds during the day. Yates provides the details for the construction of this instrument. For those inclined toward the quantitative, Trowbridge provides examples of how two observers can estimate the height of clouds. Some background in trigonometry is required to complete the exercise.

Hyetometry

The study of condensation and precipitation is known as hyetometry. This course focused on precipitation measurements made by non-recording and recording instruments. Non-recording rain gages come in a variety of sizes and prices. The National Weather Service's eight-inch diameter rain gage costs about $200 and as a result could be too expensive for just demonstrations. There are, however, more affordable instruments like the forestry-type, plastic and even the fence post gages which provide reasonable accuracy. The True-Check fence post rain gage, which costs about $7, has a large opening, measures to .01 inch and provides accurate readings if oriented properly.

If you are fortunate enough to have several types of rain gages they can be placed near one another to compare accuracies over short and long-term intervals as part of a class project. Yates provides suggestions for making your own rain gages which are easy to follow and inexpensive. Regardless of whether you purchase or make your own rain gages, the students should be made aware of variations in the accuracy of the final precipitation measurement.

caused by high winds, evaporation and gage shape. How to measure snow accurately with a rain gage should also be discussed.

The two most common recording rain gages are considerably more expensive than non-recording gages. A tipping bucket rain gage itself costs over $400 without a recorder for making a permanent record. The weighing/recording rain and snow gage costs about $900. A picture of each of these instruments plus descriptions are available in most instrument catalogs if you cannot afford to purchase them. The advantages and disadvantages of each instrument should be discussed so that students understand the environmental conditions for which each device was intended. For instance, a tipping bucket rain gage operates best in light rains and tends to underestimate precipitation amounts during intense showers. Strip charts from each of these instruments can supplement catalog pictures. These charts may be available from the National Weather Service.

There are some interesting devices for measuring precipitation for special purposes. A precipitation detector sounds an alarm to alert someone that rain/snow has begun which may adversely affect some activity. Other instruments include rate-of-rainfall gages and dew measuring devices which are rather ingenious but also expensive. Students generally find these discussions to be interesting even though catalog pictures and/or slides have to be substituted for the real thing.

Summary

Next time the course on Principles of Meteorological Instruments is taught the emphasis will be placed on the following three areas. First, the greatest amount of time will be devoted to surface instruments especially those devices for measuring temperature, pressure, humidity and precipitation. These instruments are easily accessible, relatively inexpensive and the most likely to be used by the students engaged in meteorological observations. The other surface instruments will be worked into the course as time permits. Upper-air observations can still be examined but restricted to the more common methods of acquiring data. The more specialized instruments in the text can be read outside of class and then discussed periodically as a group project to compare interpretations and strategies for the best use of the instrument.

Second, the addition of a laboratory session will provide more time for the hands-on experience that students want. This will require additional work in developing exercises but should prove invaluable in stimulating student interest. The laboratory sessions should be organized so that each student has the opportunity to use the instrument to collect, analyze and present the results in class. The students should pay careful attention to how the instrument works, its degree of accuracy, advantages and disadvantages and under what circumstances it performs best. All instruments have some degree of operational and human error associated with them. None is absolutely perfect in monitoring the environment. Students should be aware of this fact and the margin of error that is acceptable when making certain types of observations.

The final area of improvement involves more effort to combine the theoretical with the practical during lectures. Although students will have the opportunity for practical applications in the laboratory, lectures can be more stimulating if theoretical discussions are supplemented frequently with examples of practical applications including how knowledge about the operation of an instrument is important to understanding its limitations in the laboratory and ultimately in the field.

Meteorological Instruments

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