Insolation as an Instructional Tool in Atmospheric Sciences
Eleventh Annual GLOBE Conference
29 July-04 August 2007
San Antonio, Texas, USA

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Abstract

Insolation, or the measurement of solar energy at the earth's surface, is the engine that drives our environment. Any study of the Earth as a System eventually recognizes the concept of our energy balance as the controlling influence for all other atmospheric phenomenon. The science teacher at Norfork Elementary School has attempted to incorporate the measurement of insolation using a pyranometer in the school's science curriculum at a variety of levels from ordinary instruction to open ended inquiry. The results of this initiative are presented and the concept of examining other successful student-teacher-scientist collaborations are discussed, Finally, the benefits of GLOBE's adoption of an insolation protocol are presented.

Background

The amount of sunlight reaching Earth's surface is a source of practically all the energy in the biosphere. Sunlight is responsible, either directly or indirectly, for producing and maintaining the conditions required for supporting most life on this planet. For these reasons, and more, the study of what happens to sunlight as it passes through our atmosphere is crucial to many aspects of science and general knowledge.

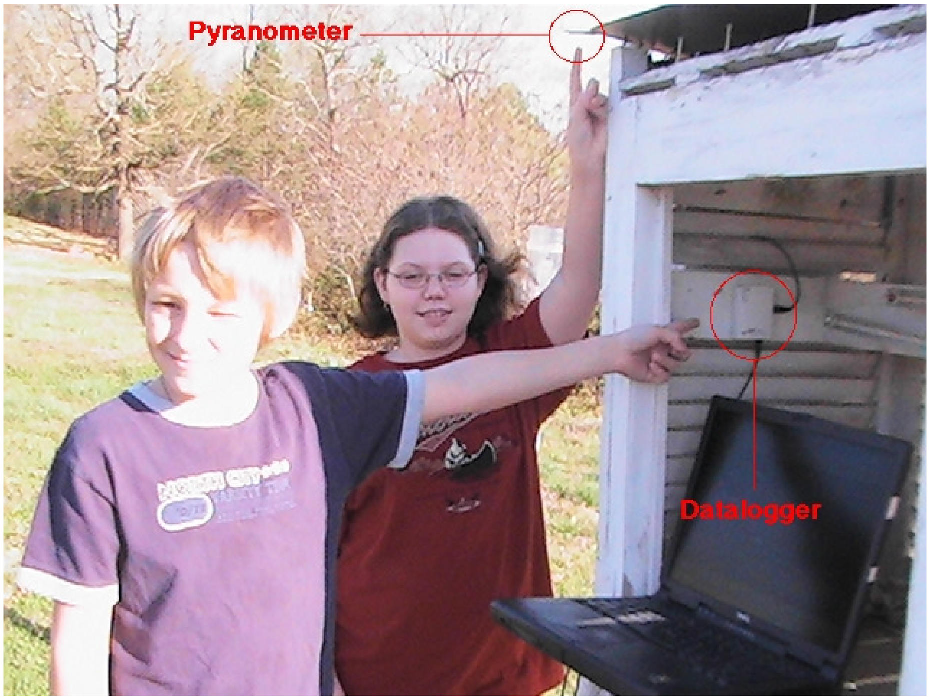

Figure 1 - Two fifth grade students point to the location of the pyranometer and datalogger on the school weather station.

The amount of sunlight reaching a horizontal surface at Earth's surface is called insolation, measured in units of watts per square meter (W/m^2). Insolation (power), or insolation accumulated over some amount of time (energy), is affected by several factors, including time of day, time of year, latitude, cloud cover, moisture in the air, and air quality. Although humans obviously have no control over the purely geometric and temporal factors, there is evidence that decreasing air quality and changing weather patterns, which are influenced by human activity, are reducing average insolation in some parts of the world. (Brooks 2007)

Brooks goes on to explain, "Instruments used to measure insolation are called pyranometers (from the Greek "pyr" (fire) and "ano" (sky). Ideally, pyranometers should measure all the radiation from the sun, across the entire electromagnetic spectrum (broadband radiation). Pyranometers based on thermopile detectors (collections of thermocouples embedded in special materials) closely approach this ideal. However, such instruments cost several thousand dollars. Much less expensive pyranometers – what might be called "surrogate" pyranometers – use miniature silicon solar cell detectors. These instruments still cost from a little less than \$20 to a few hundred dollars."

GLOBE has existing protocols that seek to measure the moisture levels in the atmospheric column as well as the effect of the suspended solids and liquids (aerosols) or haze. The GLOBE Aerosol Protocol calls for the use of a relatively inexpensive Solar Photometer to measure the voltages produced by red and green light emitting diodes acting as spectrally selective detectors. These data applied together with certain atmospheric measurements taken by the students, can produce a calculated Aerosol

Optical Thickness (AOT) value. This represents the amount of solar radiation, at these two wavelengths, that is reaching the surface of the Earth on a clear day. Of course cloud cover significantly degrades these values, but students already understand this. It is the “clear sky” values that tell them how much “invisible” matter is blocking and scattering the sunlight.

By adding a pyranometer protocol to the GLOBE arsenal of measurements, students can further investigate the dynamics of solar radiation at the Earth’s surface. I have found that students can appreciate sunlight for not just the color and brightness available through their vision, but also the energy reaching the Earth’s surface as a function of time, season, cloud cover, and even cloud thickness. By establishing a collaboration of pyranometer measurements, student investigations of the effects of latitude and spatial (geographical) displacement upon solar energy at the ground level can be realized. After all, one of GLOBE’s fundamental objectives was providing ground truth for models of remote sensed data. Using solar pyranometers, a student network of data would supplement existing datasets, signal the presence of climate related changes in insolation, and validate models used to quantify solar energy availability around the globe.

Again, Brooks relates, “You might think that such an important quantity as insolation would have high priority for ongoing measurements by scientists. However, this is not true. Although there are atmospheric research programs that include insolation measurements, the last program to provide nationwide insolation data ended in 1990. In 1992, the U.S. National Renewable Energy Laboratory (NREL) published the National Solar Radiation Data Base [NSRDB, 1992], which provides historical insolation data for several hundred locations in the U.S. However, more than 90% of these data are based on models of solar radiation, not on actual measurements. Even under "clear sky" conditions, many assumptions about the state of the atmosphere are required in order to use these models. Under real conditions, the models also depend on statistical analysis of meteorological conditions, especially cloud cover. So, although the NSRDB can tell you a lot about climatological average insolation at a particular site, it has little to say about actual conditions at any given time and place.

Even though the NSRDB is an extremely valuable tool, especially for assessing local conditions for solar power installations, many of the scientifically interesting questions that could be answered with a nationwide network of highly accurate insolation measurements, such as whether reductions in insolation due to deteriorating air quality are occurring, are not being addressed.” (Brooks, 2007)

Insolation in the Curriculum

Students in the middle school grades in this nation are expected to understand the relationship of solar radiation to all life on Earth. As early as Grade 5 in Arkansas, students are expected to investigate the physical interactions of light and matter with respect to refraction, absorption, transmission, and scattering (PS 7.5.5). By Grade 8 students are expected to be able to describe, diagram, and analyze the electromagnetic spectrum (PS 7.8.9 and PS 7.8.10). While these frameworks can be instructed in an "ideal" or oversimplified manner; actual field observations represent a huge potential for practical application of specific knowledge. Students need to be able to understand the inter-relationships of light, weather, and climate to appreciate the effects this radiation has upon our environment, or perhaps the effect of human activities on the Earth as a System. One can read and instruct students for years and still fail to provide them any real understanding of the relationship of our Sun to life on Earth. Through the use of solar photometers and pyranometers, instruction can be both a tool for discovery (inquiry) as well as form the basis for scientific investigations.

Figure 2 – Pyranometer installation viewed from above. The leveling bubble on the left assures that the instrument is properly leveled. The Teflon disc on the right covers the silicon solar cell that measures insolation.

This lack of understanding of the fundamental details of the Sun – Earth relationship can be best addressed in the areas of astronomy, physics, environmental sciences, and the Earth as a System. Studies or investigations using pyranometers can provide a valuable learning tool for students as evidenced by our schools use of pyranometers during the spring semester in 2007. During the grip of winter, Norfork students installed a pyranometer, P-003, co-located with the school weather station. On a weekly basis they downloaded its datalogger by using a laptop computer and forwarded the datafile as an e-mail attachment to David R. Brooks at Drexel University. Simultaneously, students printed and analyzed the graphs of the previous week's data. Everyone involved in this process was surprised at both the depth of questioning and the quality of discussions that analysis of these graphs provided. The remainder of this presentation deals with the discussion of these data, not only between the teacher and the students, but that conducted between this author and the Principal Investigator, David R. Brooks.

Insolation Graph Analysis

A huge amount of measurements were recorded using a Onset Computer Corporation HOBO U12-013, USB, temperature / humidity, (2) two external channel datalogger. This means that temperature and humidity were digitally recorded at the same time as instantaneous voltages of solar energy were made. How many measurements? Well, one every minute. In a single day that meant 1440 measurements. Since the night time measurements were essentially zero volts, students immediately observed that energy was produced (recorded) only during daylight hours.

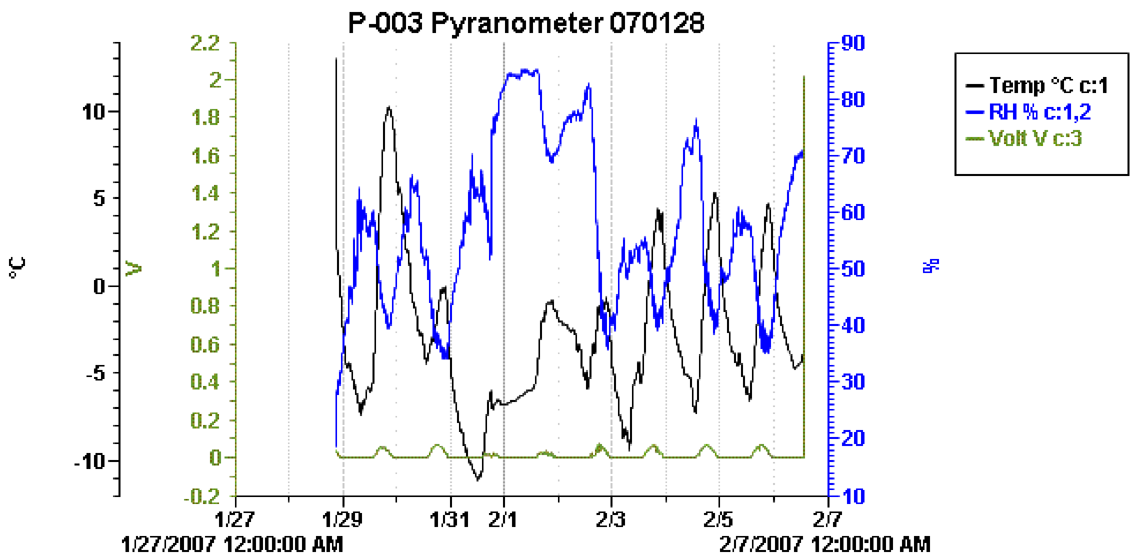

Figure 3a – This is the raw data downloaded from the U12 HOBO datalogger covering the first week in February 2007. The spike caused by connecting and disconnecting the datalogger resulted in the small relative shape of the pyranometer voltage curve.

The raw data height of the daily voltage "wave" was not very exciting in February. Viewing the raw data on many cloudy days, students referred to the voltage display as "dismal". It seems that their creative writing teacher was attempting to expand their vocabulary and they thought that word would be an appropriate term for what they saw. In actuality, the very small voltages produced by the silicon solar cell in the pyranometer was very small, perhaps even dismal in comparison with the other factors being displayed above. When these data were multiplied by a calibration factor, the graphs illustrated throughout the remainder of this presentation were produced. As Figure 3b below shows, insulation in early February was anything but dismal.

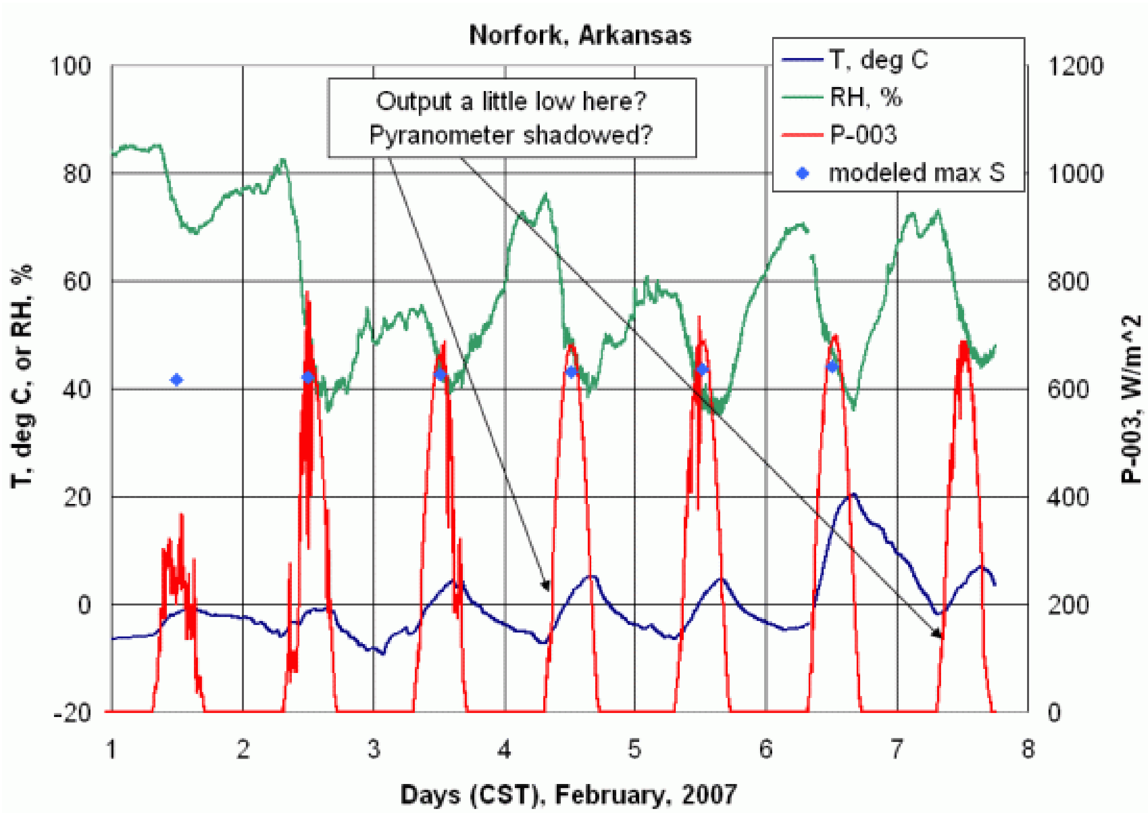

Figure 3b – This is the insolation graph covering the first week in February 2007 after calibration adjustments and model maximum values of insolation have been entered.

The graph of our data subsequent to the calibration is a much more impressive display. I feel sure that the students would have been much more impressed had they been shown this graph at that time. As the month progressed, daylight voltages increased. Insolation was increasing despite the chill students felt in the outside air.

Early on, students were alerted to a possible problem relating to the low responses in the early morning hours and they correctly deduced a site location problem affecting the measurements. The early morning sunlight came from the southeast at that time of the year and the sun was partially obscured by the top of a dormant silver maple tree in that direction. As the month progressed, and the sun's path moved northward, this problem was resolved.

Figure 4 – The obstruction of sunlight by a dormant tree in February as viewed from the pyranometer location.

Another factor the students recognized was that heavy frost possibly degraded the early morning recorded voltages. Students were divided as to whether values would be reduced or that frost on the pyranometer would make very little measured difference. Such was beyond the scope of our initial investigation and we had no free pyranometers to dedicate to any “frost-free” measurements. This issue may be investigated when we have more pyranometers and students have gained a better understanding of what they are doing. This is, after all, open-ended inquiry at the student level. They say a photograph (Figure 5) is worth a thousand words, what do you think?

Figure 5 – Frost covering the pyranometer at 0754 CST on the morning of 15 February 2007.

Even evening voltages were affected by our site location, as the school building itself obscured about five degrees of the final travel of the sun across the sky. This problem affects the value of the data somewhat, but not the value of the process to our students. As an aside, the diurnal variation of temperature and humidity displayed simultaneously on the raw data graph was enlightening to the students. They were fascinated with the pattern and magnitude of daily changes. Many observed when frost / dew was present and confirmed the accuracy of the graphed values by their own experience.

As spring approached, students became accomplished in the downloading procedure. They had to be reminded to re-launch the datalogger after downloading the data. Yes, there were a couple of days when data was not recorded due to that fault. But otherwise, data collection became routine. The dataloggers memory was limited to just over a week at the one-minute measurement interval. During spring break several days went unrecorded when the datalogger memory became full. Despite these issues, student interest actually increased. What to some was a complex procedure now became simple, with practice. This familiarity with technology will most certainly prove beneficial in their future.

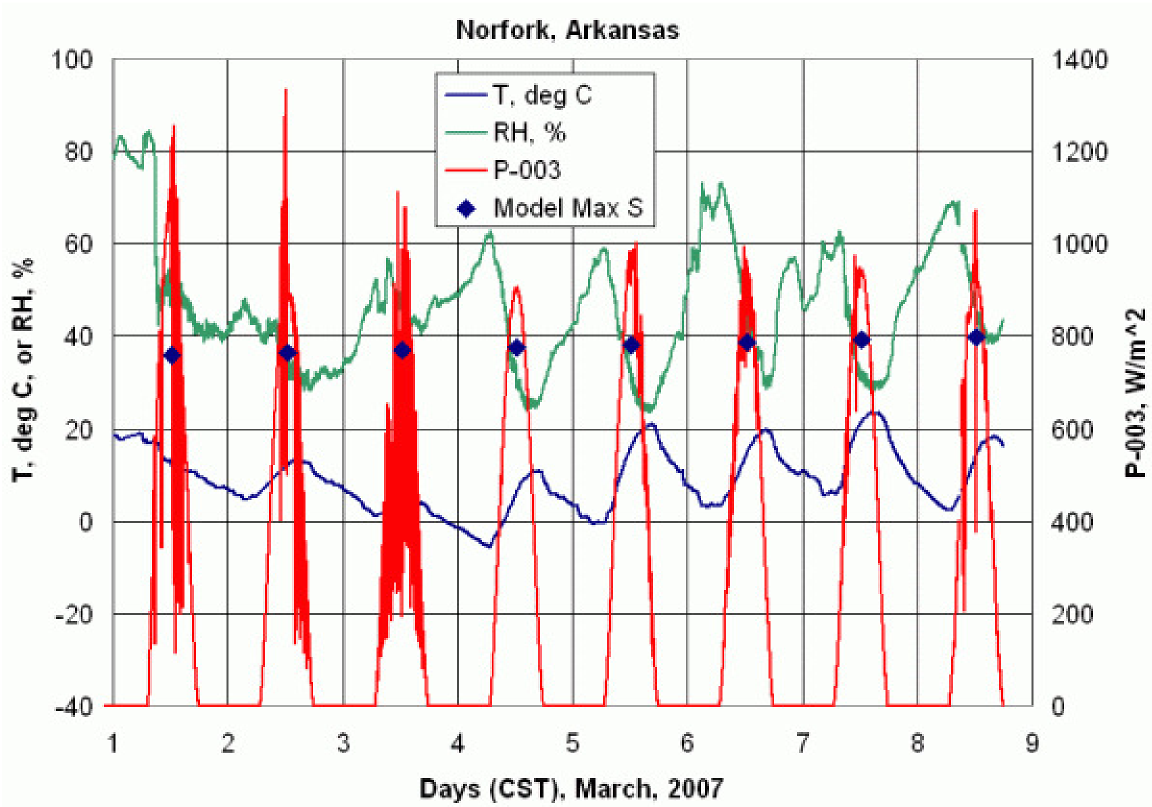

Figure 6 – Insolation graph for the first week in March. Note the increasing insolation values and the “spikes”, both up and down on the graph.

As daily sunlight voltages increased, the effect of clouds became more apparent. I will never forget the student’s analysis of their first graph illustrating abrupt and significantly higher voltage spikes recorded during a relatively clear day. They could understand the lower voltages caused by cloud shadows. They thought the increases were due to pyranometer malfunctioning. After all, the sun was producing the same amount of light as just a minute before, thus the spikes must be wrong. When asked about what happens when light strikes a white surface, they correctly answered that light was reflected. I only wish I was that astute when I first observed the graph, but David Brooks later related that effect was common on days with cumulus clouds, incident and reflected sunlight often increased insolation values at those times. A real epiphany for students and teacher alike, but it should have been obvious.

Although not part of the insolation investigation, by close examination of the raw data file values, students observed that “dawn/dusk” was happening at a different time each day. This may seem rudimentary to adults, but for youngsters that have only recently read about the ‘real reason for the seasons”, seeing it in their data was reinforcing prior knowledge. Furthermore, at the spring equinox they were able to approximately “see” the transition to 12 hours of daylight / 12 hours of darkness, thus gaining an actual appreciation of the term “equinox”. While the definition of “dawn/dusk” may be different than that recorded by the pyranometer, anything greater than night “zero” values at these times can be interpreted as daylight. In this case the term means that portion of the day when measurable voltages above the night (dark) voltage are recorded. Table 1 below illustrates what the students were able to determine.

Date	“dawn “	“dusk”	daylight hours	night hours
29 Jan 2007	0726	1712	9 hrs 42 min	14 hrs 18 min
21 Mar 2007	0627	1800	11 hrs 33 min	12 hrs 27 min
7 Jun 2007	0506	1910	14 hrs 4 min	9 hrs 56 min

*All times converted to Central Standard Time (CST)

Table 1 – Actual “dawn to dusk” times noted on raw pyranometer data files.

As seasonal changes in cloud cover increased and prevailing winds shifted more to the southwest, increased moisture and clouds affected the pyranometer values. The smooth curves common during the winter months were replaced by wildly variable insolation values. Analysis of the graphs became more difficult for my students, but even then, students grasped an appreciation for the effect of cloud cover upon insolation.

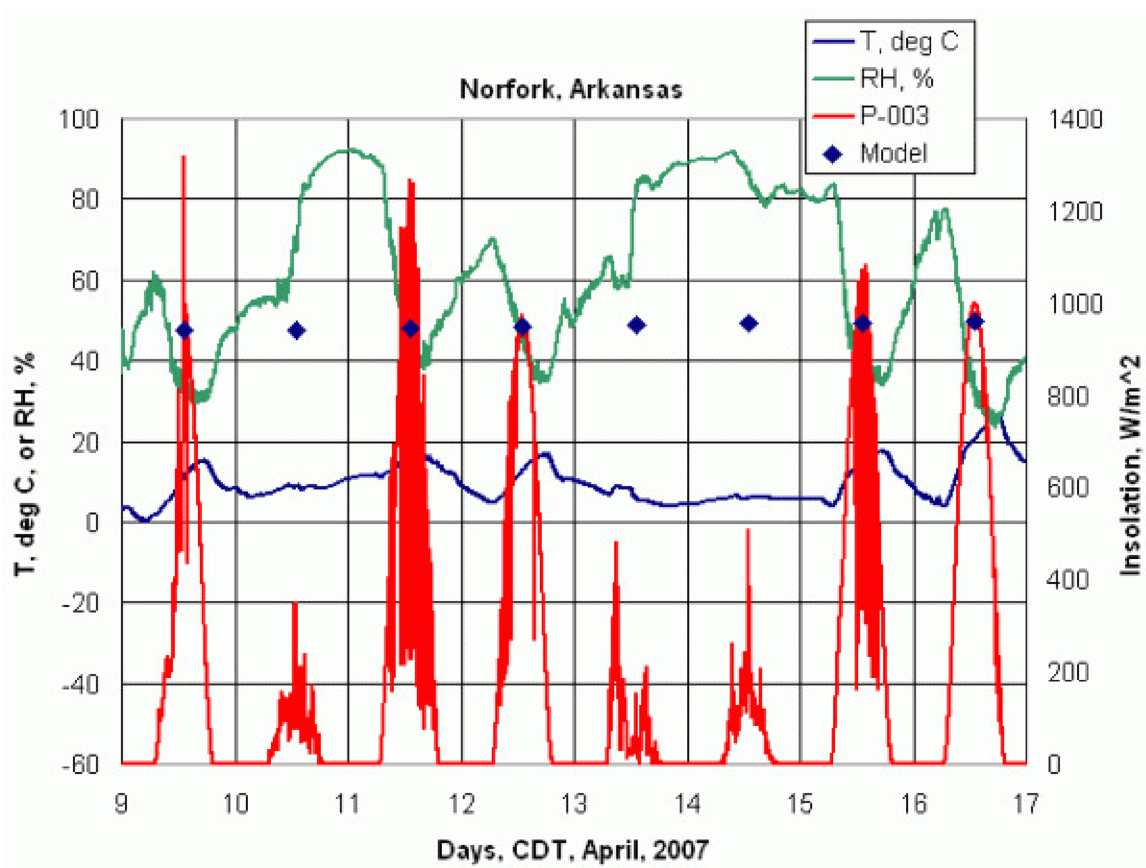

Figure 7 – Insolation graph for 9-16 April showing the effect of cloud cover and type. Can you tell which days were clear, when it was overcast, morning versus afternoon clouds, etc?

Most students related recent clear to overcast graphical responses. Some were able to relate scattered to broken cumulus responses to insolation. A few claimed the ability to relate cirrostratus to altostratus responses based upon our recorded GLOBE cloud type and cover measurements which were available to them. This type of careful reasoning and analysis can only result in greater process skills in their academic future.

Finally, our students were blessed when David Brooks made a second generation pyranometer design available for us to co-locate, examine, and compare responses. P-005 (the new pyranometer) joined P-003 (our existing pyranometer) for simultaneous measurements. Due to the fact that the HOBO datalogger had one additional available external input, both pyranometer voltages could be recorded with the same amount of effort, a fact my students related immediately.

Figure 8 – P-003 (left) and P-005 (right) co-located atop our weather station in May 2007.

When the first graphs were displayed, the students immediately noticed one pyranometer voltage value was really different from the other. This fact allowed me to introduce the concept of instrument calibration into their curriculum. Most instruments measure differences between themselves and an expensive laboratory standard instrument. When a single instrument is compared to a very precise (expensive) pyranometer the output values can be adjusted to respond proportionally. I made an analogy to the term "translated" with my younger students. It seems that P-003 and P-005 were responding in different voltages to the same sunlight, yet when a "translation" factor was introduced, both pyranometers (spoke the same words), i.e. produced essentially identical values. This is why our relatively inexpensive pyranometer can provide good data, because it has been calibrated against an expensive and more precise instrument at Dr. Brooks' calibration site. And since both instruments were calibrated at one location, their differences at their new location could be adjusted also.

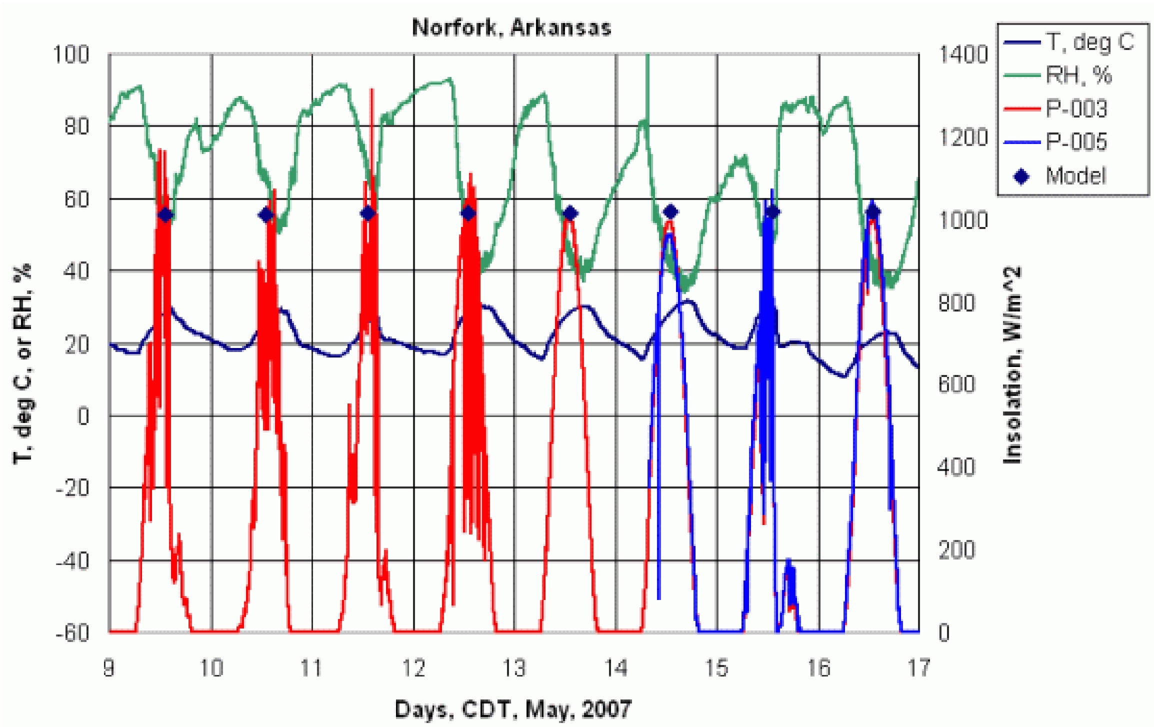

Figure 9 – Solar Insolation graph illustrating the new pyranometer (P-005 in blue) being added to the former P-003 (in red) measurements. Note the almost identical response of the blue overlapping the red curves.

Significance of Student Data

As Dr. Brooks related earlier, the National Solar Radiation Data Base listed historical insolation values for a few hundred locales within the US, most based upon model predictions. As climate changes, the accuracy of the "models" becomes suspect without ongoing validation. While earth orbiting satellites offer potential answers to insolation investigations, the transient nature of their observations precludes much of their usefulness in answering surface insolation issues. One need only visit the NASA Satellite Overpass Predictor website at the URL cited in the references to discover how infrequently each satellite passes over any spot in the US, during daylight, and within ten (10) degrees of the vertical, i.e. overhead. When one also factors in the relative absence of any diverse network of precise insolation measurement, student data stands poised to play a pivotal role in answering any changing climate effects upon insolation. Thus, this "ground truth" from a variety of locales, is the most important aspect that any student data can provide the research community.

Students Supporting Atmospheric Research

The fundamental objective of GLOBE is to provide students "ownership" of their own research process. By making observations and reporting data, students develop pride in their accomplishments, and without realizing it, they also accumulate knowledge that is both relevant to them and appropriate for their academic growth. In order for these types of collaborations between students, teachers, and scientists to be successful, one must carefully examine the needs of each of these groups of participants. GLOBE has an established expertise in managing scientific data and has historically embraced "special" measurements of selected research scientists. As an example, the Ruby Throated Hummingbird Protocols provide an excellent opportunity for student data collection related to seasonal change. Thus, GLOBE should again seek potential initiatives that students could address.

In their landmark investigative report, "Developing Meaningful Student – Teacher – Scientist Partnerships (STSP)", Tamara Ledly, of TERC, and others advocate using an inquiry approach involving students in ongoing research programs. They have identified ten major issues that must be addressed in the development of successful STSP's. (Ledley, et al, 2003) Table 2 below lists these issues and subjectively assesses their resolution by each "community" involved.

Table 2 – Analysis of GLOBE Involvement to successful student – teacher – scientist partnerships (STSP's).

Issue	Scientist addresses	GLOBE addreses	Teacher addresses
1. What is the scientific research question?	Yes	Yes	
2. What data will the students work with?	Yes	Yes	
3. How is the data quality checked and controlled?	Yes	Yes	Yes
4. What research tools are needed?	Yes	Yes	
5. What protocols will students and teachers follow?	Yes	Yes	
6. What are the logistical issues that need to be addressed?	Yes	Yes	Yes
7. What background information do students and teachers need?	Yes	Yes	Yes
8. What training is needed for teachers,	Yes	Yes	

students, and scientists.			
9. What additional research questions can students develop?		Yes	Yes
10. What are the opportunities for recognizing the students and teachers contributions.	Yes	Yes	Yes

GLOBE addresses all of these critical issues involved in successful STSP's. GLOBE, although certainly not unique among public science investigation initiatives, stands at the forefront of successful STSP's. GLOBE incorporation of pyranometry protocols will supplement their already significant atmospheric research and help answer a very real climate related question, i.e. What effect is climate change having on the amount of solar energy reaching the earth's surface?

GLOBE Implementation Obstacles

The most obvious obstacle to student investigations using a pyranometer is the lack of a GLOBE protocol at this time. Such could be easily remedied by incorporating an insolation or pyranometer protocol within the GLOBE umbrella of measurements. Precedent exists for such in the form of the automated air and soil temperature protocols as well as the Davis/Rainwise/WeatherHawk automated e-mail reporting. GLOBE's non-acceptance of e-mail attachments, while a nuisance, can be solved by converting the datafile into a textfile and forwarding it in the same manner as is currently done for the DAVAS and DLOG data files. This conversion is both confusing and time consuming for students to accomplish. The binary .hobo raw data file is compact and almost effortless to submit. For these reasons the use of a binary e-mail attachment is much preferred.

A more profound obstacle may be GLOBE's unwillingness to expand the number or type of protocols they support. I cannot think of any new protocols adopted in the past two years or so. It seems that GLOBE has focused upon curriculum development instead of data measurement and research collaboration. While some would say that measurement and collaboration are difficult to justify with limited student learning time devoted to these skills, I would remind the reader of the original purpose of the GLOBE Program, "Global Learning and Observations to Benefit the Environment". Measurement was the fundamental reason sparking my participation in the GLOBE Program. Student measurement and data entry using the internet makes the GLOBE Program what it is. No other student-oriented program exists which satisfies both the student measurement and data entry accomplishments of GLOBE. Failure to adopt new or change existing protocols will ultimately result in the creation of some new program that better address the needs of the student/scientific community. The end result of a plethora of student measurement related initiatives is duplication of effort, confusion, poor execution, and the general loss of effectiveness of each individual program. GLOBE is poised upon the threshold of the future. By not taking advantage of new opportunities, GLOBE is destined to stagnate, thus resulting in its possible and unfortunate demise.

Finally, the obstacle of cost is not much of an issue for these measurements. Pyranometer kits are available from the Institute for Earth Science Research and Education at a cost of approximately twenty dollars ($20).

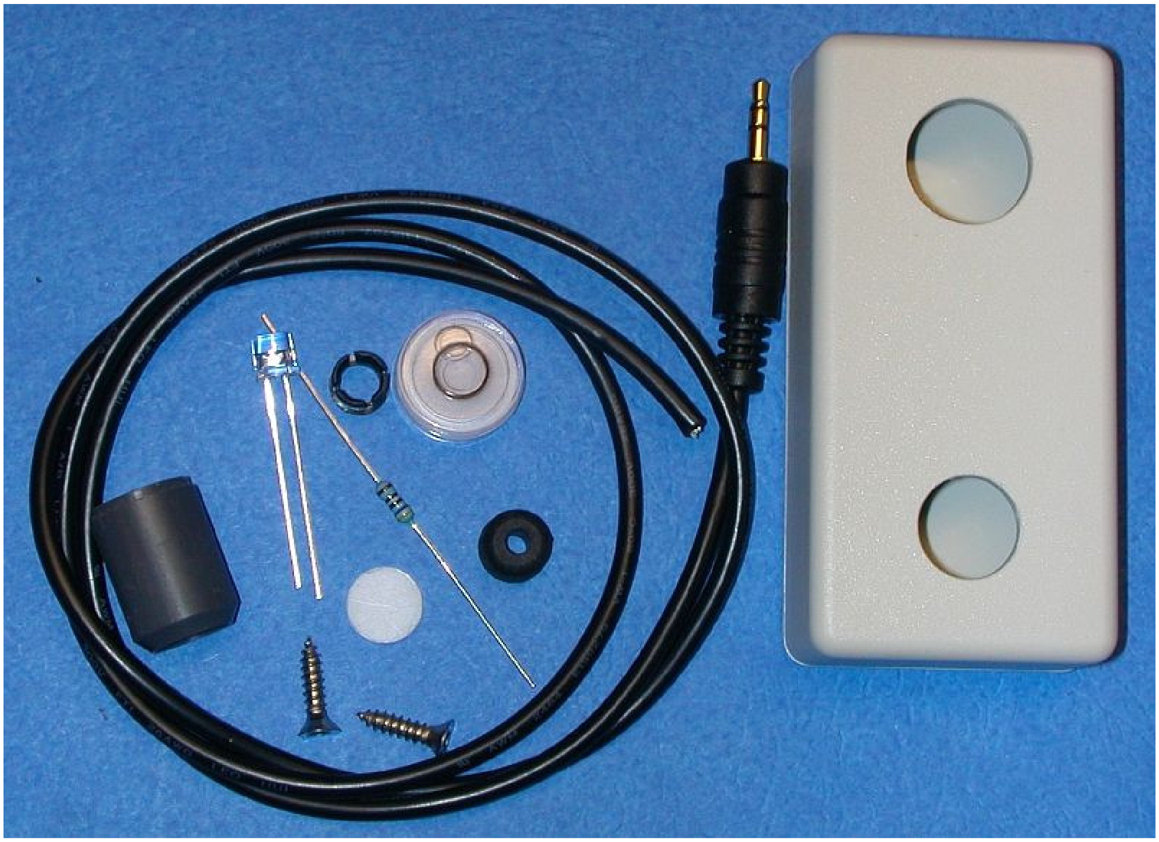

Figure 10 – A pyranometer kit before assembly.

The kits are easy to build and can be calibrated locally. Assembly instructions are available on-line at the URL cited in the reference section of this presentation. When compared to existing GLOBE protocols for surface ozone, aerosols, surface temperature, and even the digital max-min temperature protocol; the cost of the pyranometer is minimal. The cost of the HOBO U12 series datalogger and propietary software is significantly more, but still under $150 dollars. Thus, implementation of an insolation initiative is certainly within the means of almost every school in the United States. When one compares the benefits in science learning, environmental awareness, and student self-esteem; pyranometer measurement programs are certainly worthwhile.

Conclusion

Conducting insolation / pyranometer measurements as a data collection and analysis effort by science students is a beneficial and scientifically valid opportunity for GLOBE. This is a measurement that is fundamental to student learning about the Earth and its atmosphere as a dynamic and interconnected system. Student measurement can address a need for scientific research pertaining to the effects of human related changes upon insolation in many locations not being currently monitored. Unlike sun photometry, pyranometry is virtually independent of weather and a lot of "teachable" data can be accumulated in a relatively short period of time. Finally, insolation measurements can be an effective student learning and collaboration vehicle whose cumulative value extends well beyond the classroom.

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Acknowledgements

The author wishes to express his thanks to David R. Brooks PhD, President of the Institute for Earth Science Research and Education, for his generous contributions of assistance, equipment, calibration services, and data analysis. Without such assistance the realization of this instructional capability would have been impossible.

About the Author

Mr. Allan W. Geery has been a science teacher in the upper grades of a departmentalized elementary school in rural north-central Arkansas for the past fourteen years. He has participated in the GLOBE Program for the past eight years, and became a certified GLOBE Trainer in 2004. In addition to his educator roles, he has organized a local 4-H club, facilitated a collaborative water quality monitoring project of the White River in this region, and instigated a local Passive Irrigation Experiment; with each separate entity collecting and reporting its own GLOBE data. Such non-traditional sources of GLOBE data are a testament to the functionality of the entire GLOBE Program and its potential for substantial growth. Collectively, these four GLOBE student activities have accumulated over a quarter million GLOBE measurements.