

# COMBINED SOLAR PV AND EARTH SPACE MONITORING TECHNOLOGY FOR EDUCATIONAL AND RESEARCH PURPOSES

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## ABSTRACT

This paper concerns educational projects implemented at a number of Moscow secondary schools (high schools) and, secondarily, how an offshoot from this project is being tried in Oregon.

The novel feature of this program is the involvement of schoolchildren with activities utilizing satellite based real-time monitoring of the Earth's surface and making use of this data to estimate incident solar radiation. The processed data can then be used to evaluate the performance of solar energy systems.

Within the project, schoolchildren acquire basic knowledge related to renewable energy using experimental solar photovoltaic modules installed on the school's roof. Pupils monitor, in real-time, the electricity generated by the solar module and compare these data with information derived from satellites.

In Oregon, laboratory kits have been developed to explore the behavior of solar cells. These lab kits augment the work associated with measuring the solar resource and modeling the performance of solar electric systems.

## 1. INTRODUCTION

This paper describes an educational project, "Space technologies, ecology and clean energy in school of the future", based on experience at ten Moscow secondary schools. This project is evolving with input from the students and teachers. The main objective was to involve teachers and schoolchildren in activities associated with space technology used for real-time monitoring of the

Earth's surface, using the data from such monitoring to estimate the incident solar radiation. Solar panels were installed and the solar radiation data obtained from the satellite images was used to evaluate the performance of the solar panels. The modeling of solar radiation data from satellites is a work in progress.

Earlier, prototype solar cell lab kits were developed [1, 2] and used in classroom at VIESH. Similar PV lab kits and curricula were developed by the University of Oregon Solar Radiation Monitoring Laboratory (UO SRML) in collaboration with Dick Erickson, a local high school teacher. These lab kits were devised to work with the VIESH equipment used to extract solar radiation data from satellite images and form a more comprehensive solar educational package.

As discussed in a previous paper [1], the complementary components of this package consists of equipment for evaluating the performance of a working photovoltaic system combined with experiments that can be conducted in class. The performance of the solar panels can be evaluated using the "Kosmos-2M" system, the hardware/software equipment for extracting solar radiation data from satellite information. Experiments such as those that can be done with the solar cell lab kit teach how solar cells function. Together they give a more complete understanding of solar electricity.

Of course, the "Kosmos-2M" system has many auxiliary uses and the solar cell lab kit also has many diverse uses.

Collaborating with each other and sharing experiences helps build better and more versatile tools to teach solar energy. Once these tools have been fully developed and implemented in schools around the world, it is hoped that

the students can connect via the internet to share and exchange ideas and data.

This article is organized as follows: First, the satellite data acquisition system is discussed. Included in the discussion are plans to extract solar resource information from the satellite images. Organization and teaching plans around this data are next described. Information on the solar cell lab kit and lesson plans will then be presented.

The opportunity these tools represent in sharing findings with other high schools and students around the world will then be discussed.

## 2. EQUIPMENT

### 2.1 Space Receiver “Kosmos—M2”

The portable, relatively inexpensive receivers (Fig. 1) installed at a number of Moscow schools are designed to receive and process images of Earth sent by satellites in real-time. These systems are quite useful for introducing students to certain modern technologies. Images can be received without payment of a fee, helping to minimize the expense involved in teaching this subject matter. Since satellites, moving on polar orbits, pass at intervals of about 3 to 4 hours and their signals can be received reliably within a 5- to 10-minute period, receiving sessions during the classes are scheduled accordingly.

A hardware/software complex, "Kosmos–M2", is designed under supervision of Michael Schakhramanyan for receiving Earth images transmitted from the NOAA series polar orbiting satellites (NOAA-12, NOAA-14, NOAA-15, and NOAA-17), and the Meteor satellites, in Automatic Picture Transmission (APT)) format at a frequency of 137 MHz.



Fig. 1: Receiver for satellite images

NOAA satellites transmit the Advanced Very High Resolution Radiometer (AVHRR) images using two of the five channels:

1. visible, or “VIS”, during daytime or otherwise mid-infrared (NOAA-14, only) and
2. far infrared, or “IR”, with reduced spatial resolution (up to 3 km) and an 8-byte resolution in the swath about 3000 km . The Meteor satellites transmit single-channel images in the visible range with a spatial resolution of 2 km.

The satellite receiving and analysis package is useful for teaching how to receive and process Earth images transmitted from space in real-time. The students can watch changes occurring over a large territory (~7,000,000 sq. km.), analyze the images, discuss the nature and uses of the data, and make forecasts. Ultimately, there are practical applications of this technology in synoptic forecasts, and in training students in Earth remote sensing techniques, and scientific work in general. Other applications involve analysis of hydro meteorological centers, aviation, railways, oceanic shipping, the car industry, air photography, fishing and yachting, research institutions, ecological services, etc.

The pictures themselves serve several purposes:

- visual investigation of geographical objects and their characteristics;
- monitoring of natural and climatic and landscape zones (comparison to the available cartographic data);
- observing the state of large bodies of water, their hydro- and thermo-dynamic modes;
- monitoring large forest areas and irrigational systems;
- observing characteristic meteorological and climatic states;
- observing the state of the seas ice belts, large emergencies and ecological catastrophes (flood, drought, forest fires, pollution of sea waters by oil, frosts, hurricanes, fogs, dust storms);
- analyzing the geomorphologic and weather-forming factors of large mountain ranges.

This satellite receiving and software analyzing package is also a convenient tool for searching for interesting events in real time.

**TABLE 1: SYSTEM SPECIFICATIONS**

Item	Number	Dimension	Weight
Receiver	1	15x20x7 cm	700 g
Amplifier	1		
Cable	50 meters		
Aerial	1	100x100x2 cm	800 g
Software and methods	1 kit		

The components for the system are shown in Table 1.

The power supply can operate on a 220 V AC or a 12 V DC source.

Software functionality:

- overlaying of satellite images with geographical maps;
- determining the surface temperature at any point of image received;
- to measure distance from one point to another accounting the Earth geometry;
- area measurement;
- determining the height of upper cloud cover boundaries;
- detecting hazardous weather conditions, such as lowering clouds;
- detecting the wind field in a cyclone;
- forecasting precipitation.

Information receiving periodicity: 4 – 6 hours.

Information from satellites is transmitted free of charge.

The “Kosmos-M2” system is unique in its capabilities and provides many educational and practical applications.

## 2.2 Solar Module

The educational value of the “Kosmos-M2” satellite analysis package is greatly enhanced when it is used with a photovoltaic (PV) system. At the Moscow high schools, students participated in monitoring and evaluating an experimental solar module. This significantly increased their interest in the project. The solar module used in the photovoltaic system is based on the standard crystalline silicon technology. However, a new encapsulant developed at the All Russian Research Institute for Electrification of Agriculture (VIESH) was used in an attempt to increase the service life time of the module. The major factor determining the module’s performance over its lifetime is the structural stability of the encapsulating material.

Experience gained through manufacture and deployment of photovoltaic modules utilizing standard technology including thermal-vacuum lamination with application of



Fig. 2: Solar PV module developed for schools with test equipment

encapsulants based on copolymers Ethyl Vinyl Acetate (EVA), shows that their effective lifetime does not exceed 25 years in a temperate climate, 20 years in a dry tropical climate and is greatly reduced in damp tropical climates. Performance decreases as a result of the encapsulant “browning” and EVA delamination allows active corrosion.

VIESH and a professional chemical company research team worked together to identify better encapsulating materials. From the point of view of optical transparency, a wide operational temperature range and cleanliness from ionogenic impurities, the most attractive encapsulant was found to be organic-silicon polymers.

Using the new technology, 10 experimental PV modules were created. The modules had a capacity of 10 - 13 W and were 500 mm x 500 mm in area. Modules are composed of monocrystalline silicon solar cells. The front (working) surface of modules was protected by tempered glass, 4mm thick. The rear (back) cover was made from a stabilized sheet of polyethylene terephthalate (“polyester



Fig. 3: Installing of aerial and solar module on the roof of school №1533 (left) and solar module on the roof of schools №390 (top right) and №1277 (below right)

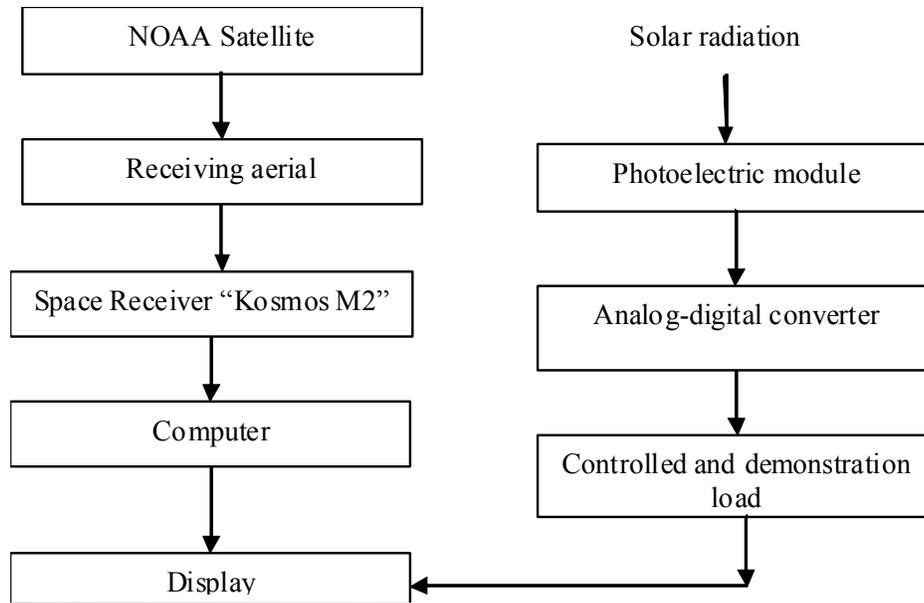


Fig. 4. The scheme of equipment on receiving of satellite images together with the PV module for monitoring solar radiation.

glass”) 1 mm thick. The modules were set in aluminum frames using a weatherproof silicone sealant.

The modules are very transparent (Fig. 2) and our initial installations are very attractive installed on buildings.

The novelty of testing a new product helped to stimulate the interest of the teachers and students. While it won’t always be possible to install innovative new technology, other approaches can be tried. For example a class could experiment with putting a mirror or reflector made of aluminum foil in front of the panel.

### 3. ORGANIZING AND TEACHING ACTIVITY

The "Kosmos–M2" hardware/software systems and solar



Fig. 5: Getting space image at school № 444

modules were installed at ten Moscow schools in the framework of the experimental project “Space technologies, ecology and clean energy in school of the future” supported by the Moscow Government.

Fig. 3 illustrates the installation of the receiver aerial (roof) and solar module (wall) at school № 1533 and of solar modules at schools №.390 and №.1277.

The flow of information from the satellite and solar electric module is shown in Fig. 4. The NOAA satellite images are downloaded via the aerial and processed by the “Kosmos—M2” kit. The information is stored on computer and sent to a display. The electricity produced by the sunlight on the solar modules is monitored and the

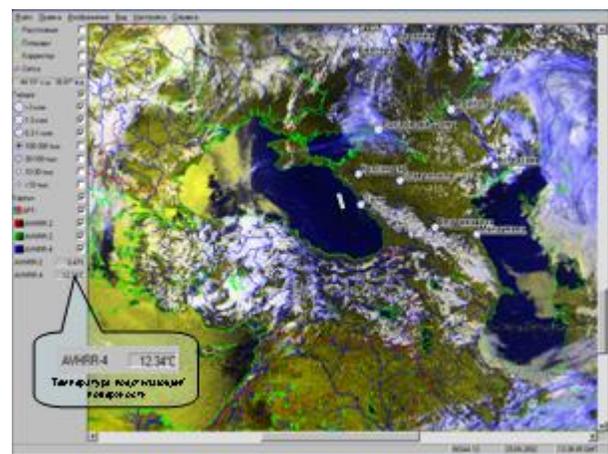


Fig. 6: Measuring underlying surface temperature using the AptView program



Fig. 7: Roundtable devoted to experimental project (October 2007)

measurements are sent to the computer for display.

Initially, all students worked with solar module traditional instruments: voltmeter, ammeter and a means to vary the load. This is an important part of the teaching activity. Next, electronic equipment is used to replace the meters and to convert the analog data into a digital format. An automatic method of measuring the IV curve was developed utilizing a specially written computer program to vary the load. The load was varied using a field transistor and a National Instruments data acquisition device (USB-6008) recorded the data.

The data from the photovoltaic module can be handled in several ways. In one design, the module circuit is hooked up to an IV curve tracer. The computer controls a field effect transistor that changes the load which allows the IV curve to be generated. The data logger stores the data that can be downloaded to the computer for display and analysis. The same data acquisition device can be used for a variety of tasks such as monitoring the photocurrent from the solar module.

Initially students work under the supervision of their teachers to learn how to interpret and manipulate the Earth



Fig. 8: Our pupil with Poltavcheko G. S. - plenipotentiary of President of Russian Federation

surface images and data downloaded from the satellite. Later on, the student can work independently. Using specially designed algorithms they will be taught how to bind these Earth surface images to the geographic maps of an extensive area of about seven million square kilometers.

On the basis of received data, schoolchildren will identify objects on the ground and measure their geodetic and geometrical parameters. Some of these objects are expected to be known to pupils, and they will have the possibility to evaluate the accuracy of calculations they have made. On the other hand, it will motivate them to learn more about the infrastructure of the district in which they live.

Data received from satellites make it possible to determine the surface temperature at any point on the digital map and to make short-term weather forecasts about, for example, the speed and direction of winds and the likelihood and amount of rain and snowfall. The frequency of space images reception is sufficient to allow schoolchildren not only to observe dynamic changes in the environment but also evaluate the reliability of forecasts. Students find the real-time images fascinating and really focus on the images as they are downloaded (Fig. 5).

A team of school students with Irina Charaeva, Geography teacher at school № 1198, were analyzing space images showing the surface temperatures in the Black Sea and discovered unusual anomalies in temperature distributions. At first, they could not explain these anomalies but thorough additional research they realized that local increases of temperatures in some areas could be explained by eruptions (and possibly flashes) of overheated gases, such as methane, from breaks in the Black Sea sea-bed. This discovery by the students has been confirmed by research work done by Ukrainian scientists. An example of space image processing is shown at Fig. 6.



Fig. 9: Our team at the exhibition (VVTS)



Fig.10. Prototype PV lab kit developed by Igor Tyukhov. This design served as the basis for the UO SRML PV kit.

Participating schoolchildren also acquire basic knowledge related to renewable energy by using experimental solar photovoltaic modules installed on the roofs of school buildings. Pupils monitor, in real time, solar radiation by measuring electricity generated by the solar modules.

This project started in the summer of 2007. After installing equipment and acquiring some initial experience, a roundtable celebrating the jubilee of the first artificial satellite, “Sputnik” (4 October 1957), was organized. The main goals were to inform the pedagogical community about the first steps of this experimental project and to provide teachers and students with an opportunity to demonstrate the usefulness of this new approach in teaching modern technology (Fig. 7). Many presentations were given by teachers, students, and other representatives of the pedagogical community. Also authorities and prominent individuals such as cosmonaut Lazutkin A. I., confirmed the great interest in the teaching about solar energy and remote Earth sensing.

The main ideas and the working equipment developed for the project “Space technologies, ecology and clean energy in school of the future” were demonstrated at the All-Russian Exhibition Centre (VVTS) at 20-22 December 2007 (Figs. 8 and 9).

#### 4. UNIVERSITY OF OREGON ACTIVITIES AND VALUE AND POSSIBILITIES OF INTERNATIONAL COOPERATION

The University of Oregon Solar Radiation Monitoring Laboratory (UO SRML) has been working with Igor Tyukhov of VIESH to develop educational and research tools for renewable energy technologies.

In a previous paper [1] the idea of using photovoltaic systems and solar cell lab kits as complementary educational tools was discussed. The UO SRML concentrated more on the monitoring of photovoltaic systems and VIESH developed solar cell lab kits. In this paper, the roles are reversed as VIESH started looking into methods to monitor photovoltaic systems and the UO SRML worked with local high school teachers to develop a solar cell lab kit with associated curriculum [http://solardata.uoregon.edu/download/Lessons/Experiments\\_with\\_PV\\_Cells.pdf](http://solardata.uoregon.edu/download/Lessons/Experiments_with_PV_Cells.pdf). Other lesson plans are also available on this Web site. We look forward to the day when students around the world will have access to these tools and can share experiences and ideas.

In this section, the solar cell or photovoltaic lab kit and associated curriculum is discussed.

The Emerald People’s Utility District (EPUD) purchased photovoltaic systems for each high school in its service territory. The output of the PV systems is viewable by the students on the internet at <http://www.fatspaniel.com/live-sites/index.html>. To augment and enhance the learning experience, EPUD sponsored the development of curricula to go along with the photovoltaic system on the roof of the building.

The UO SRML in collaboration with Dick Erickson, a high school teacher at Pleasant Hill High School in Oregon developed a PV lab kit and curriculum based on the prototype lab kit developed at VIESH. A picture of the VIESH PV lab kit is shown in Fig. 10.

#### 4.1 PV Lab Kit

The basic design for the kit contains the following components:

- three 0.5 volt PV cells, at least 10 square centimeters (1.5 sq in) in size each (PV cells are available at most scientific supply companies and many electronic stores)
- several sheets of colored transparency film in various colors, including yellow and blue (office supply stores). Small pieces should be cut beforehand just to cover the PV cells
- 30 cms of thin electrical wire (use with alligator clips unless the meter leads have alligator clips on their ends)
- DC ammeter (reads amps)
- DC voltmeter
- direct sunlight (desk lamp or flashlight could be substituted. Do not use a florescent lamp.)
- aluminum foil
- protractor
- goggles
- hair dryer

It is sometimes difficult to solder leads onto a solar cell. It is best to purchase solar cells with leads. If it is not possible to perform the experiments in sunlight, it is important to have a lamp that will expose each solar cell to approximately the same level of illumination.

#### 4.2 PV Lab Curriculum

The curriculum that accompanies the PV lab kit gives basic information necessary to understanding the experiments that can be conducted using the kit. A summary of activities, assessment questions, and suggested follow-up activities are included with the curriculum.

Eight experiments using the kit are described in the curriculum:

1. Effect of color (wavelength) on cell current
2. Effect of shading on cell current
3. Effect of shading on cell current – PV cells in series
4. Effect of shading on cell current – PV cells in parallel
5. Effect of tilt angle on cell current
6. Effect of a reflector on cell current
7. Effect of temperature on cell voltage
8. Effect of distance from light source on cell current

The first experiment introduces the concept of spectral radiation and helps explore the effect of filtering out various colors on the performance of solar cells. The experiment consists of covering the PV cells with a variety of colored transparency film and measuring the output current of the cells. The current should also be measured without any film. The recorded results can then be compared and discussed. If the experiment is done in direct sunlight, the experiment should be done on a clear day without clouds that cause the incident solar radiation to fluctuate. Sometimes it is helpful to measure the current without the transparency film in between measurements using the transparency film.

The second series of three experiments examines the effect of shade on solar cell production when the cells are in series and parallel. The goals of these experiments is to show that with a single solar cell, the solar electricity produced is proportional to the sunlight incident on the cell. However, the effect of shading is different on solar cells connected in series or in parallel. Solar cells act much like batteries and these experiments can show the similarities. This experiment is also useful in training installers by showing them the effect of shading on solar cell arrays.

The fifth experiment demonstrates that most energy can be gained if the solar cell is pointed normal to the light source. A cosine curve will result if the current is plotted

against angle of incidence. The concept of flux is sometimes difficult to grasp and this experiment presents a good opportunity to demonstrate the nature of flux.

The sixth experiment is a simple experiment using a reflector to increase the light on the solar cell and hence increase the electrical output. This experiment could become a competition between students to find the reflector design that produces the largest percent increase from the cells.

The seventh experiment explores the effect of temperature on solar cell performance. While this effect is easy to show when one is able to generate an IV curve, it is not so evident in other experiments. Experience will determine the usefulness of this experiment and establish how well students are able to measure the effects of temperature on solar cell performance.

The eighth experiment also shows the effect of light on the performance of solar cells. The intensity of light falls off as the inverse of the distance from the light source squared ( $1/d^2$ ). This isn't an experiment to perform in the sunlight, but is one that can be done with a lamp. The inverse square law is a basic principle in physics.

These experiments demonstrate a variety of properties of solar cells. In addition, they illustrate several principles of science therefore are versatile teaching tools.

Now that the prototypes of the lab kits have been built and initial curriculum has been developed, it is time to test the package in a variety of classes and develop a more refined set of instructions and experiments.

#### 5. FUTURE ACTIVITIES

The informal collaboration between VIESH and the UO SRML has resulted in the development of educational tools for teaching about solar electricity. Igor Tyukhov and the people at VIESH have been the lead in developing the equipment and initiating the concepts. The collaboration has now reached a state where solar electric experiments and curricula are being introduced into the classroom.

Part of the success of the VIESH program is that they have been able to blend the tools being used in the classroom with practical applications that can be used to assist in the evaluation and deployment of solar electric technologies. The Kosmos—M2 system can be utilized to evaluate the solar resource anywhere in the world. It can be used:

- in classrooms to check on the performance of a photovoltaic system,
- for initial tests of new hardware such as is being done with the innovative solar module being tested at high

- schools in Moscow,
- by utilities and solar electric providers to help integrate the solar electricity generated in their location into the electrical grid.

The PV lab kits can be used for education and training of solar installers. The curriculum and the kits teach how solar cells and modules work. At the same time, such system can be used to compare the performance of various types of solar cells. It isn't the high-tech super lab that gives the most accurate readings, but it can be used by researchers who don't have funding for fancy labs to make very preliminary studies or try out their ideas. With a little effort these labs can be turned into IV curve tracers such as is being done in Moscow.

Both VIESH and the UO SRML will be refining their education packages as more experience is gained from their use. It is hoped that those who utilize the equipment and lesson plans share their experience and ideas for improving the systems.

The fact that use of solar cells is increasing exponentially and photovoltaics is on the forefront of new technologies increases student interest and stimulates the learning experience. Already several groups involved in providing solar education in the Pacific Northwest have expressed interest in using these PV lab kits in their programs. Feedback from teachers using these kits will help refine and improve these tools. The aspiration is that these kits or similar tools will be integrated into science classes as the teachers become more familiar with the versatility of these labs in demonstrating a variety of useful scientific principles.

The equipment described in this paper is relatively inexpensive and can be used anywhere in the world to teach the working of solar electric systems. It makes no difference if the systems are used in the Andes mountains or the Gobi desert, the basic principles are the same and the lab packages will work the same.

## 6. ACKNOWLEDGMENTS

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