Modeling of solar irradiance using satellite images and direct terrestrial measurements with PV modules

Igor Tyukhov*[a], Michael Schakhramanyan[a], Dmitry Strebkov[a], Anton Tikhonov[a], Frank Vignola [b],
[a]VIESH, 1-st Veshnyakovski pr., 2, 109456 Moscow, Russia,
[b]Solar Radiation Monitoring Lab, Dept. of Physics, University of Oregon, Eugene, USA 97403-1274

ABSTRACT

A simple, affordable and efficient multifaceted system with technical software programs, “Kosmos 3M”, was developed for taking images of the Earth from NOAA satellites and for handling this images and analyzing many geographical and meteorological parameters. Technical software programs have been developed that utilize the “Kosmos 3M” Receiver system. Basic capabilities of the multifaceted “Kosmos 3M” system include: receiving signal from NOAA satellites; digital processing of space images with geographical fixing, superposition of maps of cities and coordinate grid; finding of geographical coordinates at any point of space image; finding of temperature of underlying surface at given points; finding of albedo (reflection coefficient) at any point of space image; finding of upper boundary of clouds (cloudiness); forecasting of dangerous weather phenomena; defining wind fields in cyclones; precipitations forecast; measuring distances between given points; measuring surfaces (areas); and forming of electronic library of images of the Earth.

Work is underway to use the “Kosmos 3M” cloudiness images to estimate the incident solar radiation values for evaluating terrestrial solar energy performance in real time. Such kind of system would have a wide variety of uses from the classroom to the field.

Keywords: monitoring solar radiation, satellite images of the Earth, photovoltaic modules.

1. INTRODUCTION

The idea of this paper came from joint activity of a Russian team that was developing satellite remote sensing and photovoltaic technology for schools and American researchers working on solar radiation monitoring with terrestrial and satellite data. Solar radiation data are important for proper design solar energy systems and for many agricultural purposes. Many factors like cloudiness, atmospheric transmissivity, latitude and orientation of the Earth relative to the Sun, time of day, slope and aspect of the surface determine the spatial and temporal distribution of irradiance incident on a surface. At the same time the availability of solar radiation data from meteorological stations is very limited, especially compared to stations that monitor temperature or precipitation. The developed tools are used in teaching activity in RF and it is planed to bring these tools to schools and universities in the USA and eventually around the world.

2. DISCRIPTION OF THE “KOSMOS 3M” SYSTEM

2.1 Main characteristics of “Kosmos 3M”

The “Kosmos 3M” is a simple, affordable and efficient system for collecting and analyzing Earth images. Specialized computer programs have been developed that make use of the capabilities of the “Kosmos 3M” system and new computer programs are being developed to enhance the capabilities and utilizability of the system. The system is based on a compact Earth Satellite Images Receiver “Kosmos 3M” with a simple aerial and special software. The “Kosmos 3M” Receiver downloads satellite images in real time. A special program was developed for receiving and data handling images from polar NOAA satellites in ATP format in diapason 137 MHz. Two spectral channels are used: visible (during day time) and middle IR (at night) with space resolution 4 km and field width 3000 km. Software allows to identify ground based coordinates for the images, and work is underway to use the images to estimate the incident solar radiation values.

A near-omnidirectional aerial is used (Fig.1). The working diapason is VHF 137 MHz. Dimensions of the aerial are 100 x 100 x 2 cm and mass is equal to 800 g. The receiver (Fig.2) has dimensions – 15 x 20 x 7 cm; and mass equals 700 g. Specialized software and methodological materials come with the system. Standard electric supply is used: AC ~220 V or DC 12 V. The aerial and receiver are connected by cable to computer with sound card. Computer Pentium 233 MHz and higher should be used.

Fig. 1. Aerial for the multifaceted "Kosmos 3M" system.

Fig.2. The "Kosmos 3M" Receiver.

Fig.3. Process of taking a real time image of the Earth is showed by the "Kosmos 3M" system.

2.2 Basic capabilities of the technical software of the “Kosmos 3M” system

The basic capabilities of the “Kosmos 3M” system of include:

- Receiving radio signal from NOAA satellites and recording;
- Digital processing of space images with geographical fixing, superposition of maps of cities and coordinate grid;
- Finding of geographical coordinates at any point of space image;
- Finding of temperature of underlying surface;
- Finding of albedo at any point в of space image (reflection coefficient);
- Finding of upper boundary of clouds (cloudiness);
- Forecasting and observation of dangerous weather phenomena;
- Defining wind field in cyclones;
- Precipitations forecast;
- Measuring distances between given points on the map;
- Measuring surfaces (areas) on the map;
- Forming of electronic library of satellite images of the Earth.

2.3 The image processing and samples of pictures

The technical software programs of the multifaceted “Kosmos 3M” system is a special tool for educational institutions with the main principles of creating and applying described below.

1. Receiving of space images should be on the free of charge basis for educational institutions and the schools would directly receive the images every three hours and can analyze the images in near real time.

2. Received images of the Earth are transformed into digital format and can be superposed on digital maps up to several millions kilometers in area.

3. The “Kosmos 3M” system allows students to independently (with assistance at the first stage and after that without assistance) to determine a number of geometrical, geodesic and meteorological parameters using data of space monitoring for integrating this information.

4. The “Kosmos 3M” system provides an opportunity of forming an archival library, by storing information over time, for following dynamic processes - both natural and anthropomorphic caused – in the environment and climate.

5. The system could be made available for educational institutions at a reasonable cost.

The software “APT Viewer” allows the user to compare actual and prognostic values for some meteorological parameters based on radiometric characteristics (brightness temperature) of cloud cover using methods developed by Roshydromet (Federal Service for Hydrometeorology and Environmental Monitoring) and certified for applying in practical analysis and forecasting weather conditions. The calculating parameters are temperature of the land and water surfaces, cloud temperature and cloud level, diagnosis and prognosis of maximal precipitations from convective and nimbostratus clouds. It is possible also to define sort of clouds (according to international classification) and severe meteorological phenomena by monitoring convective clouds, and to define their intensity for thunderstorms and/or heavy showers.

The software has several program-methodological modules (PM):

1. PM for processing and control;
2. PM for defining cloud level using satellite data;
3. PM for restoring wind field on vertical structure of clouds, obtained by satellite monitoring;

4. PM for forecasting of precipitations obtained by satellite images;

5. PM for defining vegetation index.

For example, the method of visualization cloud level is based on the dependence of radiating surface height of upper cloud level upon brightness temperature as measured by the satellite. Applying of this method makes it possible to use satellite APT-images to find height of upper cloud level (in km) by just putting cursor on seeking point cloud level (Fig.4). Running numerical value is appeared in the window "Upper cloud level". Accuracy of upper cloud level is about 1 km, close to the accuracy obtained by radar stations.

The next example is identifying the wind field using field of clouds in a whirlwind structure as observed in the images from space. The method is based on statistical connection between clouds field and air flows in the presence of whirlwind structure of the clouds. This is applicable only for defining wind in whirlwind clouds.

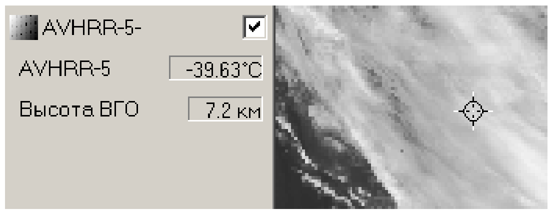

Fig.4. Computer interface of indicator cloud level.

Whirlwind clouds have different dimensions ranging from 350 to 3500 km in diameter. The location of whirlwind clouds relative to cardinal directions is somewhat variable. In order to establish statistical relations between directions of cloud strips and wind, a local frame of reference is introduced, the beginning of which coincides with center of cloud whirlwind. In this connection only cloud whirlwinds are considered analyzed which have form of hyperbolic spirals because of repetition of such kind spirals is highest. Principle of defining direction and speed of wind at standard isobaric pressure is the next. At the obtained image a cloud whirlwind with hyperbolic form cloud strips is illustrated in Fig. 5.

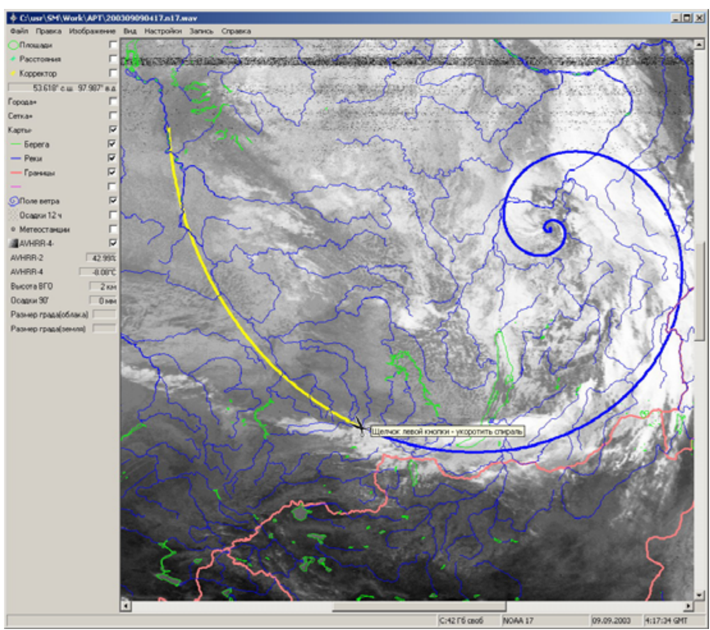

Fig.5. Installing of spiral – model of cyclone whirlwind.

A local frame of reference with the beginning in the center of whirlwind cloud is introduced, at the same time abscissa axis is directed parallel to an asymptote of hyperbolic spiral, and ordinate axis is directed perpendicular to the asymptote of hyperbolic spiral in order to have right-hand coordinate (Fig. 5).

Method can model the wind field only for clouds of whirlwind structure (Fig. 6).

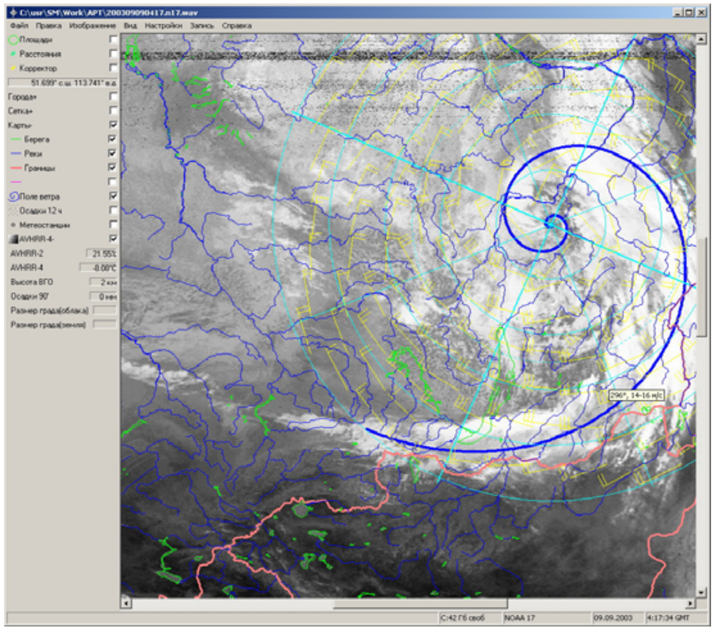

Fig.6. Modeled field of wind showed by yellow marks (height is about 850 m).

Illustration of determining temperature of underlying surface, coordinates and albedo is shown at Fig.7.

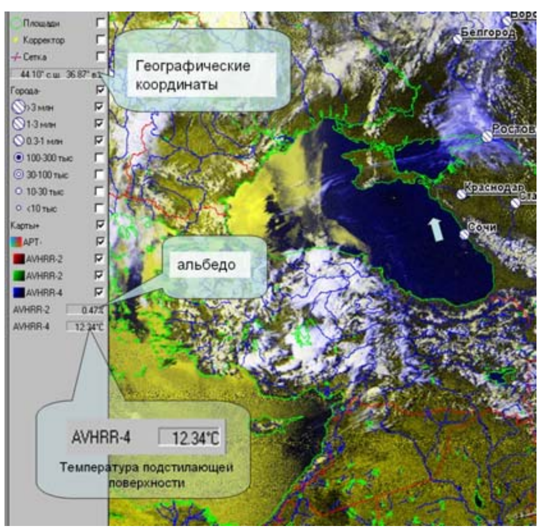

Fig.7. Determination of temperature for the underlying surface, coordinates and albedo (insets from the top are geographical coordinates, albedo, temperature of underlying surface for the given point of the Black See showed by arrows).

For defining of vegetation index using space data from NOAA satellites, it is necessary to use first and second channels of AVHRR (Fig.8). In program “APT Viewer” after choice “Snow and vegetation” the calculation of vegetation index occurs. Vegetation index (NDVI) is estimated on reflected solar radiation in near infrared (NIR) and in red (RED) diapasons of electromagnetic spectrum using formula NDVI = (NIR - RED) / (NIR + RED) or (AVHRR2 – AVHRR1) / (AVHRR1 + AVHRR2). NDVI is nonlinear function which changes between -1 and +1. Value NDVI describes absorption of red light by chlorophyll and reflection of infrared radiation by cells of leafs filled by water. Absorption occurs in the green parts of leafs and, consequently, NDVI correlates with photosynthesis.

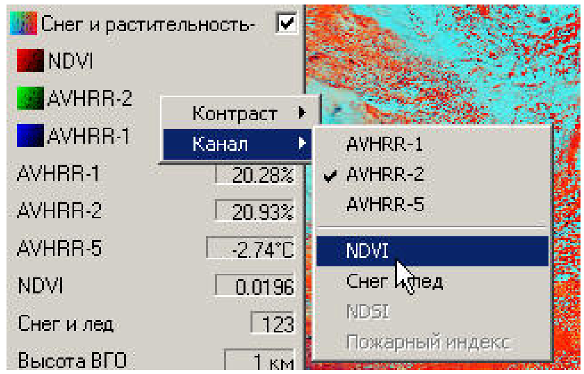

Fig. 8. Choice of NDVI channel after calculation composition “Snow and vegetation” (first line – snow and vegetation, line next to last - snow and ice, last line - height of cloud level).

The synthesized image (NDVI, AVHRR2, AVHRR1) is presented (Fig.9) and calculated by formula described above with using vegetation channel. For interpretation NDVI a special table is used in which different types of surfaces are correlated with NDVI in summer and winter time.

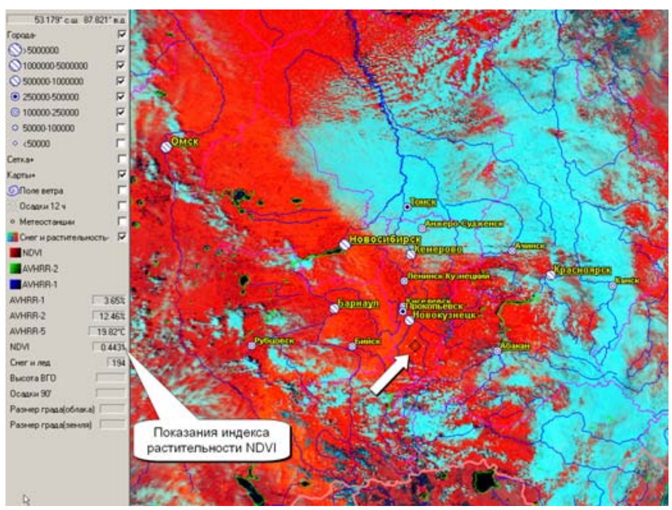

Fig. 9. Synthesis of image “Snow and vegetation” (inset is vegetation index for the point showed by arrows).

The “Kosmos 3M” system is used at more than 150 Russian high schools in in Moscow, Ryazan, Kaluga and other regions of Russian Federation for introducing modern space technology as an educational tool.

3. MONITORING OF PV MODULES AND SOLAR RADIATION

A complementary solar energy teaching tool has been developed for the analysis of photovoltaic modules (PV). It uses a National Instruments USB-6008 data acquisition system attached to a photovoltaic module along with other hardware to trace IV curves and study other PV module characteristics. A new design (plastic free - without EVA) of 10 W and 20 W solar modules with organic-silicon polymers encapsulant (VIESH) were used[1,2] (Fig.10). The size 500 x 500 mm^2 is very suitable for experiments in schools. Durability tests are performed by Poulek Solar Co Ltd. for bigger experimental samples of modules.

System of terrestrial monitoring of solar energy measuring of ampere-voltage curve of solar modules is shown at Fig. 11, and computer interface is shown at Fig. 12. LabView was used for creating program in order to process data.

Fig.10. Plastic free 20 W module of full size with mono-crystalline solar cells.

It is well known that the short circuit current of solar module is proportional to the incoming solar radiation. The short circuit current from the module can then be compared to the pixel value of satellite image. This can provide ground true data for testing the satellite derived solar radiation data, a valuable learning lesson for students. In the future, the Solar Radiation Monitoring Laboratory hopes to use the radiation data derived from satellites images in classes and in photovoltaic system analysis.

The scheme of equipment on receiving of satellite images together with the PV module for monitoring solar radiation was described[1].

At schools now it is possible to introduce solar energy at classes, covering topics from global questions (Earth-Sun system) to concrete applications, for example, using p-n- junctions for direct conversion of solar energy. Firstly developed for space applications solar modules are more and more using now at the Earth.

The experimental project is currently going on developing this system as educational tools in a number of Russian high schools and universities for introducing modern technology and basics of solar energy (PV).

The authors would like to thank Moscow and Russian Federal educational departments for support of this work.

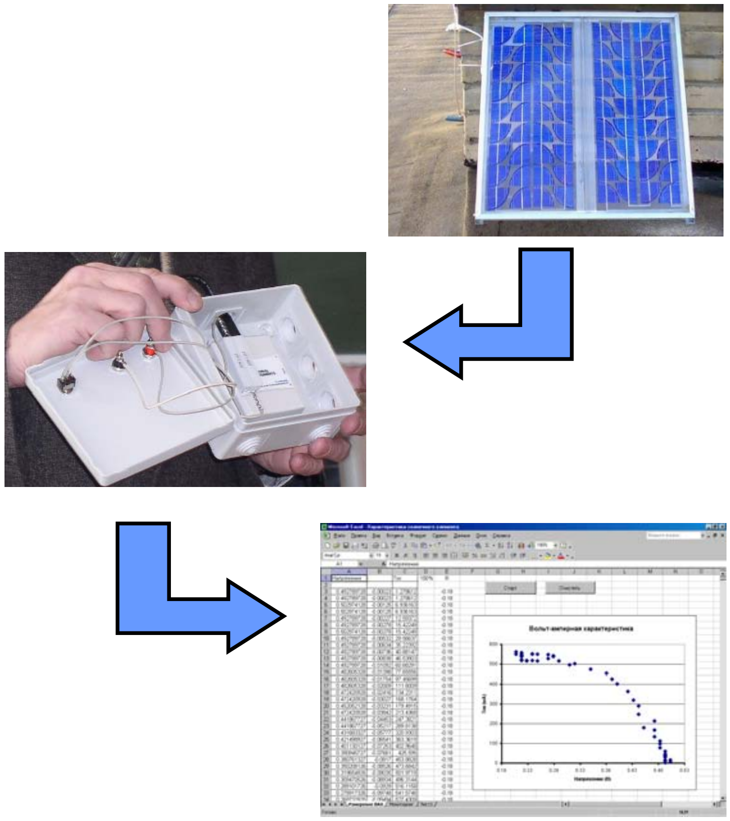

Fig. 11. Scheme of solar monitoring and measuring of IV curve of solar modules.

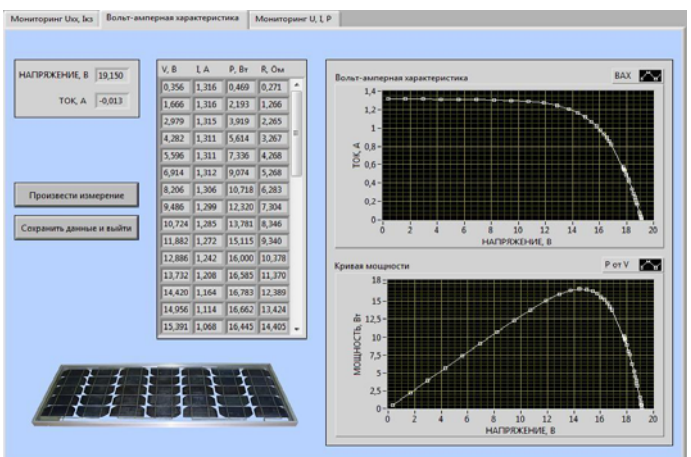

Fig. 12. Computer interface of solar energy monitoring and measuring of IV curve of solar modules.

4. CONCLUSIONS

The main ideas of the joint project are described here. Project has started in 2007 with support of Moscow government and on federal level from 2009.

• The essence of the project is to create an experimental educational platform on the basis of a number of educational institutions (secondary schools, universities, institutes of improvement of professional skill of educators).

• The main objective is to involve schoolchildren, students and teachers in activities associated with high technology of real time monitoring of the Earth surface and solar energy conversion.

• Portable, inexpensive receivers are installed at institutions designed to get and process space images of the Earth sent by satellites in real time mode.

• Students start getting the experience of work with the Earth surface images taken from the space under supervision of their teachers, and later independently.

• Using specially designed algorithms they are taught to bind these Earth surface images to the geographic map.

• Within the project, students also acquire basic knowledge related to solar energy using experimental solar PV modules installed on the roof of school building.

• Students monitor, in real time, solar radiation by measuring electricity generated by the solar module and compare these data with information received from satellites.

REFERENCES

[1] Tyukhov, I. Schakhramanyan, M., Strebkov, D., Mazanov, S., Vignola, F. "Combined solar PV and Earth space monitoring technology for educational and research purposes," Proc. Solar 2008, American Solar Energy Society Conf., San Diego, CA, CD edition, (2008).

[2] Tyukhov, I. Schakhramanyan, M., Simakin, V., Strebkov, D., Poulek, V. "PV and GIS Lab for teaching solar energy," Proc. 23rd European Photovoltaic Solar Energy Conference, 1 - 5 September, 2008, Spain, Valencia, p.3815-3818 (2008).