Quasi-real-time analysis of solar radiation with photovoltaic power using geostationary satellite

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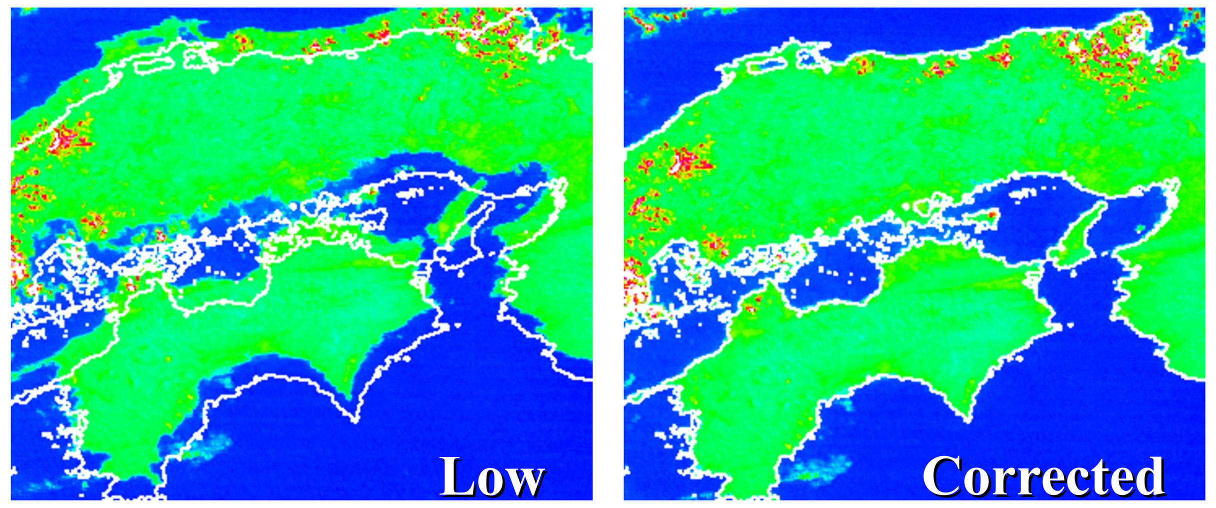
Clouds strongly influence the solar energy budget and the Earth's climate. Clouds can cool the Earth by reflecting solar radiation but also maintain warmth by absorbing and emitting terrestrial radiation. Furthermore, clouds play important roles in the energy balance at the Earth's surface and at the top of the atmosphere (TOA) and have complex connections to the Earth system and feedback processes. In this study, we developed the high speed and accurate algorithm for shortwave (SW) radiation budget and it's applied to geostationary satellite for rapid analysis. Similarly, developed algorithm is applied to quasi-real time analysis synchronous to geostationary satellite observation. It enabled highly accurate monitoring of solar radiation and photo voltaic (PV) power generation. It indicates the possibility of the fusion analysis of climate study and renewable energy.

1. Analysis Algorithm

Satellite data Geo-location correction



Geolocation information accuracy of the geostationary satellite data is modified by the phase-only correlation method by 2D-FFT using landmark of SRTM (30sec mesh) elevation data.

$$F_{sat}(u,v)=\frac{1}{N}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} f_{sat}(x,y)\,e^{\frac{-2\pi(ux+vy)i}{N}}$$

$$G_{geo}(u,v)=\frac{1}{N}\sum_{x=0}^{N-1}\sum_{y=0}^{N-1} g_{geo}(x,y)\,e^{\frac{-2\pi(ux+vy)i}{N}}$$

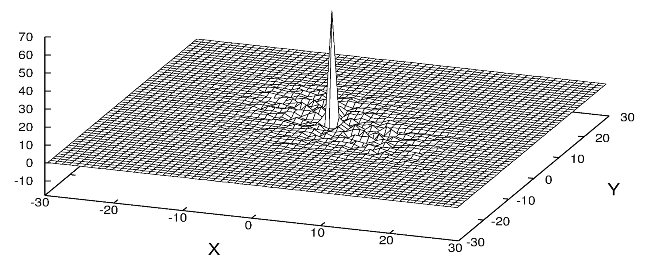
$$r(x,y)=\frac{1}{N}\sum_{u=0}^{N-1}\sum_{v=0}^{N-1} R(u,v)\,e^{\frac{2\pi(ux+vy)i}{N}}$$

$f_{sat}(x,y)$: Satellite observation data

$g_{geo}(x,y)$: SRTM elevation data

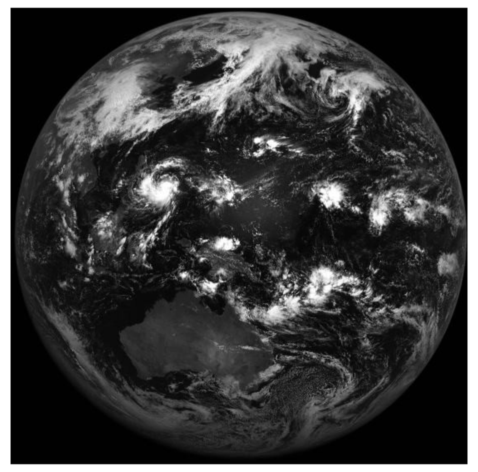
$$R(u,v)=\frac{F_{sat}(u,v)\overline{G_{geo}(u,v)}}{\left|F_{sat}(u,v)\overline{G_{geo}(u,v)}\right|}$$

POC

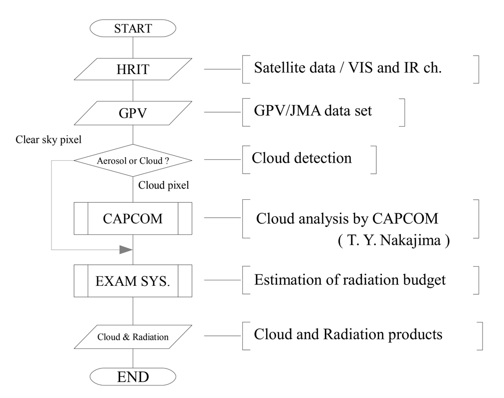


The Satellite solar radiation product is available by Quasi-real-time analysis within 10 minutes from arrival of satellite observation data. We develop a high speed and accurate algorithm using a Neural Network (NN) based on radiative transfer calculation. The advantages of the NN approach are to be speed of the computations and allows to produce numerous parameters since it does not require a large data base. Figure 1 indicates a three layers network structure. Neuro-link Network solver (NN solver) is built by improved learning algorithm "Dist.-BP" that has an anti-local minimum and a survival rule of neuron depending on nerves activities [Takenaka et al., 2011]. The NN approach is one of the solution to following problems. In general, satellite based estimate methods often use a Look-up Tables (LUT). Since pre-calculated values are used, the LUT methods are effective for large amount of data processing. However, if the effects of absorbing gasses and the particle optical characteristics are incorporated precisely, LUT becomes huge volume. An increase in parameter needs not only the increase of LUT volume but also complex interpolation of LUT. The NN solver traces radiative transfer code System for Transfer of Atmospheric Radiation (RSTAR) [Nakajima and Tanaka, 1986, 1998] for high speed and accurate computation. The Extreme speed and Approximation module Multiple drive System (EXAM SYSTEM) controls NN solvers by multi-threading.

Current operation
MTSAT-1R
MTSAT-7



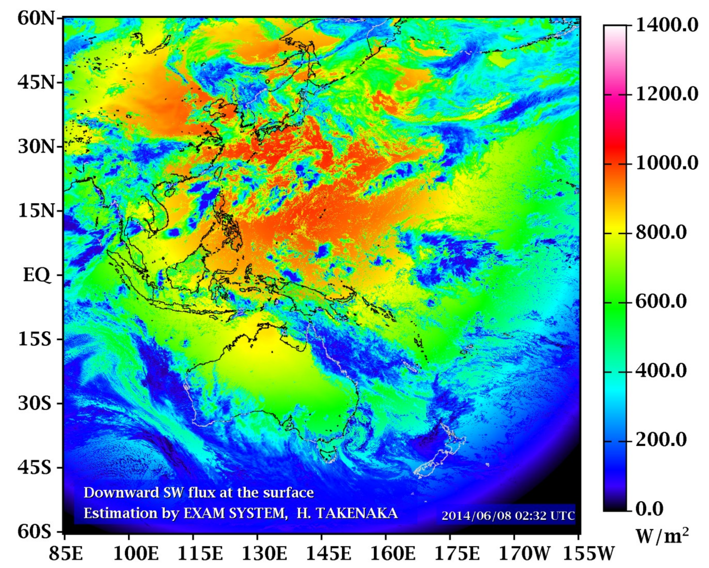
Himawari satellite estimation flowchart



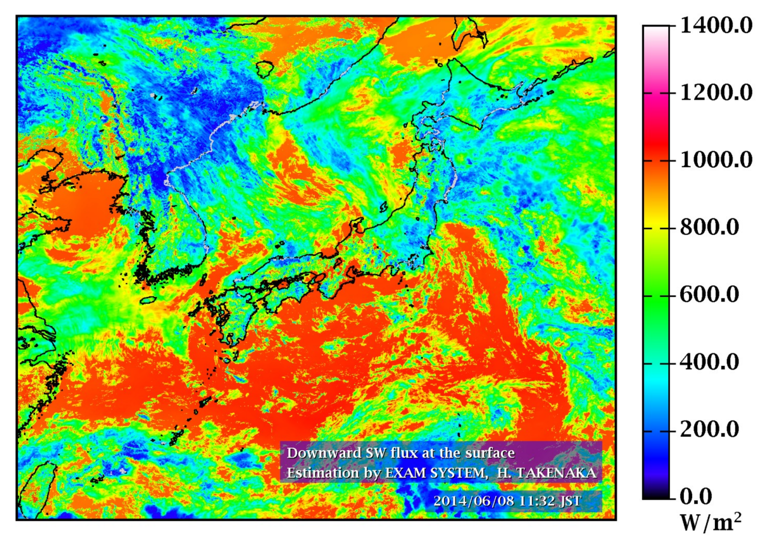
Takenaka et. al., 2011
JGR. doi:10.1029/2009JD013337

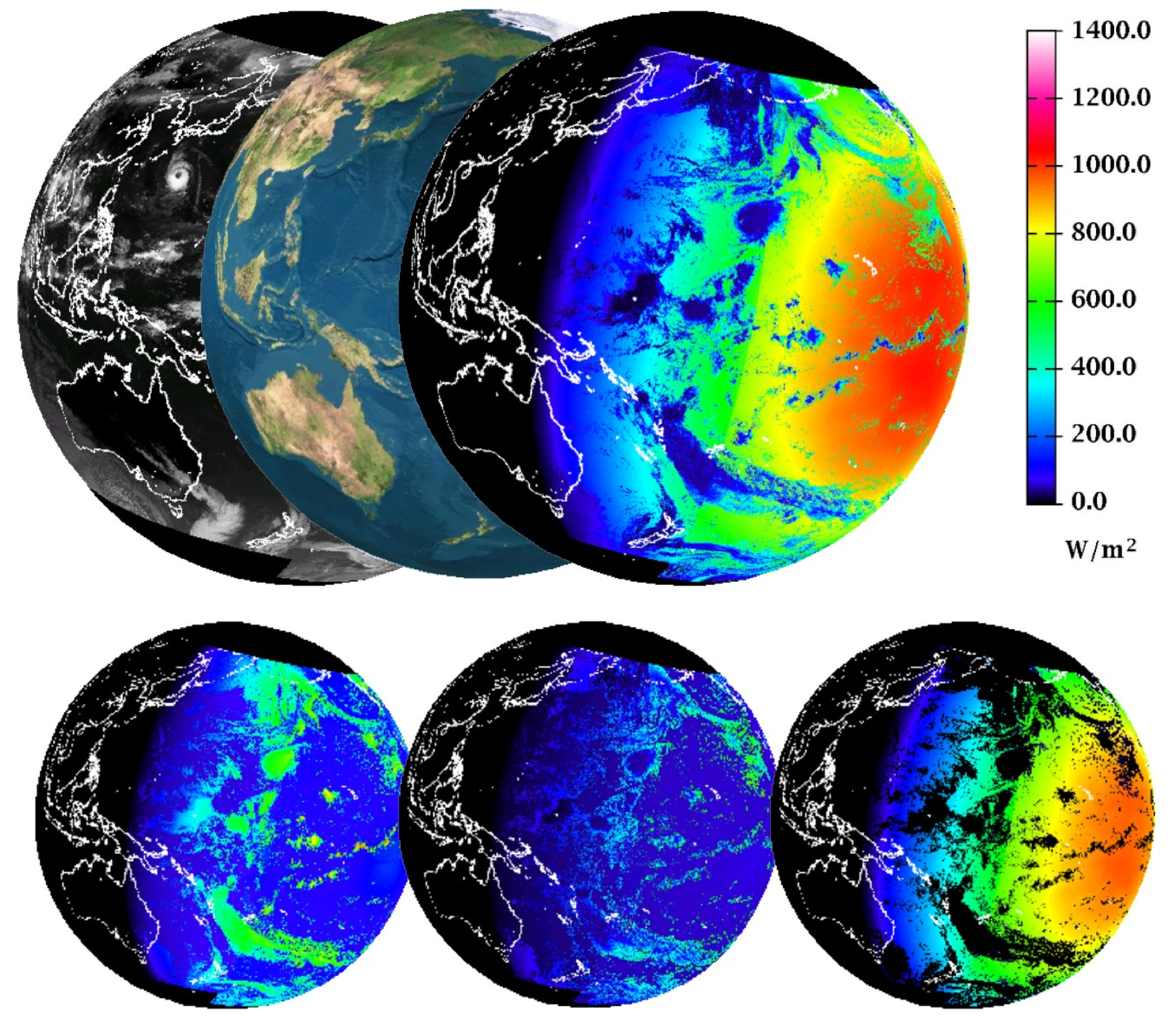
High-speed algorithm allows a Quasi-real-time analysis. The solar radiation products are analyzed by using geostationary satellite HIMAWARI observation data and objective analysis data Grid point value/Japan Meteorological Agency (GPV/JMA) basically. Process is roughly classified into three steps, 1: Satellite data geolocation information correction, 2: Cloud optical analysis, 3: Estimation of radiation at surface and TOA. Satellite raw data geolocation information has the ambiguity and It has a error depending on the attitude of the satellite. It will change from moment to moment. Thus geolocation error is correct by phase-only correlation method (POC) by 2D-FFT using landmark of SRTM (30sec mesh) elevation data at first step. Because the solar radiation depend on time and space, this is an important process. Second step is cloud analysis. Cloud is one of the biggest uncertainty of solar radiation. That accurately estimate the optical properties of clouds, is an important element in the estimation of solar radiation over cloudy sky. Cloud optical properties are retrieved by CAPCOM algorithm [Nakajima and nakajima, 1995; Kawamoto et al., 2001]. Last step, Estimation of SW radiation budget by High-speed solvers at the surface and TOA. Now 4x4km (every 60 minutes) and 1x1km (every 30 minutes) products is available..These processes will end roughly in six minutes. Appendx: right figure is sample of five geostationary satellites products (GMS, GOESx2, METEOSATx2) for global analysis.

4x4km Resolution full disk region



1x1km Resolution regional analysis

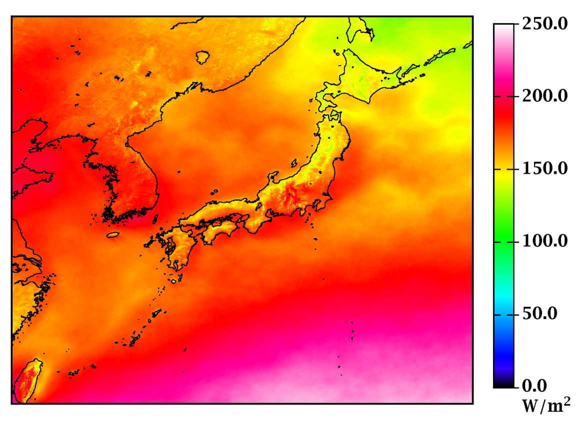


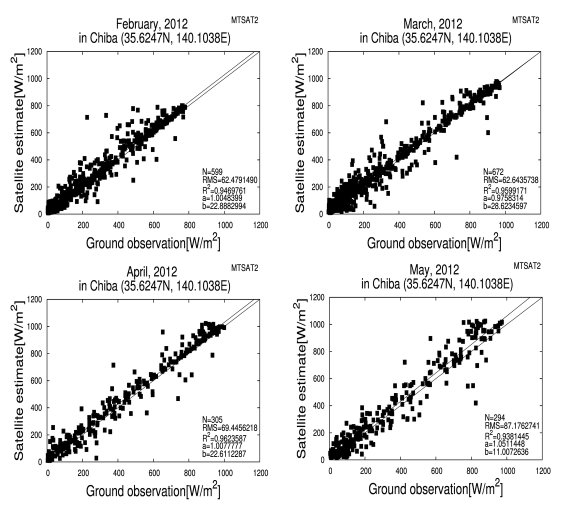


2. Re-analysis

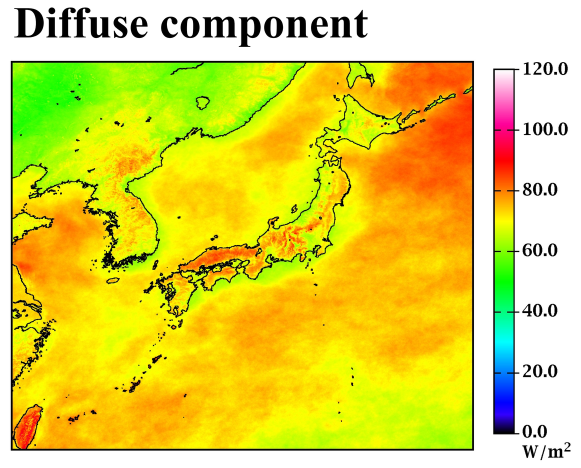
Re-analysis was processed by High-speed analysis using 2007, 2012, 2013 observation data of geostationary satellite HIMAWARI. In previous research, the analysis results showed a distinctive trend of direct and diffuse component of surface SW fluxes in North Pacific and North Atlantic ocean [Takenaka et. al., 2011]. The diffuse component is predominant in the mid-latitude region from East Asia to North Pacific Ocean. It increases until June and thereafter seems to decrease. An inverse correlation was found for the direct component. These trend indicate that the cloud optical properties and solar angle change with seasonal march. The diffuse component is stronger for thin cloud than for thick cloud, with inverse correlation between direct and diffuse component. In this section, we focused on the East Asia region of 2012 using 1x1km (every 30min) regional analysis solar radiation products. We can find increasing trend of diffuse component in June and July, and decreasing trend of direct component in June. This trend is found every year by Quasi-real-time analysis.

Global flux in 2012

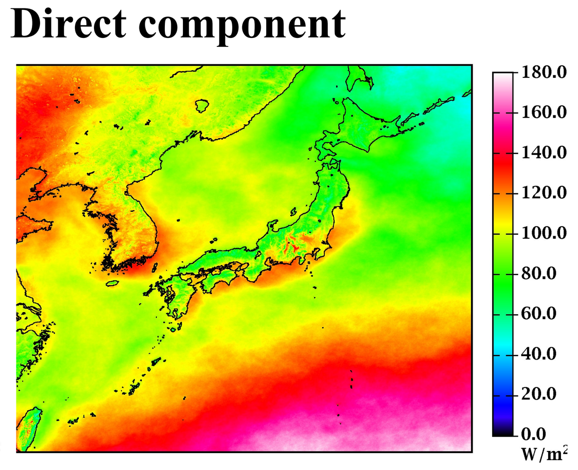




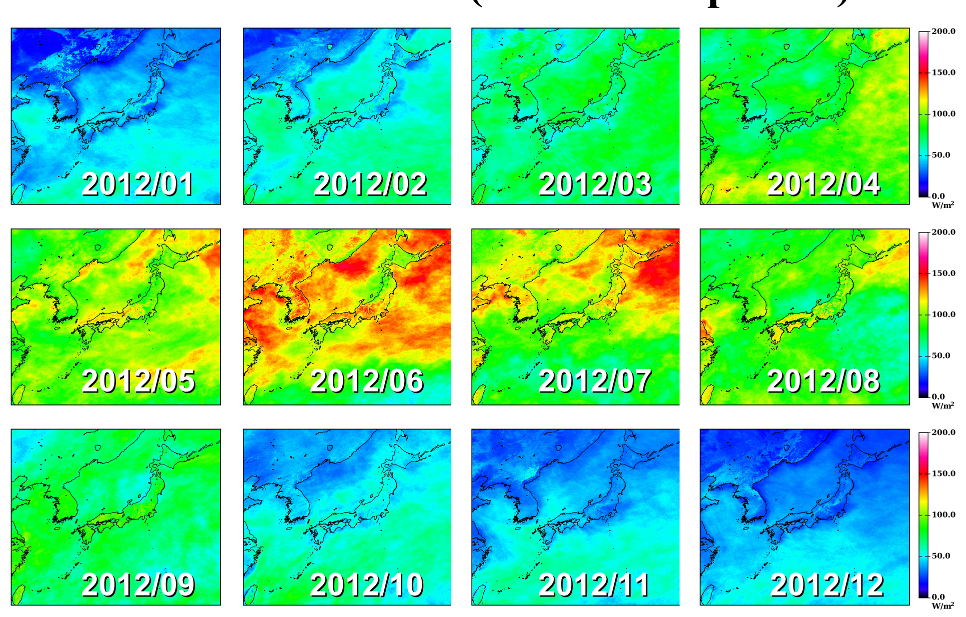
Diffuse component



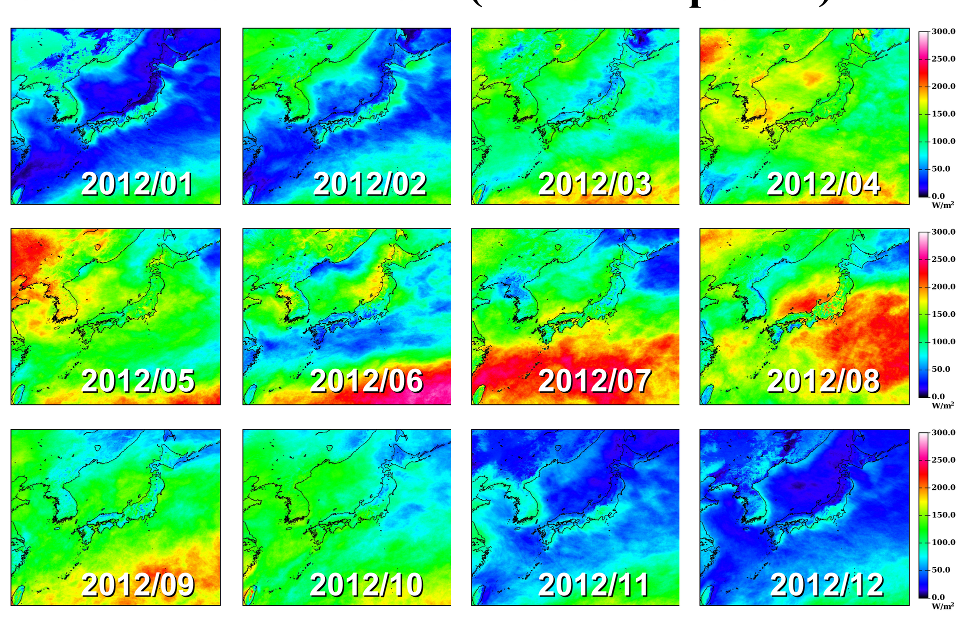
Direct component



Short wave flux in 2012 (Diffuse component)



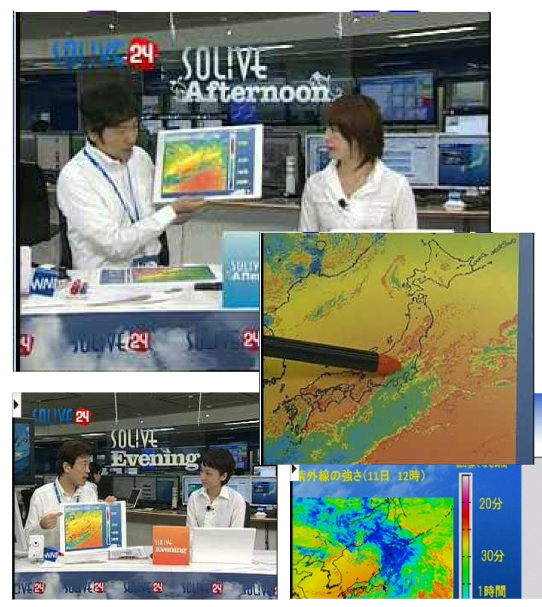
Short wave flux in 2012 (Direct component)



3. Quasi-real-time Monitoring

Solar radiation is the only energy source on the earth's climate. As one of the basic parameters, it is widely used in many fields (Climate/Meteorology, Vegetation science, Animal ecology, Photovoltaic power, Biomass, etc.). It has possibilities in various fields and immediate supply will contribute to science and society. Thus, our quasi-real-time analysis of the satellite data, programed with our high-speed estimation algorithm, has high potential. We have been applying this speedy and accurate analysis system of atmospheric radiation to different fields as collaboration works, such as weather information service, a solar car race to provide semi-real-time power information for energy management, and monitoring of photovoltaic (PV) power generation. Especially, the field of renewable energy has a possibility of progress [IPCC SCREEN report]. Ten PV systems of 10.0kW were investigated to see the validity of satellite-estimated PV power. PV panels are easily affected by heat of solar radiation; the temperature coefficient of silicon panels is almost -0.5 [%/K]. By calculating module temperature and the energy loss, we obtained accurate PV power using satellite-based atmospheric radiation. The accuracy was over 90% in daily accumulation. Also, we have developed a new PVP product: PV power generation mapping. It consists of four maps based on temperature coefficient of PV panel module and power conditioner efficiency.

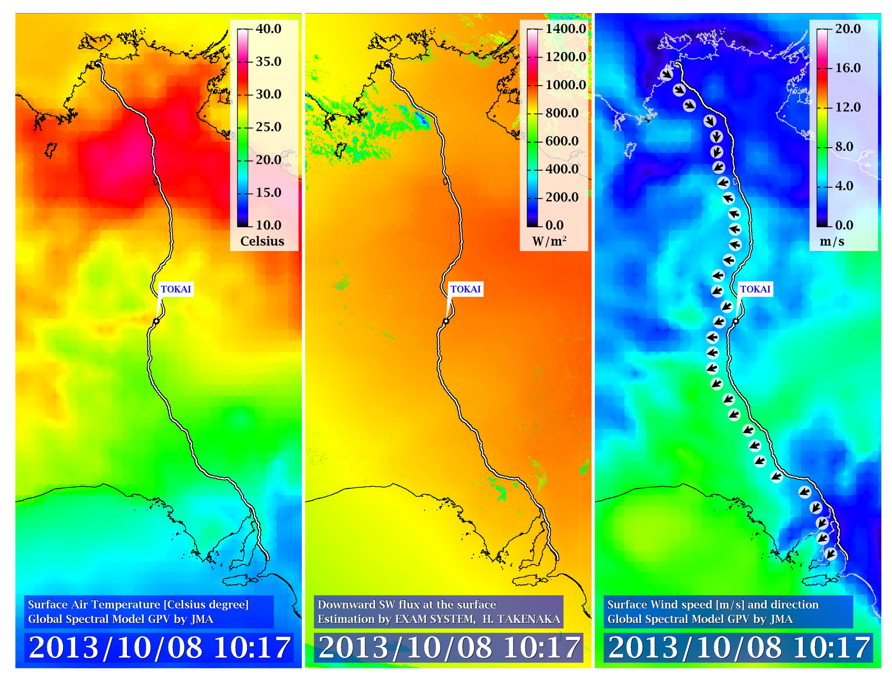
Weather information service



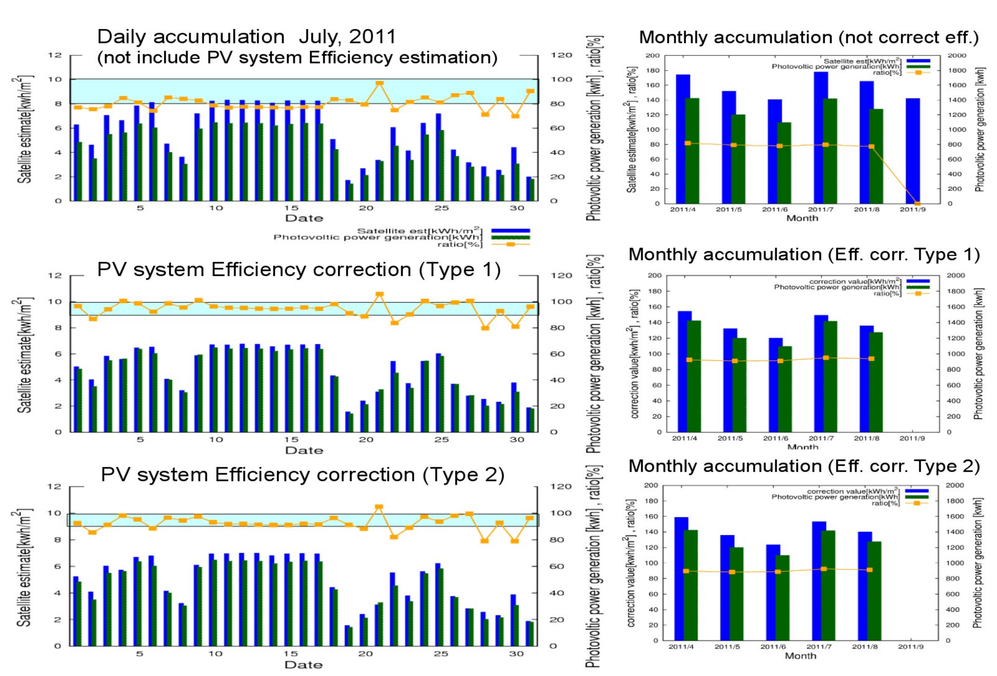
weathernews SOLiVE24

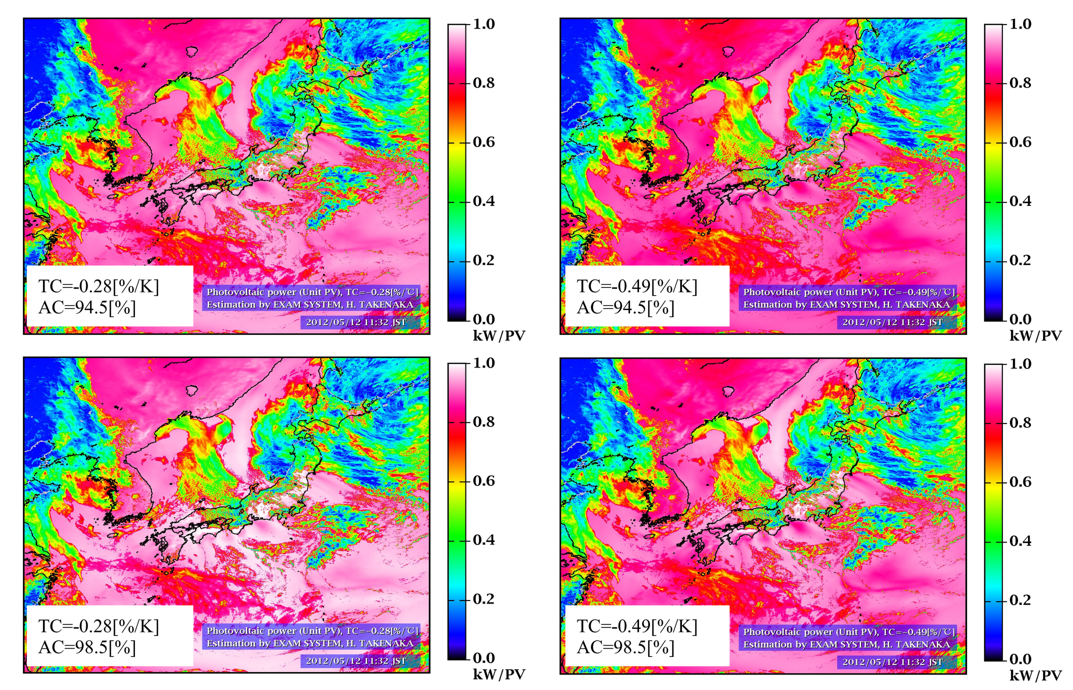
Power information for solar car

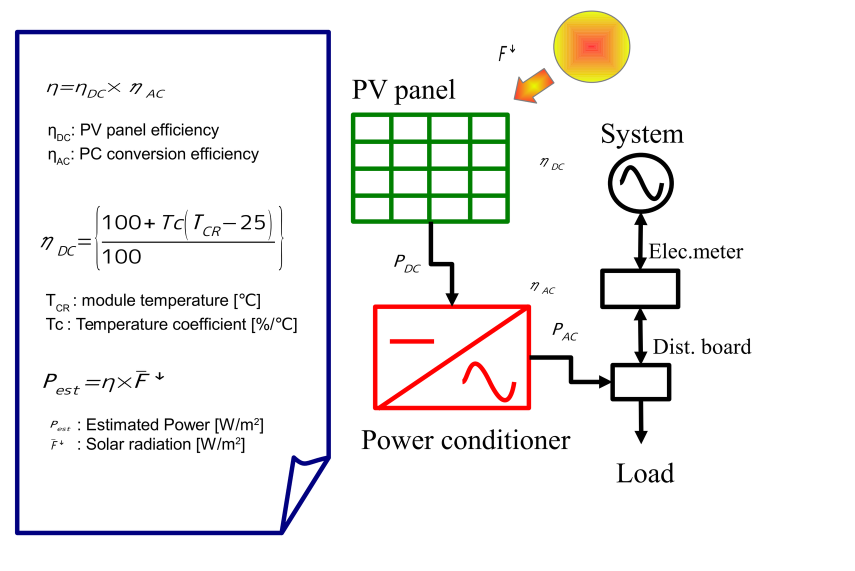
World Solar Challenge (WSC)



Monitoring of photovoltaic (PV) power







$$power(LAT,LNG)=PVP(LAT,LNG)\times PV\ system\ capacity(LAT,LNG)$$

Pixel value Given value