SOCIETY FOR SCIENCE AND EDUCATION
UNITED KINGDOM

TMLAI TRANSACTIONS ON MACHINE LEARNING AND ARTIFICIAL INTELLIGENCE

VOLUME 2, ISSUE 3
ISSN: 2054 - 7390

Estimation of solar radiation power using reference evaluation of solar transmittance, 2 bands (REST 2) model

(Case study : Semarang, central java, Indonesia)

Benedictus Asriparusa
Institut Teknologi Bandung

ABSTRACT

Indonesia is a country which has abundant energy resources of solar demonstrated by potential position of solar annual migration (around equator line). Nowadays fossil energy consumption so apprehensively, these things are due to decreasing of fossil energy while demand of fossil energy rises continuously. In 2011, fossil fuel energy of Indonesia is 66.4% besides negative effect of increasing Greenhouse Gases concentrate, which is increasing of surface temperature and creates inconvenience environment. Sun as the biggest energy resource should be use optimally for Indonesia area. Diversification of energy is a final step to get another resource so release us of dependently fossil resources. Solar radiation is a green renewable energy which has the potential to answer the needs of energy problems on the period. Knowing how to estimate the strength of the solar radiation force may be one solution of sustainable energy development in an integrated manner. Unfortunately, a fairly extensive area of Indonesia is still very low availability of solar radiation data. Therefore, we need a method to estimate the exact strength of solar radiation. In this study, author used a model Reference Evaluation of Solar Transmittance, 2 Bands (REST 2). Validation of REST 2 model has been performed in Spain, India, Colorado, Saudi Arabia, and several other areas. But it is not widely used in Indonesia. Indonesian region study area is represented by the area of Semarang, Central Java. Solar radiation values estimated using REST 2 model was then verified by field data and gives average RMSE value of 6.53%. Based on the value, it can be concluded that the model REST 2 can be used to estimate the value of solar radiation in clear sky conditions in parts of Indonesia.

Keywords : Estimation, Solar Radiation Power, REST 2, Renewable Energy

1 INTRODUCTION

Energy currently holds an important role in the development of economic sector in National Country. It would be a thing which is not disputed and often regarded as the most powerful of

DOI: 10.14738/tmlai.23.210
Publication Date: 9th June 2014
URL: http://dx.doi.org/10.14738/tmlai.23.210

the economy. This thing is recognized by developing countries in the world. Then, they always think that how to implement energy usage accurately and developing other technologies efficiently as an main requirement to increase economic sector. Indonesia is one of the developing countries that has different types of energy resources in quality and quantity. Generally, Indonesia could manage of energy resources appropriately to improve social welfare in that country.

Indonesia's location is around the equator line, which is the latitude 6^0 NL – 11^0 SL and the longitude 95^0 EL - 141^0 WL. Based on the circulation of the sun in a year (which is at 23.5^0 NL and 23.5^0 SL area), Indonesian territory will be exposed by the sun during 10-12 hours per day. Due to the location of Indonesia and position of the sun, that's why Indonesia has a solar radiation level is very high. According to the measurement from the center of Badan Meteorologi, Klimatologi, dan Geofisika (BMKG) Indonesia, they estimated that the solar radiation touching on the surface of the Earth Indonesia (especially Eastern Indonesia) on average ± 5.1 kWh/m^2 per day and given variation around 9% per month. (NN, 1994).

Based on the research, they are trying to simulate the influence of cloud sheet towards on global energy balance shows that albedo (the deviation of solar radiation are reflected and received by the earth) increases continuously from 15% to 30% which means that the quantity of energy loss is 50W/m^2. Clouds also reduce the emission of infrared light until 30 w/m^2. It makes the effect of clouds sheet in global balance system loss the energy until 20 W/m^2. While the quantity of greenhouse effect given 4 W/m^2 of global warming, even though it given the addition of the CO_2 content in the atmosphere is two times larger than the current state. It shows that method of collection Solar radiation data still not effective. (Intergovernmental Panel on Climate Change, 2001).

REST Model 2 is one of the model method to estimate the value of solar radiation for clear-sky Model Condition. This model take into measurement of atmospheric condition like humidity, water vapor, ozone layer, precipitation, and contain of gas that can be reflected solar radiation to the outside of Earth. REST Model 2 also uses the data to calculate aerosol turbidity like CO_2 and NO_2. (Gueymard C. A., 2009).

The focus area is Semarang, Central Java. It is represented by point Climatological Station in Semarang (06.967 SL and 110.417 EL). Time studies are in January and July of 2011. This research aimed to clear-sky conditions. Bandung area as comparison to confirm the validity of the model REST 2. It is represented by the location in 06.8 SL and 107.4 EL with time studies throughout the month of January 2010 and June 2010.

This research has four objectives. Those are to determine the time of maximum and minimum value of solar radiation through on estimation, to simulate the movement of CO_2 and NO_2 in

Semarang Area, to find out whether the REST 2 model is suitable applied in Indonesia., and to looking for other alternatives to fill the solar radiation data other than direct measurement.

Reference Evaluation of Solar Transmittance, 2 bands (REST 2) is a two-band models developed by Christian A. Gueymard in 2008. Band 1 covers UV wave and Visible wave, from 0.29 to 0.70 µm. The characteristic of Band I is huge absorption by ozone in the UV wave and scattering by molecules and aerosols. Band II covers near infrared wave, from 0.7 to 4 µm. The characteristic of Band II is huge absorption by H_2O, CO_2, NO_2, and other gases. Model REST 2 is an updated version of the previous model ie the Reference Evaluation of Solar Transmittance (REST). REST 2 Model is considering absorption by NO_2 (Gueymard CA, 2002) because absorption of NO_2 is an important parameter in estimating the value of the solar radiation. (Rizwan Jamil, & Kothari, 2010).

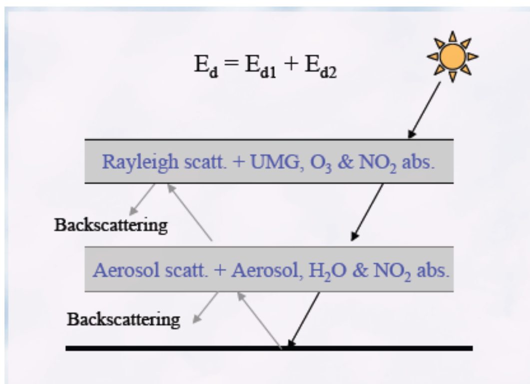


Figure 1 Scattering of two layers Scheme (Gueymard C. A., 2009)

$$E_d = E_{d1} + E_{d2}$$

$$E_{d1(band1)} = f_1\, R\, E_{SC}\, T_{R1}\, T_{G1}\, T_{O1}\, T_{N1}\, T_{W1}\, T_{A1}$$

$$E_{d2(band2)} = f_2\, R\, E_{SC}\, T_{R2}\, T_{G2}\, T_{O2}\, T_{N2}\, T_{W2}\, T_{A2}$$

Generally, REST 2 Model as clear-sky model condition has 8 input data. It is base on satellites measurement that is MRM-5 (5data input), CSR (5 input data), METSTAT (5 input data) , Yang (4 input data) , Heliosat-2 (2 input data). It is also equipped with statistical measurement that is mean bias difference (MBD) and root mean square difference (RMSD).

Based on previous research, it shows that value of root mean square (RMSE) reached 5.93% in Saudi Arabia. (Shafiqur, 1997). One of research in India also shows that the value of root mean square (RMSE) reached 3.4 % (Rizwan, et al, 2010), research in Germany shows that the value of root mean square reached 5.1% (Lorenz, 2013) and research in Spain shows that the value of root mean square reached 9% (Mateos et al, 2010). Thus, it means RMSD of REST 2 were in the range 0.7 % to 11.9% (Gueymard CA, 2011)

According to all information, it can conclude that the deviation value for REST 2 model is in the range 0.7% to 11.9%. Therefore, the value of deviation is acceptable to show that the results of the REST 2 models can be used to estimate the solar radiation in a region. So, author determined that the threshold for the value of RMSE is 11.9%.

2 METHOD OF MODEL EVALUATION

On this research, author is divided into four main parts: input data model base on observation, satellite data, modeling of dominant gas of atmosphere and data correlation to verify the model. There are 8 input data required by the model REST 2: precipitation of water, surface pressure , Angstrom's wave exponent (α), Angstrom turbidity factor, aerosol single-scattering albedo (using default), the total columnar ozone amount, total columnar nitrogen dioxide amount (using default), the solar zenith angle (calculated from the date and time).

Based on observation process, solar radiation data obtained from measurements using the Automatic Weather Station (AWS) with brand VAISALA placed in Badan Meteorologi Klimatologi dan Gofisika Semarang data available with an interval of one second. Data can be downloaded in http://aws.bmkg.go.id/MetView / # dataquery (AWS Center, 2013).

Based on satellite measurement, satellite is used satellite MTSAT. The image used is the visible image of the canal with a wavelength of 0.55 - 0.80µm and a resolution of 1 km. Data can be downloaded via http://weather.is.kochi-u.ac.jp/sat/GAME (Index of/sat/GAME/2011, 2005).

Based on simulation of dominant gas of atmosphere, solar radiation data for Bandung area obtained by recording data that is placed in the Garden of AWS Meteorological ITB. Data distribution of NO_2 and CO_2 using a simulated distribution TAQM (Taiwan Air Quality Model).

The step on this research is to collect input data required to run the model REST 2 according to observation and data measurement. The next step is the preparation of model input. Models are arranged and grouped by month. So, there are 7 input files for each month. We have 4 times per day, then the input set 07.0 pm (00:00 UTC), 10:00 pm (03:00), 13:00 pm (06:00 UTC), and 16:00 (09:00 UTC) as time arranged.

The next step is determined by time case during a *clear-sky* condition. Determine of *clear-sky* condition depends on looking the area without cloud at satellite images. Afterwards, verify the results of the REST 2 model output used 3 methods of statistical tests that is root mean-square error (RMSE), correlation, and the simulated distribution of the dominant atmospheric gases (CO2 and NO2).

Root mean square error shows that :

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mathrm{R_{ob}} - \mathrm{R_{mod}})^{2}}$$

According the results, we obtained that verification of data error gap is quite large. So we have to give some corrections to model in order to provide good results. Data observation is data received on the surface of the earth after undergoing attenuation, while data model is the solar radiation data received by the earth in the clear-sky conditions. Ratio of solar radiation received by the earth's surface is observational data divided by data model. The ratio will be provided empirical formula as a correction to the model results.

3 RESULT AND DISCUSSION

3.1 REST 2 Model Result

3.1.1 Semarang

The blue line is the result of solar radiation model, while the red line is the solar radiation observation. Graphical image shows that the blue line values has trend pattern to be higher than the red line. This is acceptable because radiation of the model is the radiation received by the earth's radiation under clear-sky conditions, while radiation of the observation is actual radiation received by the earth where there are factors that reduce the radiation that is not accounted for by the model. It is caused by cloud.

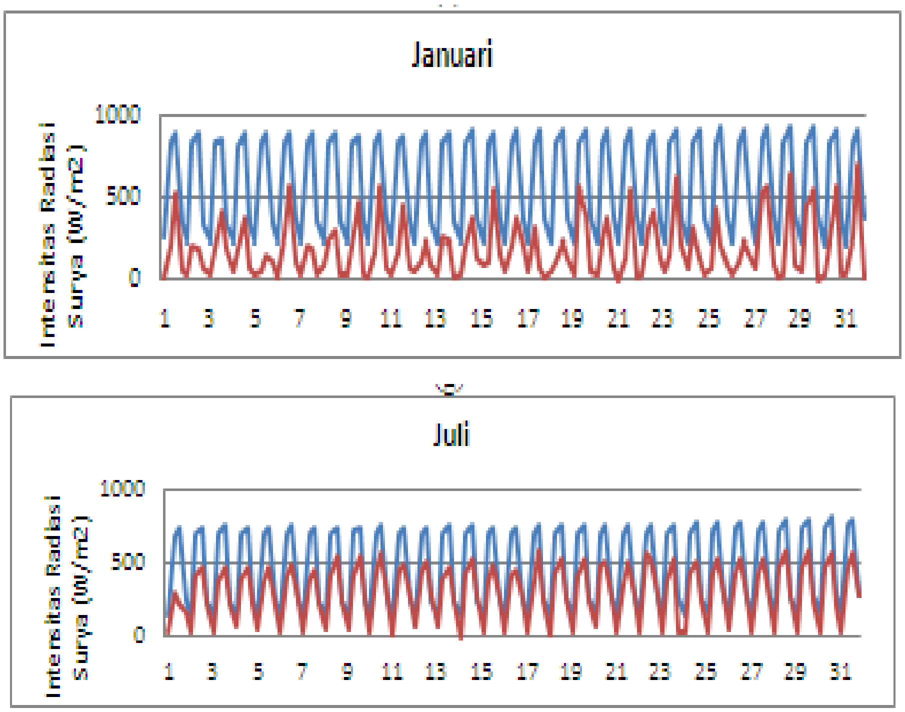


Figure 1 Solar radiation of REST 2 model (Blue line) and solar radiation of observation data (red line)

Generally, The first month (January) is the peak of the rainy season so that the growth of the cloud is very large compared to other months, while June and July are already entering the dry months so that the growth of the cloud tend to be smaller. It gives impact to the solar radiation received by the earth's surface which means that clouds are blocked all radiation that will come to earth’s surface.

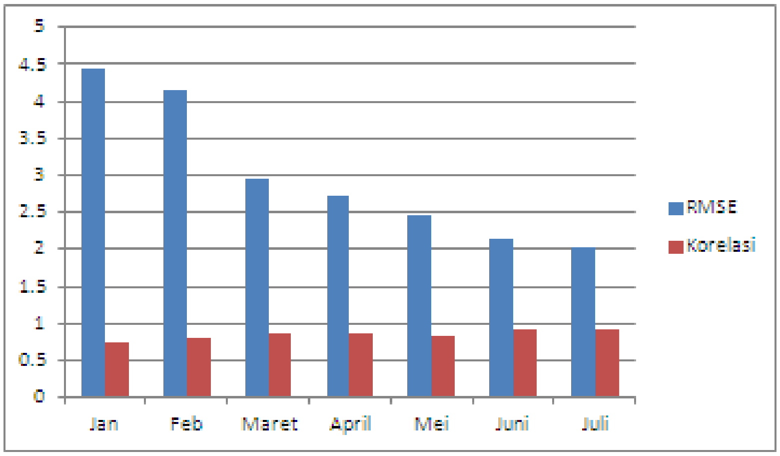


Figure 2 RMSE and correction for each month on percentage

The actual radiation in January will be smaller than in June and July, it can be seen from the RMSE is on above the graphic. RMSE in January reached 444.8W/m2 and RMSE in June and July, respectively 213.4 W/m2 and 203.3 W/m2 without gas dominant measurement, while RMSE in January reached 452.3 W/m2 and RMSE in June and July, respectively 220.6 W/m2 and 211.7 W/m2 with gas dominant measurement.

Solar radiation generated by the model REST 2 is the maximum possible values solar radiation received by the solar radiation of earth's surface. The average value in Semarang area with clear-sky condition and gas dominant of atmosphere is reached to 532.2124 W /m2, while the maximum value is equal to 954.2 W/m2 (February). The maximum value for each month are: January (934 W/m2). February (954.2 W/m2), March (945.2 W/m2), April (884.7 W/m2), Mei (795.1 W/m2), June (760.8 W/m2), and July (815.1 W/m2).

3.1.2 Bandung

In Bandung area, we also applied same method to determine solar radiation maximum and RMSE. According to calculation, it shows that RMSE value in January 2010 reaches 121.23 W/m2 while RMSE value in June 2010 reaches 84.32 W/m2. So, Bandung area as comparison shows that it confirms the REST 2 model can be applied at region of Indonesia.

3.2 Clear-Sky Condition

3.2.1 Semarang

Author have to arrange and determine the times where the research is clear-sky conditions used satelit (MTSAT). The observation of cloud cover shows in 110.417 LN and 06.967 LS point. Image A shows that clear-sky condition at Semarang area, Central Java and image B shows that satellite images which are not included the clear-sky condition.

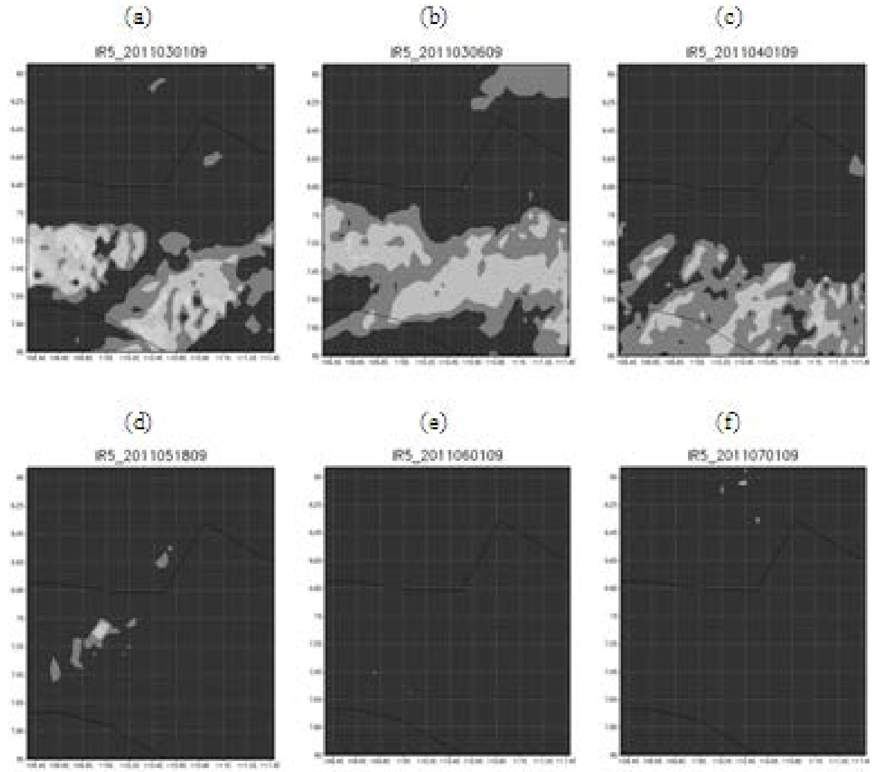
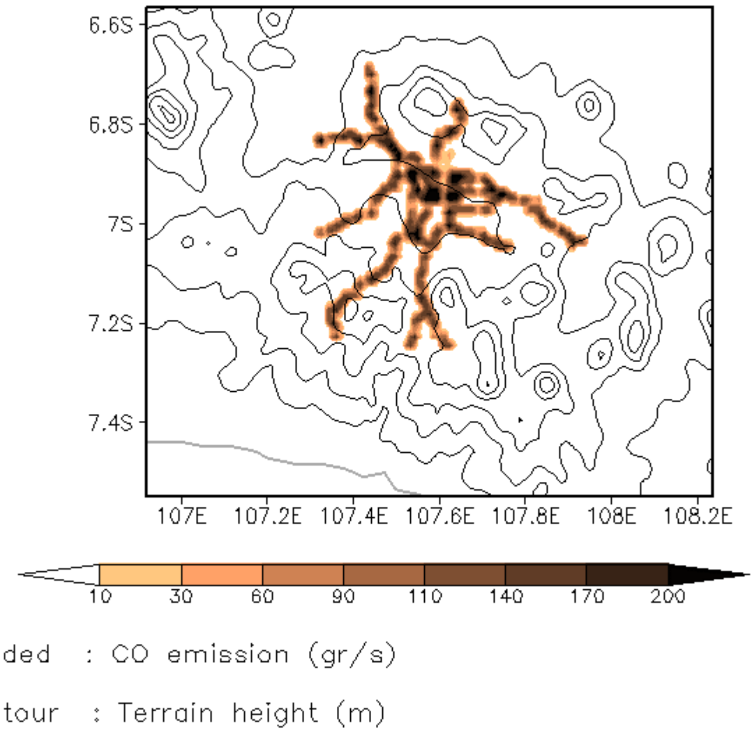


Figure 3 MTSAT satellite images (Satellite images of Central Java with Semarang area (in 110.417 LN and 06.967 LS)

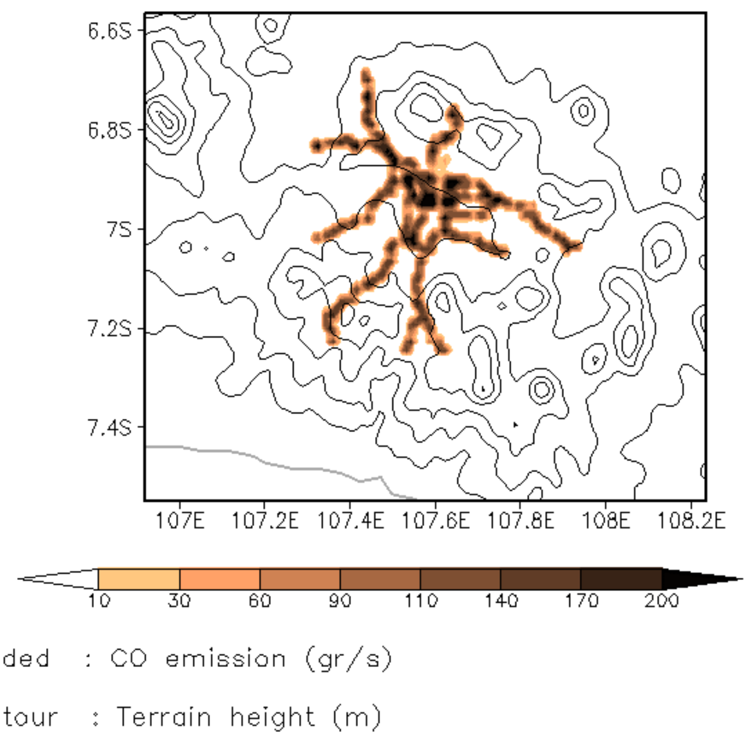
According to MTSAT satellites images, we found 67 times out of a total of 844 times that clear-sky conditions. Clear-sky conditions most commonly found in June and July, respectively 19 times and 27 times. Total RMSE for clear-sky conditions 17.23 W/m2. The average RMSE is equal to 6.53421%, and the value is smaller than the threshold value. RMSE of REST 2 model shows that the model can estimating solar radiation well in clear-sky conditions for the area of Semarang, Central Java.

3.2.2 Bandung

Clear-sky conditions at the Bandung area has quite small RMSE value. It is equal to 14.72979 W/m2 without taking into account the distribution of CO_2 and NO_2 (Tika, 2012). This is because the correction does not consider the simulation of the spread of water vapor, CO_2, NO_2, and wind. Below is a picture of the distribution of CO_2 in Bandung. Image to the left is a picture of the distribution of CO_2 in Bandung area, West Java (6.8 LS and BT 107.4) in January and to the right of the picture is in June.



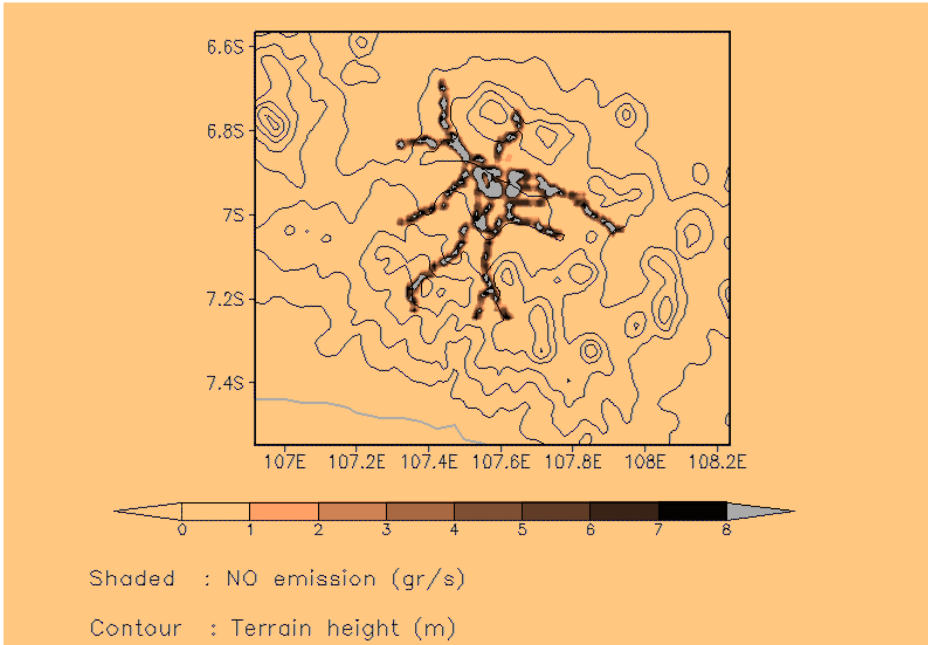
(a)



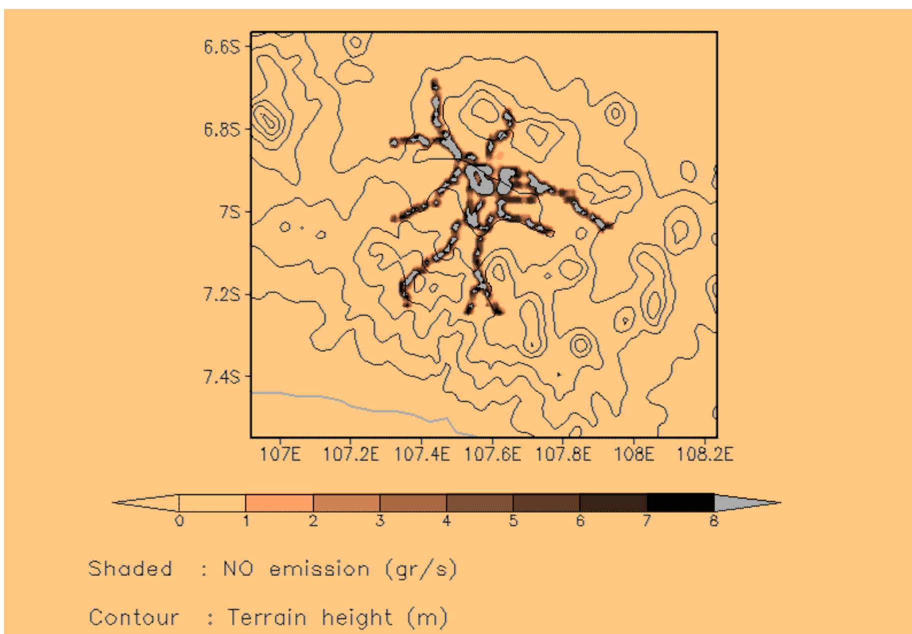
(b)

Figure 4 Simulation of Dissemination CO2 on (a) January and (b) June

RMSE values with CO_2 measurement shows that it is equal to 20.36767 W/m2. If we look to the distribution of NO_2 in the Bandung area, West Java, we can see the picture to the left of the distribution of NO_2 in January and to the left of the picture in June.



(a)



(b)

Figure 5 Simulation of Dissemination NO_2 on (a) January and (b) June

RMSE values with distribution of NO_2 measurement shows that it is equal to 27.81282 W/m2. This suggests that the distribution of CO_2 and NO_2 have considerable influence on the development of simulation models and we need to make the distribution of dominant gases in the atmosphere prior to provide better precision.

The value of REST 2 confirms that the model must be modified and verified with the dominant model of the gas distribution in the atmosphere firstly and then we currently can be used it to estimate the solar radiation in clear-sky conditions for Indonesian territory.

3.3 Correction and Evaluation of Model

3.3.1 Semarang

Based on previous result, we can see that the value of RMSE is very large. So it takes corrective measurement to improve the results of the REST 2 model. This correction gives mean that we have to count parameterization factors on the model REST 2, which is cloud factors. First step is we must find the ratio of solar radiation received by the earth's surface. The ratio is obtained by dividing the solar radiation observations to the results of model calculations of solar radiation.

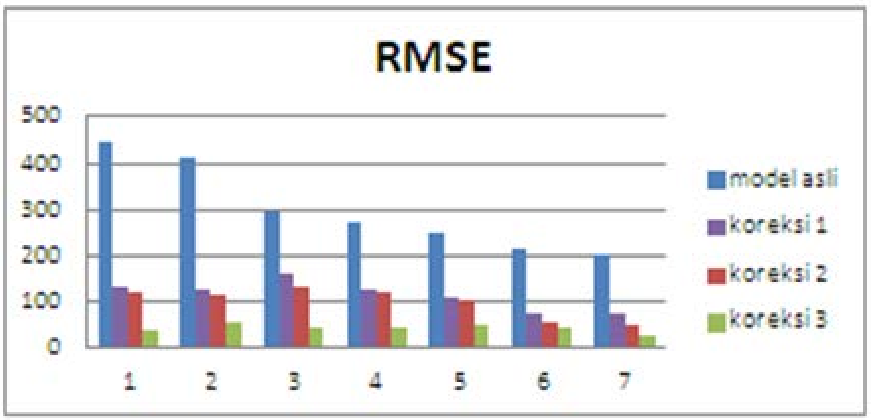


Figure 6 RMSE value comparison

In first experiment correction, ratio will calculate for each time. Then the average of RMSE values over each month has its own tendencies are influenced by season. RMSE in January reached 147.2 W/m2, March reached 179.4 W/m2 (largest RMSE) and in July reached 82.1 W/m2 (smallest RMSE).

In second experiment, we consider the correction due to the influence of the revolution of the earth's seasons and the growth of the cloud due to the movement of the earth's rotation. The growth of cloud between the morning and afternoon will distinguish.

Correlation of second experimental results gives improvement, which shows that the correlation was reduced from 0.79 to 0.77. RMSE was getting better. The large of RMSE amounting to 135.2 W/m2 in March, while the smallest was in July of 54.1 W/m2.

In third correction, the results are getting better. The correlation increased to 0.94, then the smallest correlation was 0.82 in January and the largest is 0.95 in July. RMSE improved significantly. RMSE average reached 48.2 W/m2, which means shrank 83.4 % from the previous value 290.6 W/m2. (The average of RMSE with original model).

3.3.2 Bandung

Based on previous result, we can see that the value of RMSE is improved significantly, then the correction step should be applied to other areas to ensure that the method can be used with either. The next correction method will try to the area of Bandung.

Once applied correction method, RMSE value of 57.48 W/m2 which is shrinking 32%. So, it means that the correction methods just only to correct the model output, but the results are not very significant.

REST 2 model is indeed a model for clear-sky conditions, but there needs to be a special correction on simulation of distribution dominant gases in the atmosphere when used directly without modification for the region with the cloud growth is high regardless of the dominant gases such as Indonesia, it will not be provide quite representative output.

4 CONCLUSIONS

According to this research, we can put some conclusions. The conclusions are :

- The average of estimation solar radiation value in point of Badan Meteorologi Klimatologi dan Geofisika (BMKG) Semarang is 532.2124 W/m2 (clear-sky condition and gas dominant measurement)
- The maximum value of point Badan Meteorologi Klimatologi dan Geofisika (BMKG) Semarang for each month are: January (934 W/m2). February (954.2 W/m2), March (945.2 W/m2), April (884.7 W/m2), Mei (795.1 W/m2), June (760.8 W/m2), and July (815.1 W/m2).
- Model REST 2 must used by additional data like simulation of dominant gas of atmosphere to get better precition of result so we could use it to prediction maximum value of solar radiation received by earth’s surface.
- In clear-sky conditions with the simulation of CO2 and NO2, RMSE total is 17.23 W/m2. If we converted into a percentage, the average RMSE is equal to 6.53421% (6.53%).
- REST Model 2 can be applied in Indonesia, but only for clear-sky conditions and need additional data such as the simulation of the dominant atmospheric gases to obtain more precise results.
- If we will calculate the model in a state of cloudy skies. It means the model cannot be applied directly but requires correction step (the dominant atmospheric gases, water vapor, wind, etc.).
- REST Model 2 can be used as an alternative to predict and estimate the solar radiation data other than direct measurement.

REFERENCES

Sasongko, Tika. (2013). Perhitungan Radiasi Surya menggunakan Reference Evaluation of Solar Transmittance, 2 bands (REST 2) model (Studi kasus: Semarang).

Rahman, Shafiqur. (2007). Solar Radiation Over Saudi Arabia And Comparisons With Empirical Models. Retrieved January 09, 2014, from Jurnal of Saudi Arabia Center.

Lorenz, Elke. (2013). Current status of solar PV Power forecasting. Retrieved January 09, 2014, from Jurnal and Workshop Universitat Oldenburg : http://www.3e.eu/wp-content/uploads/2013/11/Lorenz_MeteoRES-Workshop_2013-11-19.pdf

PSD Climate Data Repository. (2011). Retrieved November 25, 2013, from Earth System Research Laboratory: http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

AWS Center. (2013). Retrieved November 2013, from http://aws.bmkg.go.id/MetView/#dataquery

Gueymard, C. A. (2002). Direct solar transmittance and irradiance predictions with broadband models. Part I: detailed theoretical performance assessment. *Solar Energy* , 361.

Gueymard, C. A. (2009). Retrieved January 11, 2014, from Solar Consulting Service: http://www.solarconsultingservices.com/ReadMe_REST2_v7.1.txt

Index of /sat/GAME/2011. (2005, 11 17). Retrieved January 15, 2014, from Kochi University: http://weather.is.kochi-u.ac.jp/

Gueymard, C. A. (2011). Clear-sky irradiance predictions for solar resource mapping and large-scale applications: Improved validation methodology and detailed performance analysis of 18 broadband radiative models. *Solar Energy* .

Justus, C. G., & Paris, M. V. (1985). A Model For Solar Spectral Irradiance And Radiance at the Bottom and Top of A Cloudless Atmosphere. *Journal of Climate and Applied Meteorology* .

Mateos, D., Bilbao, J., Miguel, A. d., & Burgos, A. P. (2010). Prediction of Solar Irradiance And Illuminance Using REST2 Model. Valladolid, Spain.

Rahardjo, I., & Fitriana, I. (2006). Analisis Potensi Pembangkit Listrik Tenaga Surya di Indonesia. *Strategi Penyediaan Listrik Nasional Dalam Rangka Mengantisipasi Pemanfaatan PLTU Batubara Skala Kecil, PLTN, Dan Energi Terbarukan* , 43-52.

Rizwan, M., Jamil, M., & Kothari, D. P. (2010). Solar energy estimation using REST2 model. *International Journal of Energy and Environment* .

NOMENCLATURE

RMSE = root-mean-square error

RMSD = root-mean-square deviation

n = total data that will be used

R_{ob} = solar radiation base on observation

R_{mod} = solar radiation base on REST 2 model

R = Rayleigh scatter

G = mixed gas absorption

O = Ozone absorption

N = NO_2 absorption

W = water vapor absorption

A = scatter and absorption of aerosols