HARNESSING NON-CONVENTIONAL ENERGY POTENTIAL USING SPACE BORNE SENSORS

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ABSTRACT: India has the fifth largest power generation capacity in the world and its current renewable energy contribution stands at 57.2 GW, contributing 17.3 % of the total installed capacity, which includes 32.3 GW of wind power and 12.3 GW of solar power installed capacity in the country as on 2017. It has fourth largest installed capacity of wind power, third largest installed capacity of concentrated solar power (CSP). The Government of India has revised its target of renewable energy capacity to 175 GW by end of 2022, committed to Clean and Green Energy and is driving efforts to achieve 40% power installed capacity from non-conventional energy resources and reducing emissions by 33- 35% of its GDP by 2030. This ambitious target includes 100 GW of Solar power, 60 GW from wind power, 10 GW from biomass power and 5 GW from small hydro power. In order to evaluate the potential energy resource, accurate long-term measurements are utmost important, which is not presently possible with the limited measurements available across India. Satellite remote sensing could provide synoptic data, covering larger areas continuously for longer periods.

At Space Applications Centre (SAC), Ahmedabad one of the major centres of ISRO, valuable databases of winds, solar energy and wave energy resources have been utilised from several Indian and foreign satellite datasets synergistically. Solar Insolation has been generated at monthly interval using Kalpana satellite (2009-2016) and INSAT-3D from 2016 onwards. The end products include Global Horizontal irradiance, direct and diffuse normal irradiance, capacity utilization factor and Annual energy production available for the entire country and also at selected “Smart cities”. Monthly wind climatology over the Indian seas has been derived from QuikSCAT (1999-2009), OSCAT (2010-2014), ASCAT Metop-A (2010-2016) and Metop-B (2012-2016) scatterometers. Monthly and Annual wind energy potential has been estimated by considering the bathymetric variations within the Exclusive Economic Zone (EEZ) of the Indian coast. Relatively less exploited wave energy potential was also estimated along the Indian waters using merged altimetry products (2009-2017) and state-of-art numerical models. These datasets are very essential to assess the potential renewable energy resources within India and its neighbouring coasts. All these datasets are available for the scientific community and other users through the Visualisation of Earth Observation Data and Archival System (VEDAS – www.vedas.sac.gov.in) web portal and android based applications.

1. INTRODUCTION

Recent studies have revealed that anthropogenic greenhouse gases cause havoc to the Earth’s climatic system including oceans, land, and ecosystems (IPCC, 2007). With the exhaustion of fossil fuels and increasing awareness on these environmental issues, harnessing energy from renewable resources has become prime focus in the developing countries (Yan et al. 2010). Due to increased pressure of population and urbanization, many nations have understood that the ever growing demand for electrical energy can only be sufficed with the exploitation of new and renewable energy resources. India has the fifth largest power generation capacity in the world and its current renewable energy contribution stands at 17.3% of the total installed capacity (Figure 1) as on 2017. The Government of India has setup an ambitious target of renewable energy capacity to 175 GW by end of 2022, committed to Clean and Green Energy and is driving efforts to achieve 40% power installed capacity from non-conventional energy resources and reducing emissions by 33- 35% of its GDP by 2030. This target includes 100 GW of solar power (including 40 GW of grid-connected roof-top solar installations), 60 GW from wind power (including onshore and offshore wind farms), 10 GW from biomass power and 5 GW from small hydro power. The Jawaharlal Nehru National Solar Mission (JNNSM) is a major initiative by the Government of India to promote ecologically sustainable growth to address energy security challenges under India’s national action plan on climate change. India has already reached third largest installed capacity of concentrated solar power (CSP). With approximate 300 clear sunny days a year, India has approximately 5000 trillion kWh/m^2 incident solar energy, which is more than the possible energy output of all fossil fuel energy reserves in India. Similarly, India stands fourth largest installed capacity of wind power mostly from onshore wind farms. The presence of strong and persistent winds all throughout year, many regions along the coast of India are suitable for good potential of wind energy.

However, assessing such resources requires accurate long-term measurements. For example, the insolation maps are conventionally constructed from a high-density network of pyranometers and wind energy maps are constructed using long-term measurements of anemometers installed on meteorological masts. However, in a developing country like India, the network of Automatic Weather Stations (AWS) and offshore meteorological buoys is sparse and such observations are highly expensive. Hence, satellite remote sensing could provide synoptic data, covering larger areas continuously for longer periods. The use of remote-sensing observations from geostationary satellite sensors of high temporal sampling frequency (multiple passes every day) is ideal to capture the diurnal variability of atmospheric constituents such as water vapour, ozone, aerosols, and clouds, and thereby surface insolation on a spatial scale. The data from geo-stationary satellites could be used to estimate the solar energy over the entire country. On the other hand, wind and waves can be monitored using space-borne microwave radars like scatterometers and altimeters respectively in the polar orbits. Wave-power generation is not currently a widely used technology. With the advent of latest satellite technology, many scatterometers and altimeters are available e.g., OSCAT, the Ocean Scatterometer on-board OCEANSAT-2 from India Space Research Organisation (ISRO), SeaWinds on-board QuikSCAT from the National Aeronautics and Space Administration (NASA), advanced scatterometer ASCAT on-board Metop-A and Metop-B of the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat), SARAL-AltiKa (Ka band radar altimeter), Jason-2, 3 (Ku-band altimeters) etc catering the needs of different applications for the scientific community. In this paper, both Ku and Ka-band of altimeters are used for identification of the potential regions of wave power. Since scatterometer derived winds are not available over the land, analyses from Numerical Weather Prediction Models (NWP) like Weather Research and Forecasting Model (WRF) derived winds are generally used to estimate wind energy and the same model was used to forecast solar energy also.

At Space Applications Centre (SAC), a large volume of satellite datasets on winds, insolation and waves have been utilised from several Indian and foreign satellite datasets synergistically to generate a valuable information on the availability of renewable resources in India. The present work discusses on various methods used to generate such datasets and the major applications on solar, wind and wave energy. We also carried out some experiments and issued forecasts of solar and winds using WRF model including satellite data assimilation. The forecast can be accessed through VEDAS (https://www.vedas.sac.gov.in).

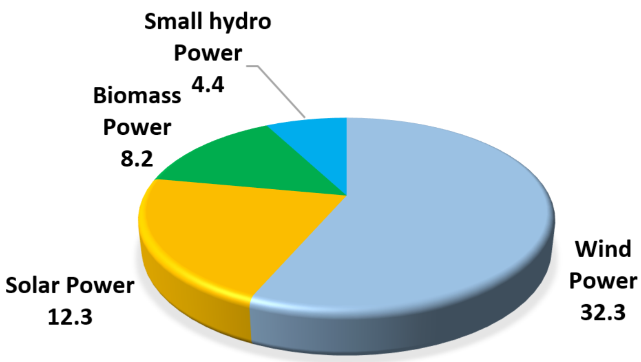

Figure 1: Renewable energy installed capacity (GW) in India as on June 2017 (source: MNRE)

2. DATA AND METHODOLOGY

2.1. Solar Energy

Sun is one of the driving force of life on Earth. It has provided various factors to germinate, sustain and evolve the civilizations on the Earth. So, it is upon us to maximise the benefits, we can derive from the sun. The solar energy is clean, pollution-free and abundant in nature. Its frequency in availability is also very high. We have attempted to derive solar energy using different Indian geo-stationary satellites.

Estimation of Solar insolation from geo-stationary satellites

The Global Horizontal Insolation (GHI), combining direct as well diffuse component of incident solar energy, is obtained from the half-hourly observations at 8 km spatial resolution in optical and thermal infrared bands from the Indian geostationary satellite KALPANA-1 Very High Resolution Radiometer (VHRR) and at 4.0 km spatial resolution from INSAT 3D. This data is available on Meteorology and Oceanographic Satellite Data Archival Centre

- MOSDAC (https://www.mosdac.gov.in) web portal. A C-language based software called as "KIRAN" (**K**alpana-1 **I**ncident solar **RA**diatio**N**) was developed to compute daily integrated solar radiation over India. A detailed flow chart of KIRAN process is shown in Figure 2. For detailed methodology on retrieving the GHI along with validation results, including spectrally integrated clear-sky and three-layer cloudy-sky models to determine the atmospheric transmittances and instantaneous surface insolation, the reader is referred to Bhattacharya et al. (2013) and Vyas et al. (2016).

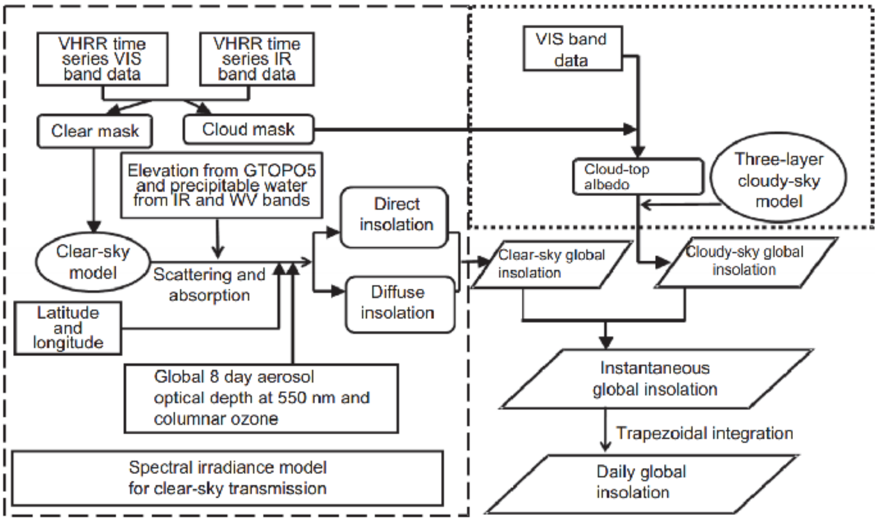

Figure 2: Flowchart for estimating instantaneous and daily global surface insolation from Kalpana-1 VHRR (KIRAN model)

Solar power Nowcasting based on satellite observations

A technique for solar power nowcasting using INSAT-3D satellite irradiance data have been developed and verified on the SAC solar plant datasets. This technique is suitable for a very short term forecasting in a temporal range of 30 minutes to 6 hours. The Power estimation was done by including parameters like panel temperature on particular day, efficiency of panel, air temperature. The method contains three phases (1) clearness index retrieval, (2) forecasting solar irradiance and (3) estimating power generation. The clearness index has been estimated as the ratio between the daily global solar irradiation on Earth's surface and outside the atmosphere (Marius, 2012). Finally, the solar irradiance forecasting was accomplished using Gaussian process regression (GPR) method. Solar power was estimated by

$$E_{PV} = E_{sol} * A * \eta_{PV} * \eta_{CPU} \tag{1}$$

where, E_{pv} = Energy output of solar PV panel in an hour, on a unit area measure in kWh/m^2, A = Area of panel in m^2, η_{pv} = Rated efficiency of PV Panel, and η_{PCU} = Efficiency of power conditioning unit including inverter.

Roof Top Solar Energy Potential in Urban Areas

Urban areas are typically characterized by the presence of multiple non-lambertian reflection effects of local environment, variability of slope, complexity of shadow effects in relation to complexity of urban geometry. This requires modelling of incident radiation on a tilted plane with complex shadow effects on diffuse and direct component. The surface solar irradiance in urban areas needs to account for the shadow effects, sky obstruction, reflection and terrain-atmosphere coupling. The 3D city buildings models created using Cartosat-1 PAN stereo-pair were used to model the effect of shadow on building roof tops and to determine the roof area suitable for installation of solar panels.

2.2. Wind Energy

Scatterometers are the missions with specific goal of observing the equivalent-neutral surface ocean vector winds across the world. Orbit-wise scatterometer wind products at 12.5 km spatial resolution from QuikSCAT (L2B version 3), OSCAT (L2B version 2) for the whole mission period 2000-2009 and 2010-2014 respectively and ASCAT (L2B version 2 coastal winds) for 2012-2016 have been processed to generate long-term synoptic monthly means in the Indian region (Lat.0-25°N; Long. 65-95°E). The mission targeted wind vector precision and accuracy are, respectively, 3.0 m s^{-1} for ASCAT, 0.5 m s^{-1} for QuikSCAT and OSCAT. The wind energy density, E is calculated from the Weibull parameters using the gamma function Γ and the air density ρ (~1.225 g m^{-3}) at sea level as

$$E = \frac{1}{2}\rho A^3 \Gamma\left(1+\frac{3}{k}\right) \tag{2}$$

Where A and k are the Weibull scale and shape parameters. The retrieved wind speed is 10 m height above the sea surface, while the height of wind turbine hub is mostly 60 – 100 m above the sea surface. In this consequence, the wind energy density should be calculated before wind power evaluation. Wind speed at hub height h is obtained by means of logarithmic law

$$v_h = v_o\left(\frac{\log\left({}^{h}/_{z_o}\right)}{\log\left({}^{10}/_{z_o}\right)}\right) \tag{3}$$

Where v_o is the wind speed at height 10 m above the sea level and z_o is the roughness length typically equal to 0.0002 m at the sea surface. Using Weibull probability density function, the shape parameter k_h and scale parameter c_h at desired height h were calculated using Safari and Gasore, (2010) and thus the energy density at hub height was calculated by Equation (2). The power generated by a turbine was computed following Mathew (2006)

$$P_{turbine} = \int_{v_i}^{v_o} P(v) f(v)\, dv \tag{4}$$

Where *P(v)* is the power expected for a wind velocity (v) derived from power curve of a turbine, *f(v)* is the probability density function of Weibull distribution derived from A and k parameters. The practical power production expected from a wind turbine was computed using the power curve of a REpower Systems 5M (REpower 5M) turbine in the offshore waters. The minimum "cut-in" (v_i), rated (v_r) and maximum "cut-off" (v_o) velocities of this turbine are 3.5, 13 and 30 m/s, respectively.

Apart from the wind energy from scatterometers, we derived the offshore winds from RISAT-1 SAR for the period 2012-2015 by using CMOD5N algorithm and utilising the equations (2) and (3). It is known that the on-shore winds cannot be estimated by scatterometers, hence a Numerical Weather Prediction (NWP) model winds are used. In SAC, we have successfully configured the community based meso-scale Weather Research and Forecasting (WRF, version 3.7) model for the Indian landmass. The model domain is extended from 4°-40°N in latitude and 64°-100°E in longitude with a nominal spatial resolution of 5km. The forecast accuracy of the model is better than 2m/s in wind speed for a daily forecast range. The analyses from the WRF is used to generate the wind energy maps. Both on-shore as well as off-shore wind energy/power maps are being updated regularly and are hosted in VEDAS for dissemination to the global users (see Figure 12).

2.3. Wave Energy

Wave Energy from Altimetry

Altimeters do not provide any direct measurements of the wave power. Employing the significant wave height (SWH) and wind speed measurements, the wave period is calculated. This computation is based on the data adaptive techniques of genetic algorithm following Remya et al (2011). The SWH and wave period is then used for computation of wave power. Thus in order to compute the wave power, the wave period estimated from altimeters is validated using the in-situ observations from the INCOIS buoys. The satellite observations used include the Altimeter measurements of Jason-2 from 2008-2014 and SARAL/AltiKa from 2013-2014. The equation for deriving wave power is given by

$$P_{wave} = \frac{\rho g^2}{64\pi} H_{m0}^2 T \approx \left(0.5\frac{kW}{m^3.s}\right) H_{m0}^2 T \tag{5}$$

Where, P_{wave} is Wave power per unit of wave–crest length, H_{m0} is the significant wave height, ρ is the density of water, g is the acceleration by gravity and T is wave period. According to this formula wave power is proportional to wave period and square of wave height.

Wave Energy from Numerical model

We have also used the Wave Watch-III model at 10 km resolution to assess the wave energy near the Indian coast. The model was run with ECMWF wind data and a monthly climatology has been constructed using this data to introspect the numerical model based wave energy assessment.

3. RESULTS AND DISCUSSION

3.1. Solar Energy

The distribution of monthly solar energy averaged over three years (2009–2011) using Kalpana-1 VHRR data is shown in Figure 3. As summer approaches, the amount of solar energy reaching the surface increases during March to May. During monsoon months it is reduced due to cloudy conditions. In winter months, the foggy conditions in the Indo-Gangetic plains (25ºN–32ºN) reduce solar energy. A prominent spatial pattern has emerged in the distribution of annual solar energy over Indian landmass, from the equator towards higher latitude. It is also observed that lower solar energy is available at higher altitudes such as in the Himalayan regions and some parts in north eastern states of Assam and Arunachal Pradesh. Between the equator and the tropic of cancer the annual solar energy varies from 1500 to 2500 kW h m^{-2} wherein majority of Indian landmass receives solar energy above 1750 kW h m^{-2}. Except few pockets in Western and Central India, it shows a lower range from 1000 to 1500 kW h m^{-2} above the tropic of cancer.

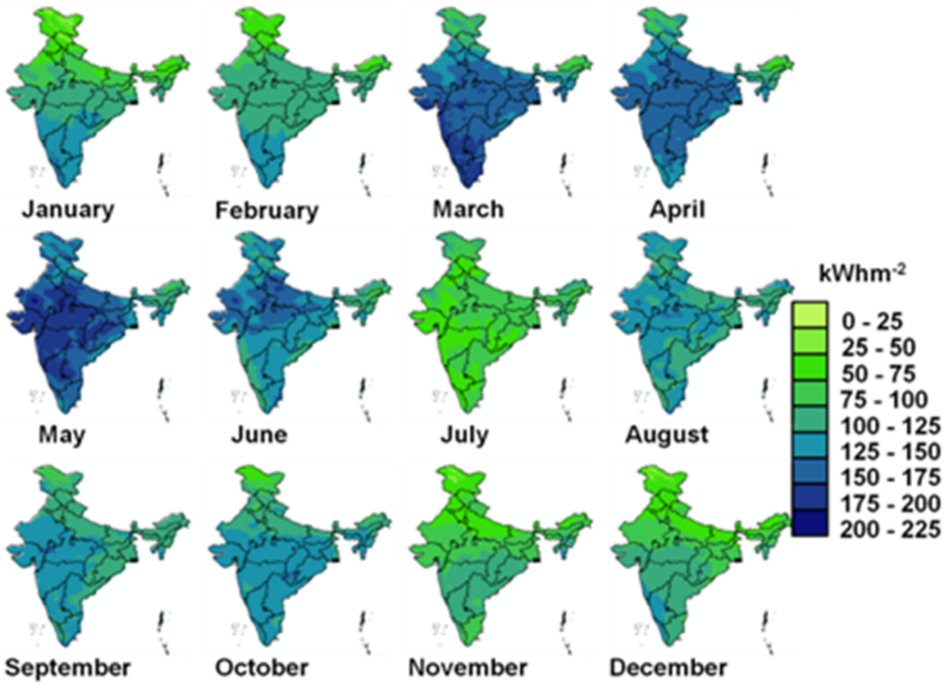

Figure 3: Monthly assured solar energy (KWhm^{-2}) derived using Kalpana-1 VHRR

With the most recent data, validation has been carried with the Solar Radiation Resource Assessment (SRRA) data installed by Ministry of New and Renewable Energy (MNRE) at some places shown in the Figure 4. Monthly mean values of solar energy were within the range of 50 – 250 KWh m^{-2} and the data from SRRA were matched well with the satellite data. Following GPR model, hourly short-term forecast of solar energy was carried out at some roof tops of SAC campus. A sample output of the model for a cloudless condition is shown in the Figure 5. The analysis shows that the model performed very good for a cloudless (clear-sky) condition but relatively poor for cloudy (overcast) condition.

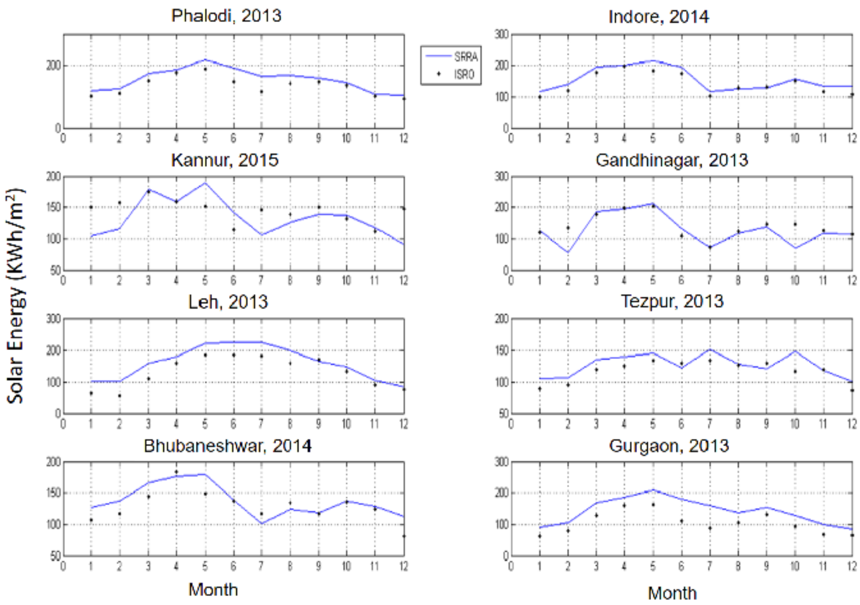

Figure 4: Validation of solar energy with respect to Solar Radiation Resource Assessment - SRRA data (data source: MNRE)

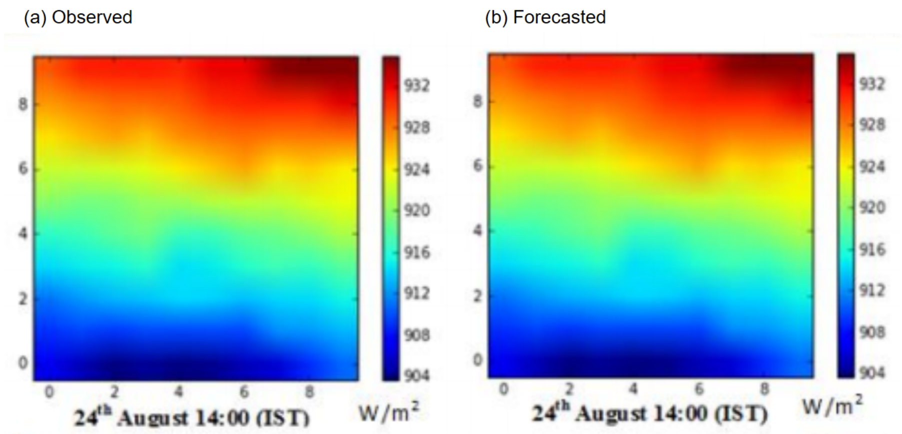

Figure 5: (a) INSAT 3D observed solar energy and (b) forecasted solar energy using GPR model on 24-08-2016 at 1400 IST (cloudless condition) at SAC campus

Figure 6 shows the 3D building model of few buildings in Ahmedabad city and corresponding length of shadow (in hours) on their rooftops for a given day. The length of shadow aggregated over entire year provide buildings suitable for installation of solar panels as well as portion of building where such panels can be placed so as to minimize the effect of shadow.

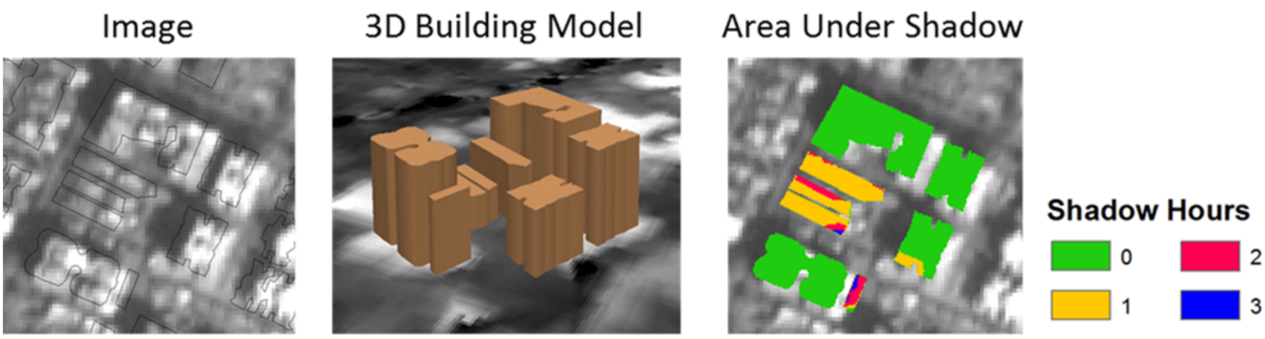

Figure 6: Shadow analysis using 3D City building model

3.2. Wind Energy

The synergetic monthly maps of wind energy combining QuikSCAT, OSCAT and ASCAT are shown in Figure 7. The combination is done by collecting samples from each satellite using a regular grid of 0.125°. Later, the scale and shape parameters for Weibull fitting have been estimated and energy density has been computed using the equation (2). The winds show a strong seasonal variability owing to Indian Summer Monsoon (ISM). The mean wind speeds derived from scatterometer data for the whole period are around 7 – 12 m s^{-1} along Kanya Kumari and Saurashtra coast (Surisetty et al. 2016). Although the wind energies are higher in the deep ocean, it is practically not feasible to extract wind power at such greater depths (>1000 m). West coast of India having wider continental shelf with more length along the Gujarat coast, makes practically viable for offshore wind farming. Although southern Tamilnadu coast is having higher wind energy potential, the depths are higher due to narrow continental shelf. Based on these monthly maps, we found that the wind energy/power is significantly higher at the Rameswaram-Kanyakumari (>1500 W m^{-2}) region throughout the year thus indicating the potential of this regions for setting up of offshore wind energy farms. The annual electric power production possible from a REpower 5MW turbine that could be extracted is around 3500 KW around Rameswaram coast and near Saurashtra region, it is around 2500 KW (Figure 8).

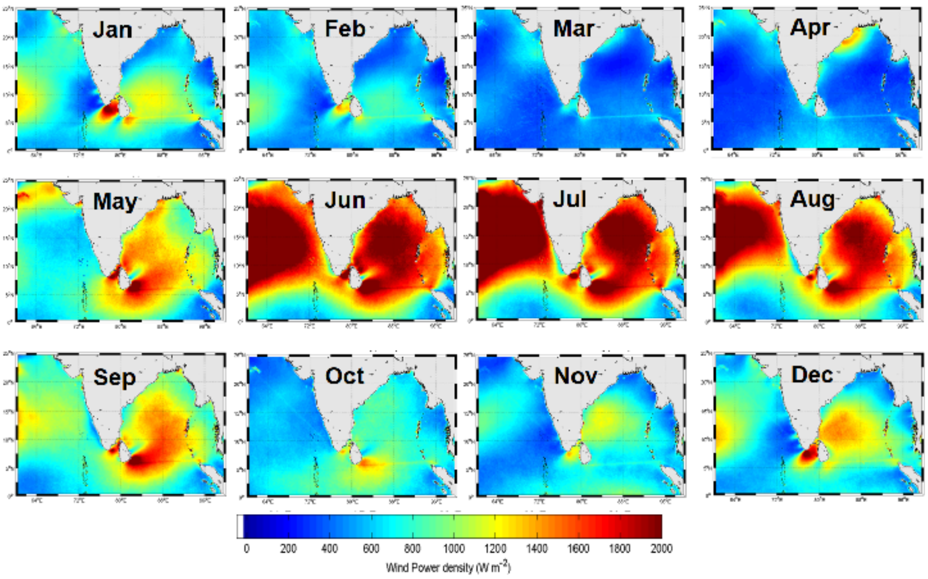

Figure 7: Monthly wind power density at 80 m height derived from QuikSCAT (2000-2009), OSCAT (2010-2014) and ASCAT (2012-2016) scatterometer data extrapolated using logarithmic law.

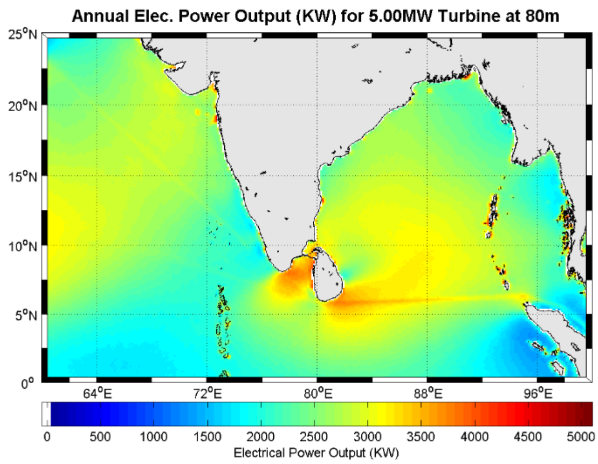

Figure 8: Annual Electrical output/generation (KW) for REpower 5MW turbine in the offshore waters

The Table 1 shows the statistics of wind energy potential in the offshore waters. The total power expected is around 285 GW (2492490 GWh) within the depths 0-35 m, which can serve more than 2.2 times of the 2017-2018 annual energy requirement of India. Total area available for installing wind turbines is around 512959 km^2, however all this area cannot be utilised for wind farms due to many restrictions within the coastal region. If at least 10% of the total area is used, it is possible to generate 791623 GWh of power from the Indian coastal region up to 1000 m depth.

Table 1: Available area, power potential, and energy generation by depth derived from 16 years of scatterometer data. The ratio between Expected Power Generation (EPG) and Required Energy (RE) of India in 2017 is also shown

Water depth (m)	Available area (km^2)	No. of installable turbines	Name plate capacity (MW)	Total Output (MW)	Betz limit (59.3%) of Total	Total Power (GW)	Annual power generation (GWh)	EPG/RE
0-35	157927	198951	994755	479816	284531	285	2492490	2.2
35-50	52348	65947	329734	152195	90252	90	790607	0.7
50-100	159207	200563	1002817	469179	278223	278	2437234	2.1
100-1000	143477	180747	903733	422721	250674	251	2195902	1.9
Total	**512959**	**646208**	**3231039**	**1523912**	**903680**	**904**	**7916233**	**6.9**

Figure 9 shows wind speed and energy derived from RISAT-1 SAR. It shows that the regions around Kanya Kumari and Rameswaram in the southern tip of India are having a good potential of wind power.

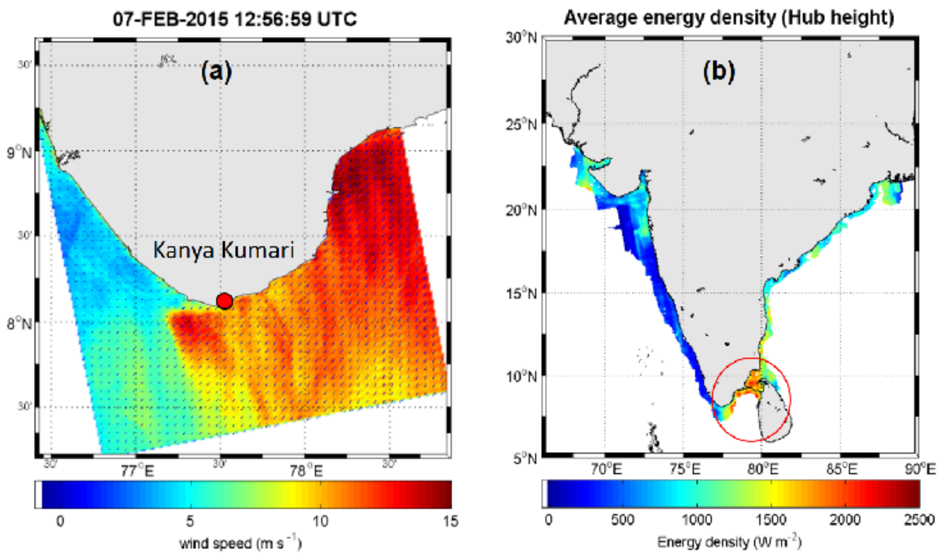

Figure 9: (a) Wind speed derived from RISAT-1 SAR using CMOD5N and (b) Average energy density at hub height (80 m) derived from RISAT-1 SAR imageries during 2012-2016. The circle shows region of high wind energy

3.3. Wave Energy

In addition to the solar and wind energy, India has very good potential of wave energy, but it is less explored and not currently a widely employed commercial technology. Wave power is generally extracted using wave energy converter (WEC), which can be deployed like a mooring system on the surface of water and then the electrical energy can be transferred to the land by electrical lines. Using different satellite altimeters, we had attempted to assess the total wave power in the Indian waters. The average wave power was computed for each month of 2008-2014 using equation (5) in order to analyse the inter-annual variability of the wave based power over the Indian Ocean region. Figure 10 shows mean wave power climatology for the month of July. It shows the wave power potential is very high of the order 50-100 KWm^{-1} in the Arabian sea. This could be due to the persistent and strong winds generating strong waves during the monsoon season.

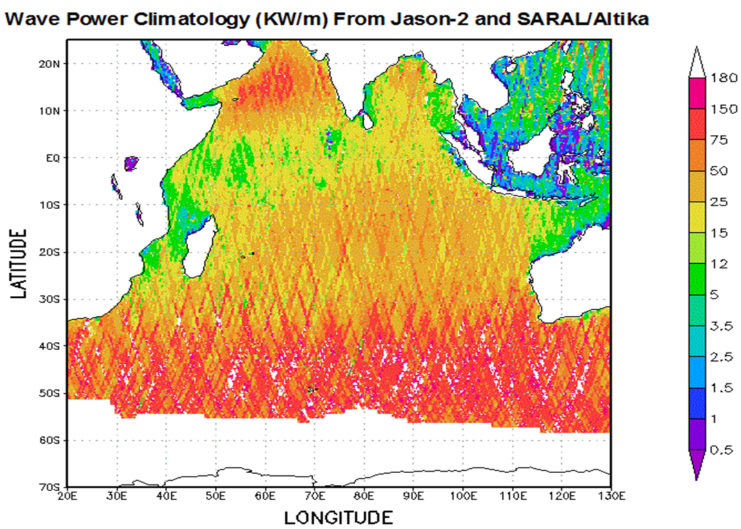

Figure 10: Wave power climatology derived from Jason-2 and SARAL/AltiKa for July averaged over the period 2008-2014

Monthly wave power was also calculated using Wave Watch-III model by assimilating satellite data. Figure 11 shows the monthly derived wave power potential in the Indian waters. It can be observed that the model has well captured the high wave power in the Arabian sea during monsoon season and the same resembles in the Figure 10.

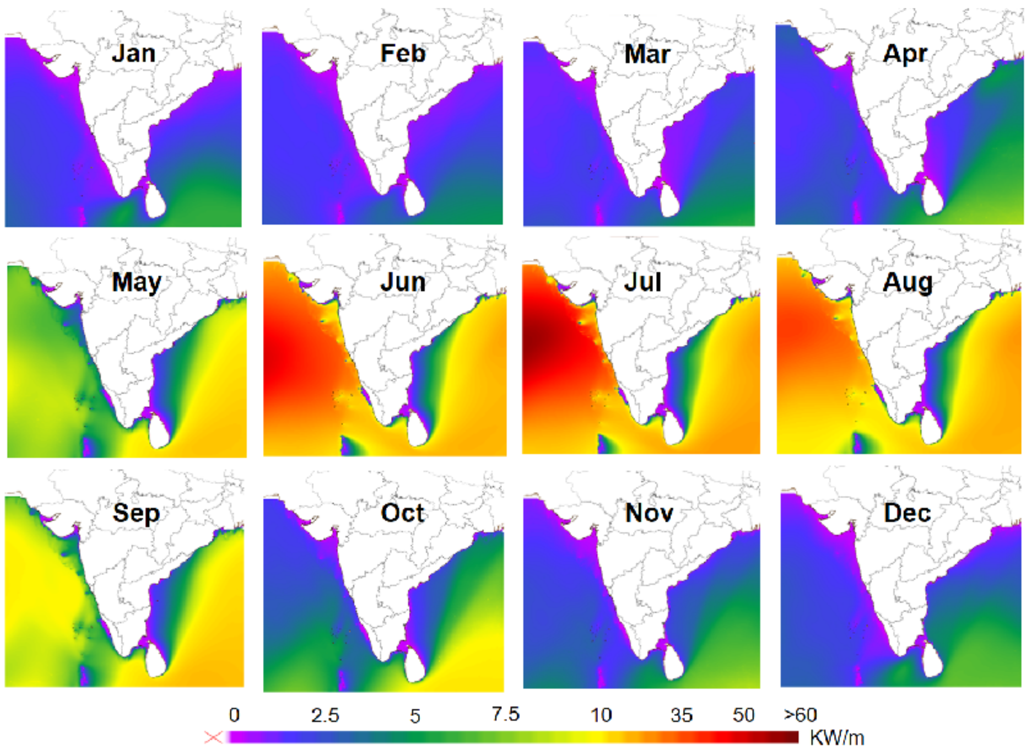

Figure 11: Monthly Wave power climatology derived from Wave Watch –III model assimilated by satellite data

3.4. Dissemination of Renewable energy data through VEDAS portal

VEDAS portal (http://vedas.sac.gov.in) provides access to various applications on different themes developed at SAC. The details of different renewable energies like solar, wind and wave can be accessed through web portal or through any smart phone. We have also developed android apps (solar and wind calculator) to get the energy details at any latitude and longitude (Figure 13) within Indian region.

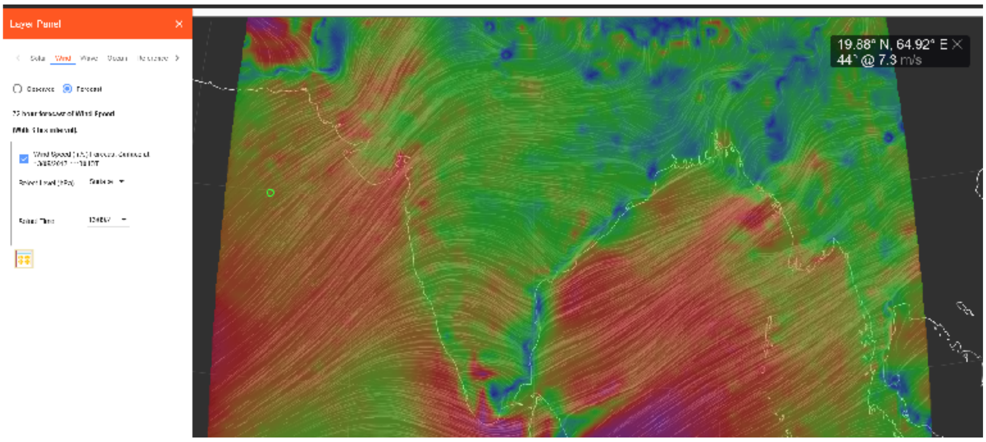

Figure 12: Web view of wind forecast dissemination through VEDAS

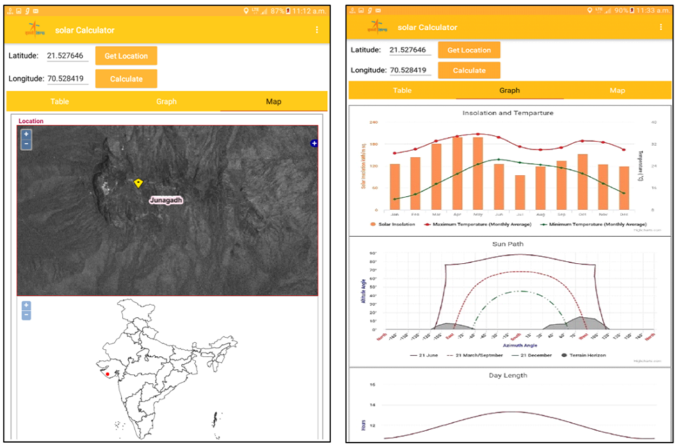

Figure 13: Solar calculator view for Android mobile

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