Evaluation of Solar Radiation from MERRA, MERRA-2, ERA-Interim and CFSR Reanalysis Datasets Against Surface Observations for Multan, Pakistan

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Abstract

The solar radiation data measured by ESMAP for Multan in South Punjab, Pakistan is compared with four reanalysis datasets (MERRA, MERRA-2, ERA-Interim, and CFSR). The validation of reanalysis estimates of solar radiation against surface measured data is performed on the basis of monthly mean time series, clearness index and statistical analysis based on MBE, RMSE and correlation coefficient (R). All reanalysis datasets overestimate the solar radiation except ERA-Interim shows both underestimation and overestimation. The MBE for four datasets ranges from 18.82 W/m^2 to 34.05 W/m^2. The monthly time series shows that the estimations of solar radiations by reanalysis datasets are relatively better in clear sky months but in cloudy months results are poor. The cloud fraction is one of the main reason for the overestimation and underestimation of solar radiation by reanalysis datasets. The bias in clearness index ranges from 0.05 to 0.11 for four reanalysis datasets. All reanalysis datasets overestimate the daily clearness index except ERA-Interim, ERA-Interim both overestimates and underestimates the clearness index. The estimates from MERRA are less accurate among all datasets whereas ERA-Interim has most accurate hence, ERA-Interim can be used for initial solar resource assessment of Multan. NCEP-CSFR also shows good results with a constant bias, which indicates that it can be used for solar forecasting for Multan.

Keywords: Solar Radiation, NCEP-NCAR, ERA-Interim, MERRA, MERRA-2, NCEP-DOE, NCEP-CFSR Pakistan

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1. Introduction

Solar energy is an important renewable energy source and fortunately, Pakistan is very rich in solar energy. Pakistan has enormous potential for solar photovoltaic and solar thermal projects. This signifies the need for reliable solar resource assessment both for commercial and non-commercial solar energy projects. The surface measured data for Pakistan is limited and long-term measured data is not available. In the absence of measured GHI (Global Horizontal Irradiance), long-term time series from reanalysis dataset is an option which can be used as an initial site assessment (Tahir and Asim, 2018).

Different long-term global reanalysis datasets have been developed by organizations in the world that are used to estimate the surface irradiance. Reanalysis use estimations from a Numerical Weather Prediction model with ground observations and reanalysis data. The reanalysis model uses the assimilation model, which uses past records to limit and guide the predictions of the Weather Prediction model. This enables the extrapolation of the variables in space and time (Zhang et al., 2016). There are an increasing number of research studies and industrial applications that incorporate reanalysis products (Juruš et al., 2013; You et al., 2013) (Pfenninger and Staffell, 2016). Slater (Slater, 2016) compared MERRA and MERRA-2 reanalysis with the ground measured data. (Pfenninger and Staffell, 2016) compared MERRA, ERA-Interim and NCEP-CSFR with the ground measured data and calculated the clearness index.

Researchers have found that reanalysis datasets show a large bias in global horizontal irradiance. All these studies found large biases in global horizontal irradiance estimations from MERRA, MERRA-2 and ERA-Interim when the datasets were compared against ground measured data of solar radiation. Mostly reanalyses showed average positive bias for MERRA and ERA-Interim (Decker et al., 2012) (Zhang et al., 2016), and strong overestimations in solar radiation were observed in regions such as Europe, Asia and North America. This positive bias was found due to an underestimation of the cloud fraction (Zhang et al., 2016; Zhao et al., 2013), although the opposite effects were also observed under clear-skies (Boilley and Wald, 2015). Cloud variables in the model of the reanalysis are one of the major limitations and bias depends on sky clearness (Alexandri et al., 2017; Yi et al., 2011). The clearness indices are also calculated for the atmospheric condition and solar radiation estimation (Boilley and Wald, 2015; Urraca et al., 2018). Zhang studied over 674 stations from 2001 to 2009, the world was

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divided into nine sub-regions which included North American, South American, Asia, Europe, Africa, Australia, Oceania, Antarctic, and the oceans. A positive bias was observed in the results obtained from the NCEP-CFSR dataset (Khaled, 2014; Zhang et al., 2016) and (El Afandi, 2014) also evaluated NCEP-CFSR dataset over the Middle East & North Africa (MENA) region and clear positive bias was observed.

2. Datasets

The measured GHI by the Energy Sector Management Assistance Program (ESMAP) of the Word Bank for Multan from January 2015 to December 2015 was used in this study. The surface solar radiation data (GHI) was measured by ESMAP of the World Bank (Stokler and Schillings, 2015). The Modern Era Retrospective Analysis for Research and Applications (MERRA) product is a second reanalysis project from National Aeronautics and Space Administration (NASA) that uses an updated new version of the Goddard Earth Observing System Data Assimilation System, it provides several different variables including global horizontal irradiance. Data ranges from 1979 to the present. Its temporal resolution for 2D diagnostics dataset is 1 hourly and its spatial resolution is $0.5^o \times 0.667^o$ (Rienecker and Takacs, 2011). The MERRA-2 dataset is an updated version of MERRA with the same temporal resolution of 1 hour but spatial resolution of $0.5^o \times 0.625^o$ which is better than MERRA. MERRA-2 is the first long-term global reanalysis to assimilate space-based observations of aerosols and represent their interactions with other physical processes in the climate system (Rienecker et al., 2011). The ERA-Interim dataset is a product of ECMWF (European Centre for Medium-Range Weather Forecasts) having a temporal resolution of three hours and spatial resolution of $0.125^o \times 0.125^o$ for solar radiation. ERA-Interim shows an overestimation of 2 W/m^2 of the incoming shortwave radiation at the top of the atmosphere (Dee, 2011). The radiative transfer model uses water vapour and cloud variables from the meteorological model and climatologic values for aerosols, carbon dioxide, other gases and ozone. The Climate Forecast System Reanalysis (CFSR) dataset by NCEP has spatial resolution $0.204^o \times 0.204^o$ (NCAR UCAR, 2017). Its first version started in 1979 which covered a period of 31 years (1979-2009) in 2010. Its second version started from March 2011 known as NCEP-CFSR v2. NCEP-CFSR second version creates many more products for forecasting with an extensive set of retrospective forecasts for users to calibrate their forecast products. CFSR second version is designed to improve consistency between the model states and the initial states produced by the data assimilation system and it includes a fully coupled ocean model, the Geophysical Fluid Dynamics Laboratory Modular Ocean Model (GFDL MOM) version 4 (Decker et al., 2012).

3. Methodology

The reanalysis datasets provide data in different variables of solar radiation, the variable generally used to represent GHI is named as shortwave radiation. The surface measured data was available with a temporal resolution of ten minutes that was converted into hourly, three hourly and six hourly datasets for comparison with the reanalysis datasets with respective temporal resolutions. The comparison is done by between solar radiation data from the reanalysis datasets and the ground measured data by plotting graphs between these two datasets and then the overestimation and underestimation are evaluated. Environmental models and climatic conditions of the station were studied to find the reasons of overestimation and underestimation of solar radiations. For quantitative evaluation of these datasets, different statistical parameters are used in previous studies. To quantify the performance of reanalysis datasets statistical analysis was performed based on mean bias error (MBE), mean absolute error (MAE), root mean square error (RMSE) and correlation coefficient (R). Scatter plots were generated to understand the overestimation and underestimation of solar radiation from the ground measurement.

Daily Clearness Indices (K_T) for each reanalysis dataset was calculated to compute the clear sky conditions and the variation of the quality of each product with the cloudiness. The clearness index is a function of solar radiation at the top of the atmosphere and the ground level and it indicates the optical state of the atmosphere. The comparison was carried out using ground measured data and reanalysis datasets clearness index (K_T). If E denotes the daily GHI and E_o denotes the daily irradiation received on a horizontal surface at the top of the atmosphere, K_T is defined as Eq. (1).

$$K_T = E / E_o \qquad (1)$$

The changes in solar radiation at the top of the atmosphere due to changes in geometry, namely the daily course of the sun and seasonal effects, are usually well reproduced by models and lead to a de facto correlation between observations and estimates hiding the potential weakness of a model. E_o is a function of the solar constant that is different for different reanalysis datasets. The solar constant is the mean yearly value of the solar radiation incident on a plane normal to the sun rays located at the top of the atmosphere. The solar constant used to calculate the K_T for ground measured data is1367 W/m^2 which is equal to that used in HelioClim-1, solar constants used for MERRA and ERA-Interim is 1365 W/m^2 and 1370 W/m^2 respectively (Boilley and Wald, 2015; Urraca et al., 2018). The values of K_T greater than 0.7 indicate clear sky conditions while the values less than 0.7 indicate less clear or cloudy sky conditions.

4. Results and Discussion

The monthly mean time series of solar radiation is shown in Fig 1 which shows a variation of GHI for the year 2015 and its comparison with reanalysis datasets. There is a sudden drop in the value of solar radiations in the months of July and August due to Monsoon. The Monsoon starts from June and lasts till September. Violent storms also occur during Monsoon in July and August. Solar radiations drop due to cloudy sky condition and increase in water content in the atmosphere after rainfall.

All reanalysis datasets overestimate the surface measured data except ERA-Interim that underestimates the surface measurements during the months of June, July and August. Overall results vary for each reanalysis dataset, but the results for ERA-Interim and MERRA 2 are better with respect to the ground measured data. June, July and August are the months of Monsoon in Multan that’s why the results of reanalysis datasets are relatively less accurate for these months. For MERRA the trend of solar radiations throughout the year is like the measured data but the overall overestimation is more compared to others. The time series of NCEP-CSFR is same as that of measured data but the variation is more as compared to others. In the month of July, there is a sudden drop in solar radiation according to NCEP-CFSR which indicates that NCEP-CFSR considers more cloud friction in its radiative transfer model.

For the months of February, March, April, October, November and December, all reanalysis datasets show smooth time series closer to measured data monthly mean time series. This is since these months are relatively dry due to less precipitation and fewer weather changes. Reanalyses datasets overestimate the solar radiations in these months reason being the improper consideration of dust particles and water vapours in their radiative transfer models.

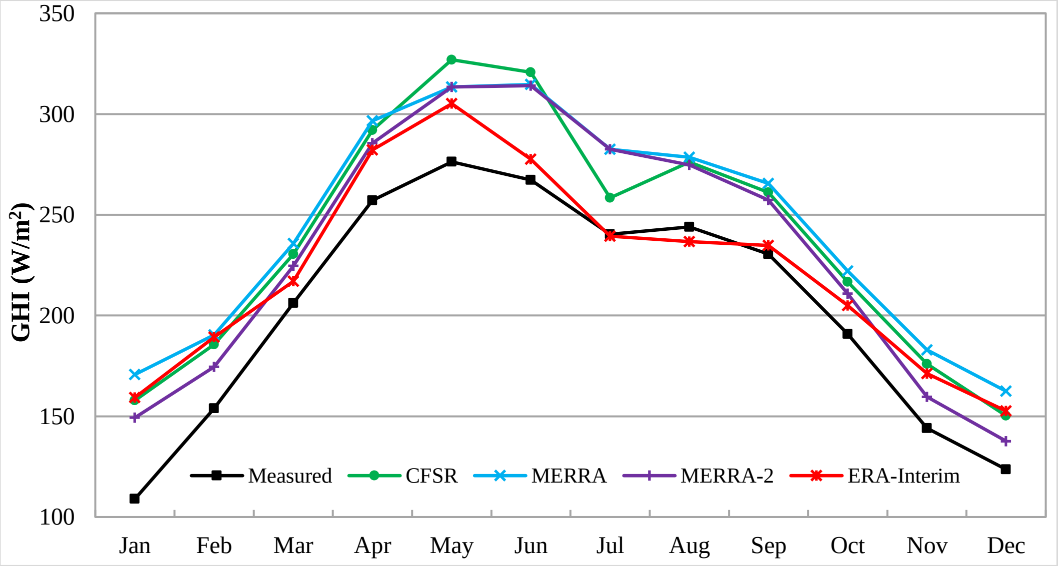

Figure 1: Comparison of Monthly Mean Time Series of GHI for the Year 2015

The statistical parameters MBE, MAE, RMSE and R have been calculated are given in Tab 1. The MBE and RMSE values are lowest for ERA-Interim while MAE is lowest for MERRA 2. MERRA differs the most in magnitude from the surface values. The values of MBE, MAE and RMSE range from 18.82 to 39.39 W/m^2, 28.55 to 41.02 W/m^2 and 38.10 to 51.29 W/m^2 respectively.

MERRA has worse results among all, the MBE, MAE and RMSE values are 39.39 W/m^2, 46.21 W/m^2 and 94.43 W/m^2 which are highest among all datasets. The correlation coefficient is 0.881 which represents that how much points are scattered along 1:1 Line, most of the points are above the 1:1 Line which shows that MERRA overestimates the GHI. The value of the slope is 0.77 which indicates that the smaller values are more overestimated than the larger ones. The value of intercept (c) is 85.7 which indicates the poor results.

The results of NCEP-CFSR are better than MERRA, the MBE, MAE and RMSE values are 34.05 W/m^2, 40.92 W/m^2 and 50.81 W/m^2 respectively. The correlation coefficient is 0.864 which represents that how much points are scattered along 1:1 Line, most of the points are above the 1:1 Line which shows that NCEP-CFSR overestimates the surface solar radiation. The value of the slope is 0.92, the trend line is parallel to 1:1 Line, the value of intercept (c) is 49.89 that is smallest among all.

Table 1: Statistical analysis of global horizontal irradiance (GHI) for Multan, Pakistan

Dataset	**MBE**	**MAE**	**RMSE**	**rMBE**	**rMAE**	**rRMSE**	**m**	**c**	**R**
NCEP-CFSR	34.05	40.92	50.81	16.71	20.08	24.93	0.92	49.89	0.864
ERA-Interim	18.82	28.55	38.10	9.24	14.01	18.70	0.74	72.70	0.879
MERRA	39.39	41.02	51.29	19.33	20.13	25.17	0.77	85.70	0.881
MERRA2	28.46	31	43.32	13.97	15.21	21.26	0.87	55.49	0.887

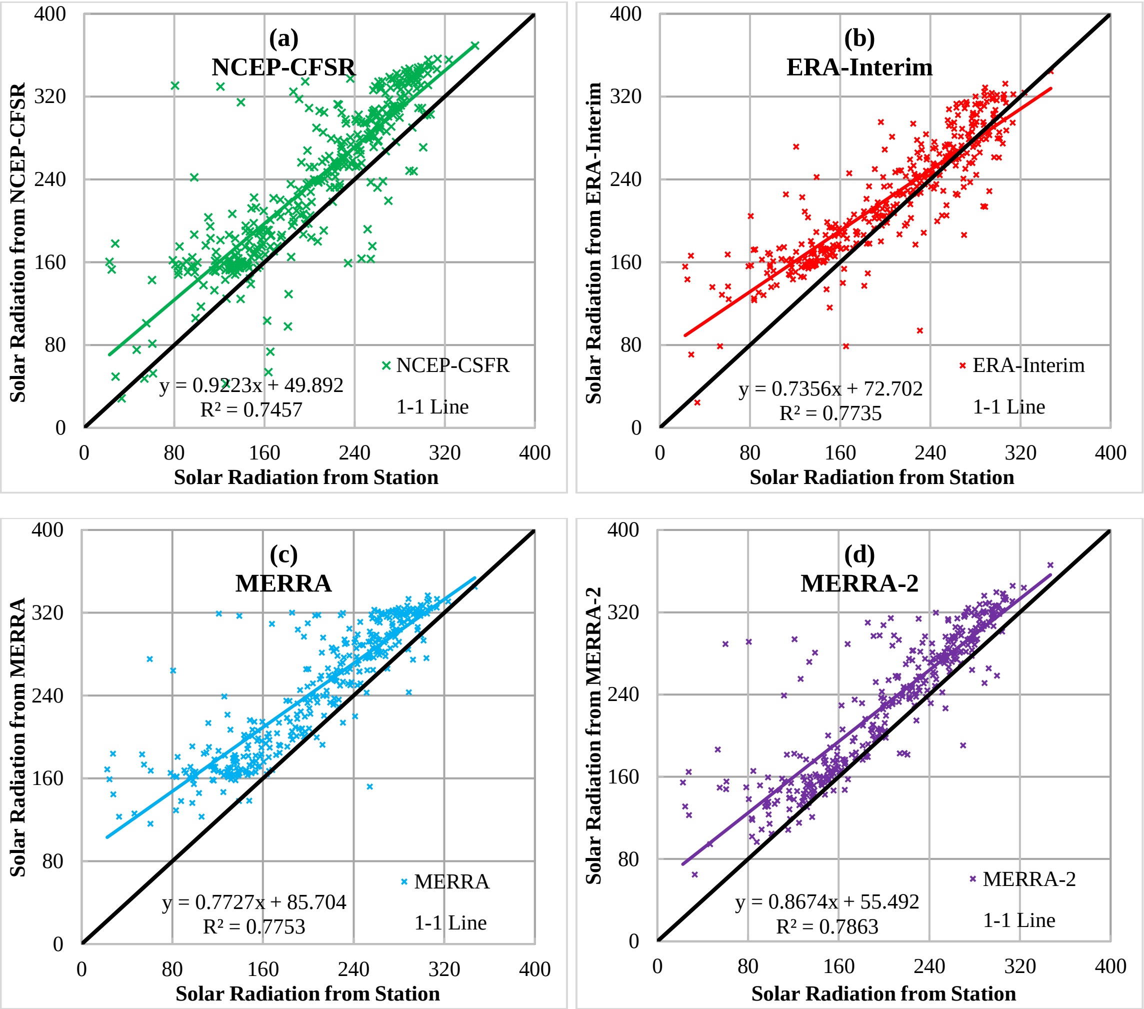

Figure 2: Scatter Plots of Daily Solar Radiation from Station and Reanalysis

The results of MERRA-2 are better than both CFSR and MERRA, the MBE, MAE and RMSE values are 28.46 W/m^2, 31 W/m^2 and 43.32 W/m^2. The correlation coefficient is 0.887 which represents that how much points are scattered along 1:1 Line, most of the points are above the 1:1 Line which shows that MERRA-2 overestimate the

GHI. The value of the slope is 0.87, the value of intercept (*c*) is 55.49 that is smaller than MERRA and Era-Interim.

The results show that ERA-Interim has MBE, MAE and RMSE values of 18.82 W/m^2, 28.55 W/m^2 and 38.10 W/m^2 respectively which are lowest among all. The correlation coefficient is 0.879 which represents that how much points are scattered along 1:1 Line, most of the points are above the 1:1 Line which shows that ERA-Interim overestimates the GHI, the higher values of solar radiation have been underestimated by ERA-Interim. The value of the slope is 0.74, the value of intercept (*c*) is 72.7 that is value is smaller than MERRA. The MAE is more than MBE which means ERA-Interim data is not consistent with respect to ground data. ERA-Interim shows both overestimation and underestimation as given in Fig. 1. Based on statistical parameters, ERA-Interim gave the better results than others.

Scatter plots of daily solar radiation between station and reanalysis datasets are shown in Fig 2. For MERRA the slope of the regression line is closer to 1 and the regression coefficient is 0.881. MERRA shows low values are more overestimated. For NCEP-CFSR the slope of the regression line is closer to 1 and the regression coefficient is 0.864 which indicates the better model performance of NCEP-CFSR. For MERRA-2 the slope of the regression line is 0.887 and intercept is 13.16 which shows that the estimation of MERRA-2 is close to the measured solar radiation values. The MERRA, MERRA-2 shows more bias for lower values of solar radiation. For ERA-Interim the slop of the regression line is 0.74 which shows that ERA-Interim both underestimates and overestimates the GHI. The value of intercept is 72.7, it is due to underestimation and overestimation due to seasonal variation. The values of the bias are low because of overestimation is compensated by underestimation.

The statistical analysis of clearness index is given in Tab 2 and comparison of clearness index for all the reanalysis datasets is shown in Fig 3. The daily clearness index for MERRA shows worse results among all, there is a large discrepancy between the measurements and MERRA data. From the scatter plot of daily clearness index, it is evident that the cloud of points does not follow the 1:1 Line. All the points are above the 1:1 Line means MERRA largely overestimates the ground measured daily clearness index. The correlation coefficient is 0.278, the cloud of points ranging between 0.5 to 0.7 are closer to line 1:1 which indicates that the estimations of MERRA are better during clear sky conditions.

Table 2 Statistical analysis of daily clearness index for Multan, Pakistan

Dataset	**MBE**	**MAE**	**RMSE**	**rMBE**	**rMAE**	**rRMSE**	**m**	**c**	**R**
NCEP-CFSR	0.10	0.12	0.14	18.01	21.61	25.22	0.62	0.31	0.619
ERA-Interim	0.05	0.08	0.11	9.01	14.41	19.81	0.45	0.36	0.579
MERRA	0.11	0.12	0.15	19.81	21.61	27.02	0.33	0.49	0.527
MERRA2	0.08	0.08	0.12	14.41	14.41	21.61	0.43	0.39	0.659

For MERRA the MBE, MAE and RMSE values are 0.11, 0.12 and 0.15 respectively. MERRA overestimates K_T overall while the slope of the regression line is 0.33 which means it underestimates the higher values. The rMBE, rMAE and rRMSE are 19.81, 21.61 and 27.02 respectively. It is evident from Fig 2 that the MERRA predicts the clear sky conditions while the actual conditions are less clear or cloudy.

The daily clearness results for NCEP-CFSR are better than MERRA, most of the values are between 0.5 to 0.7. The values of the clearness index between 0.5 to 0.7 are closer to the 1:1 Line. The points are above the 1:1 Line which indicates that NCEP-CFSR overestimates the clear sky conditions. The MBE, MAE and RSME values are 0.1, 0.12 and 0.14 respectively. The coefficient of regression and slope 0.619 and 0.62 respectively. The rMBE, rMAE and rRMSE are 18.01%, 21.61% and 25.22% respectively. The value of intercept is 0.31 which is best among all datasets. From Fig 2, NCEP-CSFR predicts the clear sky conditions when actual conditions are cloudy or less clear.

The daily clearness index for MERRA-2 shows better results than MERRA, most of the points are between 0.5 to 0.7 and the points are close to the 1:1 Line. MERRA-2 overestimates the daily clearness index, the K_T values lesser than 0.5 are away from line 1:1, the points larger than 0.5 is close to the 1:1 Line. The coefficient of regression and slop are 0.659 and 0.43 respectively, the MERRA-2 underestimates the values of daily clearness index higher than 0.7. The MBE, MAE and RMSE values are 0.08, 0.08 and 0.12 respectively, the errors are lesser than MERRA and NCEP-CFSR. The rMBE, rMAE and rRMSE values are 14.41%, 14.41% and 21.61% respectively. MERRA-2 predicts the clear sky conditions when the actual conditions are less clear or cloudy and vice versa.

The daily clearness index results for Era-interim are best among all, the points in between 0.5 and 0.7 are closer to 1:1 Line while the points less than 0.5 are away from 1:1 Line. Era-interim shows an underestimation of daily clearness index. The coefficient of regression is 0.579, the points are more scattered as it both underestimates and overestimate the daily clearness index. The slope of the line is 0.45 which shows that the high values of K_t are below the 1:1 Line. The MBE, MAE and RMSE values are 0.05, 0.8 and 0.11 respectively. The rMBE, rMAE and rRMSE values are 9.01%, 14.4% and 19.81%. Boilley and Wald in their study (Boilley and Wald, 2015) pointed out that ERA-Interim predicts clear sky conditions while actual conditions are cloudy. The opposite is also true though less pronounced: actual clear sky conditions are predicted as cloudy by ERA-Interim. This overestimation in cloudy conditions compensates the underestimation in clear sky conditions which results in a small bias overall. ERA-Interim predicts cloudy sky conditions while the actual conditions are clear. The error in prediction is greater than MERRA and less than NCEP-CFSR. The overestimation of clear sky conditions leads to an overestimation of the surface solar radiation and KT. Zhang et al. (Zhang et al., 2016) and Wael M. Khaled (Khaled, 2014) also compared these reanalysis datasets with surface observations for other stations around the globe and results were in accordance with our result.

Boilley and Wald (Boilley and Wald, 2015) found that MERRA and ERA-Interim that both predict clear sky conditions while actual conditions are cloudy and actual clear sky conditions are predicted as cloudy by both. A similar trend was observed in our study where MERRA predicted cloudy conditions as clear sky conditions. Urraca et al. (Urraca et al., 2018) found that the reanalysis overestimates solar radiation under cloudy and intermediate conditions, while they underestimate under clear-sky.

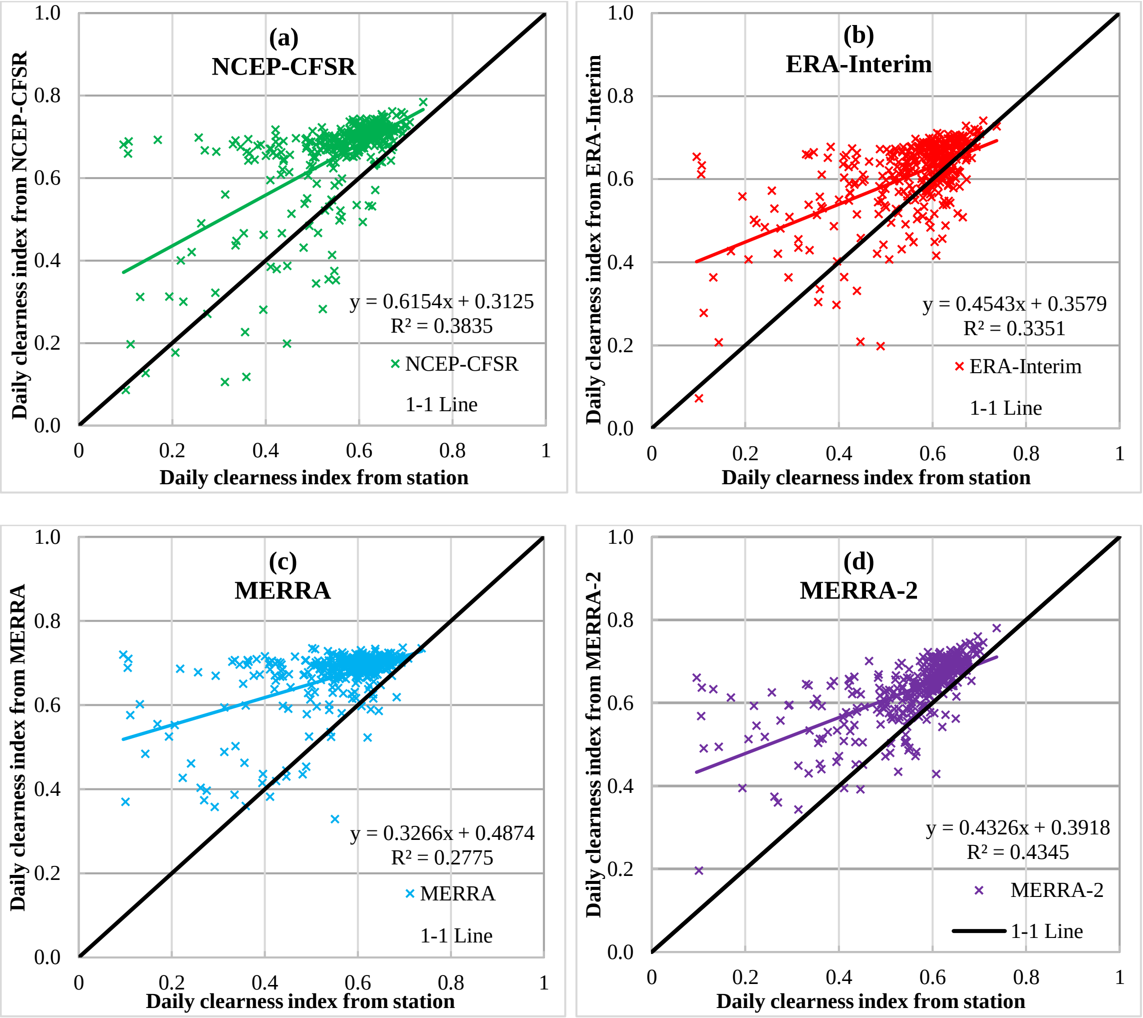

Figure 3: Scatter Plots of Clearness Index from Station and Reanalysis

5. Conclusion

The MBE for solar radiation estimation ranges from 18.82 W/m^2 to 34.05 W/m^2, all the reanalyses overestimate the GHI except ERA-Interim that underestimates. The most accurate results are for ERA-Interim while the least accurate results are shown by MERRA. The MBE values for K_T range from 0.05 to 0.11. The scatter plots of K_T show that all reanalysis datasets predict the clear sky conditions while the actual conditions are cloudy and vice versa, the overestimations and underestimations are less in clear sky conditions. Era-Interim only underestimates the daily clearness index. The maximum MBE in clearness index is shown by MERRA 0.11 and minimum MBE is shown by ERA-Interim 0.05. ERA-Interim predicts clear sky conditions while actual conditions are cloudy, the opposite is also true though not much prominent. Overall Era-interim gives the best estimation of surface solar radiations for Multan region.

6. References

Alexandri, G., Georgoulias, A.K., Meleti, C., Balis, D., Kourtidis, K.A., Sanchez-Lorenzo, A., Trentmann, J., Zanis, P., 2017. A high resolution satellite view of surface solar radiation over the climatically sensitive region of Eastern Mediterranean. Atmospheric Research 188, 107-121.

Boilley, A., Wald, L., 2015. Comparison between meteorological re-analyses from ERA-Interim and MERRA and measurements of daily solar irradiation at surface. Renewable Energy 75(Supplement C), 135-143.

Decker, M., Brunke, M.A., Wang, Z., Sakaguchi, K., Zeng, X., Bosilovich, M.G., 2012. Evaluation of the reanalysis products from GSFC, NCEP, and ECMWF using flux tower observations. Journal of Climate 25(6), 1916-1944.

Dee, D.P., and Coauthors, 2011. The ERA-Interim reanalysis: Configuration and performance of the data assimilation system.

El Afandi, G., 2014. Evaluation of NCEP climate forecast system reanalysis (CFSR) against surface observations over Egypt. Am. J. Sci. Technol 1(4), 157-167.

Juruš, P., Eben, K., Resler, J., Krč, P., Kasanický, I., Pelikán, E., Brabec, M., Hošek, J., 2013. Estimating climatological variability of solar energy production. Solar Energy 98, 255-264.

Khaled, W.M., 2014. Evaluation of NCEP-CFSR solar data against ground observation over MENA.

NCAR UCAR, 2017. NCEP Climate Forecast System Version 2 (CFSv2) 6-hourly Products. https://rda.ucar.edu/datasets/ds094.0/. (Accessed 25-12-2017 2017).

Pfenninger, S., Staffell, I., 2016. Long-term patterns of European PV output using 30 years of validated hourly reanalysis and satellite data. Energy 114, 1251-1265.

Rienecker, M.M., Suarez, M.J., Gelaro, R., Todling, R., Julio Bacmeister, Liu, E., Bosilovich, M.G., Schubert, S.D., Takacs, L., Kim, G.-K., Bloom, S., Chen, J., Collins, D., Conaty, A., Silva, A.d., Gu, W., Joiner, J., Koster, R.D., Lucchesi, R., Molod, A., Owens, T., Pawson, S., Pegion, P., Redder, C.R., Reichle, R., Robertson, F.R., Ruddick, A.G., Sienkiewicz, M., Woollen, J., 2011. MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications. Journal of Climate 24(14), 3624-3648.

Rienecker, M.M.S., M.J.; Gelaro, R.; Todling, R.; Bacmeister, J.; Liu, E.; Bosilovich, M.G.; Schubert, S.D.;, Takacs, L.K., G.-K, 2011. Merra: NASA's Modern-Era Retrospective analysis for Research and Applications.

Slater, A.G., 2016. Surface Solar Radiation in North America: A Comparison of Observations, Reanalyses, Satellite, and Derived Products. Journal of Hydrometeorology 17(1), 401-420.

Stokler, S., Schillings, C., 2015. ESMAP - Renewable Energy Resource Mapping Initiative - Solar Resource Mapping for Pakistan - Solar Modeling Report. Energy Sector Management Assistance Program, The World Bank.

Tahir, Z.R., Asim, M., 2018. Surface measured solar radiation data and solar energy resource assessment of Pakistan: A review. Renewable and Sustainable Energy Reviews 81, 2839-2861.

Urraca, R., Huld, T., Gracia-Amillo, A., Martinez-de-Pison, F.J., Kaspar, F., Sanz-Garcia, A., 2018. Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data. Solar Energy 164, 339-354.

Yi, Y., Kimball, J.S., Jones, L.A., Reichle, R.H., McDonald, K.C., 2011. Evaluation of MERRA Land Surface Estimates in Preparation for the Soil Moisture Active Passive Mission. Journal of Climate 24(15), 3797-3816.

You, Q., Sanchez-Lorenzo, A., Wild, M., Folini, D., Fraedrich, K., Ren, G., Kang, S., 2013. Decadal variation of surface solar radiation in the Tibetan Plateau from observations, reanalysis and model simulations. Climate Dynamics 40(7), 2073-2086.

Zhang, X., Liang, S., Wang, G., Yao, Y., Jiang, B., Cheng, J., 2016. Evaluation of the Reanalysis Surface Incident Shortwave Radiation Products from NCEP, ECMWF, GSFC, and JMA Using Satellite and Surface Observations. Remote Sensing 8(3), 225.

Zhao, L., Lee, X., Liu, S., 2013. Correcting surface solar radiation of two data assimilation systems against FLUXNET observations in North America. Journal of Geophysical Research: Atmospheres 118(17), 9552-9564.