IS MERRA2 ABLE TO REPLACE MERRA AS A TRUSTED REFERENCE WIND DATASET?

Morten Lybech Thøgersen[1], Lasse Svenningsen[1], Thorkild Guldager Sørensen[1]
Sérgio Augusto Costa[2]
1 EMD International A/S,
Niels Jernes Vej 10, DK-9220 Aalborg, Denmark
2 EMD Brasil Ltda & VILCO Engenharia e Consultoria Ltda
Rua Vera Linhares de Andrade, nº 2845 CEP 88034-700, Florianópolis, Santa Catarina, Brasil
mlt@emd.dk, ls@emd.dk, tgs@emd.dk, sac@emdbrasil.com

INTRODUCTION / ABSTRACT

The MERRA (Modern-Era Retrospective Analysis for Research and Applications) dataset by NASA is a well-known and widely used long-term reference wind dataset. MERRA is widely used in wind resource assessments and long-term corrections using Measure-Correlate-Predict (MCP) methods, as well as in meso-scale and in downscaling applications. However, the MERRA dataset was discontinued at the end of February 2016 – so the community faces a significant challenge to establish confidence and trust in the succeeding MERRA2 replacement dataset. This paper presents a number of analyses and conclusions that may contribute to a better understanding of the performance, capabilities and possible limitations of the MERRA2 dataset – not only as a long-term reference dataset, but also when used in meso-scale modelling applications. This paper evaluates the MERRA2 dataset with emphasis on on-shore wind energy applications and for near-shore applications.

Keywords: *Resource Assessment, MERRA2, MERRA, Long Term Reference Winds, MCP, WRF*

OVERVIEW OF THE MERRA MODELS

The two released MERRA datasets are produced by NASA Goddard Space Flight Center from the Global Modeling and Assimilation Office (GMAO). MERRA2 and MERRA both use the GEOS-5 assimilation system (Goddard Earth Observation System Version 5), but different versions. Both MERRA models assimilate a very large number of observations (millions for each 6 hourly interval) but the MERRA2 model includes a large number of satellite observations that were not available for the MERRA dataset. In fact, the data assimilated for the MERRA dataset was frozen in 2008, so no new observations have been included since then. This fact has been a strong motivation for the release of MERRA2, which includes new types of satellite observations. To illustrate the increase in observations, Figure gives an overview of the number of assimilated data and the sources (see Bosilovich et al. [3]). The data-count varies significantly over time, which potentially could influence the long-term consistency of the final dataset, which is crucial to wind energy applications.

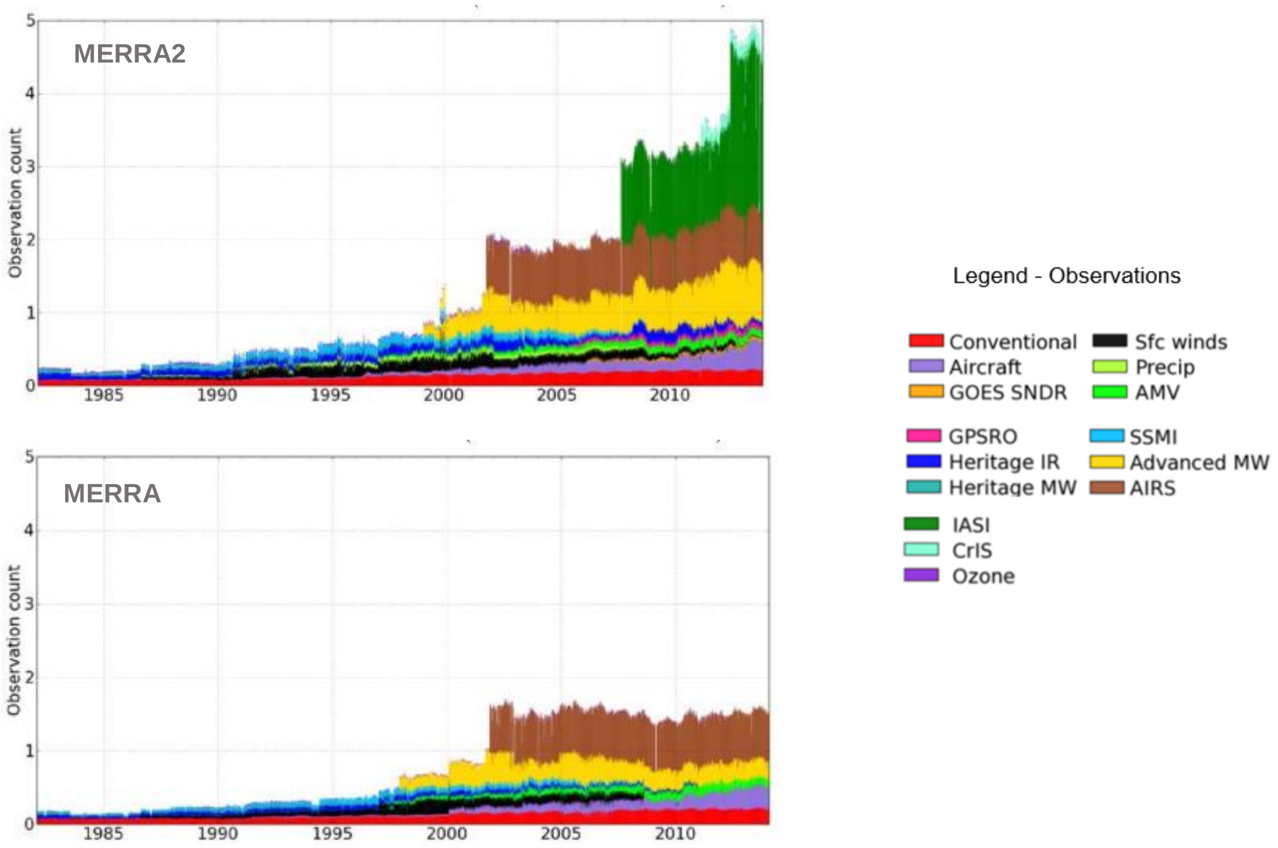

Figure 1 – Observations assimilated in MERRA2 (top) and MERRA (bottom) datasets for the period 01.1980 until 12.2014. Units are millions per 6 hours. From Bosilovich et al. [3].

Table 1 summarizes model differences of MERRA2 and MERRA. Note that the grid configuration and grid spacing differs in the two models, which make direct node comparisons impossible. For our analyses, we use the nearest neighbour nodes, which typically only differs by a smaller fraction of the grid spacing.

Table 1: Selected Features and Differences of MERRA2 and MERRA datasets.

Item	MERRA2	MERRA
GEOS data assimilation model version	5.12.4	5.2.0
Observations per 6 hourly analysis cycle	~ $5 \cdot 10^6$	~ $2 \cdot 10^6$
Grid	Cubed sphere grid	Regular latitude-longitude
Spatial resolution (longitude)	0.625 degrees	2/3 degree
Spatial resolution (latitude)	0.5 degrees	0.5 degree
Period covered (yyyy.mm)	1980.01 - present	1979.01 – 2016.02
Best temporal resolution	1 hour	1 hour

MEAN WIND SPEED CORRELATION: MERRA MODELS VS METEOROLOGICAL MASTS

The wind speeds at 50-meter height from the two MERRA models have been compared to wind speeds from the top anemometer of almost 400 individual wind energy meteorological masts situated around the globe. On average, the masts hold more than two years of measurements. We compare the correlation coefficient (R) on the instantaneous wind-speeds, as well as the monthly averages (Table 2 and Table 3). With these metrics, we get a clear picture of the performance of the MERRA2 and MERRA datasets, to validate if the improvements in the MERRA2 physical model and newly assimilated observations. In further detail, we can evaluate how the data quality is improved region by region for the areas of significant wind farm development represented by the 400 wind energy mast locations included in this study.

Table 2: Selected statistical parameters of correlation coefficient (R) of MERRA datasets versus 398 masts - considering instantaneous wind-speeds (i.e. mast-value vs. MERRA-value)

Dataset	Mean	Median	Std.Dev.	Minimum	Maximum
MERRA	0.677	0.708	0.159	0.004	0.925
MERRA2	0.689	0.718	0.141	0.011	0.925

Table 3: Selected statistical parameters of correlation coefficient (R) of MERRA datasets versus 398 masts - considering monthly averaged wind-speeds

Dataset	Mean	Median	Std.Dev.	Minimum	Maximum
MERRA	0.832	0.907	0.204	0.014	0.998
MERRA2	0.838	0.911	0.192	0.025	0.998

Table 2 and Table 3 shows the correlations coefficients (R) of both instantaneous and monthly average wind speeds. The difference between the MERRA2 and MERRA datasets is not significant, but, overall, there is a small improvement in MERRA2 data over MERRA reflected in the improved average correlation and smaller standard deviation. The average improvement in correlation coefficient is about 0.01.

REGIONAL CONSIDERATIONS: MERRA MODELS VS MASTS

Using the database of almost 400 individual masts, it is possible to analyse if significant improvements occur in different geographical regions. In this analysis, we have divided the masts according to the four continents: Africa, Americas, Asia and Europe.

Table 4: Selected statistical parameters of correlation coefficient (R) of MERRA datasets versus 398 masts considering instantaneous wind speeds at different regions

Region - Dataset		**Mean**	**Median**	**Std.Dev.**	**Minimum**	**Maximum**
Africa	MERRA	0.623	0.636	0.094	0.416	0.802
	MERRA2	0.698	0.704	0.076	0.557	0.816
Americas	MERRA	0.652	0.663	0.098	0.391	0.857
	MERRA2	0.642	0.650	0.103	0.399	0.837
Asia	MERRA	0.594	0.630	0.190	0.004	0.835
	MERRA2	0.608	0.663	0.179	0.011	0.836
Europe	MERRA	0.727	0.780	0.160	0.011	0.922
	MERRA2	0.732	0.755	0.134	0.247	0.925

The results are outlined in the Table 4. It is seen that the African region benefits significantly from the MERRA2 model improvements, with an improved mean correlation of about 0.07 and a lower standard deviation (of about 0.02). For the remaining regions, the correlations of MERRA2 and MERRA wind speeds are very similar, except for the Americas, which show a slightly lower mean correlation and increase in standard deviation; however, not a significant deterioration.

MEAN WIND SPEED CORRELATIONS: MERRA MODELS AND MESOSCALE MODELS

The MERRA dataset is a very popular long-term reference dataset and frequently used in measure-correlate-predict methods. However, the direct usage of the MERRA wind speed datasets in wind resource prospecting is slowly being replaced by higher resolution data from dedicated meso-scale models. Such mesoscale data are currently available from a number of commercial providers at a relatively low price (see Hahmann et al. [5]). To analyse the expected improvement from meso-scale data compared to the MERRA models, we have compared correlations from the MERRA models against correlation for the dedicated meso-scale on-demand setup of the EMD-WRF model [6]. The EMD-WRF On-Demand setup is run at ca. 3 km resolution, and documented in Svenningsen et al. [6]. Table 5 shows that the correlations are significantly better for the meso-scale model and suggests that future wind-energy applications should move towards using the MERRA2 to drive the mesoscale models, and focus less on direct use of MERRA2 wind speeds.

Table 5: Selected statistical parameters of correlation coefficient (R) of MERRA datasets and EMD-WRF mesoscale model versus 239 masts considering instantaneous wind speeds.

Dataset	Mean	Median	Std.Dev.	Minimum	Maximum
MERRA	0.679	0.708	0.152	0.011	0.898
MERRA2	0.698	0.728	0.126	0.247	0.896
EMD-WRF mesoscale	0.766	0.781	0.097	0.364	0.909

SPATIAL DISTRIBUTION OF INTER-ANNUAL MEAN WIND SPEEDS VARTIONS

The inter-annual variation of mean wind speeds indicates the complexity of the annual wind regimes, and is a suitable candidate for comparing the consistency of the MERRA datasets. A study by Lileó et al. [4], reports general variations (measured as standard deviation in percent of the annual mean wind speed) in the order of 3-7% over the Scandinavian region. Lileó et al. refers to a study by EWEA from 2009 [7] stating that the variability is about 6% over the European region. Figure 2 shows a global analysis of inter-annual variability for the MERRA2 and MERRA datasets using annual mean wind speed data from the 20 year period of 1995-2014 (cf. Figure). For the Scandinavian and European regions, we find quite similar results to those of Lileó et al. for both MERRA and MERRA2.

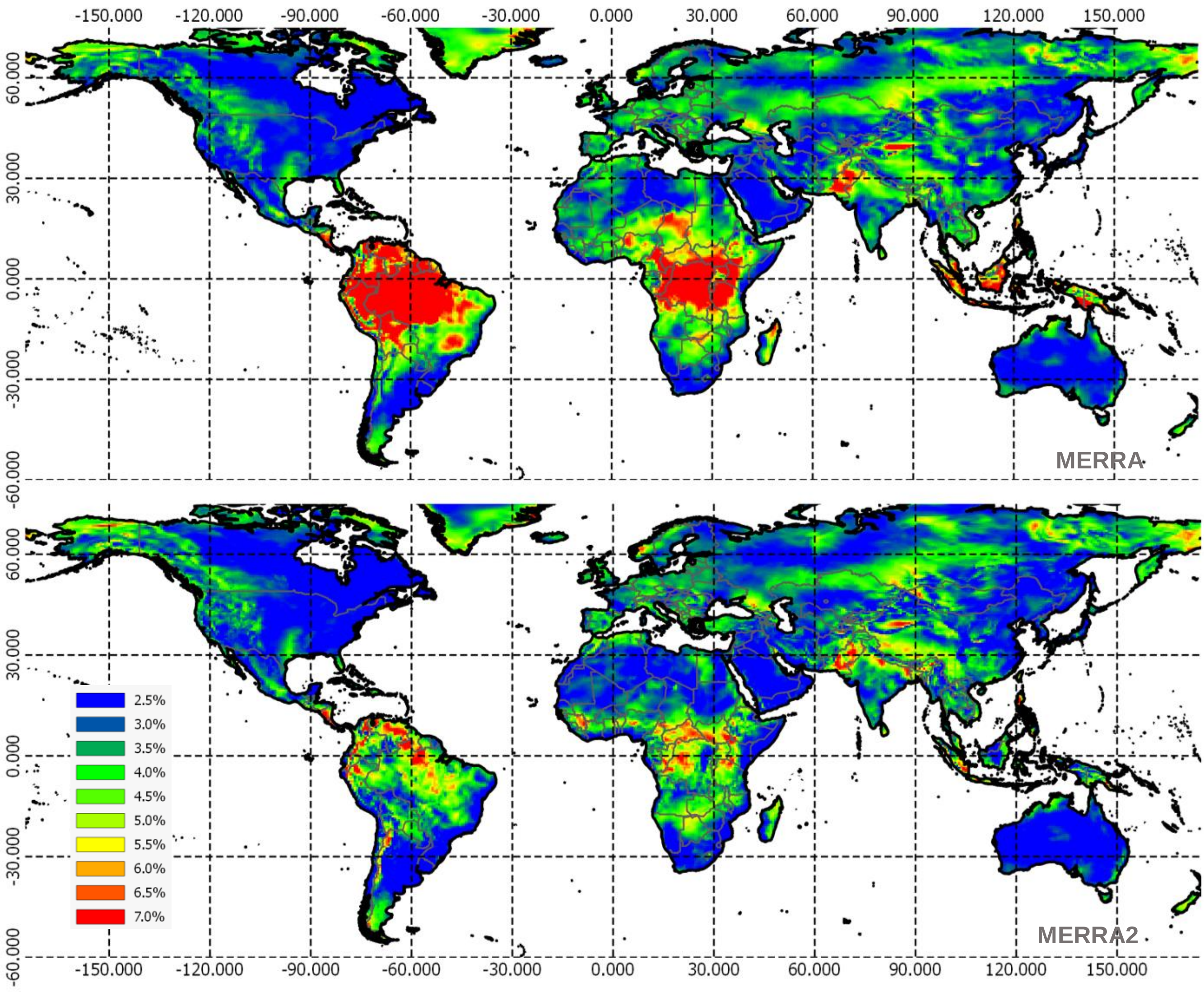

Figure 2 - Standard deviation in percent of the annual mean wind speed, based on MERRA (top) and MERRA2 (bottom). Values represent the period 1995-2014 and the same colour legend is used in both maps.

The spatial analysis of Figure 2 comparing MERRA2 and MERRA shows that the North-American and the European regions exhibit quite comparable values of inter-annual variability. For the South-American and African regions, the MERRA2 dataset resolves a more detailed variation in the local and regional variability and shows a much larger spatial variation compared to MERRA.

CONCLUSION

In summary, we see a solid support from our investigations that the MERRA2 and MERRA dataset are of comparable quality for most regions with significant wind energy development, as represented by almost 400 individual location of wind energy masts included in this study. For the mast locations on the African continent, we see a significant improvement in the correlations. For other regions, our results show that MERRA2 and MERRA are of equal quality. For the spatial variation, we see indications that MERRA2 is an improvement over MERRA, mainly in the equatorial regions of South America and Africa. This is also confirmed with our African mast data. For the Americas, we see a slight decrease in quality in terms wind speed correlation coefficients for MERRA2 using the masts in this region. It is our expectation and recommendation that the future use of the MERRA2 dataset will differ from that of the MERRA data, even if the quality is similar, as high-resolution meso-scale models driven using MERRA2 data can improve wind speed correlations significantly.

REFERENCES

[1] Rienecker, M.M. et al. 2011. *MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications*. Journal of Climate, American Meteorological Society.

[2] Bosilovich, M. G., R. Lucchesi, and M. Suarez, 2016: *MERRA-2: File Specification*. GMAO Office Note No. 9 (Version 1.1), 73 pp, available from http://gmao.gsfc.nasa.gov/pubs/office_notes

[3] Bosilovich, M.G. et al. 2015. *MERRA-2: Initial Evaluation of the Climate*, Technical Report Series on Global Modeling and Data Assimilation – Volume 43, NASA/TM–2015-104606/Vol. 43.

[4] Liléo, S., Berge E., Undheim O., Klinkert R. and Bredesen R.E. 2013. *Long-term correction of wind measurements*, Kjeller Vindteknikk, Elforsk Report 13:18

[5] Hahmann, A.N. et al. 2015*. Mesocale Modelling Benchmark Exercise: Initial Results*. DTU Wind Energy – available from http://www.ewea.org

[6] Svenningsen, L., Sørensen, T.G., Thøgersen, M.L. 2016: *EMD-WRF On-Demand*.
EMD International A/S – available from

http://help.emd.dk/mediawiki/index.php?title=EMD-WRF_On-Demand and http://www.emd.dk/windpro/mesoscale-data/emd-wrf-meso-scale-on-demand-service/

[7] Paul Gardner et al, 2009, Wind Energy – The Facts (Part I – Technology), European Wind Energy Association. Available from: http://www.wind-energy-the-facts.org/

BIOGRAPHIES

Morten Lybech Thøgersen was born in 1969 in the city of Skagen, Denmark, and has earned his M.Sc. degree in Structural Engineering from the Aalborg University, Denmark, in 1997. In his current position, he is the manager of the Wind Energy Department at EMD International A/S – and is leading a team of 9 wind energy consultants along with being the project manager for a number of external and internal R&D projects. He has specialist knowledge within topics like MCP, wake modelling, turbulence calculations, IEC classification, uncertainty analysis and probabilistic methods. He is in charge of the high-performance computing efforts at EMD – including CFD and meso-scale modelling. Morten came to EMD in early 2001 and he has been working with WindPRO software development as well as a wind energy consultancy. Prior to that, Morten was employed as a scientist at Risø National Laboratory (now DTU Wind Energy). His interests are within probabilistic methods and wind modelling as well as project management using Agile methods.

Mr. Thøgersen is a member of the Danish Society of Engineers.

Lasse Svenningsen was born in 1978 in the city of Aarhus, Denmark, and has earned a PhD in Geophysics from the University of Aarhus, Denmark, in 2007. In his current position, he is R&D manager and senior wind energy consultant at EMD International A/S. In his previous job, he worked in the wind & site competence centre of a wind turbine manufacturer.

His main areas of work are participation in research projects and development of new features for the windPRO software package, mainly improving integration of linear and non-linear flow models in wind farm development, in particular mesoscale modelling and downscaling. Other areas of his research are within wind turbine suitability with focus on the link between wind climate and load calculations. Currently, Lasse is also working on constrained wind farm layout optimization.

Dr. Svenningsen is a member of the Danish Society of Engineers.

Thorkild Guldager Sørensen was born in 1977 in the city of Farsoe, Denmark, and holds a M.Sc. degree in Software Engineering from Aalborg University. He is a member of the EMD Software Development team – and has strong competences and experience with high-performance-computer clusters and associated cluster based models. During his 7 years with EMD he has worked with windPRO software development as well as data acquisition, modelling and statistical analysis.

Sérgio Augusto Costa was born in 1979 in the city of Curitiba, Paraná state, Brasil, and has earned his undergraduate degree in Mechanical Engineering from the Federal University of Santa Catarina, Brasil, in 2002. In his current position, he is the managing director of EMD Brasil Ltda. With more than 14 years of experience in the Brazilian energy sector, specifically in the energy generation business, he worked in several engineering and consultancy companies, hydro turbine manufacturer and utility company. He is the founder and managing director of VILCO Engenharia e Consultoria Ltda., which he is the responsible for the overall coordination of activities and specialized services in consulting and engineering projects of power generation by renewable energy sources (wind farms, solar plants, hydroelectric and biomass plants). He has experience in development of more than 2 GW of wind power projects in Southern and Northeast of Brasil. His key professional interests are within wind, power, renewable energy, energy planning, energy trading, finance, capital markets, asset evaluation and project management. At the moment, he is studying MBA in Finance, Asset Evaluation and Capital Markets.

Mr. Costa is a member of the Brazilian Federal Council of Engineering and Agronomy.