Long-Term Pavement Performance

LTPP Technical Support Services Contractor - c/o Amec Foster Wheeler – 10615 Professional Circle # 100 - Reno, NV 89521 - Tel 775-329-6123

MEMORANDUM

TO:	Jane Jiang
FROM:	Beth Visintine, Travis Thompson, and Gary Elkins
DATE:	October 1, 2017
SUBJECT:	Comparison of MERRA-1 and MERRA-2 Data
	FHWA Contract No. DTFH61-15-D-00004
	Amec Foster Wheeler Project No. 6420172002
CC:	J. Groeger, J. Springer, R. Ahmad, L. Wiser

Introduction

LTPP adopted the Modern-Era Retrospective Analysis for Research and Applications (MERRA) data as a new source of climate data to supplement the previously used land-based measured weather data. The production of the MERRA dataset by NASA first distributed by LTPP ceased as of February 29, 2016. This MERRA dataset is referred to as MERRA-1 in various parts of this memorandum for clarity. It was replaced by the MERRA-2 data set which NASA indicates is improved over the MERRA-1 data set. Both the MERRA-1 and MERRA-2 used a Goddard Earth Observing System-5 (GEOS-5) atmospheric general circulation model (AGCM). However, the AGCM model used in MERRA-2 includes changes in parameterization that affect the simulated climate. According to NASA, the MERRA-2 dataset was introduced as a result of advances in the assimilation system that now include hyperspectral radiance and microwave observations. The most significant change in the spatial grid size dimension, is in MERRA-2 the latitude width has been reduced to 0.625 degrees, whereas under MERRA-1 it was 0.667 degrees.

This memo provides a summary comparison of the MERRA-1 and MERRA-2 datasets downloaded for the InfoPave Climate Tool and use in LTPPBind On-line and MERRA Climate Data for MEPDG Inputs.

MERRA Data Comparison

The first comparison of the MERRA-1 and MERRA-2 datasets were conducted for the MERRA cell with latitude of 40 degrees and longitude of -80 degrees (MERRA-1 ID: 487571; MERRA-2 ID: 144161) on the hourly level of data. This cell is roughly located in west central Pennsylvania. Table 1 presents the average and standard deviation for both datasets.

Figure 1 through Figure 14 present a sample of graphs (e.g., not all variables are presented). Two types of graphs are presented: a cumulative probability plot and a scatter plot of the variables against time that shows the difference between the MERRA-1 and MERRA-2 hourly data for this single cell. These figures along with the values presented in Table 1 show that there are

differences, some of which could be considered significant, between the MERRA-1 and MERRA-2 datasets at the hourly level.

Due to what looked like significant differences in the hourly sample data use in the initial investigation, a secondary investigation was performed based on data for the same cell whose hourly data was examined. Attachment A presents a sample of graphs for the daily, monthly and yearly rollup data for selected data elements for the MERRA data cell at longitude 40 degrees and latitude -80 degrees over a longer time period.

Attachment B provides a visual comparison of the 30-year average of annual averages from 1980 to 2010 for temperature, precipitation, and climate zones for all MERRA cells assigned to the contiguous United States. This comparison provides a broader perspective on the influences of the difference between the two data sets on long-term climate statistics.

As presented in this memorandum, differences that can be considered significant exist between the MERRA-1 and 2 data sets. For the single cell investigated in this analysis, these differences can be considered significant on just about all time scales, depending on the climate parameter.

Since this was only a summary investigation, and there is no easy way to judge which data set is better from this comparison of the two data sets, LTPP will take the following actions on MERRA data sets:

- Because support of the MERRA-1 data set has been dropped by NASA, to continue with updates of the MERRA based data set into the future, LTPP has no choice but convert to the MERRA-2 data set.

- The entire MERRA-1 dataset previously published by LTPP was replaced with MERRA-2 data.

- Due to the differences, all computed parameters such as climate zones, SuperPave binder specifications, freeze index, etc. are being recomputed from the MERRA-2 data for consistency.

Table 1. Hourly MERRA Data Elements Comparison

| MERRA Data Element	Average		Standard Deviation	
	MERRA1	MERRA2	MERRA1	MERRA2
SPECIFIC_HUMIDITY (kg/kg)	0.0023	0.0019	0.0020	0.0005
PRESSURE_HR (Pa)	97699	99137	625	802
PRECIP_FLUX (kg/sq m/s)	0.000031	0.000066	0.000067	0.000082
EVAPORATION_FLUX (kg/sq m/s)	0.00001	0.00003	0.000010	0.000009
SNOWFALL_FLUX (kg/sq m/s)	0.000011	0.000066	0.000029	0.000082
PROFILE_SOIL_MOISTURE	0.29	0.17	0.0049	0.00026
LAYER_SOIL_MOISTURE	0.30	0.19	0.012	0.00075
WATER_INFILTRATION_RATE (kg/sq m/s)	0.00002	0.000000054	0.000063	0.0000003
SNOW_MASS (kg/sq m)	2.9	10.0	2.87	3.36
SNOW_DEPTH	0.09	0.17	0.0000001	0.0000003
SNOW_MELT (kg/sq m/s)	0.000001	0.00000005	0.000004	0.0000005
FRACTIONAL_SNOW_COV_AREA	0.22	0.38	0.22	0.13
OVERLAND_RUNOFF (kg/sq m/s)	0.000002	0.00000002	0.0000054	0.0000001
TEMPERATURE (K)	-5.2	-7.4	7.2	4.0
SOIL_TEMP_LAYER1 (K)	-4.3	-6.6	4.8	2.8
SOIL_TEMP_LAYER2 (K)	-1.2	-4.5	2.4	1.91
SOIL_TEMP_LAYER3 (K)	1.7	0.1	0.73	0.12
SOIL_TEMP_LAYER4 (K)	5.0	2.7	0.28	0.18
SOIL_TEMP_LAYER5 (K)	8.9	6.3	0.20	0.19
SOIL_TEMP_LAYER6 (K)	10.0	6.8	0.003	0.001
TEMP_UNSAT_ZONE (K)	-5.0	-8.3	7.0	4.3
TEMP_SAT_ZONE (K)	-5.0	-8.5	6.6	4.1
SHORTWAVE_SURFACE (W/sq ft)	82.2	27.9	136.2	49.9
SHORTWAVE_TOA (W/sq ft)	163.9	127.8	238.7	194.1
CLOUD_COVER	0.7	0.9	0.3	0.1
SURFACE_EMISSIVITY	0.975	0.984	0.007	0.002
SURFACE_ALBEDO	0.20	0.17	0.066	0.033
NORTH_WIND (m/s)	0.4	-0.3	0.7	3.1
EAST_WIND (m/s)	1.1	3.7	0.7	3.3
AIR_DENSITY (kg/m^3)	1.3	1.3	0.05	0.03
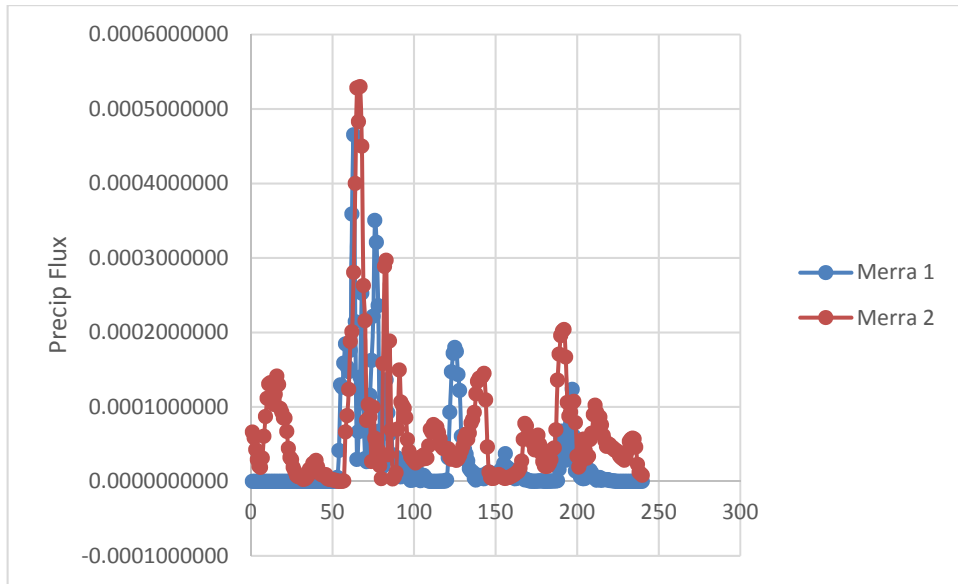
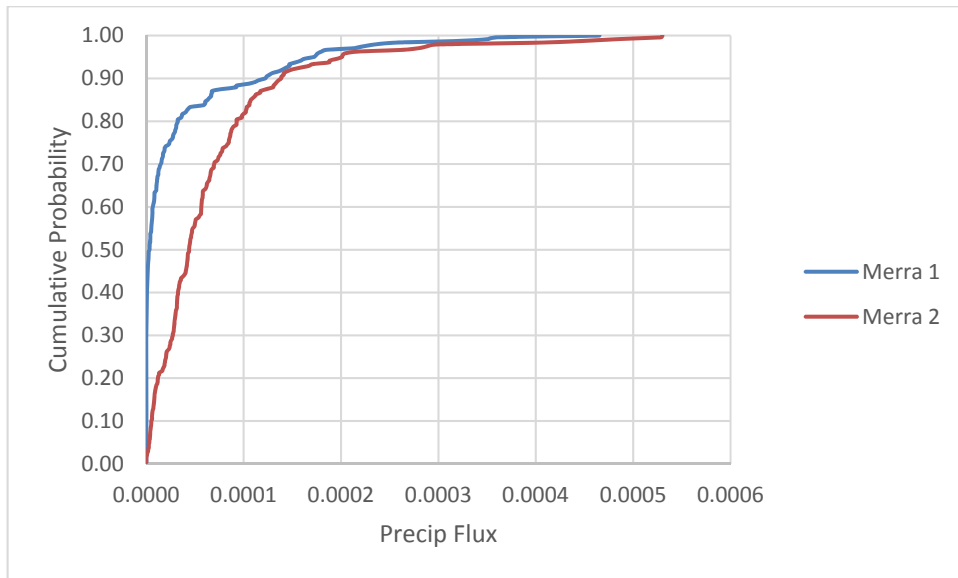**Figure 1. Hourly precipitation flux comparison.**

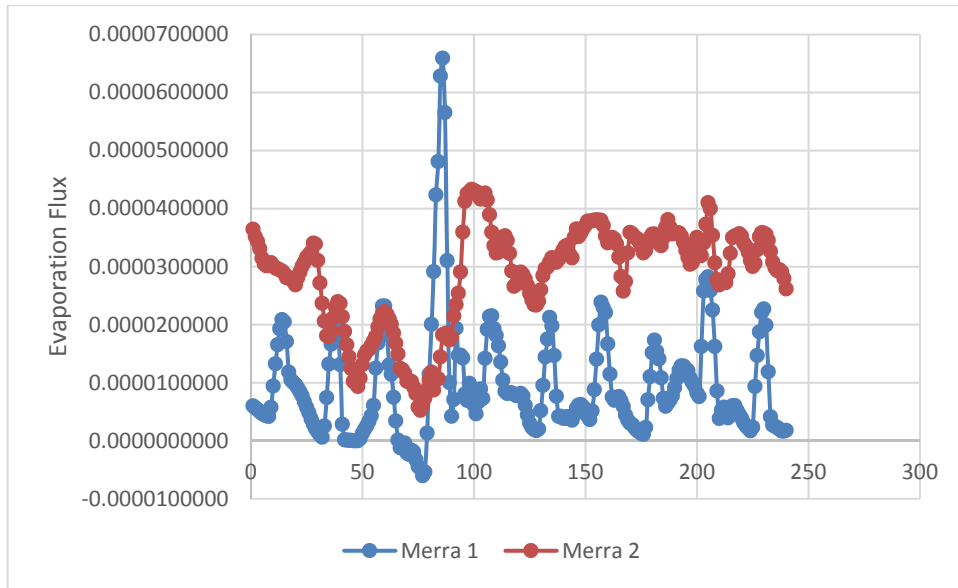**Figure 2. Hourly precipitation flux cumulative probability plot.**

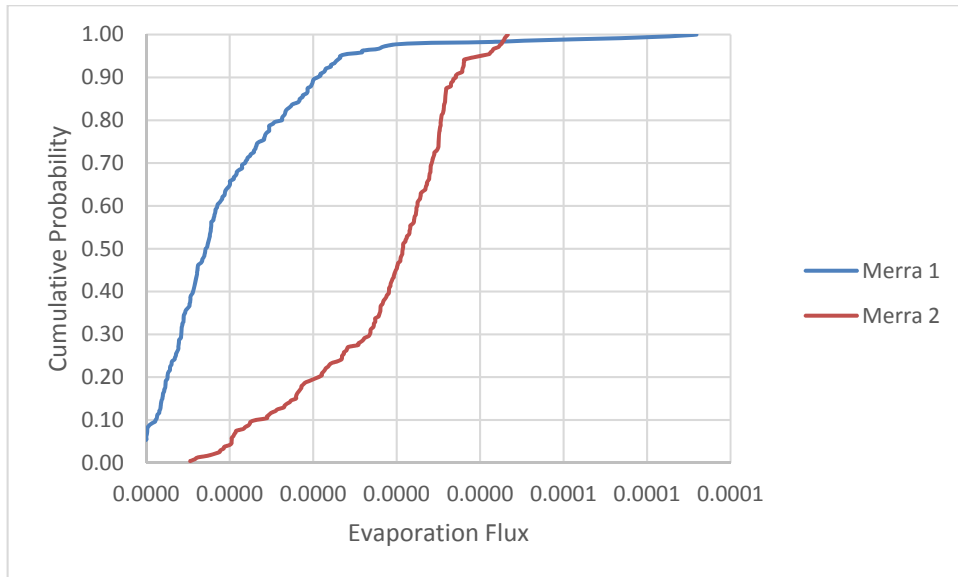**Figure 3. Hourly evaporation flux comparison.**
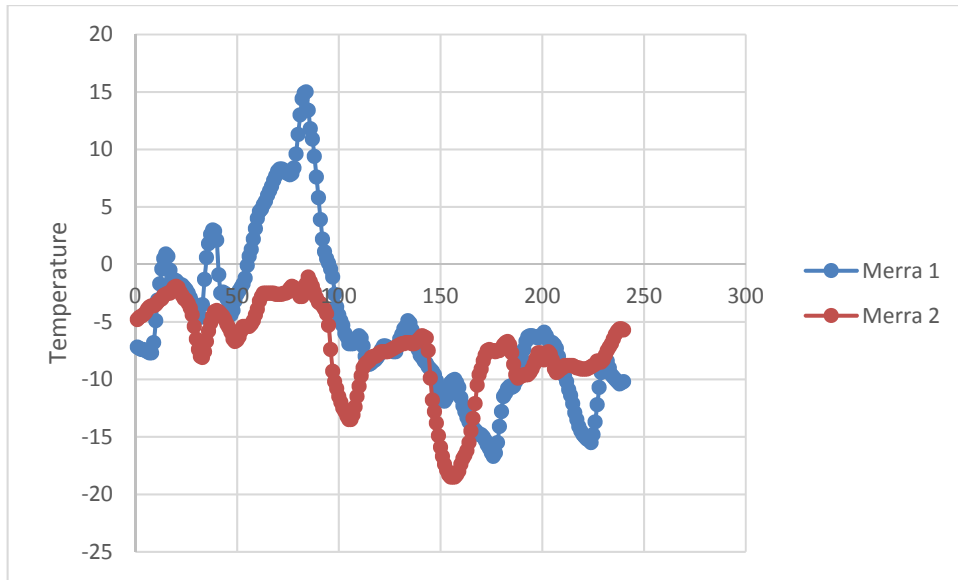

Figure 4. Hourly evaporation flux cumulative probability plot.
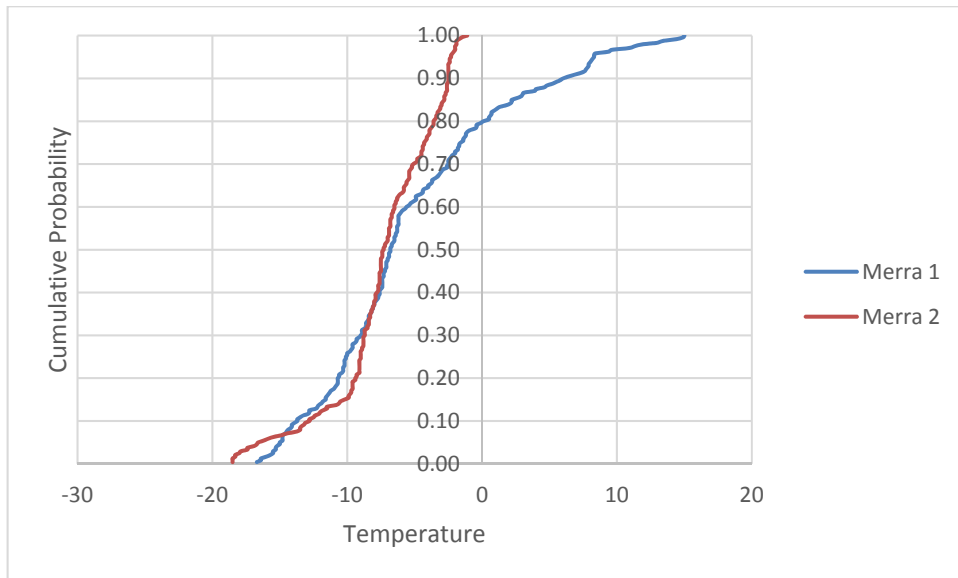
Figure 5. Hourly temperature comparison.

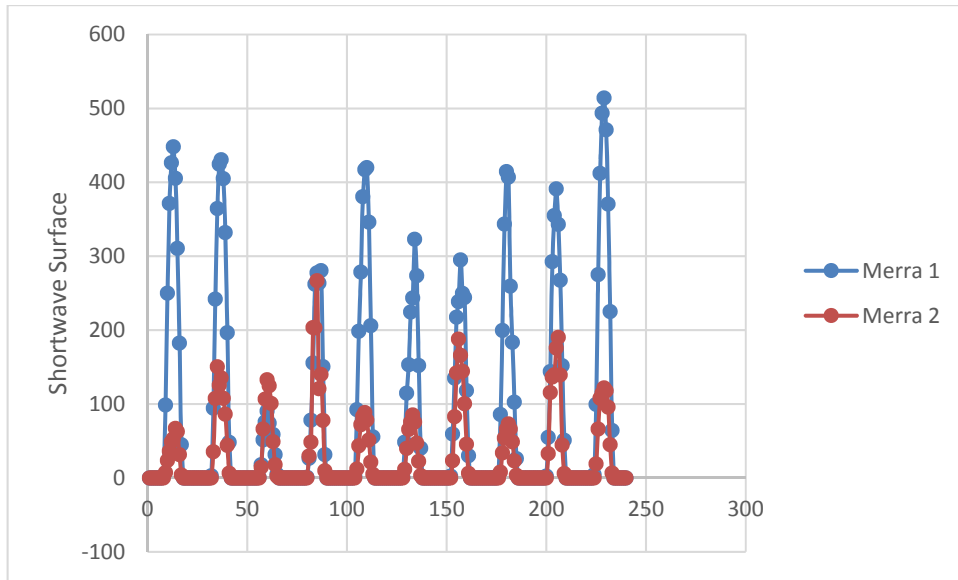**Figure 6. Hourly temperature cumulative probability plot.**
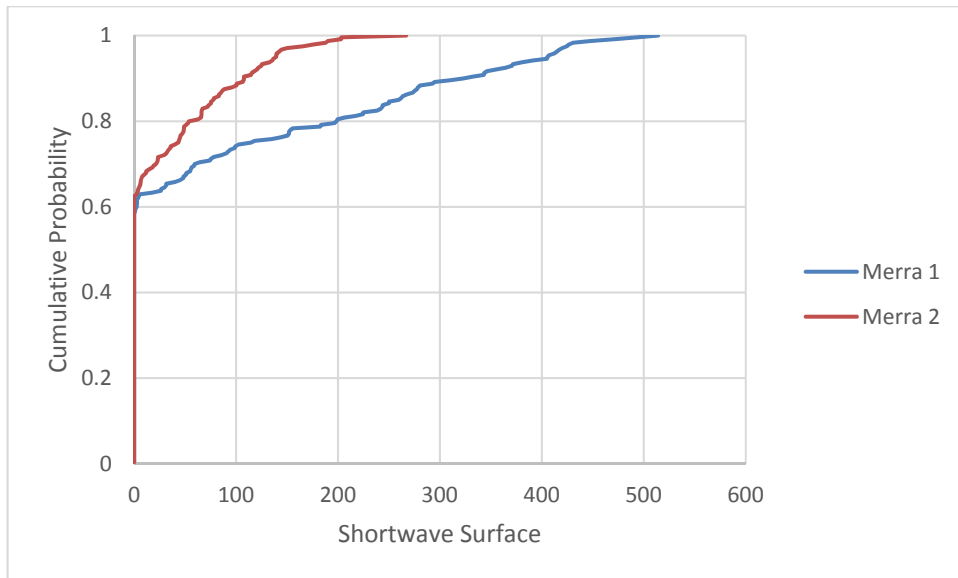
Figure 7. Hourly shortwave comparison.

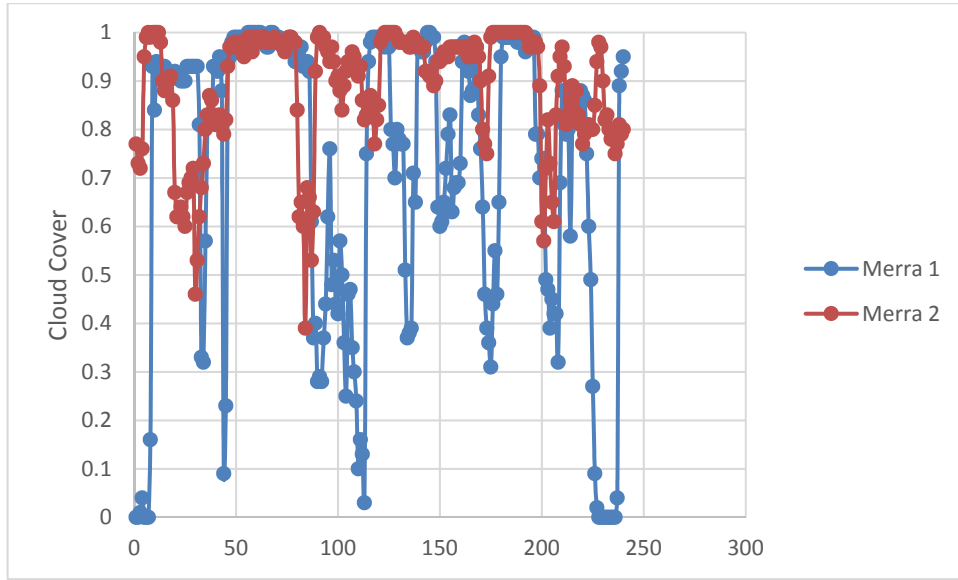**Figure 8. Hourly shortwave surface cumulative probability plot.**
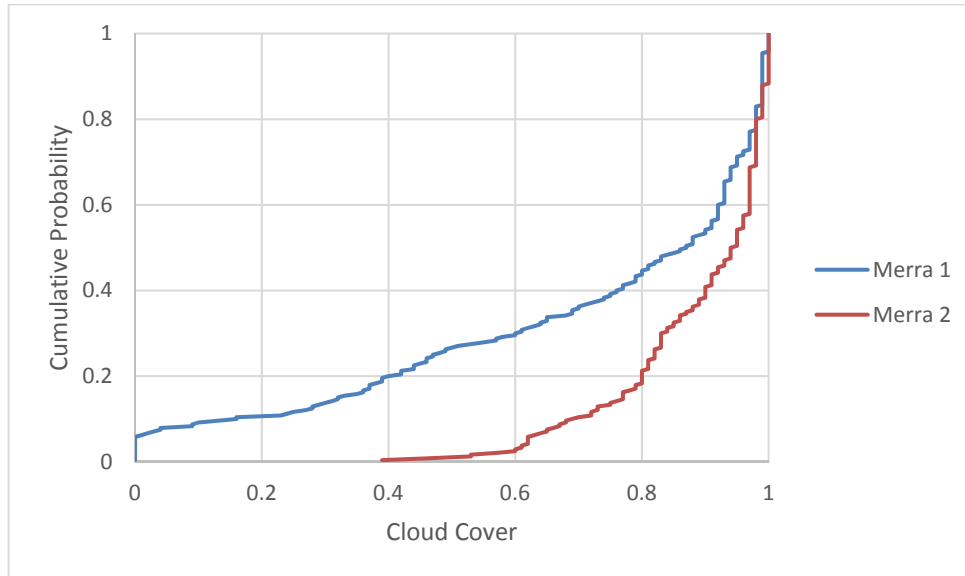
Figure 9. Hourly cloud cover comparison.

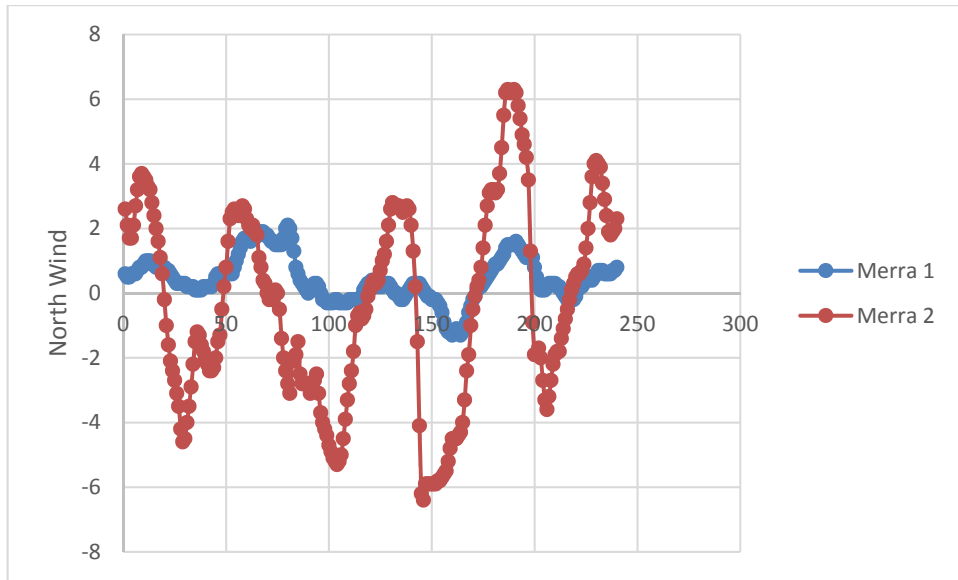**Figure 10. Hourly cloud cover cumulative probability plot.**

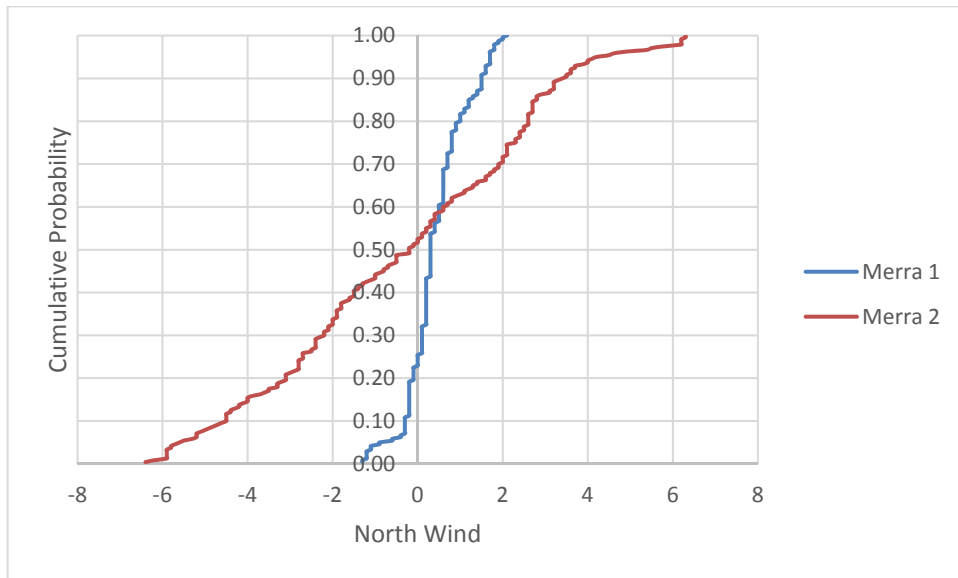**Figure 11. Hourly north wind comparison.**
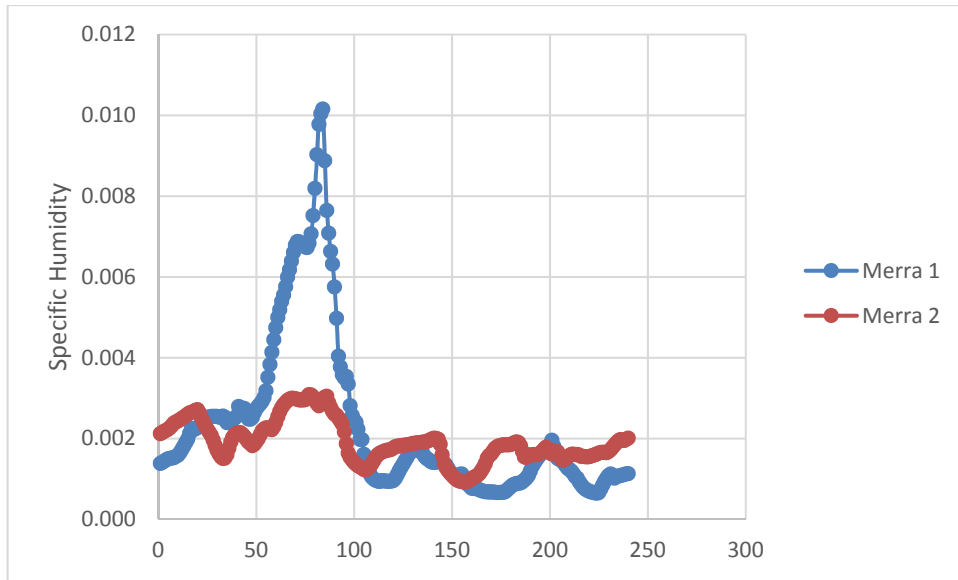

Figure 12. Hourly north wind cumulative probability plot.

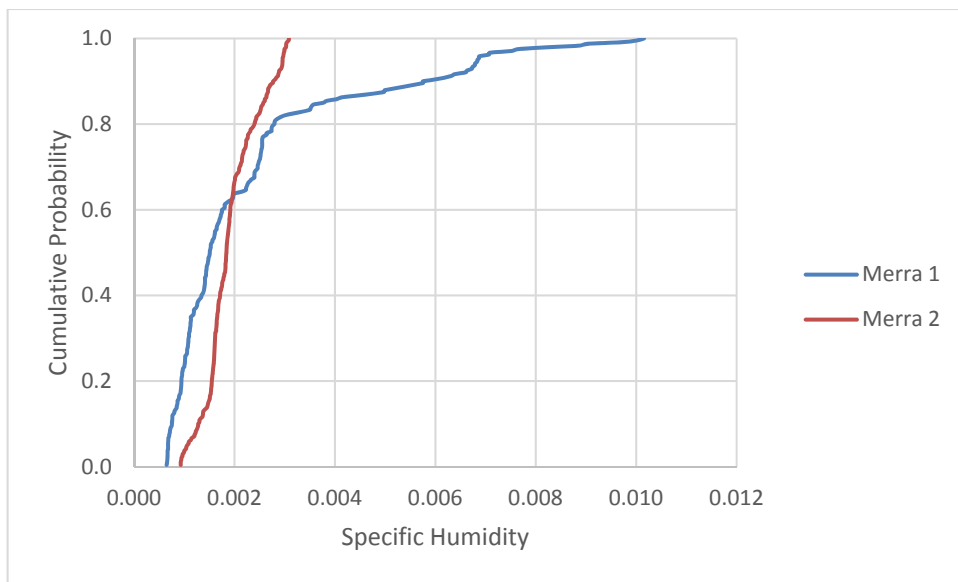**Figure 13. Hourly specific humidity comparison.**

Figure 14. Hourly specific humidity cumulative probability plot.

Literature Findings

Based on review of MERRA-2 literature, the differences between the MERRA-1 and MERRA-2 data are a result of the change in AGCM model that changed physical parameterizations. The largest difference appears to affect the precipitation data which ultimately also affects temperature and other variables. NASA only made these changes because they think better results were produced by the changes to the models and data sources.

Details of the improvements to the AGCM model from MERRA-1 to MERRA-2 can be found in the following references:

- Neale, R. B., Richter, J., Park, S., Lauritzen, P. H., Vavrus, S. J., Rasch, P. J., and Zhang, G.: The Mean Climate of the Community Atmosphere Model (CAM4) in Forced SST and Fully Coupled Experiments, J. Climate, 26, 5150-5168, doi:10.1175/JCLID-12-00236.1,2013.

- Donner, L. J., Wyman, B. L., Hemler, R. S., et al.: The Dynamical Core, Physical Parametrizations, and Basic Simulation Characteristics of the Atmospheric Component AM3 of the GFDL Global Coupled Model CM3, J. Climate, 24, 3484, doi: 10.1175/2011JCLI3955.1. 2011

- Pope, V. D., Gallani, M. L., Rowntree, P. R., and Stratton, R. A.: The impact of new physical parametrizations in the Hadley Centre climate model – HadAM3, Clim. Dynam., 16, 123-146, doi:10.1007/s003820050009,2000.

This section provides information regarding the changes that resulted in the MERRA-2 dataset as published in the references to provide an overview of the published material.

Molod, A., Takacs, L., Suarez, M., and Bacmeister, J.: Development of the GEOS-5 atmospheric general circulation model: evolution from MERRA to MERRA2, Geosci. Model Dev., 8, 1339-1356, doi:10.5194/gmd-8-1339-2015, 2015.

The focus on the development of the AGCM used in MERRA-1 version was on the behaviour of the components of the hydrological cycle in reanalysis mode while the focus of the development of the MERRA-2 AGCM was on a model that functions seamlessly in numerical weather prediction, reanalysis, climate and global mesoscale modes. Table 2 presents the changes in the parameterizations from MERRA-1 to MERRA-2.

- The parameterization of the surface layer turbulence in the MERRA-2 AGCM includes a substantial modification of the functional relationship between ocean surface roughness and wind stress.

- The effect for simulations at 2.0° X 2.5° resolution is expected to be an increase in simulated surface speeds in the mid-range of wind speeds (5-25 m s-1) from MERRA-2 to MERRA-1. Difference from the GSSTF estimate shows a reduction in the difference from up to 4 m s-1 in MERRA-1 to a difference of up to 2 m s-1 in the MERRA2 AGCM, pointing out the improvement in AGCM simulated climate due to change in roughness formulation.

- Difference between Louis scheme (MERRA) and Helfand and Schubert (MERRA2) are the stable layer stability functions and the formulation for the viscous sublayer (the laminar layer that can act to impede the flux of heat and moisture). The Helfand scheme removes the viscous sublayer over all land surfaces, including bare soil. The stable surface layer stability functions in the Helfand scheme are such that there is an increased turbulent heat exchange (of both signs) under stable conditions.

- The differences are attributable to the removal of the viscous sublayer over land in the Helfand and Schubert scheme and to the change in the stable layer stability functions.

Over most land surfaces the difference in sensible heat flux is negative, indicating less sensible heat flux when using the Louis scheme. This difference is consistent with the expectation that the removal of the viscous sublayer over land surfaces in the Helfand scheme lessens resistance to turbulent exchange.

Table 2. Changes in GCM Algorithms from MERRA-1 to MERRA-2

Module	Algorithm Change	Comments
Moist	Increased re-evaporation of precipitation	Fundamental change in model climate
	Modified autoconversion	Fundamental change in model climate
	Modified effective radius of cloud drops	Fundamental change cloud forcing
	Anvil fractions cut in half	Fundamental change cloud forcing
	AutoConvert "warm fog"	Important change in coupled simulations
	New critical RH with resolution dependence	Substantial change in simulated moisture
	Cloud bas set at planetary boundary layer (PBL) depth	Remove clouds detraining below PBL height
	RAS timescale no longer depends on turbulence	
	Stochastic RAS with resolution dependence	Substantial impact at high resolution
Turb	Remove restrictions on diffusion from Louis	Increase near surface diffusion
	Reformulate turbulent length scale in Louis	
	Reduce Lock scheme when there is wind shear	Impact on marine PBL
	Reduce cloud top entrainment for Lock plumes	Impact on marine PBL
Surf	Implement Helfand and Schubert scheme	
	Remove viscous sublayer over land surfaces	Improve land temperatures
	Change ocean roughness for middle wind regimes	Reduce wind bias in S. Ocean
	Changed ocean roughness high wind regimes	Increase tropical cyclone intensity
Land Surf	Change parameters for evapotranspiration	Impact on ratio of surface to canopy evaporation
GW (Gravity Wave) drag	Changed profile of background drag	Substantial impact on QBO
	Added intermittency of drag	Impact on timing of winter jet breakup

- The MERRA-2 AGCM RH_{crit} (Molod, 2012) represents a change in both the magnitude and vertical structure from the RH_{crit} in the MERRA-1 AGCM. Typical RH_{crit} profiles from the MERRA and MERRA2 AGCMs indicate generally lower values in MERRA-2 AGCM formulation except in the boundary layer. There is an increase in RH in the MERRA-2 AGCM-like experiment due to the increase in RH_{crit}. Relative to available observational verification, the MERRA-2 AGCM shows a general wet bias (Molod et al., 2012).

- The MERRA-1 AGCM-like experiment shows increased cloud cover in the 300-600 mb range relative to the MERRA-2 AGCM-like experiment, in particular at high latitudes in both hemispheres. In this regard, the MERRA-2 AGCM-like experiment result more closely resembles the AIRS cloud cover estimate.

- The change in boundary layer cloud between the MERRA AGCM-like experiment and the MERRA-1 AGCM-like experiment is not consistent with the free atmosphere response to the RH_{crit} change because the presence of boundary layer turbulence makes RH_{crit} less of a determining factor for model mean relative humidity there.

- The MERRA-2 AGCM scheme for re-evaporation of precipitation and suspended cloud water and ice contains a series of new parameters settings that result in a substantial increase over the MERRA-1 model in the re-evaporation of snow and ice. The removal of this change is expected to result in a drier atmosphere, in particular aloft. Direct impact of the change from the MERRA-2 AGCM to the MERRA-1 AGCM re-evaporation, and, as expected, shows the drying related to the reduced re-evaporation in the MERRA-1 AGCM-like experiment.

- The most substantial positive impact on the simulated AGCM climate was shown to be attributable to the increase of the re-evaporation of frozen cloud water and precipitation in the MERRA-2 AGCM. The resulting atmosphere had a higher moisture content, and many aspects of the boreal winter climate were substantially improved relative to reanalysis. The moisture and cloud cover amounts were shown to be further improved by implementation of an AIRS-based PDF of total water.

Reichle, R., Q. Liu, R. Koster, C. Draper, S. Mahanama, and G. Partyka. 2017. Land Surface Precipitation in MERRA 2. J. Clim doi: 10.1175/JCLI-D-16-0570.1

This paper provides explanation for the precipitation correction approach used for MERRA-2.

- The application of the precipitation corrections within the MERRA-2 coupled atmosphere-land system allows the evapotranspiration and thus the subsequent near-surface air temperature and humidity in MERRA-2 to respond to the observed precipitation. Consequently, the MERRA-2 near-surface meteorological data are more self-consistent than those of MERRA-Land. Compared to MERRA-Land, MERRA-2 not only provides an extended record, it also provides an enhanced forcing dataset for land-only modelling and data assimilation applications.

- Analysis of the global land water budget (excluding inland water and permanently frozen surfaces) suggests that land surface evapotranspiration in MERRA-2 is still too high and that runoff is too low.

- Improved precipitation leads to better quality land surface estimates in MERRA-2 and MERRA-Land, with improvement in soil moisture, terrestrial water storage, and runoff.

Raw Data Comparison

The MERRA Data Specification and MERRA Schema were used to develop the list of raw data variables used in the MERRA-1 database. The MERRA data elements and raw data variables are presented in Table 3. The raw data variables used for the MERRA-2 download by TSSC staff are the same as those previously used in MERRA-1.

It does not appear that changes to the evaporation models changed the evaporation raw data variable used for this project (EVAP). The raw data variable used does not directly deal with re-evaporation which was mostly effected by the model changes.

The RH_{crit} values are revised in MERRA-2. However, this is not a direct raw variable download since relative humidity is calculated based on specific humidity, air pressure, and temperature.

Table 3. MERRA Data Elements and Raw Data Variables.

MERRA Data Element	Raw Data Variable
SPECIFIC_HUMIDITY (kg/kg)	QV2M
PRESSURE_HR (Pa)	PS
PRECIP_FLUX (kg/sq m/s)	PRECTOT
EVAPORATION_FLUX (kg/sq m/s)	EVAP
SNOWFALL_FLUX (kg/sq m/s)	PRECSNO
PROFILE_SOIL_MOISTURE	PRMC*
LAYER_SOIL_MOISTURE	SFMC*
WATER_INFILTRATION_RATE (kg/sq m/s)	QINFIL*
SNOW_MASS (kg/sq m)	SNOMAS
SNOW_DEPTH	SNODP
SNOW_MELT (kg/sq m/s)	SMLAND
FRACTIONAL_SNOW_COV_AREA	FRSNO
OVERLAND_RUNOFF (kg/sq m/s)	RUNOFF
TEMPERATURE (K)	T2M
SOIL_TEMP_LAYER1 (K)	TSOIL1*
SOIL_TEMP_LAYER2 (K)	TSOIL2*
SOIL_TEMP_LAYER3 (K)	TSOIL3*
SOIL_TEMP_LAYER4 (K)	TSOIL4*
SOIL_TEMP_LAYER5 (K)	TSOIL5*
SOIL_TEMP_LAYER6 (K)	TSOIL6*
TEMP_UNSAT_ZONE (K)	TUNST
TEMP_SAT_ZONE (K)	TSAT
SHORTWAVE_SURFACE (W/sq ft)	SWGDN
SHORTWAVE_TOA (W/sq ft)	SWTDN
CLOUD_COVER	CLDTOT
SURFACE_EMISSIVITY	EMIS
SURFACE_ALBEDO	ALBEDO
NORTH_WIND (m/s)	V2M
EAST_WIND (m/s)	U2M
AIR_DENSITY (kg/m^3)	RHOA

References

1. Neale, R. B., Richter, J., Park, S., Lauritzen, P. H., Vavrus, S. J., Rasch, P. J., and Zhang, G.: The Mean Climate of the Community Atmosphere Model (CAM4) in Forced SST and Fully Coupled Experiments, J. Climate, 26, 5150-5168, doi:10.1175/JCLID-12-00236.1,2013.

2. Donner, L. J., Wyman, B. L., Hemler, R. S., et al.: The Dynamical Core, Physical Parametrizations, and Basic Simulation Characteristics of the Atmospheric Component AM3 of the GFDL Global Coupled Model CM3, J. Climate, 24, 3484, doi: 10.1175/2011JCLI3955.1. 2011

3. Pope, V. D., Gallani, M. L., Rowntree, P. R., and Stratton, R. A.: The impact of new physical parametrizations in the Hadley Centre climate model – HadAM3, Clim. Dynam., 16, 123-146, doi:10.1007/s003820050009,2000.

4. Molod, A., Takacs, L., Suarez, M., and Bacmeister, J.: Development of the GEOS-5 atmospheric general circulation model: evolution from MERRA to MERRA2, Geosci. Model Dev., 8, 1339-1356, doi:10.5194/gmd-8-1339-2015, 2015.

5. Reichle, R., Q. Liu, R. Koster, C. Draper, S. Mahanama, and G. Partyka. 2017. Land Surface Precipitation in MERRA 2. J. Clim doi: 10.1175/JCLI-D-16-0570.1

Attachment A. Sample of Rollup Data Comparisons for MERRA-1 and MERRA-2 Datasets

This attachment contains tables and graphs for the daily, monthly and yearly rollup data for selected data elements for the MERRA data cell at longitude 40 degrees and latitude -80 degrees over a longer time period than previously presented. Table 4 through Table 6 show tabulated descriptive statistics for the matching MERRA1 and 2 data sets for each aggregated time period.

Table 4. Daily MERRA Data Elements Comparison

MERRA Data Element	Average		Standard Deviation	
	MERRA1	MERRA2	MERRA1	MERRA2
REL_HUM_AVG (%)	75.58	76.69	11.91	10.49
PRECIPITATION (mm)	2.64	3.23	4.53	6.56
EVAPORATION(mm)	2.55	2.57	1.78	1.83
INFILTRATION (mm)	2.39	2.05	4.72	3.99
RUNOFF (mm)	0.14	0.47	0.40	0.99
SNOWFALL (mm)	0.29	0.36	1.0	1.02
SNOW_MASS (kg)	32.79	40.48	84.33	91.29
SNOW_MELT (mm)	0	0	0	0
TEMPERATURE_AVG (ºC)	9.59	9.25	10.38	10.20
TEMP_UNSAT_ZONE_AVG (ºC)	9.78	9.13	9.59	9.82
TEMP_SAT_ZONE_AVG (ºC)	9.82	9.04	9.53	9.85
SHORTWAVE_SURFACE (W/sq ft)	4475	4370	2093	2267
SHORTWAVE_TOA (W/sq ft)	7905	7887	2786	2779
CLOUD_COVER AVG	0.55	0.54	0.29	0.27
PERCENT_SUNSHINE_AVG (%)	45	46.45	28.5	26.8
EMISSIVITY	2.33	2.33	0.71	0.56
ALBEDO	23.59	23.56	0.21	0.19
WIND_VELOCITY_AVG (m/s)	0.91	0.20	0.41	0.30
AIR_DENSITY_AVG (kg/m^3)	1.25	1.19	1.2	0.06

Table 5. Monthly MERRA Data Elements Comparison

MERRA Data Element	Average		Standard Deviation	
	MERRA1	MERRA2	MERRA1	MERRA2
REL_HUM_AVG (%)	76.22	76.78	5.97	7.36
PRECIPITATION (mm)	90.16	106.60	37.59	52.09
EVAPORATION(mm)	75.22	72.12	44.86	43.87
TEMPERATURE_AVG (ºC)	10.23	9.99	9.12	9.2
TEMP_UNSAT_ZONE_AVG (ºC)	10.28	9.84	8.64	8.83
TEMP_SAT_ZONE_AVG (ºC)	10.31	9.76	8.64	8.93
FREEZE_INDEX	57.5	56.7	64.8	57.9
SHORTWAVE_SURFACE (W/sq ft)	133178	132177	53135	57861
SHORTWAVE_TOA (W/sq ft)	240529	239879	85034	84803
CLOUD_COVER AVG	0.58	0.56	0.09	0.11
PERCENT_SUNSHINE_AVG (%)	42.2	44.4	9.0	11.5
EMISSIVITY	718	737	21.2	21.6
ALBEDO	69.32	69.29	15.5	15.0
WIND_VELOCITY_AVG (m/s)	0.94	0.16	0.26	0.37

Table 6. Yearly MERRA Data Elements Comparison

MERRA Data Element	Average		Standard Deviation	
	MERRA1	MERRA2	MERRA1	MERRA2
REL_HUM_AVG (%)	76.25	76.95	2.38	2.74
PRECIPITATION (mm)	1082	1279	113.6	205.1
EVAPORATION(mm)	903	865	54.3	78.4
TEMPERATURE_AVG (ºC)	10.24	9.98	0.72	0.72
TEMP_UNSAT_ZONE_AVG (ºC)	10.29	9.86	0.66	0.67
TEMP_SAT_ZONE_AVG (ºC)	10.31	9.78	0.62	0.65
FREEZE_INDEX	311.49	312.03	128.74	106.73
SHORTWAVE_SURFACE (W/sq ft)	1598134	1586126	39217	52399
SHORTWAVE_TOA (W/sq ft)	2886345	2878553	1676	1852
CLOUD_COVER AVG	0.58	0.56	0.04	0.03
PERCENT_SUNSHINE_AVG (%)	42.2	44.5	3.6	3.5
EMISSIVITY	831.8	831.5	41.4	32.0
ALBEDO	8612	8603	14.4	11.9
WIND_VELOCITY_AVG (m/s)	1	0	0	0

Precipitation

This section presents the cumulative probability plots of precipitation for the daily, monthly and yearly rollups. Figure 15 through Figure 17 show higher precipitation for the MERRA-2 dataset.
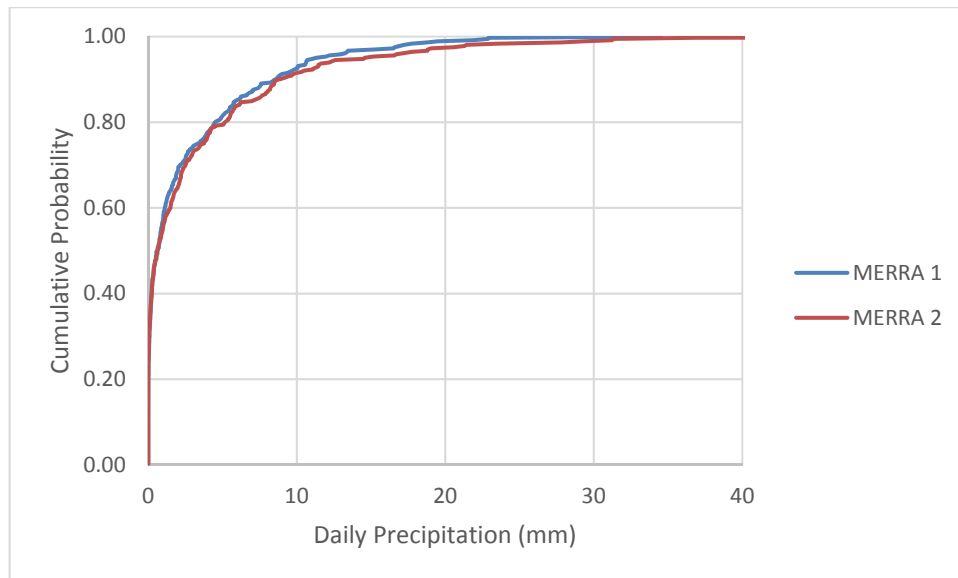
Figure 15. Daily precipitation cumulative probability plot
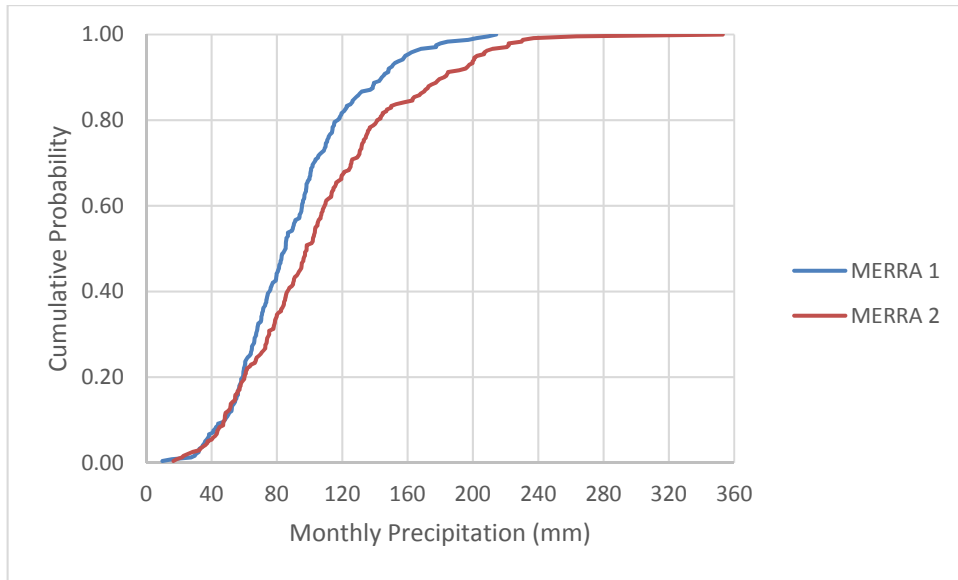
Figure 16. Monthly precipitation cumulative probability plot.
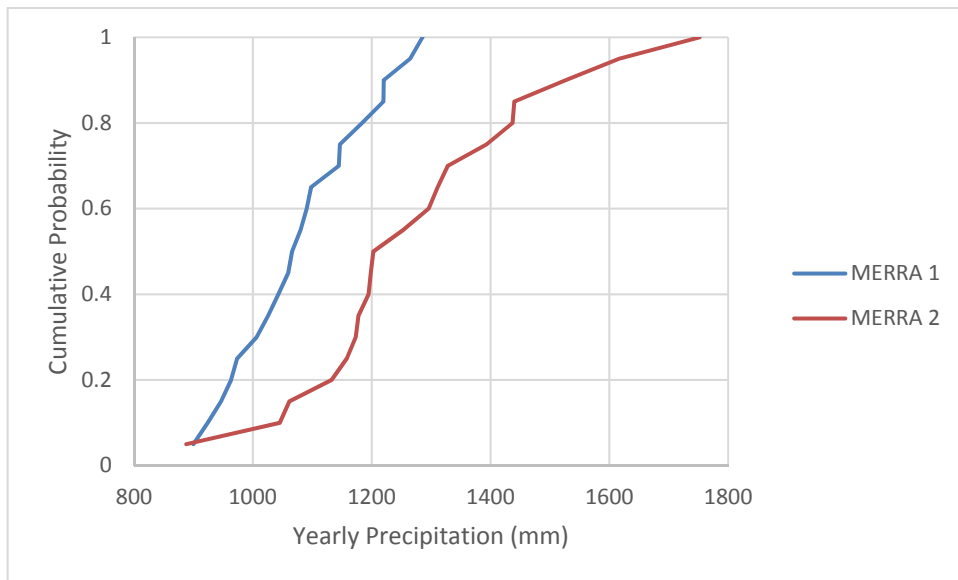
Figure 17. Yearly precipitation cumulative probability plot.

Temperature

This section presents the cumulative probability plots of temperature for the daily, monthly and yearly rollups. Figure 18 through Figure 20 show that there is not much difference in temperature between the MERRA-1 and MERRA-2 datasets but that the MERRA-1 temperature is slightly higher.
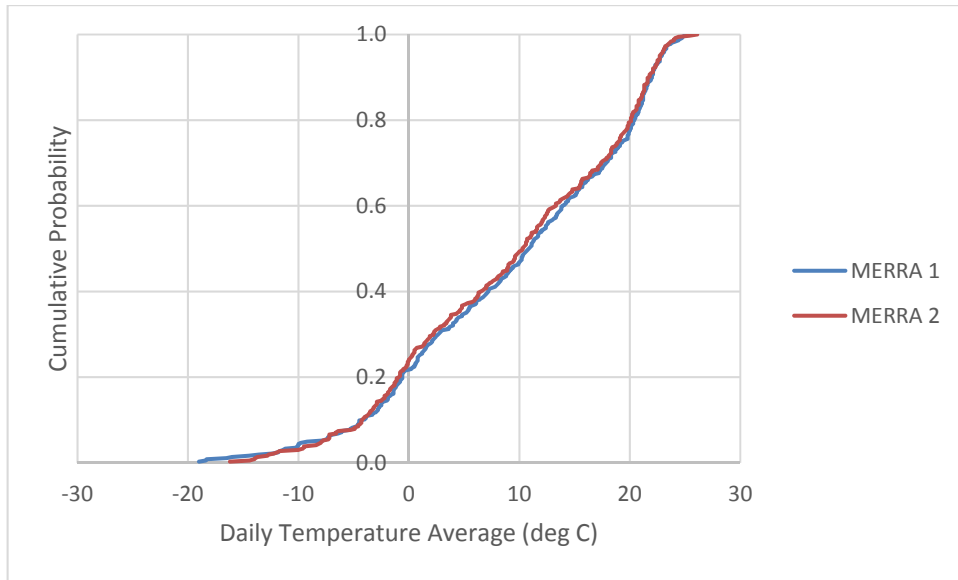
Figure 18. Daily temperature cumulative probability plot.
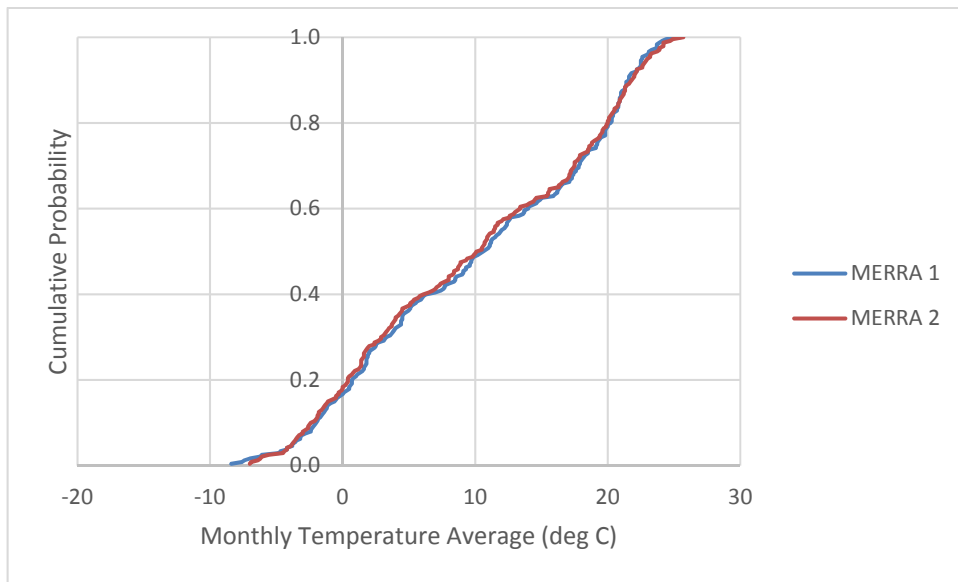
Figure 19. Monthly temperature cumulative probability plot.
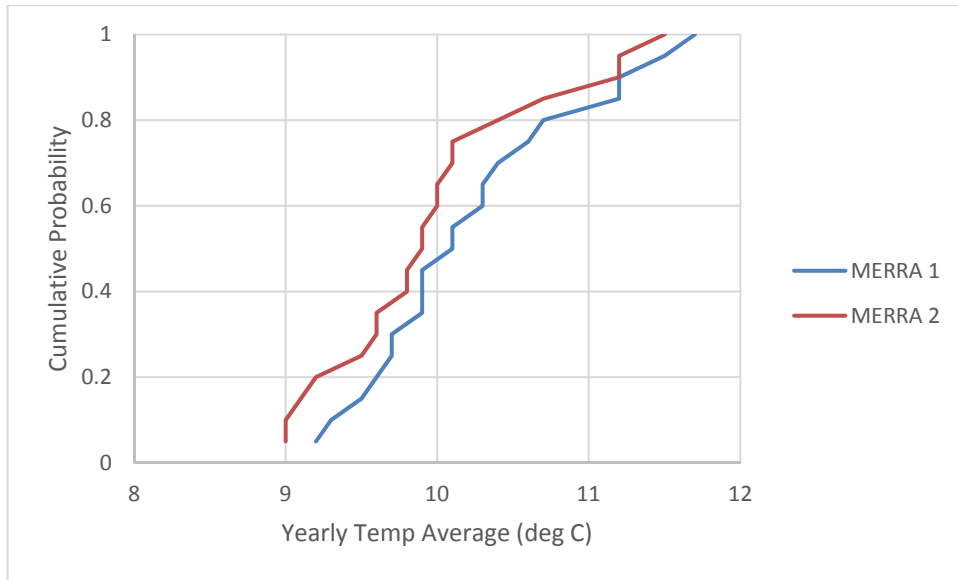
Figure 20. Yearly temperature cumulative probability plot.

Relative Humidity

This section presents the cumulative probability plots of relative humidity for the daily, monthly and yearly rollups. Figure 21 through Figure 23 show the differences between the MERRA-1 and MERRA-2 datasets.
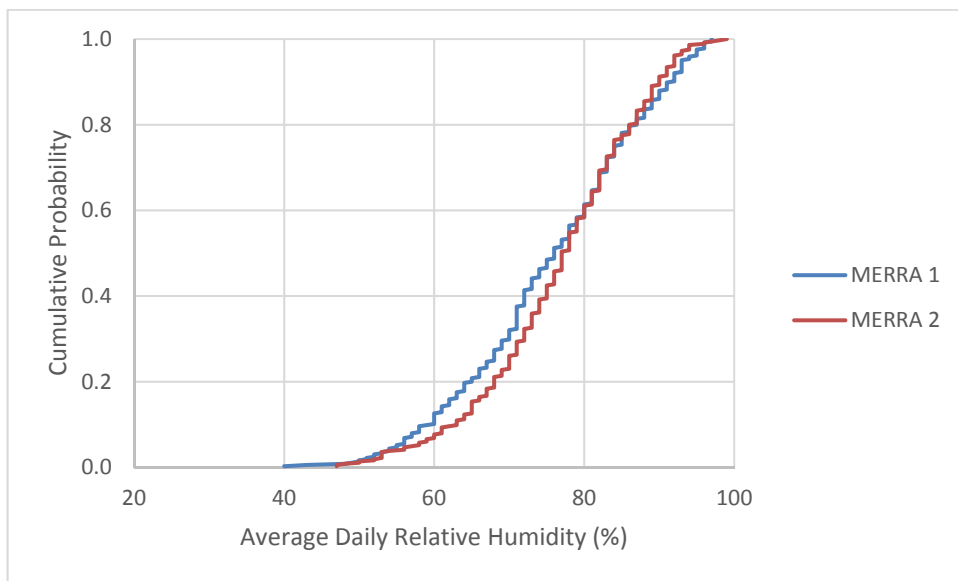
Figure 21. Daily average relative humidity cumulative probability plot.
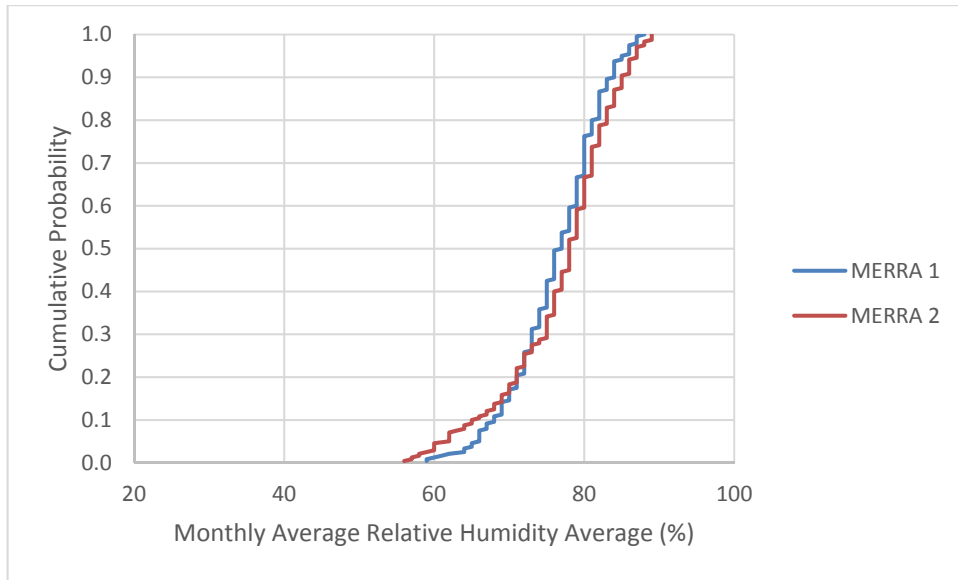
Figure 22. Monthly average relative humidity cumulative probability plot.
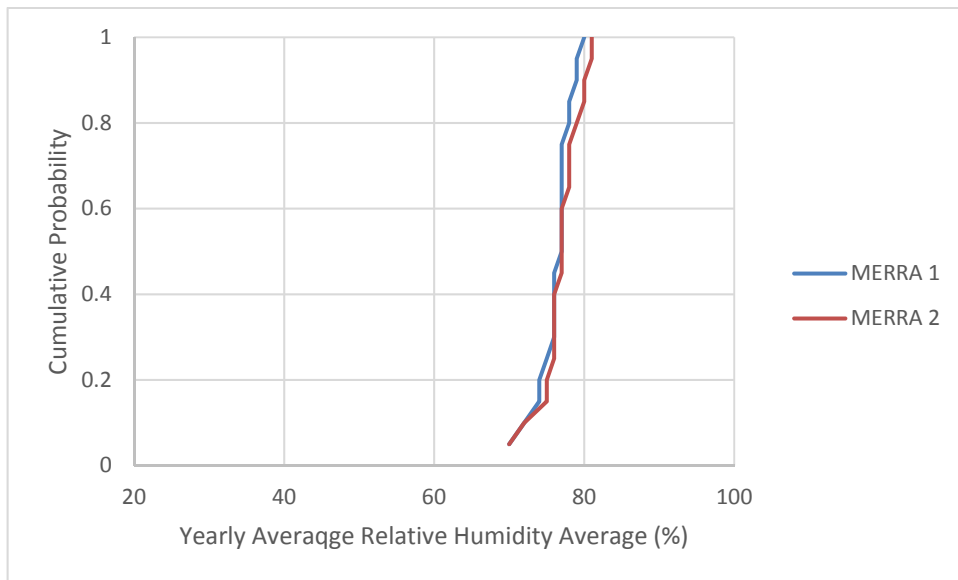
Figure 23. Yearly average relative humidity cumulative probability plot.

Wind

This section presents the cumulative probability plots of wind for the daily, monthly and yearly rollups. Figure 24 through Figure 26 show higher wind velocity for the MERRA-1 dataset. The yearly average for MERRA-2 is zero for this site.
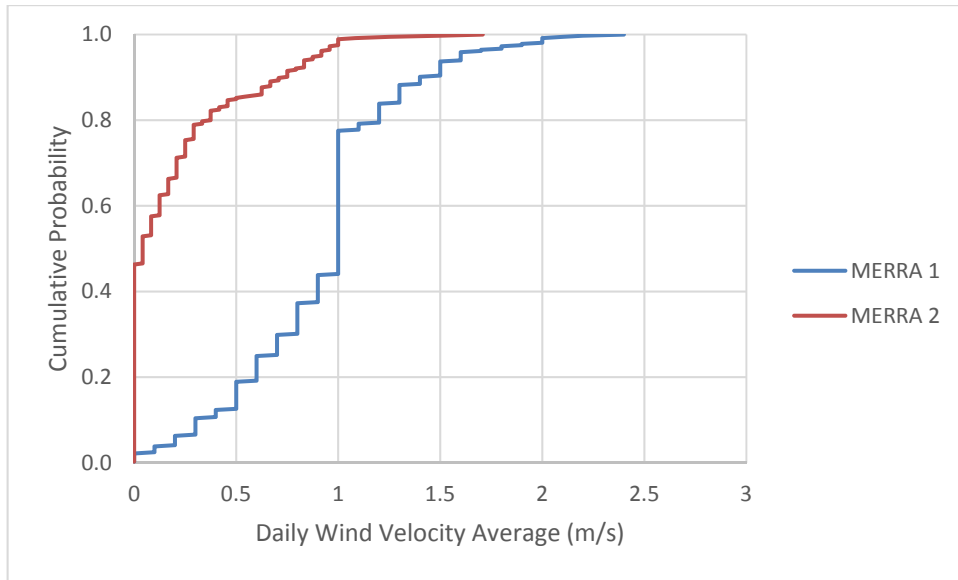
Figure 24. Daily wind cumulative probability plot.
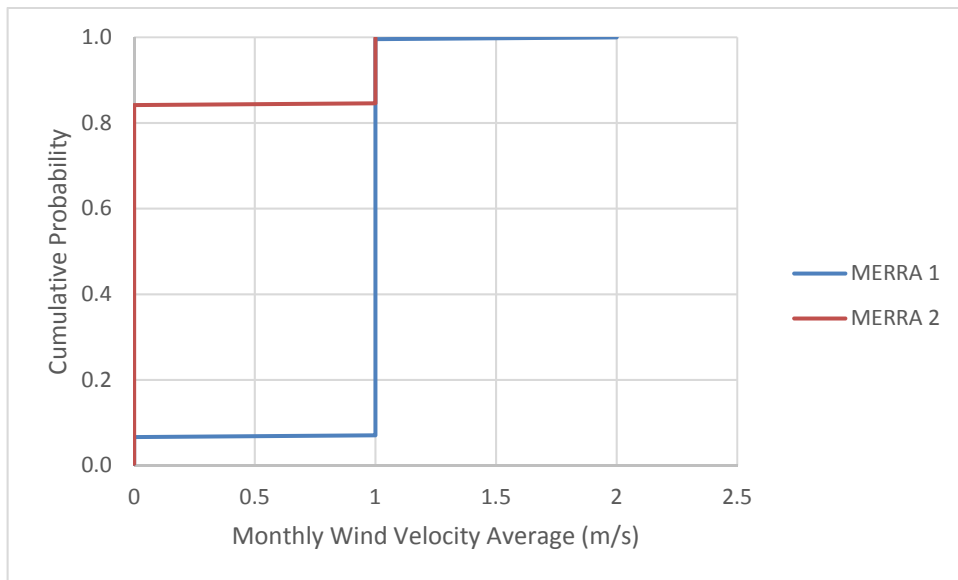
Figure 25. Monthly wind cumulative probability plot.
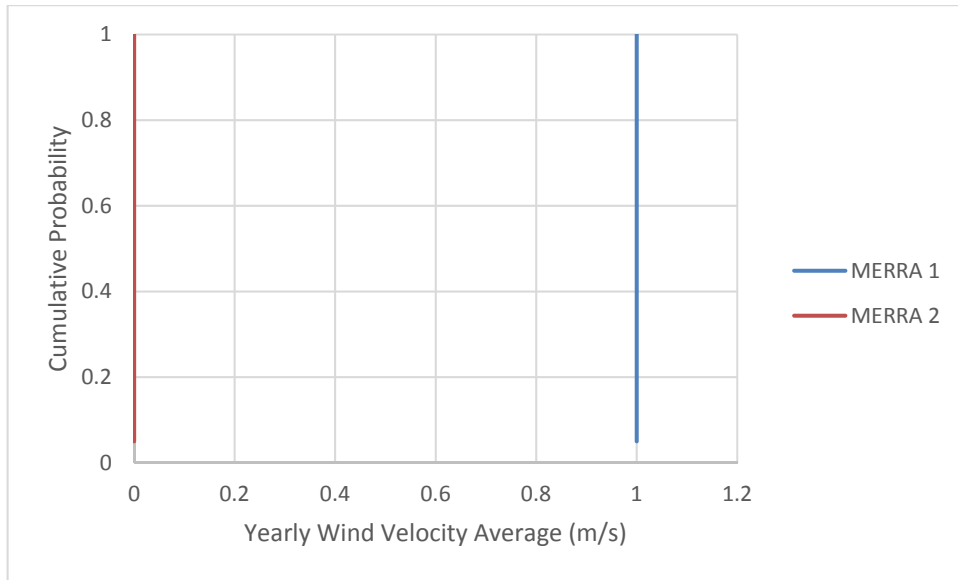
Figure 26. Yearly wind cumulative probability plot.

Solar Radiation

This section presents the cumulative probability plots of shortwave surface for the daily, monthly and yearly rollups. Figure 27 through Figure show relatively similar distributions for the MERRA-1 and MERRA-2 datasets. Figure 29 through Figure 31 show relatively similar distributions for the MERRA-1 and MERRA-2 datasets with MERRA-2 percent sunshine being slightly higher.
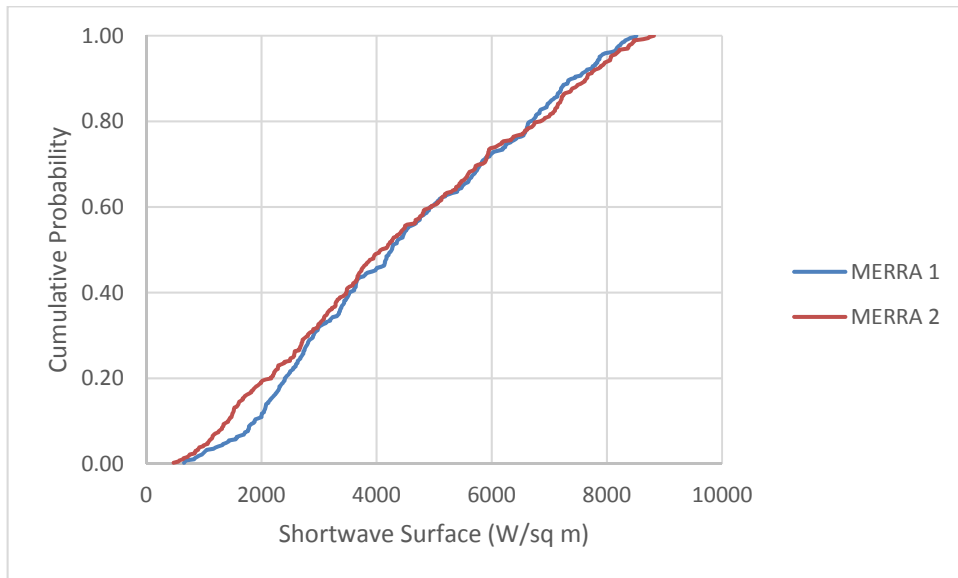
Figure 27. Daily shortwave surface cumulative probability plot.
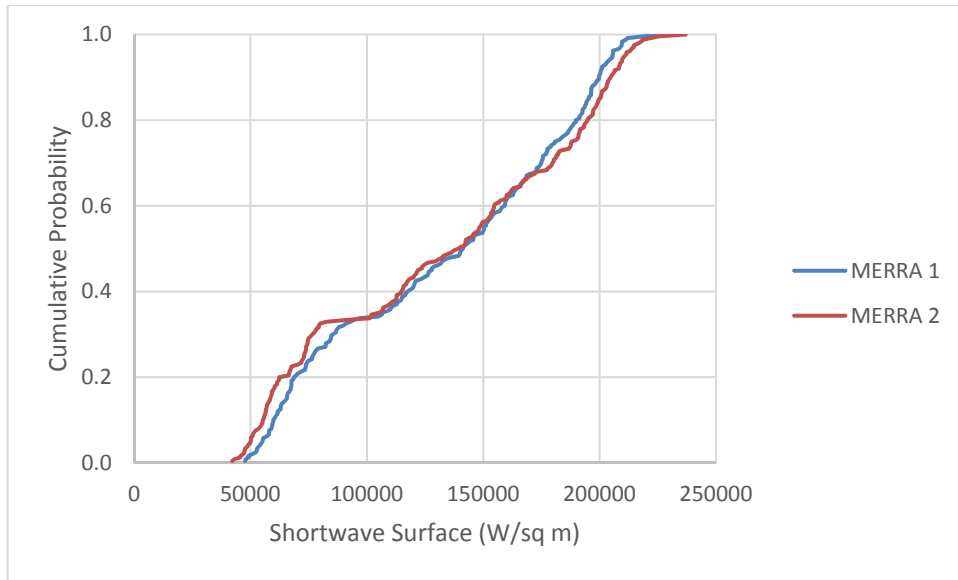
Figure 28. Monthly shortwave surface cumulative probability plot.
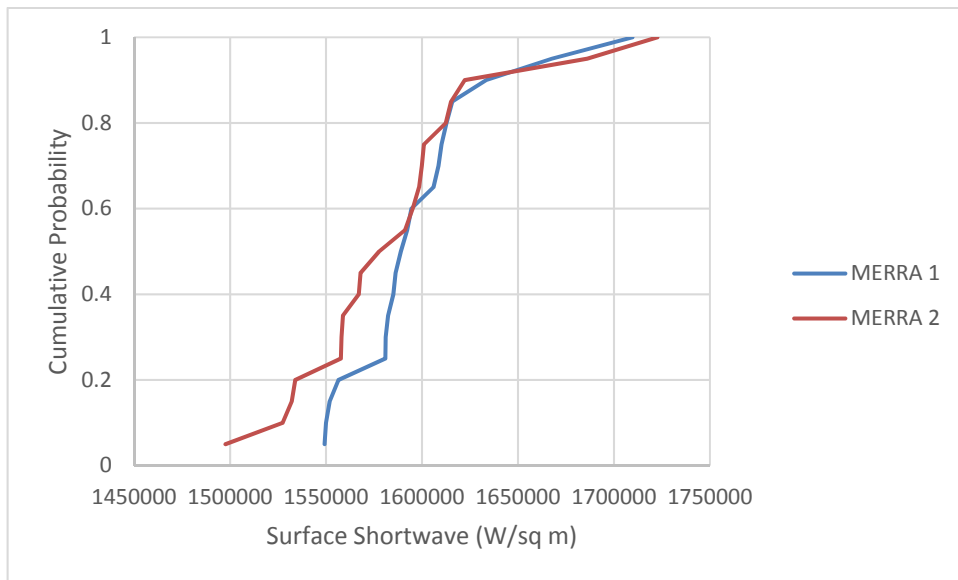
Figure 29. Yearly shortwave surface cumulative probability plot.
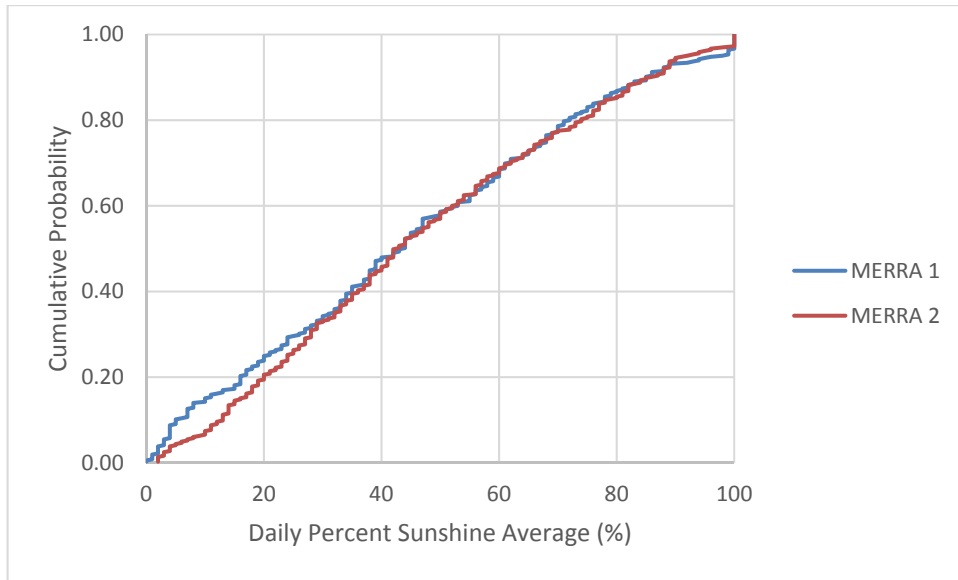
Figure 29. Daily percent sunshine cumulative probability plot.
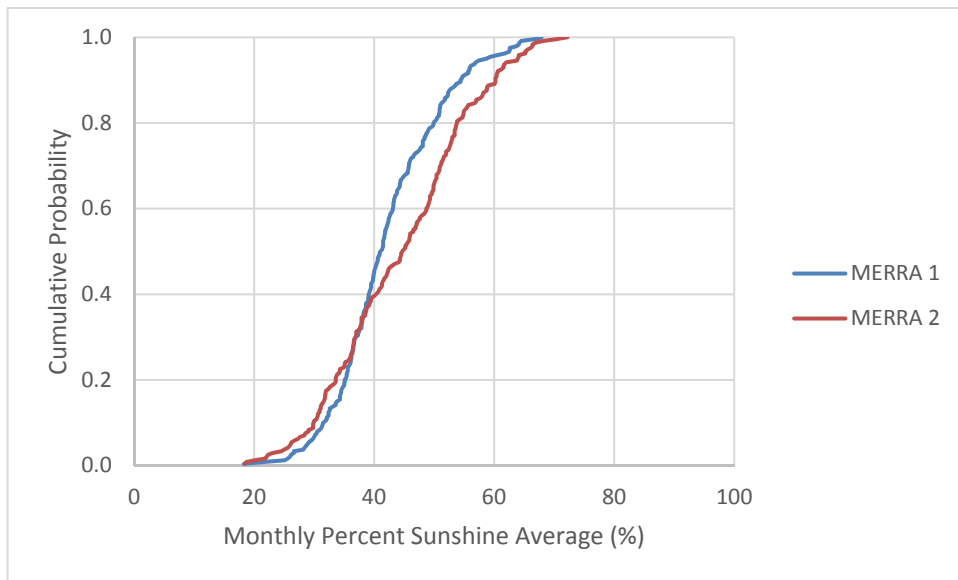
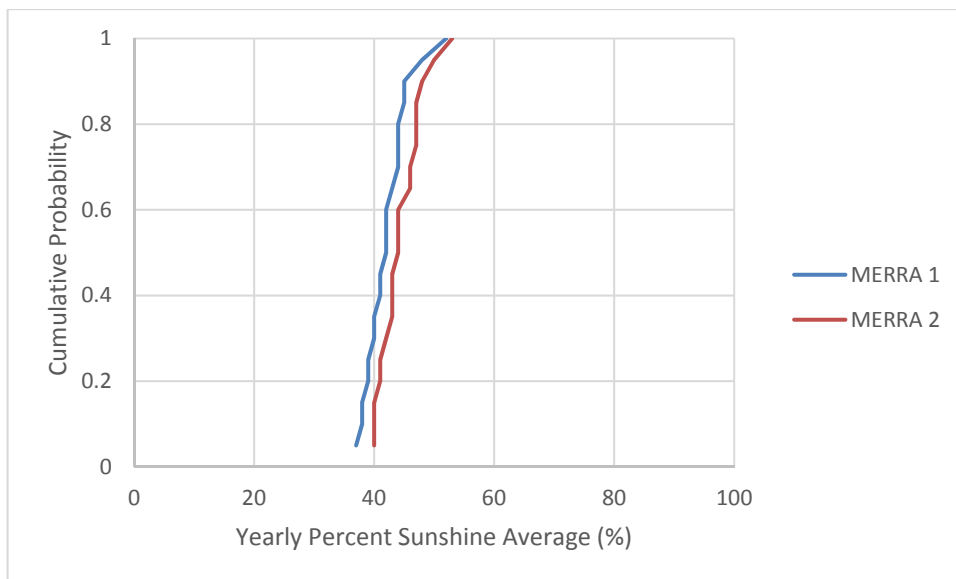**Figure 30. Monthly percent sunshine cumulative probability plot.**

Figure 31. Yearly percent sunshine cumulative probability plot.

Attachment B. Average Annual Value Distribution Comparison

This section presents a visual display of the average annual values for precipitation, temperature, and climate zone for 1980 to 2010. The figures include the cells designated for the United States only. Figure 32 and Figure 33 show average annual temperature, Figure 34 and Figure 35 show average annual precipitation, and Figure 36 and Figure 37 show the climate zone based on average annual temperature and average annual freezing index, with the commonly used dividing points of 20 inches of precipitation per year and 150 degree (F) days per year for MERRA-1 and MERRA-2 data sets respectively.

When comparing the two data sets visually, there are obvious differences, but they are typically small. Some of this is due to the different grid sizes and how the area included in each cell affects the average for a cell, and some of it is due to the differences in the models. In general, for US cells, the average values from MERRA-2 are slightly wetter and slightly colder than those from MERRA-1.

This impacts the calculated climate zone a for areas that are near the transition limits for Wet/Dry and Freeze/No-Freeze. For instance, North Dakota is mostly dry with MERRA-1, and mostly wet with MERRA-2. This is because the area is near the 20 inches/year mark – slightly below with MERRA-1, and the slightly above with MERRA-2. It is also worth noting that both data sets have a wet/dry transition much further west than expected.

Figure 38 shows the historic 1947 Thornthwaite Moisture Index plot that is most often cited in pavement engineering literature as the threshold between wet and dry zones. Of interest in this plot is the zero line in the central part of the United States. Each precipitation gradient shown in Figure 35 has an interval of 5 inches. Thus, **30 inches per year of precipitation** more closely matches with historic Thornthwaite zero line is this part of the country than the current 20 inch per year threshold previously used in DataPave and now used in InfoPave. This limited study did not allow for a more thorough investigation of wet/dry climate zones using a Thornthwaite index moisture balance perspective that is possible from other MERRA data elements.

The current LTPP threshold between freeze and no-freeze zones based on average annual air freezing index, using MERRA-2 data, have a remarkably good agreement with the historical freeze zones presented in pavement engineering literature on the subject.
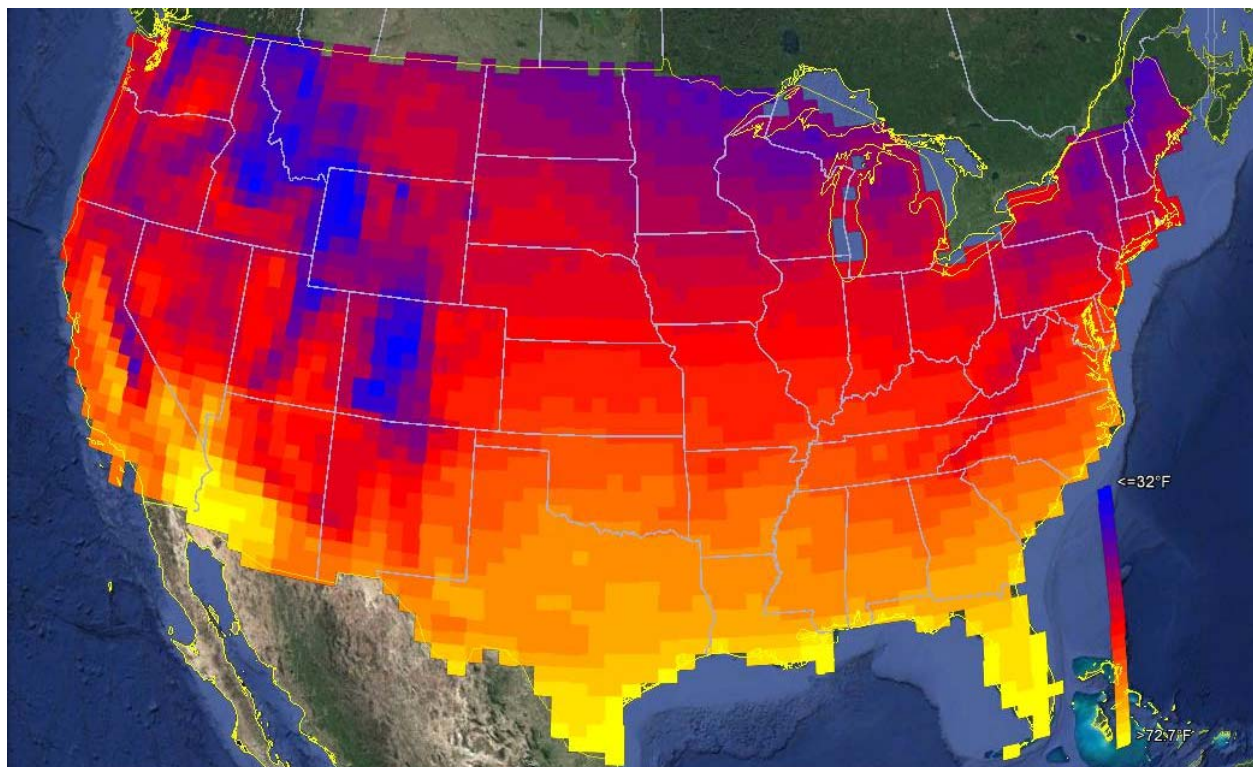
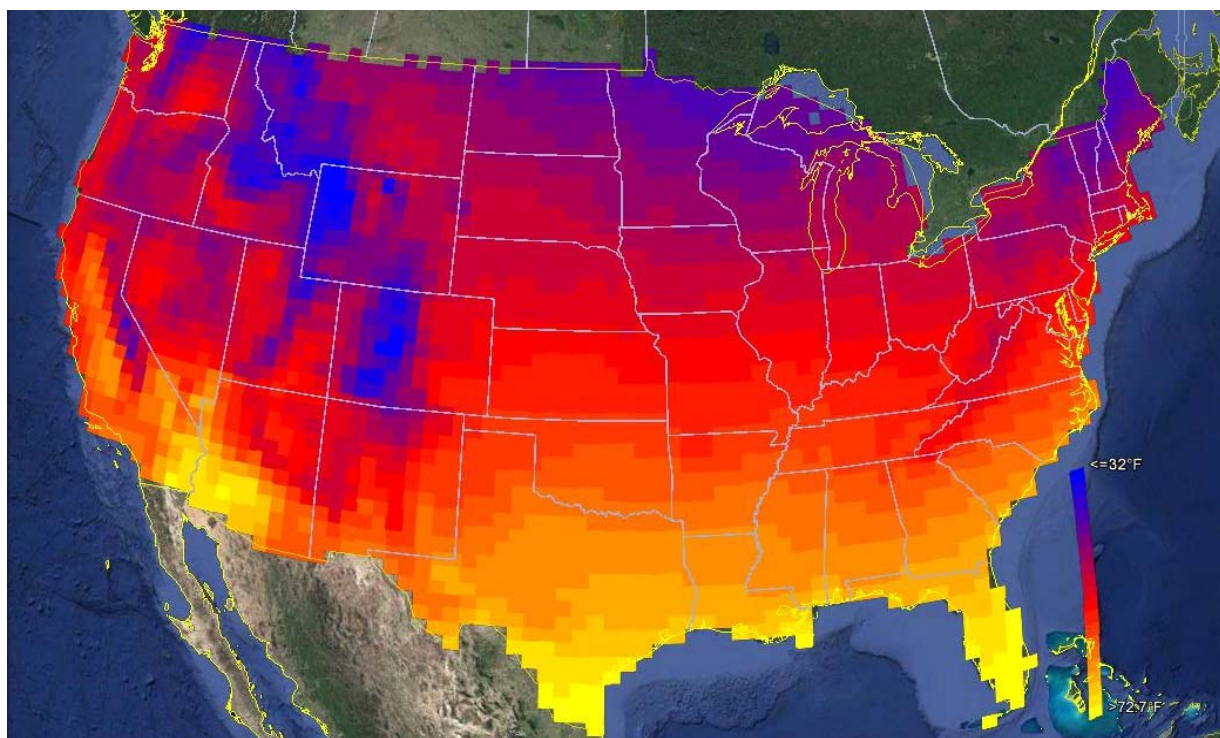**Figure 32. Average Annual Temperature using MERRA-1 data.**

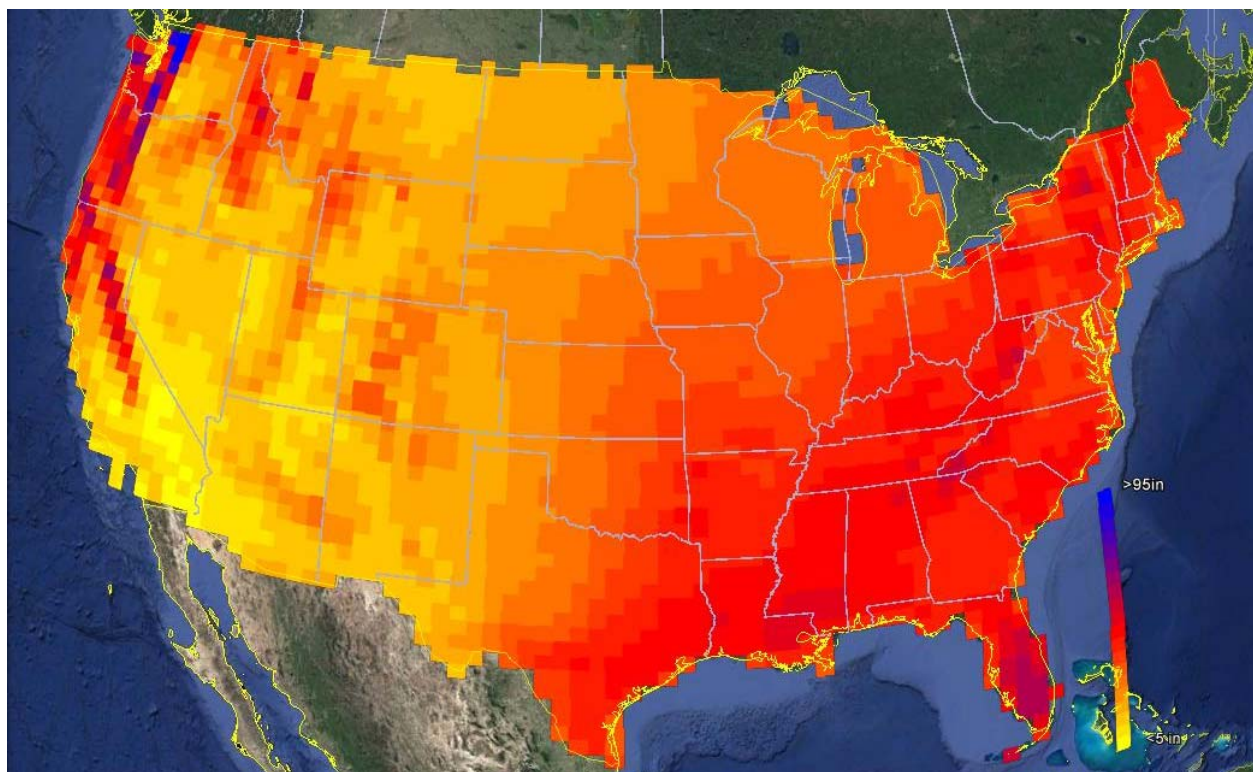**Figure 33. Average Annual Temperature using MERRA-2 data.**

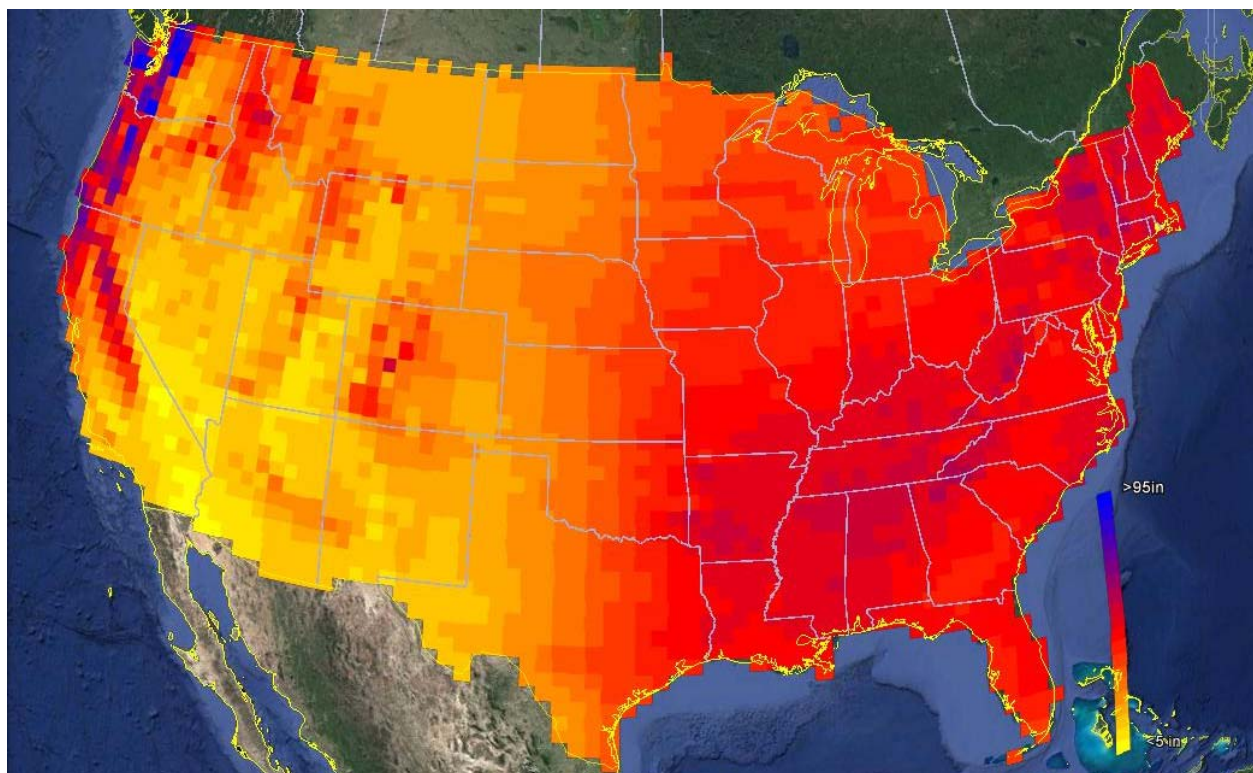**Figure 34. Average Annual Precipitation using MERRA-1 data.**

Figure 35. Average Annual Precipitation using MERRA-2 data.
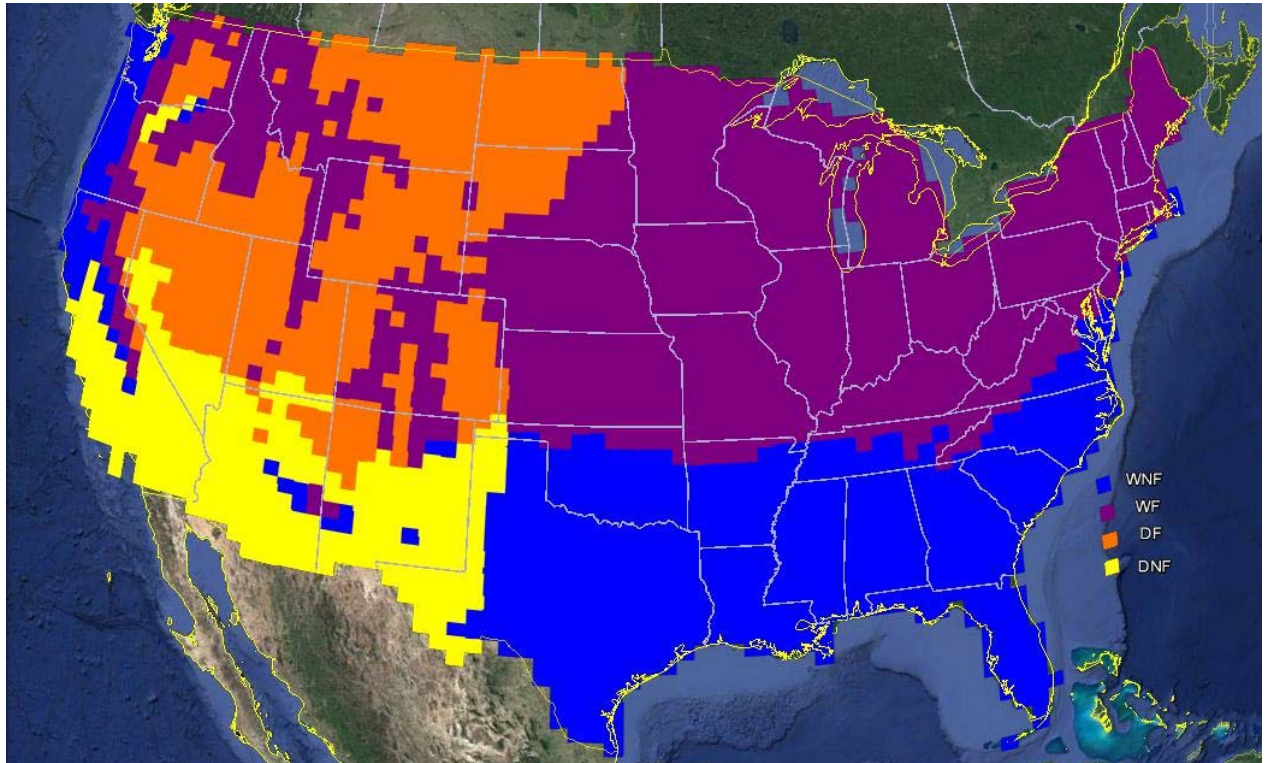
Figure 36. Climate Zone using Average MERRA-1 data.
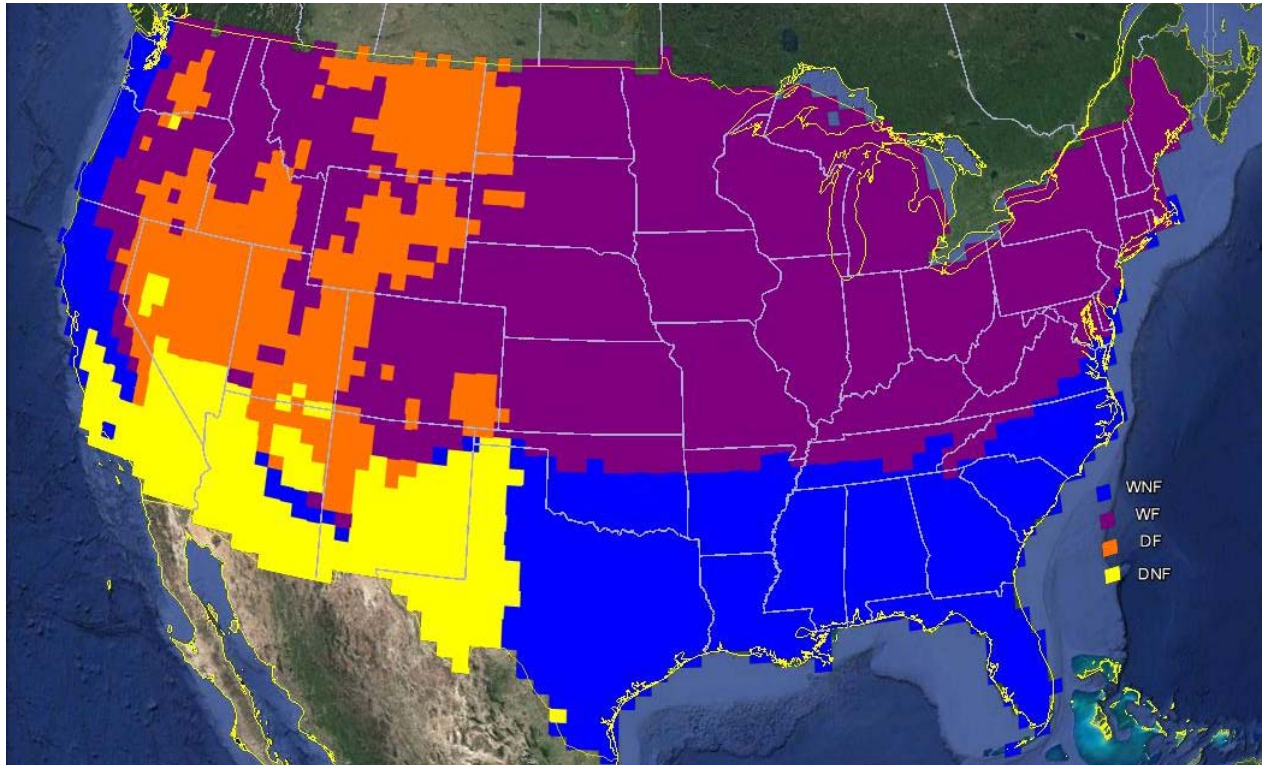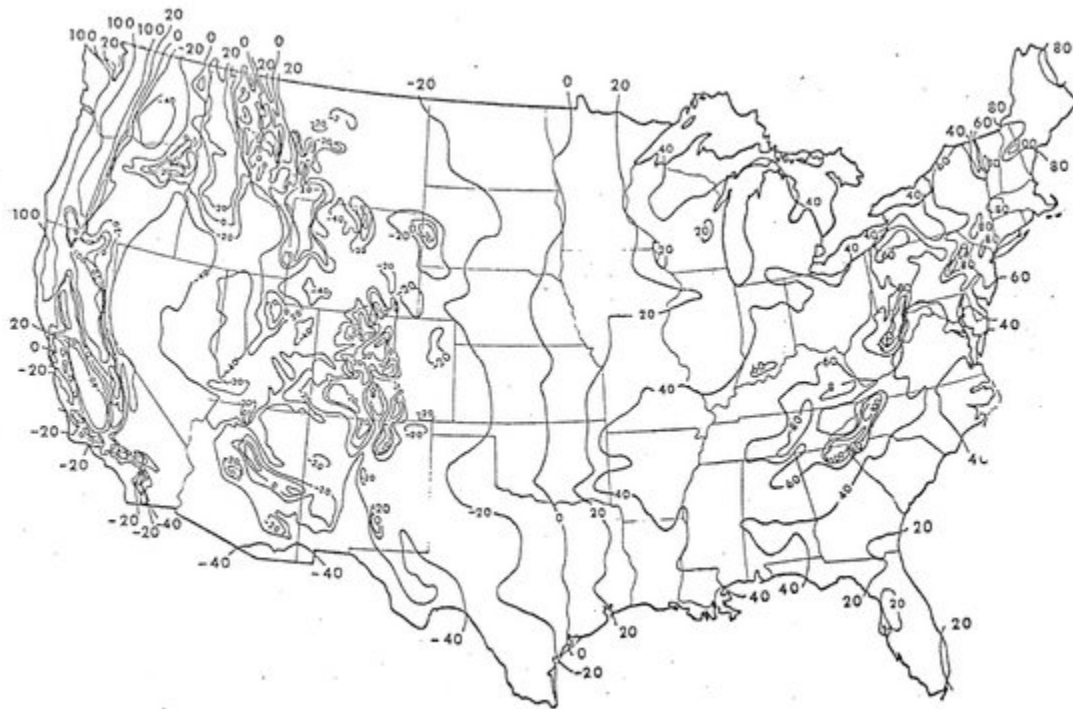

Figure 37. Climate Zone using Average MERRA-2 data.

Figure 38. Historic 1947 Thornthwaite Moisture Index plot.