8.6 METEOROLOGICAL SENSOR ARRAY (MSA) OBSERVATIONS AND HIGH RESOLUTION MODEL VALIDATION

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1. BACKGROUND

Integrated atmospheric observing systems can advance meteorological models when used to validate and verify numerical weather model results. Locating high resolution ($\leq$ 1 km), gridded observations that match micro and mesogamma atmospheric model output grid spacing is challenging. In 2014, the US Army Research Laboratory (ARL) initiated a multiphased effort to provide reliable and persistent atmospheric data resources, which allow atmospheric modelers and sensor developers to validate and compare model and sensor performance with observations at and near the surface and in close proximity to terrain of varying complexity. This project was called the Meteorological Sensor Array (MSA). In 2014, ARL initiated MSA-Phase I "Proof of Concept". In this phase, a subset of the 36-meteorological tower MSA design was constructed in a gridded model output pattern, over desert terrain. Phase II is envisioned to include all 36 towers. Future MSA phases are slated to include subsequent arrays over multiple desert locations in the southwestern United States (US). Supplemental volume measurements, such as triple LIDARS, are being considered; as well as, a mobile measurement capability, which would be designed for integration into other remote site field campaigns. For this article, however, the focus is on the MSA-Phase I.

2. MSA-PHASE I DESIGN

The MSA-Phase I "Proof of Concept" field campaign was designed around multiple objectives. Two core goals included a need to setup and test a model/observation verification process; and, to investigate atmospheric effects on and by a large Solar Photovoltaic (PV) array. The Phase I field constituents consisted of:

- Five equally spaced meteorological towers located around a large Solar PV Farm in southern New Mexico (NM);
- Measurements of pressure, temperature, relative humidity, winds and insolation;
- Solar-powered instrumentation; and
- Wireless data download, monitoring, and time synchronization.

The physical layout of the MSA-Phase I, is shown in Fig. 1. Each node represents a tower location. Three towers are on the climatologically upwind side of the solar array; 2 towers are on the climatologically downwind side. The inter-tower spacing was set as 100-m, to simulate a microscale model grid spacing.

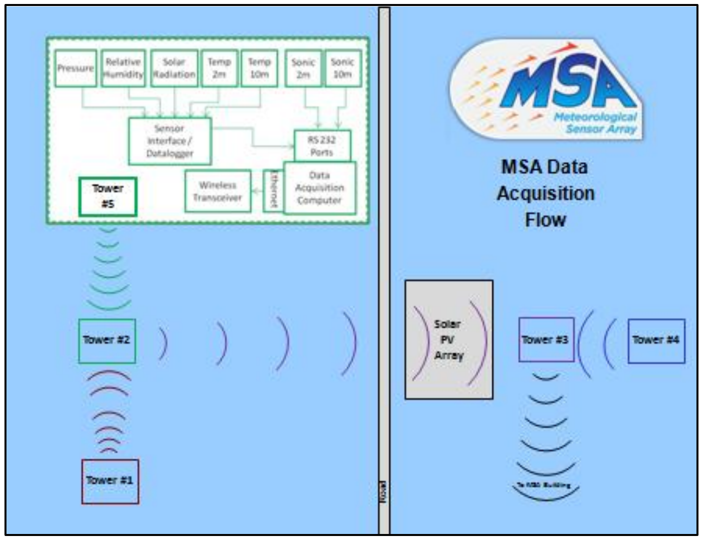

Fig. 1 A top-down view of the 5-tower, MSA-Phase I layout; each node represents a meteorological tower

3. MSA-PHASE I MEASUREMENTS

The MSA-Phase I “Proof of Concept” field campaign sampled measurements from portable lightweight, aluminum towers, with sensors mounted at the 2 and 10-m above ground levels (AGLs). All 5 10-m towers were instrumented with the standard meteorological sensors, as well as a Pyranometer. Fig. 2 shows the sensor distribution. Table 1 captures the sensor details. Solar PV panels powered each tower and were positioned away from the tower. All sensors were subjected to a pre-exercise relative calibration, with factory-issued calibration sheets establishing sensor baselines.

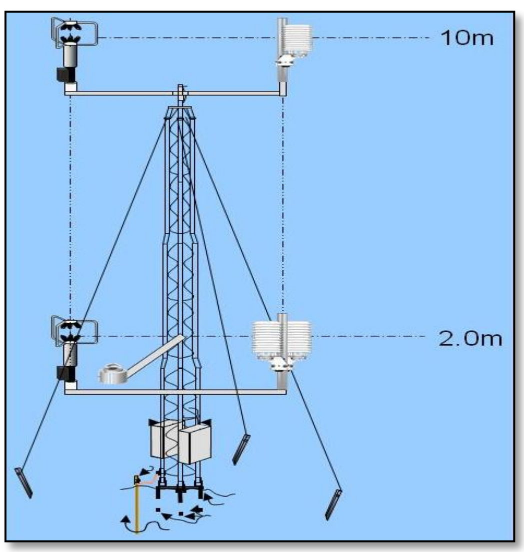

Fig. 2 MSA-Phase I meteorological sensor configuration

Table 1 MSA-Phase I sensor specifications

HEIGHT (m AGL)	VARIABLE	SENSOR	MANUFACTURER	MODEL	UNITS
1	Pressure	Barometer	Vaisala	PTB-101B*	mb
2	Temperature	Thermometer	Rotronics	HC2S3	C
2	Relative Humidity	Hygrometer	Rotronics	HC2S3	%
2	Winds	Ultrasonic Anemometer	RM Young	81000	m/s, degrees
2	Solar Radiation	Pyranometer	Kipp/Zonen	CM3/CMP3	W/m^2
10	Temperature	Thermometer Probe	Campbell	T107	C
10	Winds	Ultrasonic Anemometer	RM Young	81000	m/s, degrees

*Campbell model number: CS106

The data acquisition systems (DAS) were divided into 2 categories: Thermodynamic and Dynamic DAS. Thermodynamic 1-min averaged data were assimilated by a Campbell Scientific CR23X micrologger. The variables included pressure, temperature, relative humidity, and insolation. The Dynamic data were acquired by RM Young 81000 Ultrasonic anemometers sampling at 20 Hz. The variables measured were wind speed, wind direction, u-component, v-component, w-component, speed of sound, and sonic-temperature. For the daily data assessment process, raw dynamic data were reduced to 1-min averages. These 1-min averages were merged with the thermodynamic 1-min data, using a multiport adapter. A Network Time Protocol (NTP) was used to synchronize the system clock on each tower. Data were wirelessly communicated to a central location (Fig. 1). Data visualization tools were developed to inspect for anomalies and potential atmospheric events of interest to the Phase I researchers.

4. MICROSCALE MODEL DESCRIPTION

The microscale model used for setting up and testing the MSA Validation and Verification (V&V) process was the Three Dimensional Wind Field (3DWF) model; a model developed at ARL by Wang et al, (2005). The 3DWF model is a diagnostic wind field model (Hanna et al., 2011), typically initialized by upwind observations. The model computes a high resolution, three dimensional wind field around surface obstacles, using conservation of mass and building wake parameterization routines. The model output is generally displayed in planar or cross section views, streamlines and color-coded wind speeds. The model has been used operationally with grid-spacing of 2 to 100-m resolutions. One of the model signature strengths for operational environments is the very fast (2–10 min) processing times.

The model was designed to determine the mass consistent effects of topography on wind flow, through an iterative process of removing convergence/divergence from the predetermined 3-dimensional wind field initialization. A logarithmic vertical wind profile was applied uniformly for the initial wind field throughout the horizontal domain for all of the case studies that follow. Holding the wind direction in the initialization fixed for stronger or weaker flow, the final modeled fractional wind speed differences and differences in wind directions between 2 spatial locations do not change. This model attribute was used to frame the subsequent analysis explained in Section 5.

In 3DWF, the flow patterns around objects not produced by mass consistency were parameterized (e.g., a building leeside cavity flow, canyon flow, etc.). Parameterized cavity flows were implemented into 3DWF by modifying the initial wind field. The parameterization was developed from wind tunnel observations of flows around structures (Hosker, 1984; Snyder et al., 2004).

5. DETERMINING MICROSCALE MODEL VALIDATION ASSESSMENT PROCESS

The first challenge of the microscale model validation assessment process was to determine if the MSA-Phase I data were appropriate for validating the 3DWF model. MSA-Phase I data attributes were investigated, along with field site characteristics. The results were expected to improve both the future MSA designs and the microscale model validation process.

5.1 *MSA Observational Data Analysis*

The MSA-Phase I wind speed magnitudes (2-m AGL) downwind of the PV array were, in general, less than those measured velocities upwind. To aid in later model comparison, the fractional wind difference between 2 stations were binned according to the average wind direction between these 2 stations, on 26 and 27 April 2014 (Fig. 3). Two meter AGL winds (averaged between towers) greater than 5 m/s were included. While Fig. 3 only presents the furthest downstream measurements (Tower 4) compared against the upstream data (Tower 2), decreased wind speeds were noted at both climatologically downstream tower locations. No flow reversal was observed in the array's leeside data.

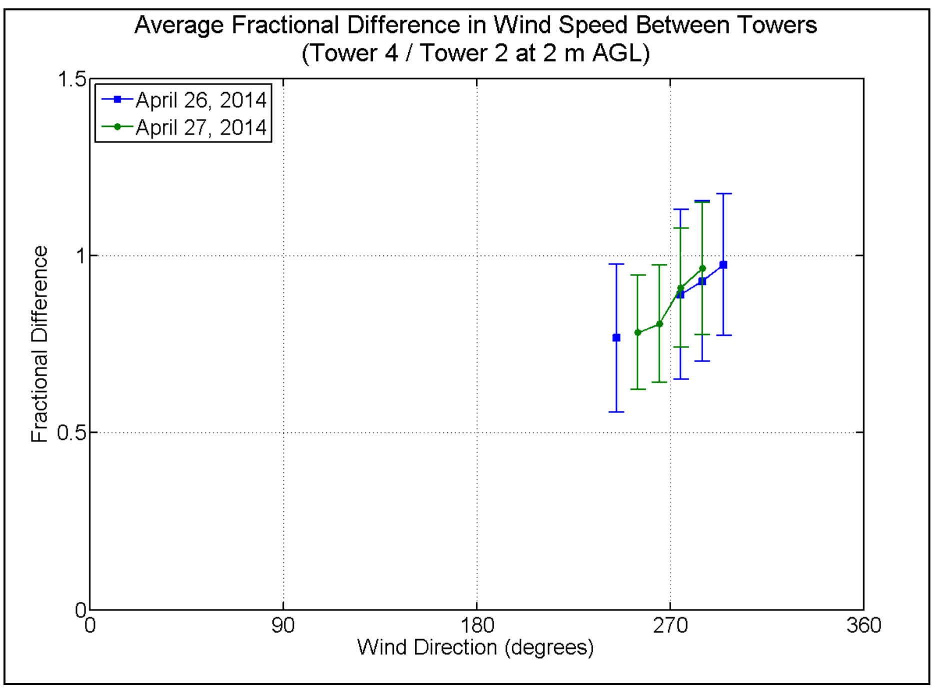

Fig. 3 The average fractional difference in horizontal 1-min averaged wind speed measurements between downstream (Tower 4) and upstream (Tower 2) PV array locations. Measurements from each day were binned by wind direction, and averages (dots) were determined for each bin. The bars show the standard deviation.

5.2 *Model Mass Consistent Wind Field Versus MSA Data Attributes*

The influence of terrain on the wind flow at MSA towers was explored with 3DWF. This portion of the investigation addressed the question of whether the current MSA gridded tower locations could provide informative microscale model V&V data.

In Fig. 4, the modeled surface wind flow, excluding building effects, are presented. For this case, the model was run with a horizontal resolution of 10-m, and vertical resolution of 0.25-m. At this “high” model resolution, terrain data from the United States Geological Survey (USGS) National Elevation Dataset were used, which provided terrain elevation data at 1/3 arcsecond (approximately 10 m) horizontal resolution.

The influence of terrain on modeled wind speed output was only a fraction of a percent at 2-m AGL between MSA-Phase I tower locations (Fig. 4). The small terrain influence on model wind speeds did not provide an explanation for the observed decrement in the downstream wind field. Because of the small terrain influence, the modeled mass consistent effects of terrain could not be conclusively tested using the current MSA-Phase I tower configuration. Consequently, cases utilizing the building parameterizations to explain the decreased magnitude in wind speeds downwind of the PV array were explored. These cases are explained in Section 5.3.

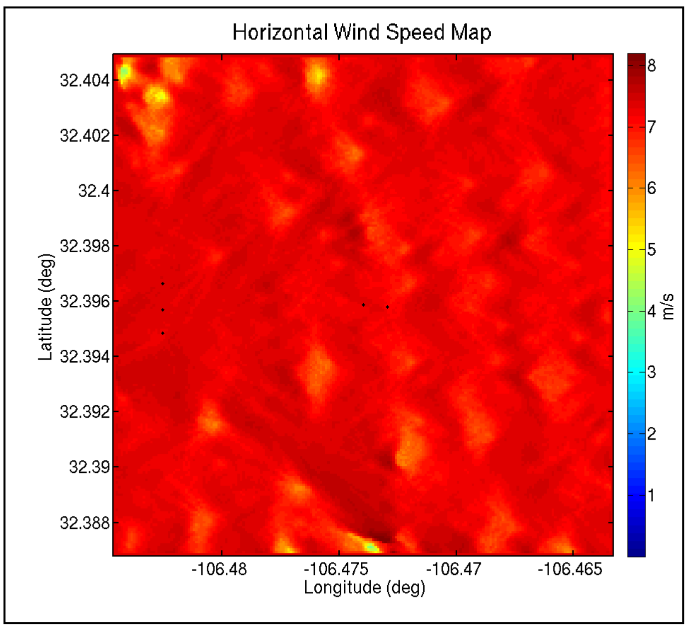

Fig. 4 The 3DWF 2-m AGL horizontal wind speed surface map with the domain centered over an MSA-Phase I (Tower 3) for wind coming from the west. MSA-Phase I tower locations are indicated by dots. The PV array is not modeled with this map. The horizontal domain is 2-km in both directions.

5.2.1 Testing Topographical Impact

To better assess the 3DWF Model's mass consistent effects, concurrent wind data from a mountain pass near the MSA-Phase I "valley" location were acquired. The vertical rise separating the MSA-Phase I and San Augustin Pass Surface Atmospheric Measuring System (SAMS) weather tower was about 500 m. The horizontal separation was about 8.7 km. Comparing wind direction measurements and requiring wind speeds to be greater than 5-m/s (at the MSA Tower 2), the difference in MSA-Phase I tower wind direction measurements appeared to be largely explained by the mass consistent effects of topography in 3DWF (see Fig. 5). Figure 5 shows a comparison of 10-m AGL wind direction at San Augustin Pass versus wind direction at MSA Tower 2. The 15-min wind direction averages from San Augustin Pass were binned according to the MSA tower wind direction every 30°. The dots represent the binned (measured) wind direction averages; and the bars are the standard deviations. The solid line is the 3DWF Model wind directions at the Pass versus Tower 2. Because of the location spacing, the modeled values were determined from a 100-m horizontal resolution model run. The general agreement between observed and modeled values re-enforces the concept that the mass consistent effects are more easily discernible in areas of varying topography. This preliminary test suggests that future MSA designs intended to validate mass consistent effects should be situated in locations of varying terrain.

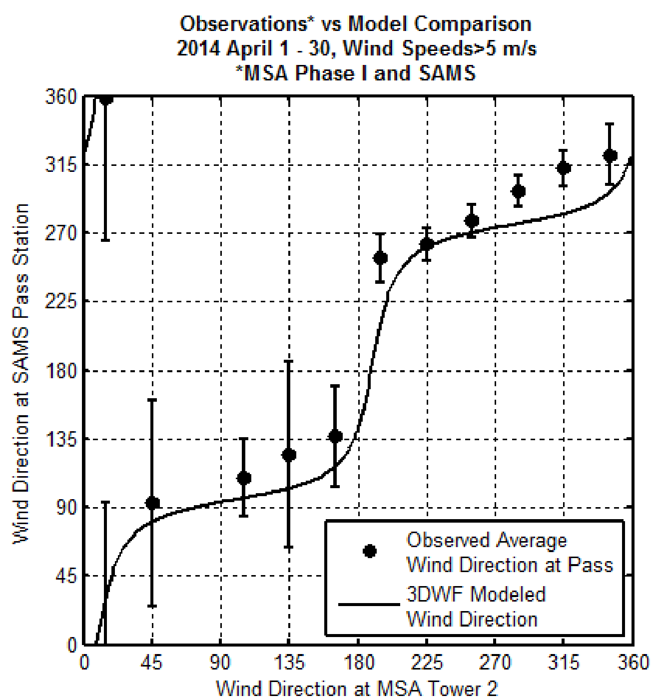

Fig. 5 Comparison of observed (*MSA Tower 2 and SAMS San Augustin Pass) and modeled wind directions

5.3 *Model Parameterization and Solar Array Representations*

Testing the model validation process continued with an investigation into whether the solar PV array's influence on the wind flow could be represented using the current building parameterization scheme. Specifically, would the parameterization scheme reproduce the observed decreased wind flow near the array? Four different building configurations were tested. These designs included multiple small buildings of comparable size to a PV tracker, columns of PV trackers, rows of trackers, and a single building.

5.3.1 Multiple Building Types

Modeling the solar array as many small box-shaped buildings prompted the Model parameterized cavity flow effect. Simulated buildings with scale sizes of meters to tens-of-meters in the horizontal direction were examined. The buildings were placed at locations to equate the individual PV array "trackers". This PV array representation produced a notable (> 1%) modeled effect on the wind speed at only 1 downstream MSA-Phase I station location, and not the 2 stations, as observed.

Grouping the rows and columns of PV trackers into extended buildings was also examined. The simulated building scales for these cases were tens-of-meters in width and hundreds-of-meters long. This building configuration produced inappropriately shaped cavity flows due to an unresolved coding issue. The physical motivation and building orientations for these cases were purely exploratory.

5.3.2 One "Large" Building

The only building representation that influenced the wind speed significantly at both downstream tower locations was a single large building representation of the PV array. This 1 large building depiction by the model produced a reversal in flow in the lee of the building, which was not observed in the MSA data. Figure 6 shows the 3DWF results, using a 1-building Solar PV Array representation. In this figure, a 2-m AGL, 3DWF zonal wind map is shown, with the domain centered over the MSA-Phase I Tower 3. Winds were westerly. MSA-Phase I tower locations are indicated by dots. The visualized horizontal domain is 2-km in both the x- and y-directions. A smooth surface was implemented for this case, since the 3DWF building parameterization applies a fixed elevation to the building top, which would have made the building's height either too large or too small to represent the PV array—if the terrain elevation data had been used. This case uses the same model resolution and domain as in Fig. 4.

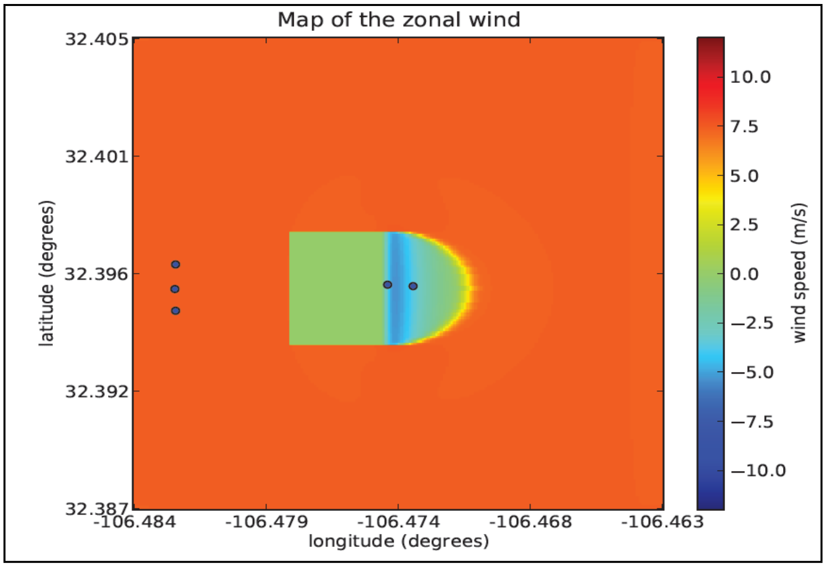

Fig. 6 Solar PV Array simulated using a 1-building representation in 3DWF

6. CASE STUDY RESULTS

Results of the ongoing investigation suggests that for the diagnostic, mass consistent microscale model 3DWF, larger topographical differences between observational data points would provide more informative model-observation comparisons. A case study that integrates meteorological data from a mountain pass near the MSA provided an example of the varying topography type needed for V&V on the terrain-induced mass consistent effects modeled by 3DWF. Wind direction differences between the MSA site and nearby San Augustin Pass appeared to agree with 3DWF model values, under high wind conditions.

The building parameterizations, which assumed single or multiple isolated “box-like” buildings, reduced wind velocities in the lee of the simulated structure. A velocity decrease pattern was noted in the MSA observations. The modeled cavity flow reversals, however, were not observed in the leeside MSA data. Therefore, investigating into more detailed PV simulations or designing a model parameterization specifically for PV arrays, are advised.

7. SUMMARY AND RECOMMENDATIONS

One of the more difficult challenges in validating high resolution atmospheric models is finding a high resolution ($\leq$ 1 km), gridded observation dataset that matches the model grid and intended purposes. In 2014, ARL constructed a gridded MSA “Proof of Concept” in the New Mexico desert. The long term MSA program is aimed at improving micro and mesogamma-scaled atmospheric models by optimizing high resolution forecast-observation comparisons. Meteorological sensor development and model sensor sensitivity studies are also part of the MSA vision.

For the MSA-Phase I “Proof of Concept” field component, 5 equally distant towers sampled standard meteorological parameters and insolation: 3 10-m towers were placed along a north-south axis, west of a Solar PV Farm, and 2 10-m towers were situated along an east-west axis, east of the same Solar PV Farm. Along with microscale model improvements, this field design was used to investigate atmospheric impacts of a large Solar PV Farm.

Two months of 24/7 data acquisition were successfully acquired. These data were used to test the process for validating microscale model output. The model selected for testing the process was 3DWF. The 3DWF model is a diagnostic, high resolution, wind field model, initialized by upwind wind observations, which computes three dimensional wind fields around surface obstacles, using conservation of mass and building wake parameterization routines.

Before testing the V&V process, MSA-Phase I data were analyzed for notable patterns. Data comparisons between up and down wind towers noted a general slowing of wind velocities on the leeside of the PV Array. This signature attribute was used in the preliminary assessment of the V&V process.

The V&V process first examined the mass consistent features of 3DWF. Results suggested that larger topographical differences between data points would provide more informative model-observation comparisons for the mass consistent microscale model. Examples of such varying terrain include ridges, mountains, hills, etc. A preliminary test using meteorological data from a nearby mountain pass confirmed this recommendation.

Exploring the building parameterization schemes of 3DWF found that “box-like” buildings reduced wind velocities in the lee of the simulated structure, which was consistent with the observed (MSA) data. However, the model also created building leeside flow reversals, which were not observed. The presumption that the PV array and/or individual PV trackers could be represented by rectangular building simulations was replaced with a recommendation for designing a model parameterization specifically for PV arrays and/or PV trackers.

Developing a high resolution, observational dataset to validate models continues to be a challenge. In this ongoing investigation, there is a reminder that every model seeking a V&V assessment comes with unique requirements. Consequently, the future MSA design(s) will need to include a built in flexibility to successfully meet the challenge.

8. REFERENCES

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