Proposed Modifications to the HYSPLIT Dust Emission Algorithm

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Introduction

The HYSPLIT dust emission algorithm has been revised and the results compared with Air Now PM coarse measurements at several locations for the period 29 March to 30 June, 2010. This period corresponds with the start of experimental testing at NCEP of the original algorithm[1]. Three issues were identified during the initial testing at NCEP. First, there is a tendency to show persistently high concentrations in the California-Arizona-Mexico (CAM) border region. Second, in the other major source region of western Texas, many smaller dust events were under-predicted. Third, in many of the other western states, multiple small observed dust events were not predicted at all because there were no dust sources defined in those regions.

Current Algorithm in Experimental Testing

Potential dust source locations are defined on a monthly basis based upon a climatology of MODIS Deep-Blue AOD values. Dust emissions are presumed to occur at these locations, defined at a minimum resolution of 0.25 degrees, when the forecast friction velocity exceeds the threshold friction velocity. The threshold friction velocity was computed from the AOD climatology at each location assuming that the probability the friction velocity will exceed that value is the same as the probability that the AOD will exceed 0.75. Naturally each grid point has a different PDF (Probability Density Function) and therefore each grid point has a unique threshold friction velocity. Furthermore, the slope of the higher AOD values and their corresponding friction velocities in the PDF defines the dust emission density, when multiplied by $[U_* - U_{*t}]$ and the area of the dust sources, gives the emission rate from that location.

Revised Algorithm

A preliminary evaluation suggested that switching to an AOD threshold of 0.5 rather than 0.75 to determine the monthly climatology of dust source locations provided a slight improvement in the prediction in terms of increasing the probability of detection and a reduction in the over-prediction. Lowering the threshold had two effects; it doubled the number of potential dust source locations and it reduced the dust emission density because now a lower AOD value (0.50) was included in the PDF. Other tests were inconclusive. For instance, using a cubic equation for emissions $U_* [U_*^2 - U_{*t}^2]$ versus the linear equation $[U_* - U_{*t}]$; arbitrarily increasing or decreasing the threshold friction velocities, or adjusting the emission rates by constant factors.

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[1] Draxler, R. R., P. Ginoux, and A. F. Stein, 2010, An empirically derived emission algorithm for wind-blown dust, J. Geophys. Res., 115, D16212, doi:10.1029/2009JD013167.

One of the issues of using a lower AOD threshold is that it may incorporate new locations that had elevated AOD because of other mechanisms (anthropogenic). Also there is the issue that the AOD climatology that defines the monthly source locations may not be applicable for the day of the forecast. For instance, the erodible dust may have already been depleted from previous events, or vegetation covers a region that was previously barren, or drought or anthropogenic activity created new source locations. Some of these issues are not easily addressed using climatology to define emission locations.

In the proposed revised algorithm, the emission points will be defined by one annual average value for threshold friction velocity and dust density (computed from only the non-zero emission months). The result of using the annual average value is that any location that had emissions during any one of the twelve months could potentially emit dust if the threshold friction velocity is exceeded. This addresses the previously identified problem of missing dust sources outside of the CAM border area. The previous monthly climatology values accounted for variations in soil and land-use properties, such that the spring months showed perhaps three times as many emission points as the winter months. However, various moisture parameters are already part of the meteorological data base, and can be incorporated into the dust prediction.

Moisture Modulation

The dust prediction cannot use the annual average emissions input file without modulating the emission points based upon real-time land use conditions. The Bowen ratio is proposed as the simplest way to address variations in soil moisture and land-use (vegetation cover) at the same time using a single variable. Recall that the Bowen ratio is defined as the ratio of the sensible to latent heat flux. Desert areas may have Bowen ratio's exceeding 10. Because the already defined dust emission points are all potentially emitting, the criterion will be relaxed such that emissions can occur at a location if the threshold friction velocity is exceed, and

1. the maximum afternoon Bowen ratio (15-21 UTC) ≥ 2.5,
2. the absolute latent heat flux ≥ 5, and
3. the absolute sensible heat flux ≥ 25.

The advantage of this approach is that one emission points file can be used for the entire year, but the points each day will reflect the daily and seasonally changing land-use and soil conditions as parameterized by the meteorological forecast model.

The best way to illustrate the utility of the Bowen ratio in this application is to examine its time series at several locations known to be sources of dust. In general, most of the potential dust locations in the western U.S. correspond to low elevations areas of river flood plains, such as the Gila River, upwind of the Air Now site in Phoenix, an area with frequent dust events. A time series of hourly afternoon Bowen ratio (33N 113W), PM coarse air concentrations, and precipitation (all zero), are shown in Fig. 1. Note that frequent dust events occur until the end of May. Bowen ratios are above five for the entire period and progressively get larger with time as the soil dries out. However, during the driest period after June, dust storms are not more frequent, presumably because the winds are not as strong as during the spring months.

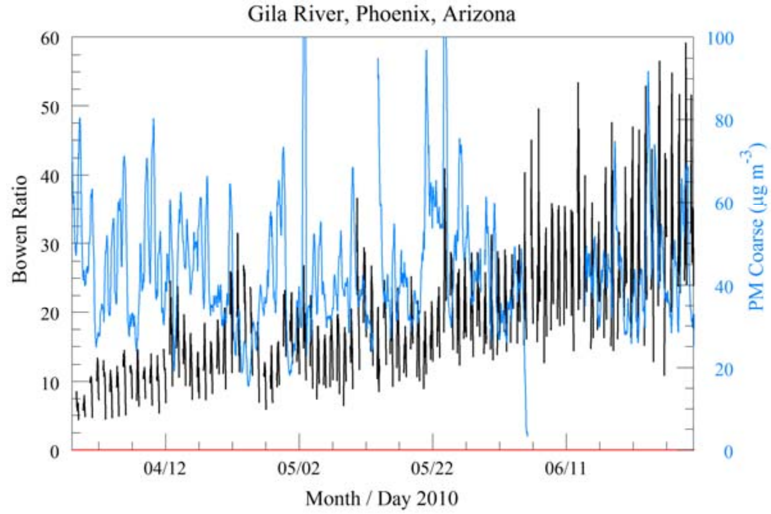

Figure 1

The other nexus of dust emissions occurs in the Pecos River basin (31N 103W) near El Paso, Texas, shown in Fig. 2. At this location the strongest dust events occurred in April. Note the driest periods did not correspond with the largest dust events, but in all the dust events, the Bowen ratio was at least 2.5. Also note also how quickly the Bowen ratio rises after each rain event. Not all rain events affected the Bowen ratio. This may be because the actual precipitation did not match the model predicted precipitation.

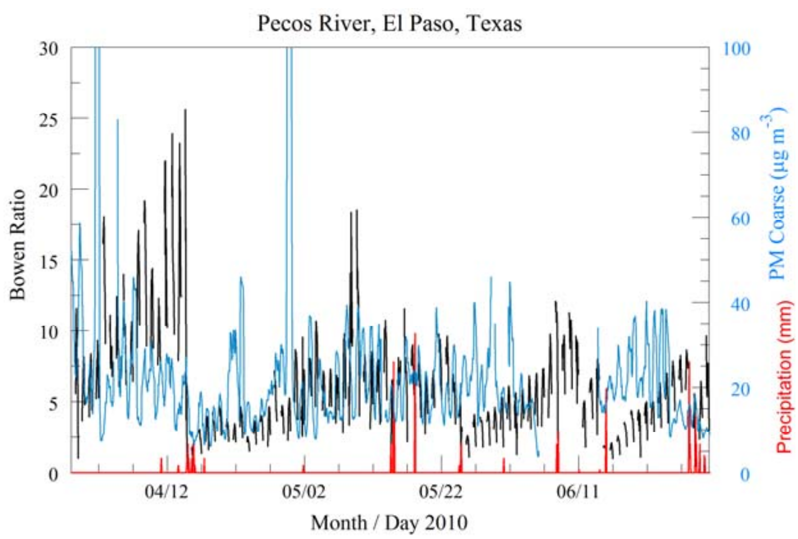

Figure 2

As a contrast to dust emission regions, the last example, shown in Fig. 3, the Marcos River (30N 98W), near San Antonio, Texas, is an area with no dust emissions. Here frequent rain events also lower the Bowen ratio, but the ratio stays below 2.5.

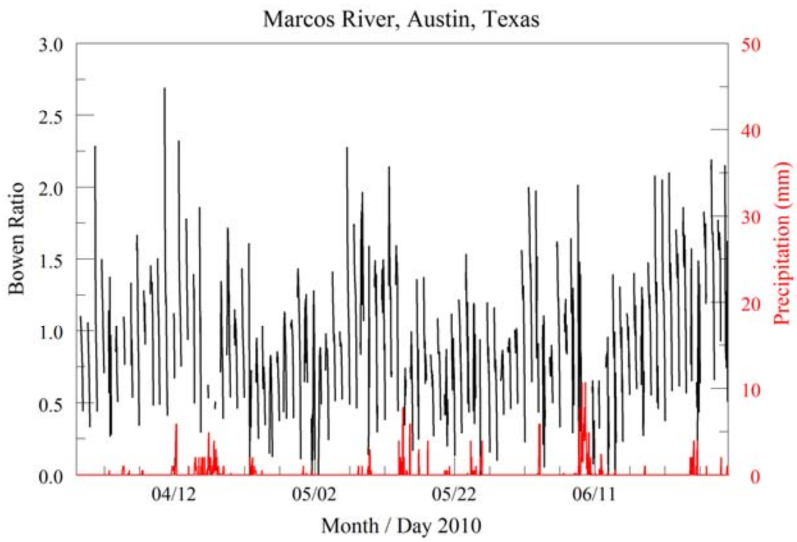

Figure 3

The effect of modulating the number of emission points according to the Bowen ratio was tested for an entire year (April 2010 through March 2011) by computing the number of potential dust locations each day according to the Bowen ratio at each location. These results are shown in Fig. 4 alongside the number of monthly locations defined from the 0.50 AOD climatology. The daily number of emission points has the same minimum to maximum range, however the peaks and minimums occur at different months than the AOD climatology. This result shows why it is important to modulate the location of the potential dust sources with the current meteorological conditions. Presumably a different year could show the maximums and minimums at different times.

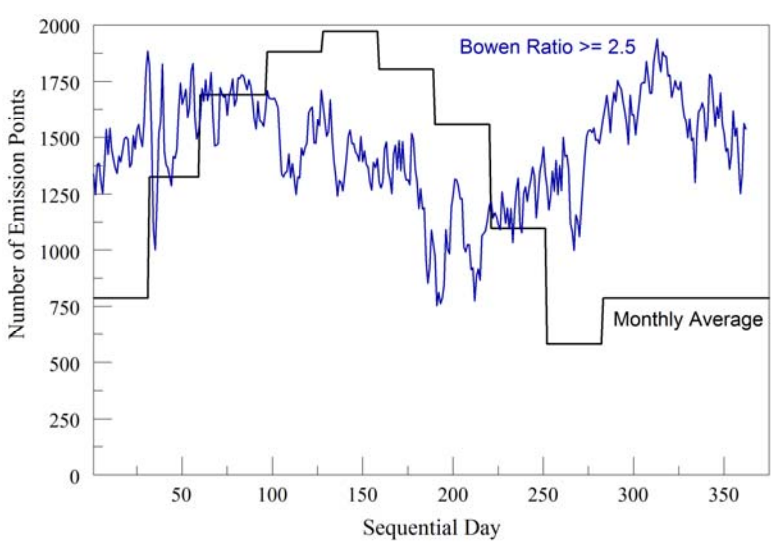

Figure 4

Model Performance Time Series Results

The dust model results for the test period (29 March - 30 June 2010) for Phoenix are shown in Fig. 5 for the current NCEP simulation configuration and the proposed Bowen ratio modulation approach. To make the results easier to visualize and more consistent with the "daily" prediction approach, the hourly results were smoothed using a 12-h average running smoothing filter. In general, the revised algorithm shows slight under-prediction instead of gross over-prediction. All dust events predicted by the old algorithm are predicted by the new algorithm and in one case the new algorithm predicted a dust event not well captured by the old algorithm (around May 2nd).

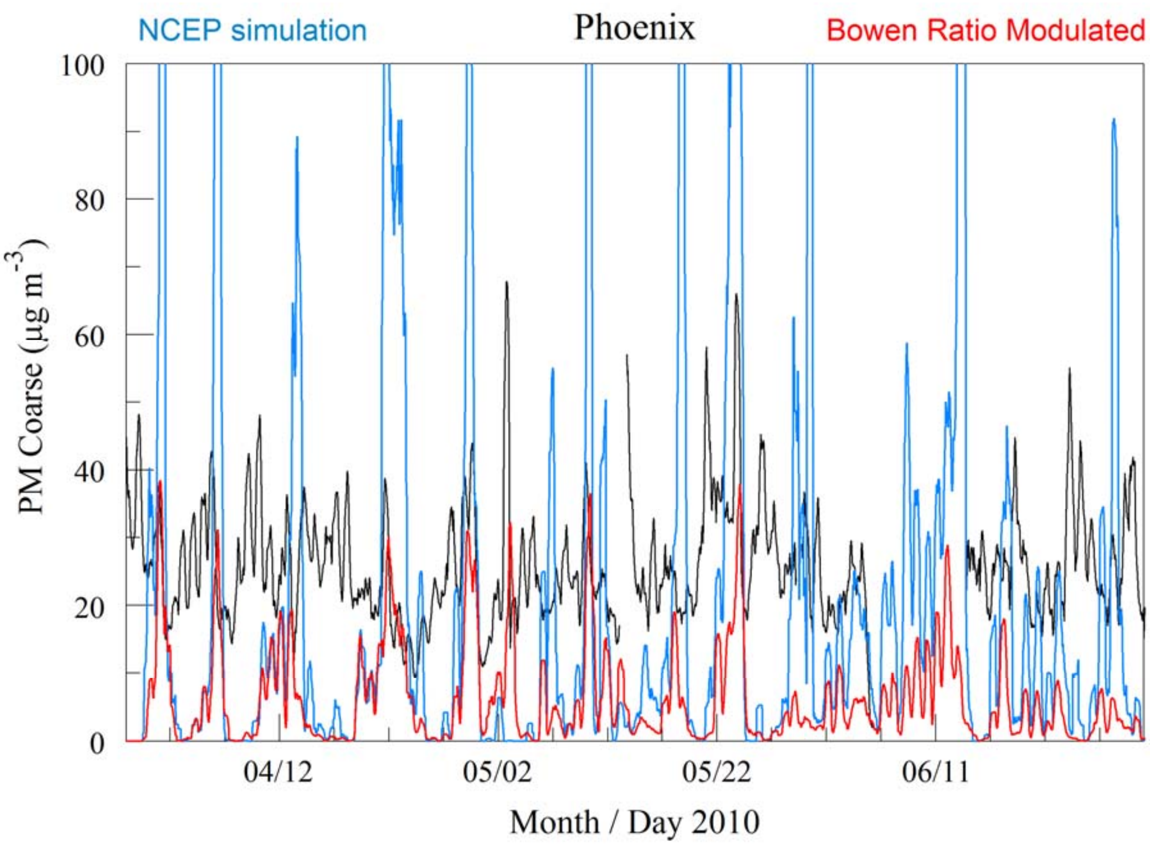

Figure 5

The dust model results for El Paso are shown in Fig. 6. Although the site does not show very many dust events, two large events, one in April and one in May, were predicted with the revised algorithm and not using the original algorithm.

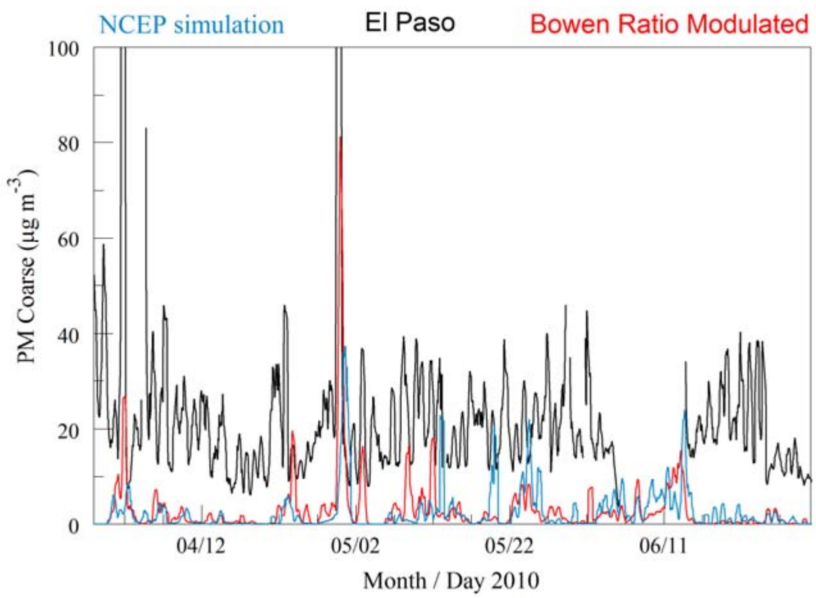

Figure 6

The dust model results for Tucson are shown in Fig. 7. In this case the original algorithm seems to perform very well, at least in terms of predicting the magnitude of the peaks. The revised algorithm substantially under-predicts the events. No new dust events were predicted with the new algorithm.

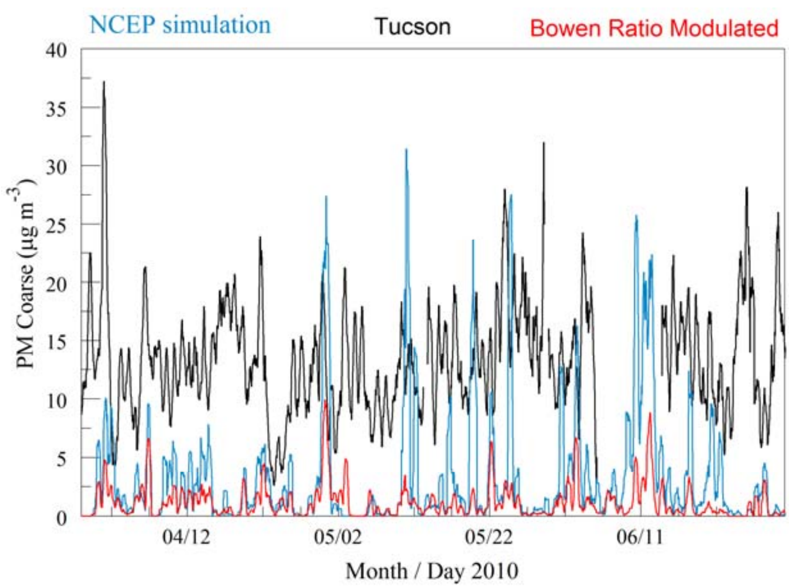

Figure 7

The last location examined is Ogden, Utah, shown in Fig. 8. Although both approaches predicted the same dust events, in this case the original algorithm substantially under-predicted peak concentrations while the new algorithm predicted concentrations compared favorably with the measured values.

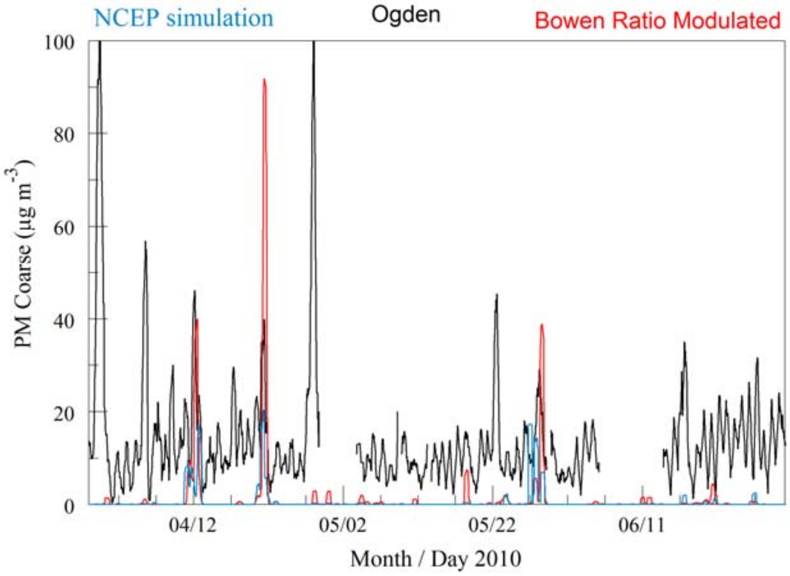

Figure 8

Previously one of the indicators that the original algorithm was over-predicting was the persistent high values near the CAM border region. This calculation is shown in Fig. 9 as a 3-month average with the corresponding Air Now average values shown at Phoenix, Tucson, and El Paso. Although the measured Phoenix average value is close to the model prediction, we know from Fig. 5 that the model over-predicted the peaks and under-predicted the remaining days, resulting an average value that closely approximated the measurements.

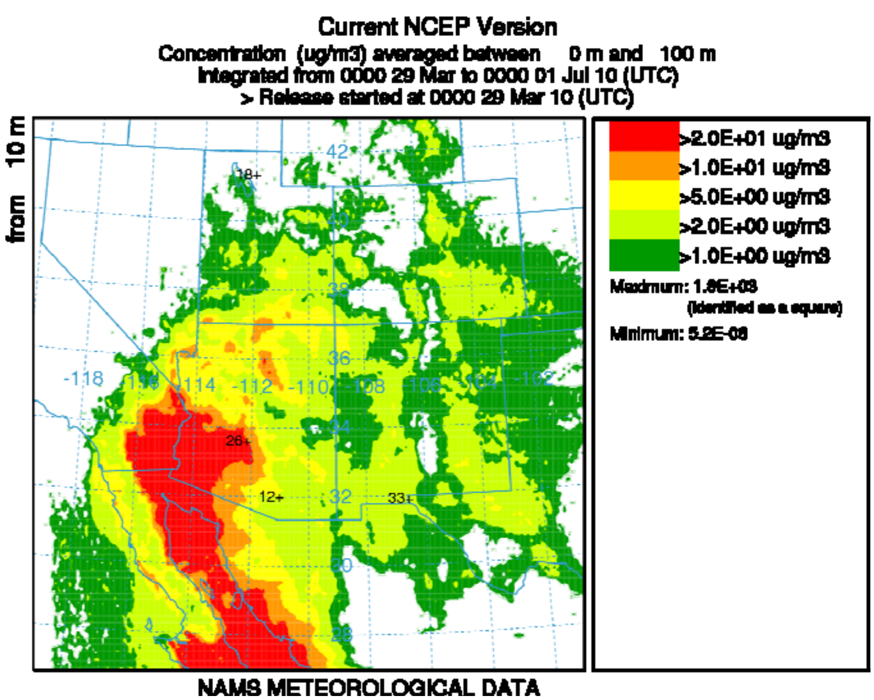

Figure 9

The revised algorithm 3-month average concentration is shown in Fig. 10. The persistent region of high concentrations has been eliminated and the dust emission points within that region are now more clearly visible. The new approach also shows more potential dust source locations in northern Nevada and Utah. A result consistent with the better model performance shown at Ogden in Fig. 8.

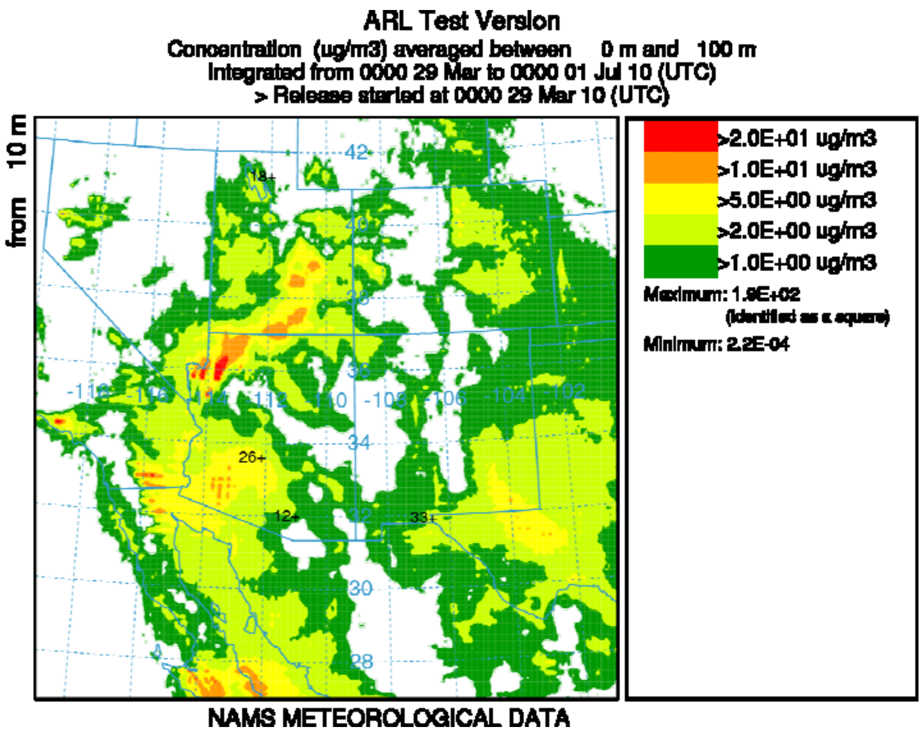

Figure 10

Model Performance Contingency Tables

The last evaluation approach is to determine how frequently the model correctly predicts dust events. This leads to the question of how to define an event using only the PM coarse measurement data. A cumulative frequency distribution is shown in Fig. 11 for seven different Air Now sites using the hourly values. Typically in these situations it may be possible to identify dust versus background because the slope of the distribution changes and the inflection point would be defined as the dust threshold concentration. A sharp delineation is not evident in Fig. 11. If forced to select one number, perhaps 20 μg m^{-3} can represent that value. Because of plume timing mismatches, a point-to-point comparison using hourly data results in very few matches, the model and measurement values converted to daily averages prior to computing the contingency table statistics. The averaging means that the hourly dust threshold of 20 should be closer to 10 when considering daily averages. Also the model prediction threshold for dust was assumed to be one μg m^{-3} because the model does not predict any background concentration.

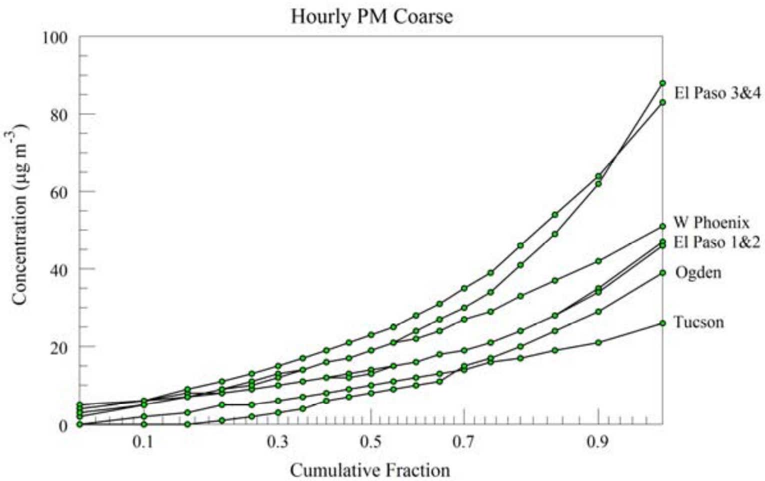

Figure 11

The contingency table includes the following parameters, where **m** represents measured, **c** represents calculated, and the subscripts, **0** and **1**, represent no dust event, or a dust event, respectively.

Probability of Detection (POD) = $m_1c_1 / (m_1c_1+m_1c_0)$
False Alarm Rate (FAR) = $m_0c_1 / (m_1c_1+m_0c_1)$
Accuracy (ACU) = $(m_1c_1+m_0c_0) / (m_1c_1+ m_0c_1+ m_1c_0+ m_0c_0)$

The contingency table results are summarized in Fig. 12 for the two simulations at the four different Air Now sites. In addition, the correlation coefficient and 95th percentile concentrations are also shown. In terms of POD and ACU the results are comparable, two sites better and two sites worse. In terms of the 95th percentile concentrations two sites went in the right direction (higher at El Paso, lower at Phoenix) and two went in the wrong direction.

Thresholds: Measured=10 Calculated=1

	El Paso	Phoenix	Tucson	Ogden
NCEP simulation				
POD	49	84	63	21
FAR	3	0	17	17
ACU	48	84	59	60
N	58	49	58	50
R2	0.00	0.02	0.00	0.01
M95th	34.0	36.0	19.0	26.0
C95th	7.8	88.3	10.2	8.5
Bowen Ratio Simulation				
POD	68	75	46	25
FAR	3	0	21	14
ACU	67	75	45	62
N	58	49	54	50
R2	0.20	0.00	0.01	0.03
M95th	34.0	36.0	19.0	26.0
C95th	13.3	20.9	3.5	4.1

Figure 12

Summary

In terms of statistical results the new algorithm is comparable to the old algorithm in terms of the contingency table statistics. However, in terms of over-prediction in the primary dust source region of the California, Arizona, Mexico border region, the model over-prediction has been eliminated using the new algorithm. In addition, the use of the annual average emission points with moisture modulation incorporates new dust sources in northern Nevada and Utah that were not present in the old algorithm. Therefore, it is proposed that the current algorithm in experimental testing be replaced by the new algorithm.

Code Update Requirements

The modifications to the existing system, although relatively minor, do introduce two new executables, one to extract meteorological information at a point from the HYSPLIT formatted meteorological files, and the other to select dust emission points, based upon the meteorology at that point (the Bowen ratio). The changes are summarized below.

/fix/dustUSA_controlXX - Contains the annual average U_{*t} and KA from the monthly emission points. Only non-zero points were averaged.

/sorc/hysplit_dustedit.fd - Selects locations from /nwprod/fix/dustconus_controlXX that meet certain selection criteria based upon current meteorological conditions at each location. A new file is written that is used in the dust script instead of controlXX.

/sorc/hysplit_xtrctstn.fd - creates a time series of meteorological variables from file interpolated to a specific lat-lon point

/ush/dustUSA_prep.sh - the following code section has been added:

```
export pgm=hysplit_xtrctstn
${EXECuser}/${pgm} -f${FIXuser}/dustUSA_controlXX <<EOD
${DAT}
hysplit.t${CYC}z.namsf
2
LHTF 01 1.0
SHTF 01 1.0
0
hourly_data.txt
1
24
EOD
${EXECuser}/hysplit_dustedit -b2.5 -i${FIXuser}/dustUSA_controlXX \
-mhourly_data.txt -odustconus_control.txt
```