Evaluating, Modeling, and Attributing Particulate Matter Air Quality in Borrego Springs

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Executive Summary: UC Irvine proposes a three-year project to improve understanding of, and inform mitigation efforts related to, particulate matter air quality issues in and around Borrego Springs. The project will evaluate current and historical air quality trends in Year 1, develop and calibrate a particulate matter air quality model of the region in Year 2, and attribute likely sources of air quality degradation in Year 3. A graduate student in the Department of Earth System Science, guided by two faculty with relevant expertise, will conduct the research.

Background: Borrego Springs (pop. ~3500) is in eastern San Diego County, surrounded by Anza Borrego Desert State Park (ABDSP, California's largest state park), close to the Salton Sea. Tourism and recreation are major drivers of the local economy, and the community has expressed concerns that recent trends in particulate matter air quality (PMAQ) adversely affect those sectors, quality of life, and, potentially, human health. Community leaders including representatives of the Borrego Valley Endowment Fund (BVEF) approached UCI faculty to solicit information and potential studies intended to mitigate environmental concerns in the region. This white-paper outlines a three-year study by UCI to evaluate, model, and attribute recent changes in regional PMAQ.

Introduction: Borrego Valley is on the western edge of the Sonoran Desert, and receives ~7" precipitation annually. These arid conditions and fine sandy soils make the region susceptible to soil erosion in the presence of strong wind or other disturbance (e.g., off-road vehicles). Anecdotal evidence suggests (yet does not prove) recent deterioration in PMAQ, a major component of which is airborne mineral dust. Other potential PM contributors include inorganic aerosols from agricultural or off-road activities in the Salton Sea region of Riverside and Imperial counties.

Our proposed study comprises PMAQ characterization, modeling, and attribution; each stage building on the previous and requiring about one year of effort. Characterization and evaluation of historical air quality will occur in Year 1 (Y1). Modeling of regional PMAQ, with particular attention to dust will take place in Year 2 (Y2). Modeling studies to probe attribution and potential mitigation of negative PMAQ episodes will occur in Year 3 (Y3). A UCI graduate student (Ms. Morgan Gorris, CV attached) has expressed interest in devoting 50% of her research time to these studies that complement her thesis research and broader interests in environmental and health-related issues in the desert southwest.

Year 1: We will characterize the current state, trends, and historical variability of PMAQ using the best available data for the Borrego Springs region. In Y1 we will assemble and integrate these data over the measurement record so that current trends, if any, may be identified and placed in the context of historic norms and variability. This same dataset will serve in Y2 to evaluate, improve, and build confidence in the model ability to predict present (and past) PMAQ.

The relevant sources/types of data that we will draw from include: 1. Historical *in situ* PMAQ measurements from air quality monitoring stations, 2. Space-based (i.e., satellite) measurements that sample the region routinely, 3. Forecasts from models that assimilate aerosol (aka particulate matter = PM) observations.

Station measurements reliably report size-segregated PM concentrations that can resolve the relatively short duration (hours) of many dust events. Most stations operate continually and are unaffected by the presence of clouds. However, stations are sparsely distributed and are strongly affected by local weather conditions and terrain so their measurements must be carefully calibrated before any extrapolation to the surrounding region. Passive remote sensing instruments aboard satellites overfly Borrego Valley daily and provide complete spatial coverage (in the absence of clouds) typically at the same local time, during daylight hours. Satellites are best at retrieving total atmospheric column PM. Instrument design and signal-to-noise issues make vertically resolved retrievals more difficult towards the Earth's surface. Station and satellite measurements complement each other, and can be assimilated together (via interpolation and extrapolation techniques) to estimate hourly PM throughout the region when a strong correlation can be shown to exist between the station-measured PM (at the surface) and the satellite-retrieved PM (from the lower atmosphere). The strength of the relationship between the surface and column PM in Borrego Valley is TBD.

Models continually assimilate PM observations and forecast PM across large (even global) regions. The observations assimilated are often satellite-retrievals rather than station observations (which are often idiosyncratic and difficult to assimilate). Such models are best at forecasting long-range transported aerosol plumes visible to satellites for many hours or days. Typically these models have spatial resolution of ~100 km, so their forecasts of surface PMAQ must be carefully evaluated against station data to determine their local accuracy. The US Navy Aerosol Analysis and Prediction System

(NAAPS) and NASA GEOS-5 are two operational models that may provide insight into PMAQ in the Borrego Valley.

We will use data from many of the same satellite sensors assimilated by operational models. However, we will exploit these products at their finest spatial resolution (about ~3 km for regularized, quality-controlled products and ~1 km for individual swath imagery), to construct more detailed maps of Borrego Valley PMAQ. Retrievals from NASA's MODIS and MISR sensors will form the bulk of these products. These data began in 2000, and may provide an adequate baseline to assess recent PMAQ changes. Longer term changes must rely on products (e.g., from NASA TOMS) of lower quality and spatial resolution that began in 1979. As mentioned earlier, the greatest understanding of local surface PMAQ will be reached when the satellite retrievals are calibrated against local *in situ* station measurements.

Three counties or air quality monitoring agencies have jurisdiction over stations relevant to Borrego Springs PMAQ. The Southern California Air Quality Management District operates two stations in Mecca, Riverside County. These stations are typically not upwind of Borrego Springs, and are likely heavily influenced by urban activities, yet they may still provide useful information on regional air quality events. The Imperial Irrigation District (IID) funds a network of six stations along the coast of the Salton Sea, immediately east of Borrego Springs. Their purpose is to monitor dust emissions and inform long-term development plans. These are the closest PMAQ stations to Borrego Springs that we know of, and long-term time series of their measurements would be invaluable in establishing historical PMAQ in the region. The Imperial County Air Quality Control District operates three stations south of the Salton Sea (Westmoreland, El Centro, Calexico). These stations are heavily influenced by regional agriculture and urban activities and may not sample much information relevant to changes in Borrego Springs PMAQ. The San Diego County Air Pollution Control District, within which Borrego Springs and ABDSP resides, does not appear to operate any PMAQ stations west of the Cleveland National Forest.

Borrego Springs is often upwind and less-often downwind of the IID stations to its east. A cursory examination of regional climatology shows that the prevailing winds shift from northwesterlies in late fall and winter, to southwesterlies during spring, to southeasterlies in late summer. Fortunately, the recent (2014) opening of the UC Reserve Steele/Burnand Anza-Borrego Desert Research Center (SBDRC) provides a natural home-base for UCI researchers to observe the region. UCI Prof. Travis Huxman will soon expand an existing network of automated weather stations from coastal Orange County into ABDSP (expected deployment Winter, 2016). These seven new stations will include high quality samplers measuring PMAQ in the region surrounding Borrego Springs.

In summary, Y1 activities focus on assembling a coherent dataset of historical and current PMAQ in the Borrego Springs region. Data sources will include station and satellite-borne measurements, as well as model forecasts. Important new stations will feed into this dataset as nearby stations in ABDSP come online. We will present a report summarizing these data at the end of Y1.

Year 2: Measurements alone provide only snapshots of PMAQ (or its proxies) from which it can be difficult to distinguish cause and effect, or the particulate source and its destination. Models are necessary to perform forecasts that can be used for planning and hypothesis testing. We will devote Y2 to setting-up and adapting the Weather Research and Forecast (WRF) model to predict PMAQ in the Borrego Springs region. WRF is widely used for regional predictions of weather phenomena such as aerosol emissions and transport around complex terrain.

Performing useful PMAQ simulations with WRF is a sophisticated task that requires completion of three main prerequisite steps. First, WRF must be installed on a powerful scientific workstation or (preferably) workstation cluster so that it can compute solutions at spatio-temporal resolution equal to or finer than the scale of the best-available measurements. Part of this challenge is obtaining high quality time-varying meteorological boundary conditions to drive WRF at the edges of the model domain. Such data are freely available from NASA and NOAA, though it requires expertise to appropriately reformat the data for WRF.

The second prerequisite to applying WRF to PMAQ issues is ensuring that all physical processes relevant to PM emission/formation are adequately represented. Proper representation of dust emissions will be critical to this project. Dust emissions depend on soil characteristics, moisture, vegetation, wind speed and soil disturbance. Prof. Zender is a domain expert in dust emissions and transport, and has already collaborated with others (Z. Yang, University of Maryland) to implement his Dust Emission And Deposition (DEAD) model within the most recent version of WRF.

DEAD represents dust emissions as a two phase process. First it uses physics to compute dust mobilization that would take place on an idealized surface at a given wind speed. DEAD then multiplies the idealized emissions by a factor called the "erodibility". Determining erodibility is difficult, and the best results are obtained empirically by observing the response of soil to meteorological conditions. Moreover, erodibility varies strongly with terrain under natural conditions, and anthropogenic disturbance (e.g., off-road vehicles) can increase it by factors of 10-100.

The final prerequisite to performing useful studies of PMAQ with WRF is model calibration. Calibration, also called tuning, is an iterative process of adjusting free model parameters until the simulations give the best possible fit to observations. The dataset assembled in Y1 will, presumably, exhibit short-lived PMAQ episodes from nearby sources (e.g., off-road vehicles) and strong events (e.g., dust storms) that punctuate a mean background state determined by continual emissions and long-range transport. The model must be iteratively tested, tuned, and re-run until it reproduces the background PMAQ levels recorded in the Y1 dataset. We expect that tuning the erodibility will be required to reproduce strong variations in dust emissions. Incorporating and adjusting emissions of other aerosols such as sulfates and nitrates may also be required. It is not necessary in Y2 to reproduce all PMAQ events, as some may be caused by one-time disturbances nearby a station. Sporadic events such as smoke aerosols from fires need not be represented at all.

In summary, Y2 activities focus on installing, testing, and tuning a modeling infrastructure capable of predicting (aka hindcasting) the major features of PMAQ found in the dataset assembled in Y1. UCI will supply the required tools (WRF, computing resources) and expertise (meteorology forcing datasets, PM emission processes, tuning). We will demonstrate the capabilities and skill of the WRF PMAQ forecasts at the end of Y2.

Year 3: The Borrego Valley Endowment Fund seeks to understand the causes of any PMAQ trends prior to planning efforts to mitigate degradation of local air quality. UCI will pursue attribution of PMAQ contributors in Y3, or once WRF robustly hindcasts background PMAQ levels.

In environments where a pollutant cannot be unambiguously ascribed to a given source (e.g., via a radioactive or chemical fingerprint), source attribution requires multiple lines of evidence. In Borrego Springs, fugitive dust is thought to be a main contributor to degraded air quality. If the data show that to be true, then the focus of attribution in Y3 will be on identifying where (and to a lesser extent, when) the dust is emitted. Regions that can preemptively be ruled out are those covered by vegetation (too sheltered), irrigated for agriculture (too wet), or lacking in fine soil (no source material). In other words, the vast majority of the Borrego Valley is a potential source region.

Resources and maintenance prohibit carpeting the potential source region with PMAQ samplers. Instead, UCI will employ three complementary strategies to identify the most active source regions. First, the satellite-retrievals assembled in Y1 may exhibit local features (e.g., dust plumes with identifiable origins) with resolution ~1-3 km. Second, residents may know or suspect the location of local emission "hotspots" based on visibility. Such regions will be marked as candidates for tuning with higher than average erodibility in the WRF model. Third, UCI will experiment with tuning the erodibility of candidate emission regions in WRF to evaluate the hypotheses that the source candidate explains PMAQ seen in the observations but not the control model.

Activating a candidate region in WRF and showing that the simulation better reproduces PMAQ observations is, by itself, insufficient to attribute observed emissions to a region. The problem is non-uniqueness: activating other regions may also improve a given simulation, so which region is the true source? Robust attribution requires that the identified source improves simulations of multiple events, that it need not be arbitrarily "turned-off" to avoid degrading quiescent periods, and that other candidate regions are not better at explaining the events in question. The consistency of identified sources with satellite imagery and visual inspection will improve the objectivity of attribution. Consequently, attribution is expected to be an iterative process of candidate identification, simulation, attempted refutation, and final verification by independent means such as satellite imagery and site visits.

In summary, Y3 focuses on attribution to provide actionable information for planning. Testing hypotheses for candidate emissions regions and processes will involve numerous simulations with WRF, evaluation of results against the Y1 dataset, and local consultation and occasional site visits. We will present our conclusions on PMAQ trends, sources, and mitigation options at the end of Y3.

Synergies: This project is mutually beneficial to other UCI research efforts including: 1. Identifying the environmental niche of the fungal spore (Coccidioides) which causes the infectious disease called Valley Fever. The Randerson and Treseder labs are sampling soil and air in support of future efforts to model the dispersal of Cocci. across the desert southwest. 2. Understanding changing water resources and costs and benefits of semi-arid land degradation and restoration. The Huxman lab operates long-term research sites to study water and land-use issues important to fugitive dust emissions. 3. The Bradley lab spearheads UCI's Salton Sea initiative which brings numerous UCI faculty together with the local government agencies charged with Salton Sea management.

UCI graduate student Morgan Gorris is encompassing the theme of how climate change will affect human health throughout her thesis research. Advising on potential mitigation strategies for Borrego Springs will include a long-term consideration of how climate change may exacerbate regional PMAQ concerns. PM is known to cause adverse health effects based on the size of the particulate, and other aerosols such as the fungal spore Cocci. can cause additional health concerns. Air samples will be analyzed throughout the duration of this project and analyzed in collaboration with the Randerson and Treseder labs. She will advise on potential health concerns the Borrego Springs region may face based on the PMAQ assessment and air sample results.

Resources, Budget, and Logistics: UCI requests (see attached preliminary budget) that BVEF award funds to support one graduate student (Ms. Morgan Gorris) half-time on this project. The funds will cover half of all the graduate student's UCI tuition, fees, stipend and overhead for three years. UCI will provide, at no additional cost, the computer resources and faculty effort to manage the project and to mentor the graduate student.

Charlie Zender, UC IRVINE
Morgan Gorris Fellowship

	Year 1	Year 2	Year 3	Total
	1/1/2016	1/1/2017	1/1/2018	Requested
	12/31/2016	12/31/2017	12/31/2018	from Agency
SALARIES & WAGES				
Morgan Gorris, Graduate Student Researcher				
50% time academic year (one quarter)	$ 6,573	$ 6,573	$ 6,573	$ 19,719
100% time summer	$ 8,764	$ 8,764	$ 8,764	$ 26,292
	$ 15,337	15,337	15,337	$ 46,011
Subtotal Salaries & Wages	$ 15,337	15,337	15,337	$ 46,011
EMPLOYEE FRINGE BENEFITS				
GSR academic year: @ 1.3%	$ 85	$ 85	$ 85	$ 256
GSR summer: @ 3%	$ 263	$ 263	$ 263	$ 789
Graduate student resident fees	$ 5,828	$ 6,177	$ 6,548	$ 18,553
Subtotal Employee Benefits	$ 6,176	$ 6,525	$ 6,896	$ 19,598
TOTAL SALARIES, WAGES & BENEFITS	$ 21,513	$ 21,862	$ 22,233	$ 65,609
TRAVEL				
TOTAL TRAVEL EXPENSES	$ -			$ -
OTHER DIRECT COSTS				
Misc. supplies				
Publications				
Long distance phone charges, copying, etc				
TOTAL OTHER COSTS	$ -			$ -
TOTAL DIRECT COSTS:	$ 21,513	$ 21,862	$ 22,233	$ 65,609
INDIRECT COSTS: 54.5%	$ 8,549	$ 8,549	$ 8,549	$ 25,646
TOTAL REREQUESTED FROM AGENCY:	$ 30,062	$ 30,411	$ 30,782	$ 91,255
Base	$ 15,685	$ 15,685	$ 15,685	