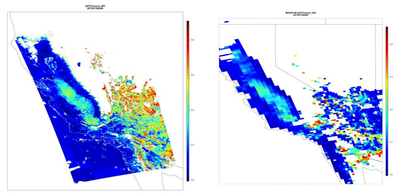
First Full Maps Indicating San Joaquin Valley Particulate Pollution: Use of the MODIS MAIAC Product with Locap PM2.5 Measurements During the DISCOVER-AQ Period

Robert B. Chatfield, Robert F. Esswein, NASA Ames Research Center

Much credit to Alexei Lyapustin, Yujie Wang, and Robert Levy
… but please, no blame!
NASA Goddard Spaceflight Center



MAIAC Deep Blue

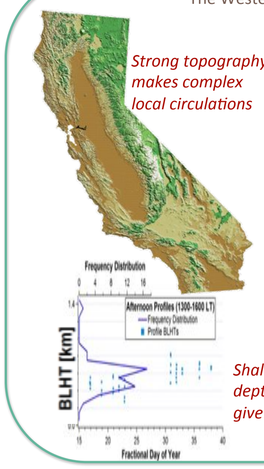
MAIAC and Deep-Blue (v.6) retrievals of Aerosol Optical Thickness (AOT) give promising views of column-integrated aerosol scattering in the San Joaquin Valley during the DISCOVER-AQ period (Jan 18, 2014)

This is a first report of recent work !

The San Joaquin Valley suffers from severe episodes of respirable aerosol (PM2.5) in wintertime. We provide maps of aerosol episodes using daily snapshots of PM2.5 and its changing features despite numerous difficulties inherent to sampling the region, with special focus on the DISCOVER-AQ intensive airborne measurement period, Jan-Feb 2013, which had many supporting measurements. Both high pollution and retrieval difficulties tend to occur in many Mediterranean agricultural regions. One difficulty is the relatively bright surfaces with considerable exposed soil. NASA's MAIAC (Multiangle Implementation of Atmospheric Correction, Lyapustin and Wang) and retrieval techniques are shown to have considerable skill even at low aerosol optical thickness (AOT) values, evaluated by concurrent AERONET sunphotometer measurements. MODIS Deep Blue v.6 (Levy and colleagues) techniques may be expected to provide similar estimates at lower spatial resolution. More significantly, these AOT values can correspond to high daytime PM2.5 since aerosol mixed layer depth is thin and variable, 200m – 600 m. The thin layers derive from typical subsidence of dry air between more stormy periods. This situation provides an advantage: water vapor column is also almost completely limited to a similar mixed layer depth, and can thus serve as a measure of aerosol dilution.

We seek a physically based methodology to estimate PM2.5 from MODIS Aerosol products.
However, there remain several difficulties
– Physical methods should estimate aerosol mixed-layer depth accurately (Routine meteorlogical models rarely estimate wintertime mixed layers.)
– Composition of aerosol (NH_4NO_3, other nitrates, smoke) is unusual and may vary in time
– Current MAIAC retrievals still exhibit puzzling, day-to-day but region-wide variations in sensitivity for both AOT and separately for column water vapor.
We used a statistical method, mixed-effects (a.k.a. random-effects) regression modeling to separate these difficulties and provide maps of estimated PM2.5 pollution valid for regions similar to the existing ground-based PM2.5 network concentrations used.

The Western US poses large problems for Aerosol Mapping



Strong topography makes complex local circulations

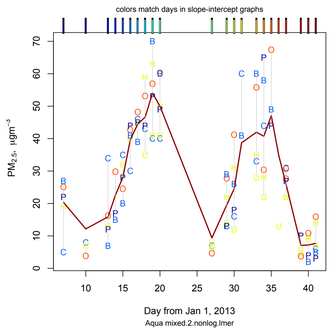
Bright surfaces make scattering difficult to quantify

Also, strongly variegated surfaces at <~ 1 km scales

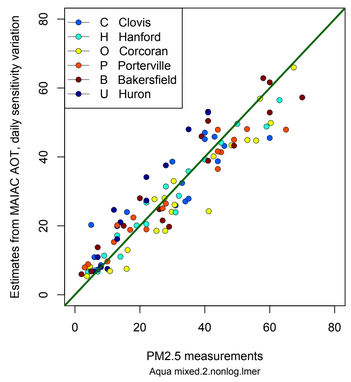
Shallow PBL depths 250–800 m give low AOT, high PM2.5

Previous work: Strawa et al. J AWMA 2013

Two cycles of buildup and cleanout of PM2.5 at the six sites shown in the map to the right … during the DISCOVER-AQ airborne sampling period



Fitted results agree at 6 stations R = 0.93



Results of the estimation showing excellent reproduction of the data at the six sites which could be compared. The use of more sites would be desirable. Since the results are dependent on day but approximately independent of site, we proceed to apply the relationship for AOT for all days, incorporating the daily variation in PM sensitivity

Note that in most cases, the maps indicate uniformity or localized concentration in agreement with the scatterplot. The estimation is conservative, so that several of the highest values measured are underestimated in the maps.

We feel that the mapping method is likely useful for the northern, Sacramento Valley, but less so for the complex coastal environments. The southern Imperial Valley should be amenable to similar estimation.

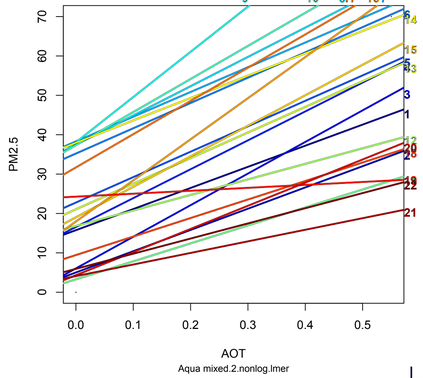
We made a direct estimation of the relation of reported MAIAC AOT to PM2.5 as measured at these stations, but allowing an estimate of the linear relationship to vary for each day. Each station was assumed to respond similarly, though reasons for site variation can be imagined.

$$PM_{i,j} = (b_0 + b_j)\tau_{i,j} + (c_0 + c_j)$$

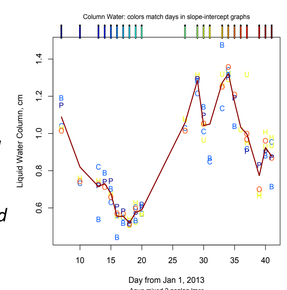
Since there are two sources of variation, a more complex linear equation must be solved, so as to allow separation of effects. This is the mixed-effects model and the "random effects" are the changes in PM2.5-sensitivity for each day. The daily effects are summarized in the regression lines shown below.
The clearest indication is that there are changes in intercept from day to day which arise from variations in sensitivity of the algorithmic AOT from day to day, but uniformly in space. Differences in slope may be due to variations in the MAIAC algorithm, but aerosol composition and especially depth of mixed layer are likely and cannot be distinguished.

An analysis of AERONET vs MAIAC has been begun, and does suggest some variation in slopes for the sensitivity. There are not enough complete cases to allow results for this PM2.5 mapping study.

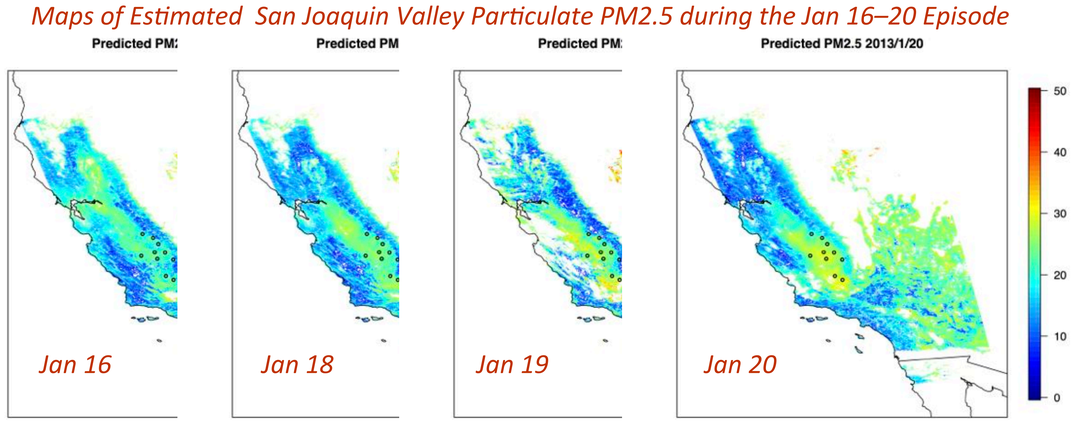
Adjustment for sensitivity, PBL depth, etc by day



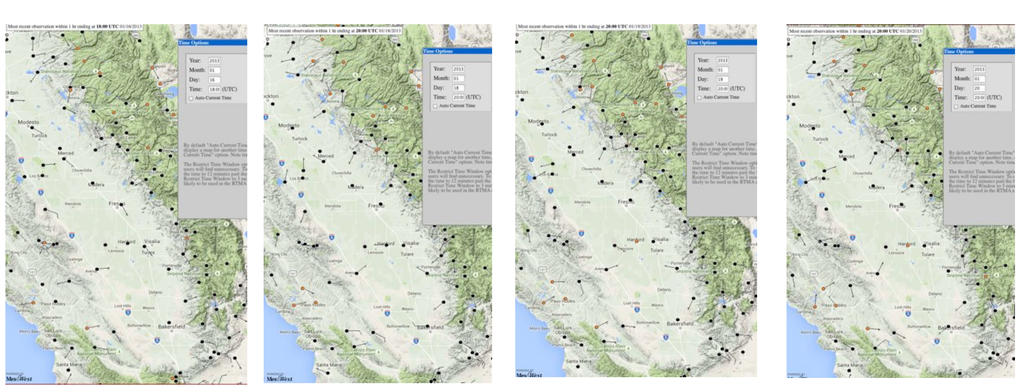
Water-vapor column (cm of liquid water equivalent) estimates from the MAIAC technique also exhibit (different) day-to-day sensitivity variations. Partially cleaned data is shown. The ratio of water-vapor mixing ratio to water-vapor column gives a mixed-layer depth in cm, since typical subsidence produces very dry atmospheres above the mixed layer (usually, little added water-vapor column, and quantifiable).



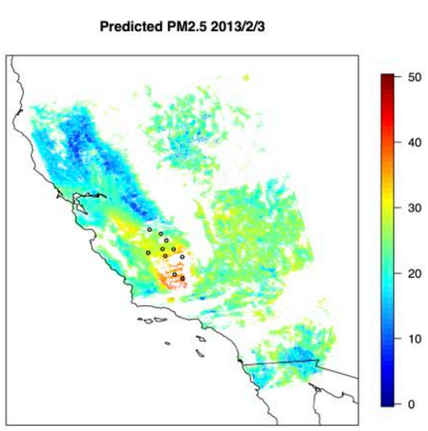
Maps of Estimated San Joaquin Valley Particulate PM2.5 during the Jan 16–20 Episode



Winds for the period



Feb 3: Southern Valley Episode



Conclusions and further work:

- *There is a rich dataset of DISCOVER-AQ lidar (HSRL2) and on-board measurements of particles and mixed-layer structure which deserves comparison*
- *An examination of the AOT sensitivity functions for the MAIAC and Deep-Blue retrievals should be carried out and rationalized with the PM2.5 results.*
- *Examination of the morning MODIS-Terra results is in order, although mixing is likely to be less complete.*
- *When AOT sensitivities are clearer, alternative measures of effective mixed-layer depth are in order, using, e.g. MODIS water-vapor column measurements (example below) and surface RH to define MODIS –> PM2.5 inferences more physically.*
- *Further maps of the 2005–2015 record of MAIAC retrievals will be profitable. See our colleague's work (Sorek-Hamer et al., 2015,Assessment of PM2.5 concentrations over bright surfaces using MODIS satellite observations. Rem. Sense. Environ., DOI: 10.1016/ j.rse.2015.03.014 .)*