Use of MODIS Satellite Images and an Atmospheric Dust Transport Model To Evaluate *Juniperus* spp. Pollen Phenology and Dispersal

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Abstract - Pollen can be transported great distances. Van de Water et. al., 2003 reported *Juniperus spp.* pollen was transported 200-600 km. Hence local observations of plant phenology may not be consistent with the timing and source of pollen collected by pollen sampling instruments. The DREAM (Dust REgional Atmospheric Model, Nickovic et al. 2001) is a verified model for atmospheric dust transport modeling using MODIS data products to identify source regions and quantities of dust. We are modifying the DREAM model to incorporate pollen transport. Pollen release will be estimated based on MODIS derived phenology of *Juniperus spp*. communities. Ground based observational records of pollen release timing and quantities will be used as verification. This information will be used to support the Centers for Disease Control and Prevention's National Environmental Public Health Tracking Program and the State of New Mexico environmental public health decision support for asthma and allergies alerts.

Keywords: Pollen, Phenology, MODIS, Allergies, *Juniperus*

1. INTRODUCTION

Pollen can be transported great distances. Van de Water et. al., 2003 reported Juniperus pollen, a significant aeroallergen was transported 200-600 km. Hence local observations of plant phenology may not be consistent with the timing and source of pollen collected by pollen sampling instruments. Direct detection of pollen via satellite is not practical. A practical alternative combines modeling and phonological observations.

The DREAM (Dust REgional Atmospheric Model) is a verified model for atmospheric dust transport modeling using MODIS data products to identify source regions and quantities of dust (Nickovic et al. 2001). The use of satellite data products for studying phenology is well documented (White and Nemani 2006). We are modifying the DREAM model (PREAM - Pollen REgional Atmospheric Model) to incorporate pollen transport. The linkages already exist with DREAM through PHAiRS (Public Health Applications in Remote Sensing) to the public health community. This linkage has the potential to fill this data gap so that health effects of pollen can better be tracked for linkage with health outcome data including asthma, respiratory effects, myocardial infarction, and lost work days.

2. BACKGROUND

DREAM is an integrated modeling system designed to accurately describe the dust aerosol cycle in the atmosphere. In DREAM, there are two major components integrated: one is the aerosol model and the other is the atmospheric model driver. Currently, NCEP/Eta is used as a driver, but it is planned to be replaced by the WRF/NMM model.

The dust modules of the entire system incorporate the state of the art parameterizations of all the major phases of the atmospheric dust life such as production, diffusion, advection, and removal. These modules also include effects of the particle size distribution on aerosol dispersion. The dust production mechanism is based on the viscous/turbulent mixing, shear-free convection diffusion, and soil moisture. In addition to these sophisticated mechanisms, very high resolution databases, including elevation, soil properties, and vegetation cover are utilized.

Results from the NASA/REASoN-sponsored airborne dust prediction system PHAiRS now includes: (a) a realistic, quasi-operational particulate forecast and simulation model (DREAM) that is being tested by state health and air quality offices; (b) the particulate model embedded in-line with the National Weather Service operational weather forecast (Eta) model, which is supported with NWS real-time data streams; (c) a web-based data and information clearinghouse; (d) a NASA data downloading and processing facility that includes services for frequent model initialization with MODIS surveys of land cover and dust source regions; and (e) an established outreach program that interacts with Arizona and New Mexico offices for air quality and health services and the Mexico/US Border Health Commission, among other user groups.

As part of the work reported here, DREAM is being modified to use pollen sources instead of dust. Pollen release will be estimated based on satellite derived phenology of key plant species and vegetation communities. The MODIS surface reflectance product (MOD09) will provide information on the start of the plant growing season, growth stage, peak greenness, dry-down and pollen release. Ground based observational records of pollen release timing and quantities will be used as verification. Techniques developed using MOD09 surface reflectance products will be directly applicable to the next generation sensors such as VIIRS.

Information on pollen concentrations, timing, and sources are deficient for most areas of the southwest. Current surveillance programs suffer from several problems: 1. low count frequency from one to several days, 2.very few, if any sampling stations for a given area 3.varity of sampling instruments. 4. only identifiable pollen “grains” are counted 5. expertise in counting/identification is important, no automated procedure for counting samples. 6. Refusal to release sampling information-”We do not reveal the sources for our data for privacy and proprietary, competitive reasons. Some pollen counts are conducted privately, and are not meant to be broadcast to the public”.

Levetin and Van de Water (2003) determined that pollen forecasting is very dependent on accurate meteorological forecasting. The importance of understanding the effects of meteorology in the transport of pollen is not limited to just the physical transport processes or climate/weather conditions for pollen production and release, but include a significant alteration in the pollen size distribution. Taylor et al. (2004) found that birch pollen would rupture in high humidity and moisture and drying winds would release an aerosol of particles from catkins. The ruptured pollen grains ranged in size from 30 nm to 4 microns, much smaller than the range of typical allergenic plant species pollen of 17 to 85 microns.

The use of satellite data products to determine vegetation phenology is well documented (White and Nemani 2006). In the current project MODIS data will provide critical input to the PREAM model providing pollen source location, timing of pollen release, and vegetation type.

A major uncertainty includes determining the pollen densities available for transport. Yearly pollen production and release timing are significantly impacted by regional weather patterns. Another uncertainly that must be addressed is the particle size distribution of the pollen and possible pollen fragments to be used for transport. Pollen gain size distributions can easily be determined from ground based sampling data for intact pollen grains. The exact size distribution of the ruptured pollen material has only been studied for a few species (birch, *Juniperus spp*., and grasses). There is a risk is not representing the particle size distribution correctly.

The proposed linkage in this project will provide critical information on the location, timing and modeled transport of pollen directly to the EPHT.

3. METHODS

We utilized MODIS satellite time series datasets of reflectances and vegetation indices from 2000 through 2008 to characterize spatial distributions and interannual variations in seasonality as related to land cover type, juniper species and juniper concentrations (Table 1).

Table 1. MODIS data products downloaded and analyzed for this study.

Data Product	Spacecraft/ Sensor	Temporal/ Spatial resolution
Level 3 Surface reflectance, MOD09, version 5	Terra, Aqua MODIS	8-day/ 500 m
Level 2G Surface reflectance, MOD09GA, v5	Terra, Aqua MODIS	Daily/250 m, 500 m
Level 3 Vegetation Indices, MOD13Q1, v5	Terra, Aqua MODIS	8-day (combined), 250 m
Vegetation Indices, computed from level 2G MOD09GA	Terra, Aqua MODIS	Daily/ 250 m

The SR products (MOD09, Table 1) include daily and 8-day composites and gridded (Sinusoidal) at 500m resolutions, with quality assurance metrics, observation geometry, and geolocation statistics. The daily surface reflectances are provided at 250m resolution (bands 1-2, red & near-infared), and at 500m resolution (bands 3-7, visible, infrared bands). Quality information for the MOD09GA product is provided at three different levels of detail: for individual pixels, for each band and each resolution, and for the whole file.

Seven sites were selected for intensive analyses with satellite data (Table 2):

Table 2. Locations of 7 study areas for MODIS satellite data analysis.

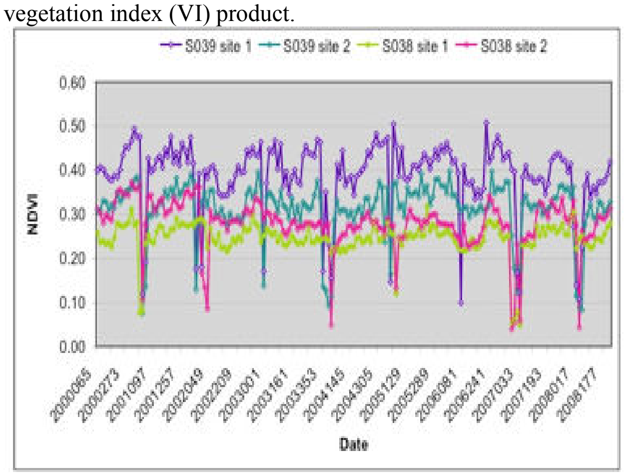
ID	Class	Lat	Lon
Site 1	S038-S074	35.245838	-106.274728
Site 2	S038	35.207455	-106.296617
Site 3	S038-S112	34.497617	-106.382710
Site 4	S074	35.715936	-105.981849
Site 5	S038	35.185749	-105.532165
Site 6	Forest-1	34.275627	-107.895185
Site 7	Forest-2	36.087928	-106.702683

S038: Southern Rocky Mountain Pinyon-Juniper Woodland
S074: Southern Rocky Mountain Juniper

4. MODIS PHENOLOGY RESULTS

Examples of MODIS phenology profiles, as measured by the standard vegetation index (VI) product (Fig. 1) show a fairly strong seasonal signature in the EVI measure of vegetation activity through periods of snow, understory green-up and brown-down, and peak periods of vegetation activity. There is also quite strong interannual seasonal variability that is useful in analysis of the pre-conditions for timing and magnitudes of pollen release.

Fig. 1. MODIS phenology profiles, as measured by the standard vegetation index (VI) product.



One can also observe some noise and secondary variations in the seasonal profiles, resulting from variable sun-surface-sensor viewing geometries and residual contamination from subpixel clouds and aerosols. Various time series- based algorithms (Timesat, fourier and harmonic analyses) are available to minimize higher frequency noise but these also have the potential to remove or distort weak but important phenology events. Furthermore, the 8-day and 16-day products may be too coarse, temporally, to identify and separate a pollen event from other signal sources. These products are purposely aggregated and composited to remove high temporal frequency signals within the 8- or 16-day compositing period. Nevertheless, these products are useful in characterizing the seasonal and interannual dynamics of the juniper communities with the aim of developing prognostic capabilities through analysis of the precursor activities leading up to serious pollen events.

A multi-variable linear regression model between EVI values and sun and sensor zenith angles and DOY(day of year) was used to correct bidirectional effects in the daily EVI data and to obtain a *residual* EVI seasonal signal (eqs. 1, 2). The residual signal indicates that the pollen event may influence the seasonal signal to an extent that would allow detection, given accurate QA filtering and BRDF(bi-directional reflectance) corrections (Fig. 2). When pollen is released and blown, it coats much of the green leaf surface of the plant with a yellow pollen ash. We wish to assess the capability and confidence in spectral detection of the juniper pollen signal (in pollen production and release stages), not only in the daily vegetation index signal, but in the daily spectral, or color, signal from the 7 MODIS reflectance bands. We also wish to quantify this signal into pollen severity classes with accuracy estimates.

Modeled VI =a*(sensor zenith) +b*(solar zenith)+c*DOY +d (1)

Residual VI signal = observed VI – modeled VI (2)

With prognostic information, the team will employ MODIS daily data to build a response system similar to the one used for fire detection. Live local and regional environmental data benefit decision-making because traditional MODIS products have severe time lags to eliminate noise. While not as "clean", direct readout data are more appropriate for time-sensitive applications. Direct readout technology has become more accessible and tools are available now to make data easier to acquire and process. These data are processed by versioned algorithms to make surface reflectances, vegetation indices, land surface temperature, snow cover, and atmospheric aerosols. The latest version of the surface reflectance algorithm for MOD09_SPA (version 5.3.18, June, 2008) produces level-2 calibrated and geolocated radiances.

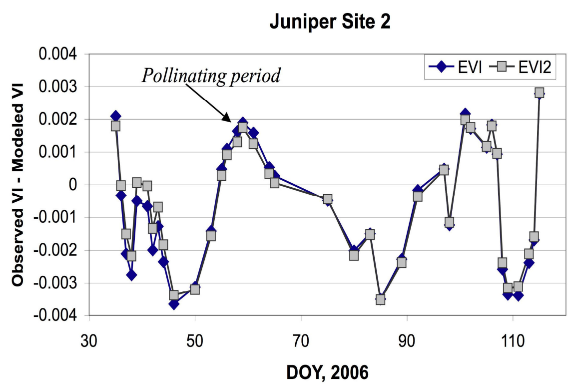


Fig. 2. Using good quality daily MODIS data (fair and bad quality days filtered out) and applying a BDRF model to remove sun and sensor view angle influence, a 'residual' signal found for the period late February and early March, 2006.

5. PRELIMINARY TESTS WITH PREAM

<u>*Setup of the atmospheric model*</u>
Model horizontal domain: SW US
Model top: 100 hPa (~16 km)
Model resolution: ~40 km
Simulation period:
15-19 February 2006 (initial spinning up dust field)
20 February – 20 March (effective simulation)
Boundary conditions: 1deg global forecasts used to refresh
initial conditions every 24 hours
boundary conditions every 6 hours
<u>*Pollen aerosol model*</u>
General setup:
DREAM (dust) is modified to simulate pollen grain atmospheric cycle
Connection to the atmospheric process:
DREAM-POLLEN is online driven by the atmospheric model driver
Dynamics:
Use of DREAM numerical schemes

for diffusion advection and deposition processes

Emission:
- The viscous-sublayer parameterization
- Power dependence of concentration on friction velocity of the atmospheric model

Initial conditions:
- "cold start" (C=0) used for the very first day
- simulated 3D concentration from the previous day is used as initial condition for the next day simulation

Sources:

A composite of the 4 for most widely distributed pollen sources - based on the MODIS/Terra Surface Reflectance Daily L2G Global data.

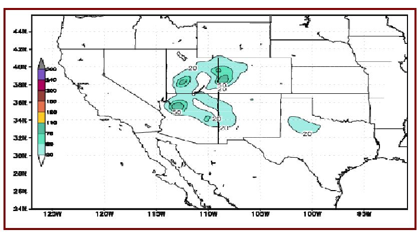
Particle sizes:

4 particles with diameters of 8, 12, 16 and 20 µm.

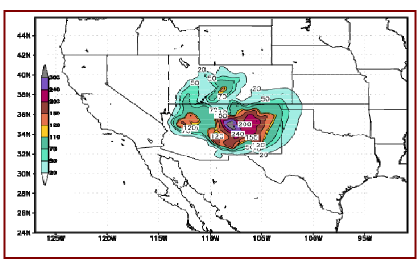
Preliminary results

The simulation period is chosen following the information that in the first 2 weeks of March 2006, there was an increase in allergy occurrence in Albuquerque, Santa Fe and Los Alamos. The PREAM modeled near-surface concentrations (Nm^{-3}) shows the transport patterns of *Juniperus spp*. pollen over a 5 day period (Fig. 3). Typical scales of the simulated transport process are regional. In the period 9-13 March there is an increase of simulated concentrations for the Los Alamos site. The simulated concentrations are comparable to typically observed pollen counts at Los Alamos (Fig. 4).

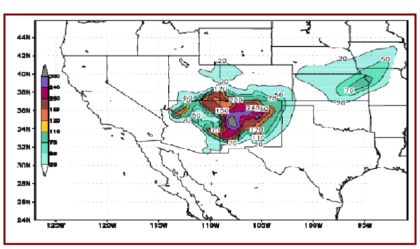
Fig. 3. PREAM modeled near-surface concentration (Nm^{-3})



March 6, 2006 00 UTC

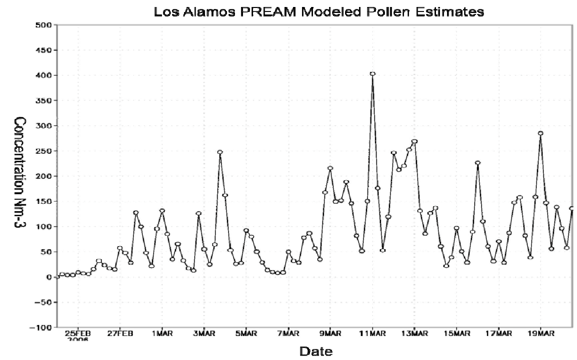


March 9, 2006 00 UTC



March 11, 2006 00 UTC

Fig. 4. Near-surface concentration (Nm^{-3}) 21 Feb – 20 Mar 2006



6. CONCLUSIONS

These initial results are very promising. The reflectance change in the *Juniperus* spp. forest canopy due to pollen producing male cones can be detected by MODIS data. Initial PREAM model runs appeared to model pollen transport timing that is consistent with ground based pollen observations. Future work will be done to compare PREAM model results with medical records and ground based pollen observations.

7. REFERENCES

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9. ACKNOWLEDGEMENTS

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