Aerosol Size Distribution Measurements During the 2014 NASA SARP Campaign in the Central Valley and Sierra Nevada Mountains in California

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AEROSOL SIZE DISTRIBUTION MEASUREMENTS DURING THE 2014 NASA SARP CAMPAIGN IN THE CENTRAL VALLEY AND SIERRA NEVADA MOUNTAINS IN CALIFORNIA

A Capstone Experience/Thesis Project

Presented in Partial Fulfillment of the Requirements for

the Degree Bachelor of Science with

Honors College Graduate Distinction at Western Kentucky University

By

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Western Kentucky University
2015

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ABSTRACT

Aerosols are directly and indirectly related to global climate by scattering radiation and also by seeding cloud formation. As a part of the 2014 NASA Student Airborne Research Program (SARP), research flights were conducted over the Central California region to better understand air quality in large urban California cities and also in the Central Valley. Using a Droplet Measurement Technologies Ultra High Sensitivity Aerosol Spectrometer (DMT-UHSAS), aerosol size distributions were measured across geographic regions of interest. Previous research has suggested that aerosols originating in the Central Valley may travel eastward to the Sierra Nevada and, once lifted orographically, could suppress precipitation in the clouds over the mountains. High concentrations of aerosols were found over the Central Valley during the SARP campaign. Wind trajectories as well as meteorological variables were used to verify whether or not these aerosols travel to the mountains and affect cloud formation. Wind data supports transport toward local mountain ranges and aerosol concentrations at the top and base of the mountains will be discussed.

Keywords: Aerosol, NASA, SARP, California, Meteorology, Clouds
Dedicated to my friends and family who have always supported my love for science.
ACKNOWLEDGEMENTS

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FIELDS OF STUDY

Major Field: Meteorology
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>ii</td>
</tr>
<tr>
<td>Dedication</td>
<td>iii</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>iv</td>
</tr>
<tr>
<td>Vita</td>
<td>v</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vii</td>
</tr>
<tr>
<td>Chapters:</td>
<td></td>
</tr>
<tr>
<td>1. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>2. Study Area and Methods</td>
<td>5</td>
</tr>
<tr>
<td>3. Results and Discussion</td>
<td>12</td>
</tr>
<tr>
<td>4. Conclusion</td>
<td>33</td>
</tr>
<tr>
<td>Bibliography</td>
<td>35</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>6</td>
</tr>
<tr>
<td>2.2</td>
<td>7</td>
</tr>
<tr>
<td>2.3</td>
<td>8</td>
</tr>
<tr>
<td>3.1</td>
<td>12</td>
</tr>
<tr>
<td>3.2</td>
<td>15</td>
</tr>
<tr>
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<td>15</td>
</tr>
<tr>
<td>3.4</td>
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</tr>
<tr>
<td>3.5</td>
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<td>26</td>
</tr>
<tr>
<td>3.15</td>
<td>27</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>3.16</td>
<td>NARR total cloud coverage on June 25, 2014</td>
</tr>
<tr>
<td>3.17</td>
<td>GOES-WEST satellite imagery on July 1, 2014 at 0Z</td>
</tr>
<tr>
<td>3.18</td>
<td>HYSPLIT Backward Ensemble ending on June 30, 2014</td>
</tr>
<tr>
<td>3.19</td>
<td>NARR vertical velocity and surface wind vectors on June 30, 2014</td>
</tr>
<tr>
<td>3.20</td>
<td>GOES-WEST satellite imagery on July 6, 2014 at 0Z</td>
</tr>
<tr>
<td>3.21</td>
<td>HYSPLIT Backward Ensemble ending on July 5, 2014</td>
</tr>
<tr>
<td>3.22</td>
<td>NARR vertical velocity and surface wind vectors on July 5, 2014</td>
</tr>
</tbody>
</table>
CHAPTER 1

INTRODUCTION

Aerosols are particulate matter in the atmosphere produced from human-created emissions as well as anthropogenic and natural sources. They are linked to the growth and properties of clouds (Hobbs, 1993; Myhre et al., 2007; Costantine et al., 2010). Aerosols are transported through the atmosphere and act as cloud condensation nuclei (CCN) (Hobbs, 1993; Lohmann and Feichter, 2005; Freud, et al., 2008; Rosenfeld, et al., 2008). Some anthropogenic aerosols are hygroscopic which allows them to attract water vapor and become cloud droplets. The diameter and concentration of the aerosol particle determines the properties of the resulting cloud (King et al., 1992; Kaufman, et al., 2005). Smaller particles take longer time to grow sufficiently heavy to rain out (Ramanathan, et al., 2001). As a result, smaller particles create an optically thick, long-lasting cloud (Sekiguchi, et al., 2003). On the other hand, clouds formed with fewer, yet larger particles, become heavy relatively quickly and rain out in less time. This creates an optically thinner, shorter-lived cloud. In clouds with high concentrations of small CCNs, the collision-coalescence process is not as impactful because the droplets take longer to grow (Rosenfeld, et al., 2008). This process is responsible for most of the precipitation in lower-level clouds, such as the ones that form orographically over the mountains.
A significant amount of research has been completed to better understand aerosol-cloud interactions (King et al., 1992; LeNoir et al., 1999; Whiteaker, et al., 2002; De Young et al., 2005; Kaufman, et al., 2005; Myhre et al., 2007; Wen, et al., 2007; Rosenfeld, et al., 2008; Costantine et al., 2010). Several studies were conducted over California due to its large and widespread urban areas as well as rural environment (LeNoir, et al., 1999; Whiteaker, et al., 2002; De Young, et al., 2005; Cubison, et al., 2008; Rosenfeld, et al., 2008). In addition, topographic differences are also significant with coastal areas on the west (along the Pacific Ocean), central valley in the middle, and mountains in the east. Rosenfeld, et al. (2008) measured and analyzed particles found near urban coastal regions. These particles were hypothesized to travel eastward toward the Sierra Nevada mountain range and affect the orographic clouds that form over the mountains.

Since smaller particles inhibit precipitating clouds more than larger particles, Rosenfeld, et al. (2008) hypothesized that the particles measured in the urban regions were suppressing precipitation over the Sierra Nevada during the rainy season. Using their Suppressed Precipitation (SUPRECIP) Program, they quantified cloud properties and found that the high concentrations of aerosols were most impactful during the spring season, when convection carries the particles further up into the atmosphere. Precipitation in the orographic clouds was reduced by as much as 30% during the spring season (Rosenfeld et al., 2008).

This study also found that the concentration of particles over the mountains was higher than over the urban areas, which was unexpected. This led to the hypothesis that more anthropogenic aerosols were being collected elsewhere by the traveling air mass.
After analyzing cloud base measurements and properties of sea spray CCNs versus anthropogenic CCNs, Rosenfeld et al. (2008) suggested that extra concentrations of anthropogenic aerosols were coming from the agriculture fields in the Central Valley.

Other studies also supported this idea. For example, De Young et al. (2005) used an aerosol lidar system to find high concentrations of aerosols at the base of the Sierra Nevada. Using HYSPLIT backward wind trajectories, they had suggested that these aerosols were coming from along the Central Valley. Wind played a vital role in the transport of aerosols in this study. Freud et al. (2008) used Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data to analyze cloud depth, height, and base temperature and concluded that anthropogenic aerosols were noticeably affecting convective clouds over Sweden. This study also utilized the HYSPLIT model to track wind patterns across Sweden. Note that satellite images are quite helpful in understanding cloud properties. When resources are not available to measure in situ cloud properties, remote sensing is the next best option. What remains unknown in the Rosenfeld, et al. (2008) study is the origin of the anthropogenic aerosols found over the Sierra Nevada. The goal of this project is to use various methods found in other studies to test the hypothesis of aerosols originating in the Central Valley and being carried to the Sierra Nevada.

Using in situ measurements of aerosol concentration over the Central Valley and Sierra Nevada during the 2014 NASA Student Airborne Research Program Campaign, high concentrations of aerosol particles were analyzed to see where they are possibly generating and traveling with time. Various methods were utilized to predict the future tracking and development of these aerosol concentrations. HYSPLIT Wind Trajectories
were created in order to understand the wind flow during the research period (Draxler and Rolph, 2015). Satellite imagery was analyzed to determine any potential correlations between cloud cover and aerosol concentrations. Integrated Data Viewer (IDV) was used to create synoptic and mesoscale maps of parameters affecting the transport of aerosols, as well as cloud properties over the Sierra Nevada. These parameters included mid-level cloud coverage, relative humidity, vertical velocity, wind speed, and wind direction.
CHAPTER 2

STUDY AREA AND METHODS

Each year, NASA hosts a Student Airborne Research Program (SARP) for college undergraduates from across the United States. The 2014 SARP campaign was held in Southern California during the weeks of June 15-August 8. During these eight weeks, two weeks were spent in Palmdale, California conducting research flights and collecting data at the NASA Armstrong facility. This facility is the home of the NASA DC-8 aircraft – an airborne laboratory that can hold varying numbers of scientific instruments. These instruments measure atmospheric properties by detecting chemical traces and particulate matter characteristics. The laboratory is also capable of remote sensing with radar and lidar instrumentation. The 2014 DC-8 research flights had a payload of 6 instruments: MODIS/ASTER Simulator (MASTER), Photochemical Gas Trace analyzer (PTG), Atmospheric Vertical Observation of CO2 in the Earth's Troposphere (AVOCET), Whole Air Sampling, Miniature Chemical Ionization Mass Spectrometry (MiniCims), and Ultra-high sensitivity aerosol spectrometer (UHSAS) (Figure 2.1). MASTER was the only remote-sensing instrument on the aircraft, while the other five instruments measured various properties of the atmosphere.
Figure 2.1. Image showing instruments and their approximate locations on the SARP 2014 Research Flights.

Table 2.1 shows the relevant data information for the research flights. Additional flight data information can be found at https://www.eol.ucar.edu/raf/Software/iwgadts/IWG1_Def.html.

Table 2.1. List of relevant data and metadata measured on the SARP 2014 Research Flights.

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<th>Sampling Interval (s⁻¹)</th>
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<td>Pressure Altitude</td>
<td>GPS</td>
<td>feet</td>
<td>--</td>
<td>1.0</td>
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The Droplet Measurement Technologies Ultra-high Sensitivity Aerosol Spectrometer (DMT-UHSAS) measures aerosol concentration as well as particle diameter (Figure 2.2). The UHSAS first collects air from an intake valve connected to a
window on the aircraft. It then focuses particles into a highly concentrated jet stream of air traveling perpendicular to the source laser. Multiple detectors collect light that is scattered by the particles and convert it to particle diameter. The frequency of the light detection corresponds to the concentration of aerosols measured. The UHSAS measures at a rate of 10Hz, or 10 scans per second. Once measured, the air is sent to an exit value on another window of the aircraft. Figure 2.3 shows a schematic of the UHSAS.

Figure 2.2. Image of the UHSAS outside of the aircraft in the Bertram Group Laboratory (University of California, San Diego).
The in situ measurements consisted of particle counts ranging from 1-25 with diameters ranging from 60 nanometers to 1 micrometer. The particle counts were later normalized to the logarithmic size distance between the diameter bins. Particle concentration was found by using the following equation to divide total number of counts by the volume of the bin,

$$\frac{dN}{d \log D_p}.$$  \hspace{1cm} \text{Eq. 1}

All data conversions were calculated using Matlab. Additional analysis included converting the flight time and UHSAS measurement time to fractional Julian day in order to sync all the data.
During the 2014 NASA SARP campaign, five research flights were conducted along the central California region June 23 through June 25. Two flights were conducted on June 23, including a morning flight and an afternoon flight. Additionally, two flights were conducted on June 24, also a morning and afternoon flight. On the last research flight day, one 7-hour flight was conducted that included parts of the Central Valley and Sierra Nevada. For purposes relevant to the research question, the June 25 flight was the primary SARP research flight used in this analysis.

As the DMT-UHSAS was taking measurements over the Central Valley, very high concentrations of small aerosols were observed. With the findings over the Central Valley that paralleled other studies, a hypothesis was proposed which suggested that if the particles could be tracked using wind data, they would eventually arrive near the mountains. Moreover, if they are transported to the mountains, they would likely affect the clouds that form over the mountains (Rosenfeld, et al., 2008).

Post flight, wind trajectories were simulated using HYSPLIT wind trajectory models. HYSPLIT models create predicted wind trajectories, both forward and backward, from real-time and archived model data. Archived 12km NAM data was used for this project. Trajectories were estimated for each day of the month of June in order to understand the average wind flow through the Central Valley during this time frame. All wind trajectories began in Fresno, California at 2100 UTC (1:00 pm local time). This

<table>
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<th>Sampling rate (sccm)</th>
<th>Sampling Interval (s⁻¹)</th>
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<td>50</td>
<td>0.1</td>
</tr>
<tr>
<td>Particle diameter</td>
<td>nm</td>
<td>60 – 1000</td>
<td>50</td>
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time was chosen due to the corresponding flight time over the Central Valley during the research flight. Using the HYSPLIT model for a location directly centered in the Sierra Nevada 24 hours post-flight, the wind flow’s origin was analyzed with respect to the mountains. One limitation of the HYSPLIT models was its failure in simulation of localized orographic flow near the mountains. Orographic flow, or wind traveling up the mountain slope, is known to occur in the Sierra Nevada but was not estimated by the HYSPLIT models.

To better capture the orographic flow over the mountains, IDV was used to map near-surface wind over topography. Other synoptic scale variables were mapped over the region of interest using North American Regional Reanalysis (NARR) data, including: mid-level and total cloud coverage, relative humidity at hybrid level, 700mb vertical velocity and specific humidity greater than 1 g kg⁻¹ at 850mb and 500mb (NCEP Reanalysis data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their website at http://www.esrl.noaa.gov/psd/). The NARR database provides 3-hour datasets dating back 25 years. Datasets are a compilation of NAM and ETA models and have a resolution of 32km. Mapping these variables helped understand the transport of the measured particles in the Central Valley and over the mountains, as well as any possible interaction between the particles and present water vapor. Cloud cover during and after the research period was analyzed using GOES-WEST Satellite imagery.

Additionally, normalized particle concentrations were compared at various points along the research flight paths, with the Central Valley concentration and Sierra Nevada concentration being of utmost importance. The concentrations found at these two locations were compared to concentrations measured during the flyover of the Santa
Barbara Channel (June 25 flight) and the missed approach at the LA/Ontario International Airport (June 23 flight).
CHAPTER 3

RESULTS AND DISCUSSION

During the three-day research flight period, California was experiencing its third consecutive year of drought. The area most severely affected with drought corresponded with much of the research flight area. According to the U.S. Drought Monitor, the worst drought stretched from the coast of Mid-California to the edge of the Sierra Nevada (Figure 3.3). The Central Valley was located in the region most affected by drought. Because of these drier than normal conditions, cloud coverage was severely impacted over the areas of interest.

Figure 3.1. U.S. Drought Monitor for June 24, 2014 showing the widespread drought conditions across California (source; U.S. Drought Monitor, 2014)
Synoptically, the U.S. had an upper-level shortwave ridge over the Midwest and an upper-level shortwave trough immediately downstream. The areas of interest were located underneath upper-level zonal flow. A weak jet streak was located just off the coast of northwest California. At the 500mb level, a negatively tilted shortwave trough was positioned over California and a shortwave ridge was immediately to the east. The shortwave trough and ridging pattern translated down to the 700 mb level as well. Relative humidity values were extremely low over much of California, and especially over the areas of interest. At the surface, a high pressure system was just off the California coast with moderate high pressure across the state. Surface winds were primarily from the northwest over the areas of interest. These synoptic scale factors will play a major role in the transport and interaction of the parameters measured during the June 25 research flight.

The June 25 flight began around 1200 UTC and ended at approximately 1900 UTC. Between 1500 UTC and 1800 UTC, the research flight began collecting data over the Central Valley and Sierra Nevada thereafter. While over the Central Valley, average altitude of the plane remained within the boundary layer at approximately 1000 meters. The UHSAS collected particle count and diameter during this time. After performing calculations on the particle counts using Eq. 1, the normalized aerosol concentrations were plotted along the flight path and plotted on a Google Earth map. The UHSAS reached its maximum count of 25 particles while collecting data over the Valley, so it is possible that counts higher than 25 were not recorded. After normalization, aerosol concentrations ranged from 0 to $20 \times 10^6$ counts per volume (Figure 3.2).
The same analysis was completed for the data collected over the Sierra Nevada. The plane flew in a pattern known as “Neon Lines” over the mountains, which is a series of back and forth flyovers across the research area. During the neon line collection, the UHSAS measured high counts of particles near the top of the mountains, but not as many as what was measured in the Valley. After normalization, aerosol concentrations ranged from 0-500 x 10³ counts per volume over the mountains (Figure 3.3). Unfortunately, the plane flew the neon lines around 4000-6000 meters and particle counts could not be measured near the base or along the sides of the mountains.

Thought to be unrelated to the research topic, aerosol concentrations south and east of the Sierra Nevada foothills were initially omitted from data analysis. However, a region of high aerosol concentration directly behind the foothills raised speculation that a localized wind flow could be carrying the particles around the base of the mountain and depositing them in that location. A turbulent eddy, well-known to locals, occurs near the southern base of the Sierra Nevada, just east of Bakersfield. A primarily northwesterly wind flow that travels through the Central Valley curves eastward as it reaches the foothills and loops back around to the west. This creates a constant eddy flow at the base of the mountains which could cause orographic flow on the east side of the foothills, thus lifting the particles to the elevation at which they were measured. The concentrations at the foothills, once normalized, ranged from 0-250 x 10³ counts per volume, which was very similar to the measurements made over the Sierra Nevada (Figure 3.4).
Figure 3.2. Aerosol concentration plotted with the flight path over the Central Valley. Highest concentrations were observed south of Fresno where the plane decreased its altitude and flew over agricultural farms.

Figure 3.3. Aerosol concentration plotted with the flight path of the Sierra Nevada. Highest concentrations were observed at the top of the mountains where altitude was around 20,000 feet.
Figure 3.4. Aerosol concentration plotted with the flight path at the base of the Sierra Nevada. A high concentration of particles was located north of Lancaster. Wind data were analyzed to determine the cause of this high concentration.

Data were analyzed using Matlab where code was created to apply the necessary normalizations to the data (Eq. 1). Concentrations along latitude and longitude were plotted with altitude in three dimensional space. The concentrations of aerosol observed during the flight are visible along the flight path. Overall, the highest aerosol concentrations were seen within the boundary layer as the plane flew 1500 meters or less over the Valley. Once the plane reached altitudes over 2000 meters, the air became significantly less polluted over the neon lines, where aerosol concentrations increased once again (Figure 3.5).

Aerosol measured in the boundary layer had much variability with respect to altitude versus total number of particles (Figure 3.6). The total number of particles seemed to have an overall increasing trend as altitude increased. The edge of the boundary layer is clearly visible in the plot, as particle counts were lowered dramatically. Particle counts remain somewhat null until the plane reached higher altitudes at the Sierra
Nevada, and particle counts begin to increase with height once again. As speculated, there are not as many particles over the mountains as in the boundary layer. Relative to the surrounding clean air near the mountains, high particle counts were observed over the neon lines.

Figure 3.5. Aerosol concentration plotted for the latter half of the June 25 flight. Lower altitudes are the Central Valley flyovers and at higher altitudes are over the Sierra Nevada.
Figure 3.6. Total number of counts plotted against altitude to show trends in particle counts over the flight. Higher particle counts correspond with Central Valley altitude, while lower particle counts correspond with Sierra Nevada altitude.

In the Central Valley, highest concentrations were found south of Fresno in an area of agricultural farming. After further assessment, it was determined that the area consists of nut farms. The Pacific Almond Company was one such farm located in the area of highest aerosol concentration. It was observed that the particle concentrations occurred south of Fresno, and urban aerosol did not play much of a role in the concentration measured.

Over the Sierra Nevada, the concentrations increased with altitude. At the peak altitude at which the plane flew (around 6000 meters), the highest concentrations from the neon line flyover were observed. The initial assumption for this increase in concentration is the typical orographic flow occurring from the base of the mountains to the top. This wind flow, in theory, could carry the aerosol particles measured within the boundary layer up the mountain slope and disperse them near the top of the mountains.
Wind data from various sources was analyzed in attempt to capture the orographic flow occurring at the base of the mountain.

The low-level wind flow through the Central Valley was primarily from the northwest as winds flow west to east from the ocean and curve southward to follow along the Sierra Nevada range. Using HYSPLIT trajectory analysis, wind flow for the month of June was plotted on a composite Google Earth map to better understand the average wind flow during the research period (Figure 3.7). The results suggest that the wind was, on average, northwesterly and turning at the base of the mountains, creating the eddy current near Bakersfield. The same analysis was conducted for the day prior to the flight, as well as the day of the flight to understand the wind flow during the research flights (Figures 3.8 and 3.9). Wind flow was plotted at 1000, 4000, and 6000 meters. At 1000 meters on June 24, the wind flow followed the same path as the composite wind flow. At 4000 and 6000 meters, the wind flow shifted slightly to be more westerly, but it is still northwesterly. At 1000 meters on June 25, the wind flow followed the same path as the composite map. At 4000 and 6000 meters, the wind flow became more zonal and travels along a straight path from west to east.

HYSPLIT backward trajectory ensembles were used to verify the origin of the wind over the Sierra Nevada (3.10). A coordinate was chosen over the mountain range, centered over the neon line flight pattern and backward ensemble trajectories for 24 hours prior to the flight day were created. The trajectories show wind was coming from the northwest, travelling through the Central Valley and eastward into the mountains.
Figure 3.7. Composite HYSPLIT Trajectories for the month of June, 2014 which shows an overall northwesterly wind flow through the Central Valley in California.

Figure 3.8. HYSPLIT Forward Trajectory model showing wind flow at 1000, 4000, and 6000 meters on June 24, 2014.
Figure 3.9. HYSPLIT Forward Trajectory model showing wind flow at 1000, 4000, and 6000 meters on June 25, 2014.

Figure 3.10. HYSPLIT Backward Ensemble Trajectory for coordinates over the Sierra Nevada showing wind trajectories 24 hours prior to June 25, 2014 at 1800 UTC.
The HYSPLIT model simulations show that wind is capable of carrying the aerosols to the mountains at higher heights, which is possible if aerosols are lifted due to convective heating. Closer to the surface, HYSPLIT models did not capture orographic flow. Several parameters must be known to determine if aerosol transport to the mountains could be occurring, including surface winds to show horizontal motion and vertical velocity to show convective lifting. Using IDV, the surface winds plotted over topography shows the orographic wind flow over the mountains. Surface winds close to the base of the mountains travel eastward and upward, making it possible for aerosol transport (Figure 3.11). Additionally, NARR 700mb vertical velocity maps for June 25 show a region of upward motion throughout the Central Valley (Figure 3.12). The vertical motion increased during the day and was most widespread at 2100 UTC, or around 1pm local time when convective uplift was strong.

Figure 3.11. NARR relative humidity at hybrid level and surface wind vectors plotted against topography for 0000 UTC, 1200 UTC, and 2100 UTC on June 25, 2014.
IDV surface wind and vertical velocity maps were supportive of the transport of aerosol to the Sierra Nevada both horizontally and vertically. As seen in the trajectories simulated by the HYSPLIT models, if the particles were lifted to 4000-6000 meters, they would travel southeast to the Sierra Nevada. Alternately, if the particles stayed near the surface, they would be lifted orographically by the wind flow on the side of the mountain. It is difficult to show conclusively that the particles measured over Sierra Nevada during the SARP campaign were the same particles measured over the Central Valley that same day. Particle distribution analysis was conducted on the measurements to determine if any similarities in distribution existed between the two sites.

The normalized aerosol concentration was normalized once again to peak diameter size and particle counts were plotted against diameter (Figure 3.13). The distribution of particles over the Central Valley was plotted and as expected, most particles were of smaller diameter in the 60-100 nanometer range. This size range is typical for anthropogenic pollution aerosols. The distribution decreases exponentially,
with only few large particles measured. The distribution of particles over the Sierra Nevada was plotted and followed the same pattern as the particles in the Central Valley. The particle distribution over the Sierra Nevada had a slightly larger normalized peak diameter, which is explained by the age of the aerosol particles after they are transported to the mountains. Based on the back trajectory simulations, it takes approximately 18-24 hours for the particles to reach the mountains. This gives the particles time to age and become larger by attracting other smaller particles. There were only slight differences in the distribution curve between both sites, supporting the hypothesis that these particles are of the same origin; however, it is impossible to determine an exact correlation without chemical information of the particles.

To verify the particle distributions are of significance between the two sites, they were compared to particle distributions at other sites with various elevations and characteristics. Particle distribution of aerosol concentration measurements from the Santa Barbara Channel and a “missed approach” at Ontario Airport (ONT) were compared to the particle distributions from the Central Valley and Sierra Nevada. The particles from the Santa Barbara Channel had smaller normalized diameters, as much of the aerosol came from salt spray off the ocean. Ontario had larger peak diameter sizes from the heavy air pollution commonly found over the area. The Central Valley and Sierra Nevada were the only two sites out of the four with a noticeable similarity in distribution.
Rosenfeld, et al. (2008) concluded that small diameter pollution aerosols from an unknown source were being transported to the Sierra Nevada and were contributing to orographic cloud properties and precipitation processes over the mountains. Transport mechanisms are available for particles from the Central Valley to be carried to the mountains, as shown by the HYSPLIT trajectories and NARR parameters analysis. Similarities exist between the particle distributions of aerosol concentrations measured in the Valley and in the Sierra Nevada. There is enough evidence to support the transport of these aerosols; unfortunately, no data collected during the SARP Campaign verifies the aerosol interaction with cloud properties over the Sierra Nevada. Rosenfeld, et al. (2008) did find negative interactions between the anthropogenic aerosols and orographic clouds. Precipitation amounts decreased with an increase in pollution aerosol. Knowing these interactions exist and are potentially originating within the Central Valley, more research may be conducted on the relationship between only the anthropogenic aerosol sources in
the Central Valley and their impact on orographic cloud properties and inhibition of rainfall.

Attempts were made during the SARP Campaign to correlate the high concentration measurements with cloud coverage from satellite imagery. Due to lack of moisture in the atmosphere, quantifying any correlation was extremely difficult. On June 25 during the research flight, relative humidity values were too low for any cloud formation over the Sierra Nevada (Figure 3.11). Specific humidity values at 850mb remained at approximately 4 \( g \ kg^{-1} \) and values at 500mb remained at approximately 2 \( g \ kg^{-1} \) (Figures 3.14 and 3.15). NARR data for 0000 UTC, 1200 UTC, and 2100 UTC shows a lack of cloud cover over most of California (Figure 3.16). This is due to the upper-level ridge and prolonged drought in California during the time period.

![Figure 3.14. NARR specific humidity greater than 1g kg\(^{-1}\) at 850mb on June 25, 2014 at 0000 UTC, 1200 UTC, and 2100 UTC, respectively.](image)
Two days with orographic cloud cover on GOES-WEST Satellite imagery were chosen for analysis to see if any cloud properties could be discerned. On July 1 at around 0Z, convective clouds were observed via satellite. (Figure 3.17). The color of the clouds could be due to more reflective CCN within the clouds. HYSPLIT backward ensemble
trajectories at 1000 meters over the Sierra Nevada show a northwesterly wind flow through the Central Valley (Figure 3.18). NARR 700mb vertical velocity and surface wind vectors plotted at 0000 UTC, 1200 UTC, and 2100 UTC on June 30 show widespread vertical motion near the Central Valley, providing lift for these particles into an area of more zonal flow (Figure 3.19). Wind vectors at the surface also show transport to the mountains.

Figure 3.17. GOES-WEST Satellite imagery on July 1 at 0000 UTC. The inset is of the cloud coverage is located in the top left corner.
Figure 3.18. HYSPLIT Backward Trajectory model at a point directly over the Sierra Nevada showing backward trajectories at 1000 meters ending approximately 24 hours before the GOES-WEST satellite cloud cover.

Figure 3.19. NARR vertical velocity at 700mb and surface wind vectors over topography on June 30, 2014 at 0000 UTC, 1200 UTC, and 2100 UTC, respectively. Red shading represents upward motion and blue shading represents downward motion. The same properties appeared in the orographic clouds on June 6 around 0000 UTC (Figure 3.20). The clouds appear to contain whiter patches, due to potential anthropogenic aerosol pollution. HYSPLIT backward ensemble trajectories at 1000
meters over the Sierra Nevada also display a northwesterly flow through the Central Valley (Figure 3.21). NARR 700mb vertical velocity and surface wind vectors show a similar pattern as on June 30 (Figure 3.22). During much of the 24-hour period, vertical velocity was located in most of the Central Valley and Sierra Nevada region. Surface wind vectors also show wind flow following the same northwesterly pattern.

For the research period, the wind flow remained consistently out of the northwest. On days where enough moisture in the atmosphere allowed cloud coverage, orographic clouds formed over the mountains and some areas appeared whiter than others, following the principles of reflective properties in smaller diameter aerosols. As shown with HYSPLIT models, NARR parameters, and similarities between particle distributions, the wind flow and similarities between particle distributions agree with the hypothesis that aerosols are being transported from the Central Valley to the Sierra Nevada. This supports Rosenfeld et al.’s (2008) conclusion that smaller CCNs from an unknown source, believed to be the Central Valley, were affecting cloud and precipitation processes over the mountains during the rainy season.
Figure 3.20. GOES-WEST Satellite imagery showing cloud coverage on July 6, 2014 at 0000 UTC.

Figure 3.21. HYSPLIT Backward Trajectory model at a point over the Sierra Nevada 24 hours prior to the cloud coverage in the GOES-WEST satellite image.
Figure 3.22. NARR vertical velocity at 700mb and surface wind vectors on July 5, 2014 at 0000 UTC, 1200 UTC, and 2100 UTC, respectively. Red is for locations of upward motion and blue for downward motion.
CHAPTER 4

CONCLUSION

During the 2014 NASA SARP Campaign, five research flights were conducted over Central and Southern California in an attempt to understand the role of aerosols and meteorological conditions in air quality over the state of California. The Droplet Measurement Technologies Ultra-high sensitivity aerosol spectrometer (DMT-UHSAS) was used in this project to analyze the aerosols data. The DMT-UHSAS measured particle counts and diameter along the research flight. High concentrations of aerosols were measured over the Central Valley farmland and Sierra Nevada regions, showing similar characteristics in particle distributions. Earlier studies concluded that smaller diameter particles were being deposited over the Sierra Nevada and acting as CCN. The smaller particles mentioned in this study were believed to be from the Central Valley. Measurements from the SARP Campaign support this idea and further research using HYSPLIT Trajectory models, as well as NARR data, show that transport of the aerosols from the Central Valley to the Sierra Nevada is very likely to occur with the average northwesterly wind flow in California.

Although instrument limitations on the SARP Campaign inhibited the study of cloud properties over the Sierra Nevada, GOES-WEST satellite images were analyzed for
days with wind flow from the Central Valley and with enough moisture for cloud cover to develop. Satellite imagery did show areas of brighter cloud cover amidst the total cloud cover. However, it is unknown as to whether this difference in brightness is due to more reflective CCN properties or other causes. Future studies will be conducted to determine similarities in aerosol chemical properties found in the Central Valley and Sierra Nevada. Precipitation totals along the Sierra Nevada range will also be considered to support the results found in the Rosenfeld et al. (2008) study.
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