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Integrating MISR, MODIS, and CALIPSO Satellite Data with In Situ Measurements at Mount Bachelor to Determine Aerosol Plume Characteristics

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1. Introduction/Overview

Large aerosol plumes can be advected from Asia to the western U.S., especially in the spring when conditions are favorable for long range transport. Air quality forecasts for populated regions of the U.S. west coast currently do not account for this "imported" aerosol, which can cause forecasts to substantially underestimate aerosol load. Combining satellite, surface and free troposphere observations has the potential to greatly improve the initial conditions of these models by accounting for episodic import of dust, smoke, and pollution.

2. Methods

1.Since its establishment, the Mount Bachelor Observatory (MBO, 2763 m MSL) (Figure 1a, b) has proven to be well positioned to observe Asian industrial, dust, and biomass burning plumes.[1]

2.Multi-wavelength sub-μm aerosol scattering (σ_{sp}) and absorption (σ_{ap}) were measured at MBO with a TSI Model 3563 integrating nephelometer[2] and a Particle Soot Absorption Photometer. [3] The measurements were used to identify aerosol plumes of Asian origin.

3.Aerosol Optical Depth (AOD) fields from the MISR and MODIS satellites were used to locate these specific aerosol plumes in cloud-free regions up and downwind of MBO.

4.The MODIS instrument is onboard the Terra and Aqua satellites, the latter of which is in the "A-Train" Satellite Constellation (Figure 1c).

5.CALIPSO, another A-Train satellite, trails Aqua by ~1 min., providing nearly concurrent vertical profiles of the aerosol plumes. The CALIPSO aerosol product is used to determine plume height and aerosol type[4].

6.The Terra Satellite also houses the MISR instrument (Fig. 1d), which provides more detailed measurements of aerosol optical properties.

7.The goal is to integrate these measurements to better understand the timing and extent of aerosol impacts at the surface.

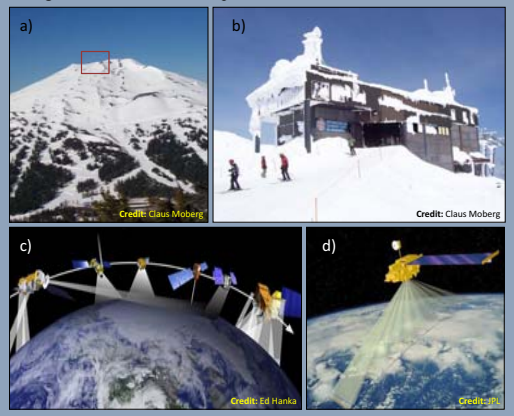

Figure 1: (a) Mt. Bachelor summit, in Central Oregon, and the Summit Observatory (within the red box). (b) Summit Observatory, where the instruments are housed (c) A-Train Satellite Constellation (d) Terra Satellite, home of both MODIS and MISR

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2. Anderson, T. L., and J. A. Ogren (1998), Determining aerosol radiative properties using the TSI 3563 Integrating Nephelometer, *Aerosol Science and Technology, 29, 57-69.*
3. Virkkula, A., N. C. Ahlquist, D. S. Covert, W. P. Arnott, P. J. Sheridan, P. K. Quinn, and D. J. Coffman (2005), Modification, calibration and filed test of an instrument for measuring light absorption by particles, *Aerosol Science and Technology, 39, 68-83.*
4. Omar, A. H., et al. (2009), The CALIPSO automated aerosol classification and lidar ratio selection algorithm, *Journal of Atmospheric and Oceanice Technology, 26, 1994-2014.*
5. Fischer, E. V., D. A. Jaffe, D. R. Reidmiller, and L. Jaegle (2009), Meteorological controls on observed peroxyacetyl nitrate (PAN) at Mount Bachelor during the spring of 2008, *Journal of Geophysical Research, accepted doi: 10.1029/2009JD00012776.*
6. Fischer, E. V., and D. A. Jaffe (2009), Optical properties of aged Asian aerosols observed over the U.S. Pacific Northwest, *in preparation for submission to Atmospheric Chemistry and Physics.*

3. Overview of Spring 2008 Measurements

An analysis of the MBO aerosol data over spring 2008 and 2009 yielded seven well defined Asian aerosol plumes. Two of the 2008 events were well covered by the satellite observations: 1) April 17–April 19, and 2) April 25 –April 28. These are highlighted in the time series below.

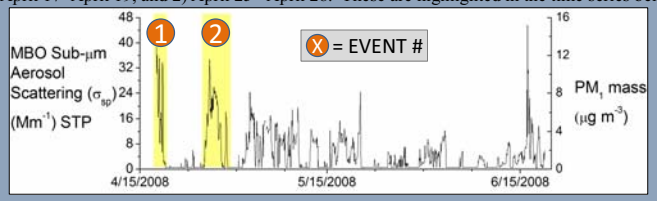

Figure 2: Sub-μm aerosol scattering at Mt. Bachelor during spring 2008, with the selected plumes highlighted.

Monitoring sites at lower elevations all across the Pacific Northwest measured elevated fine particles during these two events, more so in the second event. The locations and measurements from eight regional sites are shown below. The first event was observed primarily in Oregon, and the second event was seen all across the Pacific Northwest.

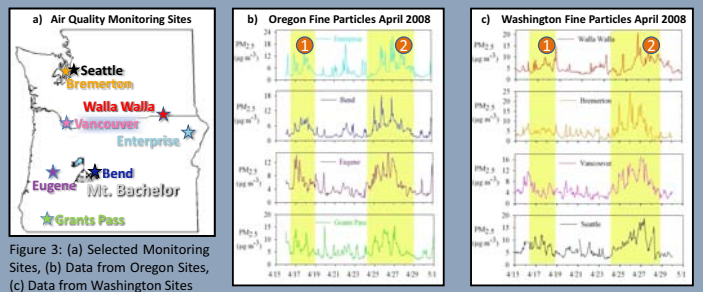

Figure 3: (a) Selected Monitoring Sites, (b) Data from Oregon Sites, (c) Data from Washington Sites

4. Event 1: Smoke Arriving at MBO April 17-18, 2008

Elevated aerosols were observed at MBO from April 17-18, 2008 (Figure 4). The plume travelled northwest to southeast and was captured by MODIS at 19 GMT 4/18 after passing MBO (Figure 5).

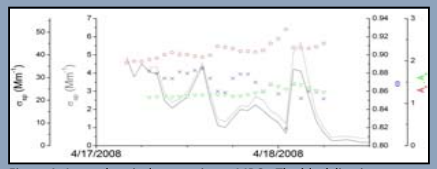

Figure 4: Aerosol optical properties at MBO. The black line is σ_{sp} at 550 nm . The grey line is σ_{ap} at 550 nm. Hourly averaged single scatter albedo (ω) at 550 nm, and the scattering and absorption Ångstrom exponents ($Å_s$ and $Å_a$) are plotted as blue x's, red circles, and green triangles respectively.

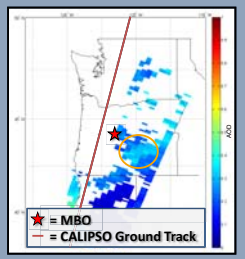

Figure 5: The MODIS Terra AOD field captures the plume (circled) at 19 GMT 4/18. Also plotted is the ground track of the 10 GMT 4/18 CALIPSO swath seen in Figure 6.

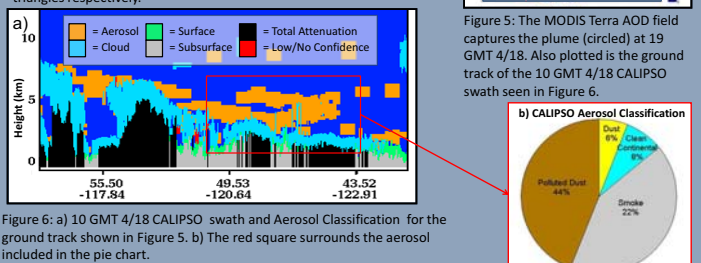

Figure 6: a) 10 GMT 4/18 CALIPSO swath and Aerosol Classification for the ground track shown in Figure 5. b) The red square surrounds the aerosol included in the pie chart.

The CALIPSO satellite passed to the northwest of MBO (Figure 5) at 10 GMT 4/18. The aerosol layer was observed at lower elevations toward the south (Figure 6), which is consistent with the pattern of surface observations. This plume likely had a Siberian Biomass burning source. [5]

5. Event 2: A Mix of Dust and Smoke at MBO April 25-28, 2008

A second period of elevated aerosol scattering and absorption was observed at MBO for the period 25 – 28 April (Figure 7). This plume was also observed along the Pacific coast from Alaska to Oregon. This large plume was observed by MODIS and CALIPSO both before and after it was observed at MBO. There is strong evidence that this plume was a mixture of Asian dust and smoke.[6]

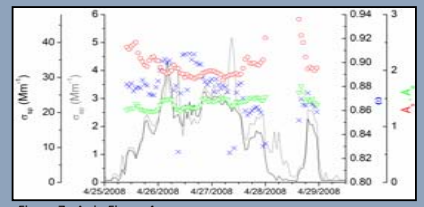

Figure 7: As in Figure 4.

Plume Arriving from the NW on 4/25:

The plume was captured by MODIS Aqua as it approached the Oregon coast from the northwest at 21 GMT 4/25, Figure 8a. A nearly concurrent CALIPSO overpass indicates the plume extended from 3 to 7 km MSL (Figure 8b). The CALIPSO algorithm suggests that this plume had a large coarse mode dust component.

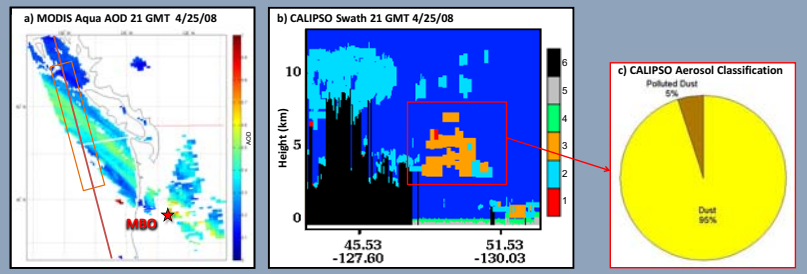

Figure 8: a) MODIS AOD, with the CALIPSO ground track (magenta). The box outlines the segment shown in Figure 8b. b) CALIPSO Lidar segment with classification. Key: 1= Low/No Confidence 2= Cloud 3= Aerosol 4= Surface 5= Subsurface 6= Total Attenuation c) The red square surrounds the aerosol included in the pie chart.

Dust at the Surface 4/26 - 4/27:

MODIS Terra got a largely cloud-free view of the Pacific Northwest at 19 GMT 4/26 and observed a vast region of high AOD (Figure 9a) coincident with the MBO observations of elevated aerosol. As seen in Figure 9a, the CALIPSO satellite passed almost directly over MBO 10 GMT 4/27 and a thin near-surface aerosol layer is visible Figure 9b. Again, CALIPSO classified this plume to be a mix of dust and polluted dust, consistent with the low scattering Ångstrom exponents observed at MBO.

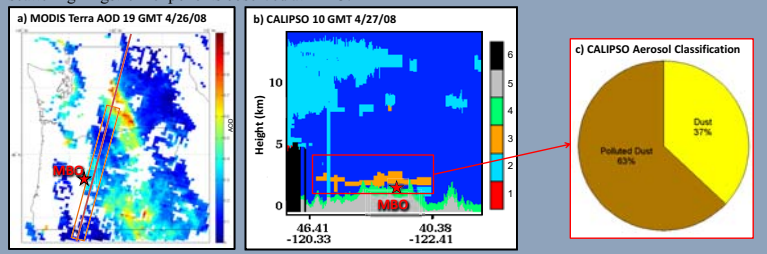

Figure 9: a) MODIS Terra AOD 19 GMT 4/26, with the ground track of the CALIPSO swath seen in Figure 9b. b) CALIPSO swath and aerosol classification. Key: 1= Low/No Confidence 2= Cloud 3= Aerosol 4= Surface 5= Subsurface 6= Total Attenuation, c) The red square surrounds the aerosol included in the pie chart.

6. Summary

1. Satellite observations complement in situ observations at MBO. We gain information on plume vertical and horizontal extent using satellite data from either MISR or MODIS (horizontal) and CALIPSO (vertical).
2. Lack of data is a major issue. The periodic nature of satellite data, along with frequent cloud contamination, cause most events observed at the surface to be difficult to identify in satellite observations. An analysis of the Mt. Bachelor data over the two spring seasons of 2008 and 2009 yielded seven well defined Asian aerosol plumes. Two of these were well covered in the satellite observations.
3. These results suggest that MODIS and CALIPSO data can be used to predict surface concentrations of PM in some cases. Further work is needed to elucidate the meteorological conditions when free tropospheric aerosols are brought down to the surface.

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