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## **JPLSIP Final Report - MISR Interactive eXplorer (MINX): Production Digitizing to Retrieve Smoke Plume Heights and Validating Heights against Lidar Data**

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The height at which smoke from a wildfire is injected into the atmosphere is an important parameter for climatology, because it determines how far the smoke can be transported. Using the MINX program to analyze MISR (Multi-angle Imaging Spectro-Radiometer) data, I digitized wildfire smoke plumes to add to an existing database of these heights for use by scientists studying smoke transport and plume dynamics. In addition to using MINX to do production digitizing of heights, I assisted in gathering lidar data for an ongoing validation of MINX and helped evaluate those data.

The MISR instrument aboard the EOS satellite Terra is a radiometer with nine cameras pointing from 70.5 degrees forward, to 70.5 degrees aft. It collects calibrated radiance data in four color bands: blue (446 nm), green (558 nm), red (672 nm), and near infrared (866 nm). For all nine cameras, the red band has a resolution of 275 m, while the other bands have 275 m resolution only in the nadir-looking camera, and 1100 m resolution in the other eight cameras. The satellite is in a near polar orbit and repeats 233 separate ground tracks every 16 days. Terra takes approximately 99 minutes to orbit the earth, completing approximately 15 orbits per day. It takes about 9 days to acquire complete coverage of the earth's surface [1].

The MINX program allows a user to visualize MISR data and determine aerosol heights using a stereoscopic technique. By comparing camera images and using a

correlation matcher to find pixel disparities, MINX can calculate wind-corrected heights for user-digitized regions. The program returns the data graphically as well as storing the data in text files for further use. Although the MISR project has a standard stereo product that is automatically processed for every orbit, it is inadequate for small features like smoke plumes because the wind direction is calculated in 70 km areas. An advantage of the MINX algorithms over the standard product lies in that the user defines a wind direction that he interprets from the scene. By supplying a wind direction, the user removes one unknown, allowing MINX to calculate heights and winds at the same time. This improves accuracy, because heights can be very sensitive to differing wind directions [2].

Smoke plume height is an important parameter in the transport of wildfire aerosols. The atmosphere is composed of multiple layers, and depending on how high smoke is injected into the atmosphere, it could settle into different layers. The height and wind speed associated with a smoke plume can be used to model how far smoke can be transported and how long it remains in the atmosphere. Of particular interest is the planetary boundary layer, because if smoke rises above this layer it can be transported long distances and remain aloft for longer periods of time. Consequences of this can be a deterioration of air quality and because ash is an absorbent aerosol it can change the energy absorbance and emittance in a region. If an accurate database of heights and wind speeds from smoke plumes is made available, then the transport of these aerosols can be modeled and their effects predicted. MINX can retrieve those values stereoscopically from MISR data. This need for an accurate database of smoke plume heights is the basis for the MISR plume height project [3, 4].

The objective of the plume height project (which is a major component of my summer research project) is to collect a statistically large number of smoke plumes from various regions and time periods and make them available for climatology studies. This database is currently available online at <http://misr.jpl.nasa.gov/getData/accessData/MisrMinxPlumes/> and contains about 10,000 plumes. These have been gathered over the past several years by previous summer students and MISR team members. To start a new portion of this project, a region is selected by members of the MISR team who would specify an area of interest studied. The next step is to reduce the number of orbits that need to be examined. By using thermal anomalies from the MODIS (MODerate resolution Imaging Spectro-radiometer) instrument (also on Terra), it is possible to detect the infra-red radiance emitted by a fire and to identify when and where a fire is occurring. These are used to select only those MISR orbits and blocks (an orbit is broken into 180 blocks) that might contain smoke plumes.

To retrieve a plume's data, the user digitizes the plume's outline using the mouse and provides a wind direction. Then MINX calculates the wind-corrected heights and the wind speeds from the pixel disparities. Repeating the process for all the visible fires in the processed blocks creates a group of files that can then be added to the database. MINX also saves several other parameters from the data such as top of atmosphere albedo, aerosol properties of the smoke when available, and the radiative power in megawatts of the fire.

The errors that can occur during digitizing arise from geometric misregistration of cameras, bad digital elevation model (DEM) data, along track winds, cloud

contamination, and obscured radiative power. Misregistration problems occur when the cameras are not aligned properly with respect to each other. This can affect the pixel disparities calculated, although often this can be corrected inside MINX. When the DEM data are incorrect, the ground will appear to move as different cameras are viewed, and this will affect the retrieved heights of the smoke. Along-track wind is indistinguishable from movement due to parallax. MINX can separate the two, given a wind direction, but if the wind is too close to the along-track direction, there is no way to separate the two. Sometimes the smoke from a fire can be dense enough to obscure its own infrared radiation, and the power of the fire will be incorrect.

This summer I digitized 3438 objects in seven regions. The regions include: North America for January to June 2010; Bolivia and Paraguay for August and September 2006 and 2007; the African Congo for June 2006 and 2007; and southern Africa for September 2006 and 2007. Other than the North American data, a common element of the regions is that data were acquired during their fire seasons. My observations while digitizing all these fires were that fires vary greatly by region, terrain, and time. From the North American data (the longest times series I looked at) there are major differences between the winter fires and the summer fires. The trend I saw is that the fires tend to be larger and more numerous in the summer for North America. Also the fires tended to be much larger in Alaska and Canada than in the lower U.S. and Mexico. My observations for South America were that the Amazon basin tends to fill with smoke as the fires in the area burn. I observed the entire region having a pall of smoke (easily distinguishable from cloud cover in many cases because of color), and numerous fires either barely visible under the smoke or right at the edge of the smoke. In Africa there were many

more fires visible in an area of given size than in either South America or North America. Several scenes I saw contained more than 100 fires in a single MISR overpass, although not all of them could be digitized. In the Amazon basin there could be many obscured fires, so I do not know if there was a comparable number of fires in the Amazon. Another interesting feature in Africa was that the areas burned by fires were readily distinguishable from vegetated areas. Using MISR's near infrared band (which vegetation reflects) large dark areas with MODIS thermal anomalies at their edges were observed. This indicates that these areas have little vegetation and are burn scars, leading to the conclusion that some of the areas burned in Africa are several thousand acres in size.

The other project I assisted with is an ongoing project to validate MINX stereo heights, which has never been formally done. To start the validation a large dataset has to be collected to compare to some other instrument that is considered accurate. In this case lidar data is being compared with the height retrievals from MINX. Ground lidar instruments send a laser beam straight up and collect data on the backscatter from whatever aerosols the beam encounters [5]. The instruments will be used as ground truth for the validation. Difficulties encountered include finding coincident overpasses with lidar sites that meet the criterion for validation data. The data must include an aerosol that was strongly detected by the lidar at the same time MISR overpasses the area without contamination from higher clouds. Although MISR overpasses every point on earth (except at the poles) at least once every nine days, the issue is that the lidar I was using was ground based. To determine the heights accurately there had to be an aerosol that would not block the signal completely over the lidar site at the time MISR saw it. Clouds can be completely impenetrable to the lidar beam which leads to a "cloud block" in

which data are unavailable above a certain height. Another issue with validation is that lidar data are collected at a spatial point with a time series of data, while MINX acquires data at a point in time, over a spatial area. Others have collected space-based lidar as well to add to the pool of validation data. From an initial, visual inspection of the MISR and lidar retrievals, it appears there is not a large difference between the two.

Overall the majority of my summer project was involved in expanding the plume height database. The usefulness of this database is that modelers have a statistically significant set of data to study so injection heights can be used to predict the transport of aerosols. Also the datasets will help determine which areas will garner further attention for the project. Collecting validation data for MINX was to assist in an ongoing project.

- [1] (1998) Multi-angle Imaging SpectroRadiometer (MISR) Instrument Description and Experiment Overview, *IEEE TRANSACTIONS ON GEOSCIENCE AND REMOTE SENSING*, VOL. 36, NO. 4, JULY 1998
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- [5] <http://mplnet.gsfc.nasa.gov/instruments.html> "Instruments Overview"