Using MISR and MODIS Data For Detection and Analysis of Smoke Plume Injection Heights Over North America During Summer 2004

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Overview

This investigation is part of a larger project investigating the relationship among climate, fires, and air quality in order to predict the effect of possible future climate change on North American air quality. To initialize and calibrate chemistry transport models such as GEOS-Chem, we are using satellite imagery to gather statistics about smoke plumes from fires over North America during a five-year period.

One key feature we are measuring is the injection height of smoke plumes, which is derived from MISR's stereoscopic height product that takes advantage of the instrument's multiple camera views. In order to detect fires and measure their radiative power, we are using data from MODIS, taking advantage of its thermal infrared spectral bands. Note that in order to use data from both instruments, it is necessary to coregister them.

Our analysis is highly automated, using data mining, machine learning, and machine vision techniques to automatically identify potential smoke plumes within tens of thousands of candidate scenes, then automatically merge various sources of information to compile statistics on the properties of these plumes that are of interest to us.

MISR and MODIS

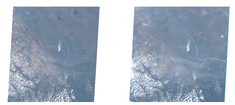
We are fusing data from two different instruments onboard the Terra spacecraft: MISR and MODIS. This is one of the largest studies to make use of both instruments together in a science investigation, in terms of the volume of data analyzed.

The Multi-angle Imaging SpectroRadiometer (MISR) has four spectral bands (red, green, blue, and near-infrared) and nine camera angles ranging from 70° forward to 70° aftward, and a ground resolution of 1.1 km (275 m for some cameras and bands). Stereo pattern matching techniques during automatic ground data processing produce a stereo height product with approximately 500-m vertical resolution.

The MODerate resolution Imaging Spectroradiometer (MODIS) has 36 spectral bands ranging from 400-14,000 nm, covering visible and thermal infrared, with a ground resolution of 1 km (250 m for some bands). Automatic processing algorithms produce standard daily, weekly, and monthly products with estimates of the locations of fires and their radiative power.

MISR L1B Radiance

Note how the smoke is more opaque in MISR's 45° view of this scene, due to the increased optical path length.



Nadir view — 45° forward view

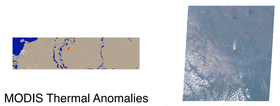
MISR L2 SVM Scene Classifier

A pixel classifier [1,2] developed using SVMs, a statistical learning technique, identifies smoke pixels (pink) and separates them from clouds (white), land (brown), and water (blue).

MISR Nadir Radiance — SVM Scene Classifier

MODIS L3 Thermal Anomalies

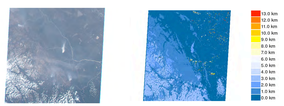
This product uses the 4μm brightness temperature and the difference between the 4μm and 11μm brightness temperatures, in comparison to nearby pixels for context, to detect fires and other thermal anomalies.



MODIS Thermal Anomalies (red/yellow) — Overlay on MISR image

MISR L2 Stereo Height

This product uses pattern matching in multiple MISR images to compute the height of each 1.1-km pixel above the surface. In this scene, the smoke plume is clearly visible in the stereo height image and reaches a height of 3 km.



MISR Nadir Radiance — Stereo height

MODIS L3 Clim. Modeling Data

This monthly, low-resolution product contains computations of the total area that was on fire in a given 0.25-degree cell, along with the mean radiative power in megawatts. Using this information, we can relate the smoke plume characteristics to the size of the fire and the energy it is produces.

Plume Detection

Thousands of scenes contain both smoke and fire, even in our initially limited study period that included only four months in the summer of 2004. Our automated technique to find smoke plumes uses MODIS fire locations as candidate starting points, then uses the MISR SVM classifier in combination with dynamic thresholding of the red-band radiance to determine pixels that might belong to a plume, resulting in a smoke mask.

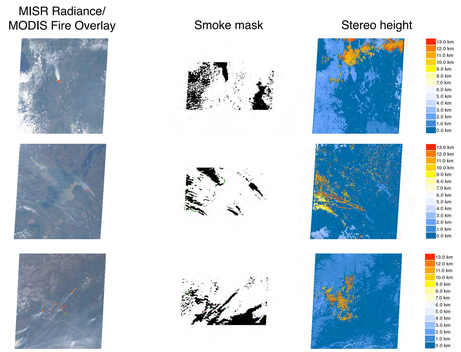
Using machine vision techniques, we determine if a long, thin shape appears in the mask starting at the fire location, and if so, we do a breadth-first search and create a mask of all pixels belonging to that plume, which we then use in the next step for further analysis.

MISR nadir image with MODIS fire detection overlay

Smoke mask image. The detected plume is shown as the red square with a blue tail.

Plume mask image. This particular plume is in black, all other smoke is in gray.

Additional examples

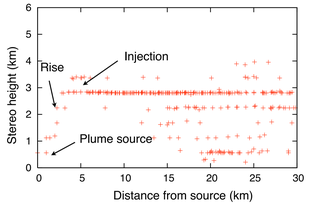


Plume Statistics

Using the plume mask gathered in the previous step, along with the five input data products, we collect the following characteristics of each smoke plume into a database:

- Location, date, time
- Instrument statistics:
  - Terra orbit number
  - MISR block number
  - MODIS granule ID
- Plume orientation
- Injection height
- Aerosol optical depth and angstrom exponent
- Active fire size and total burned area (km^2)
- Mean fire radiative power (megawatts)
- Wind direction and speed
- Land surface type
- Plume albedo

The plot on the right shows an analysis of the injection height of the smoke plume identified in the previous step. The plume rises from the surface and reaches a height of about 3 km.



Conclusions and Future Work

Preliminary analysis indicates an average smoke plume height of 1.7 km for fires during the summer of 2004. In the next few months we will be completing our database of summer 2004 fires and analyzing the relationship among the different variables listed above. We are also in the process of scaling up our computing facilities and algorithms, so that over the next year, we can apply this analysis to a full five years of MISR and MODIS data.

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References:

[1] M. Garay, D. Mazzoni, R. Davies, D. Diner. "The application of Support Vector Machines to the Analysis of Global Datasets from MISR." *Proc. of the 4th Conf. on Artificial Intelligence Applications to Env. Sciences, American Meteorological Society*, San Diego, CA, January 2005.

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