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NRL Satellite Volcano Ash Plume Detection

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Aviation Problem:

- Aircraft engines can be damaged by ingesting volcanic ash,
- Accurate knowledge of ash plumes problematic due to detection inefficiencies,
- Flights expanding, especially along great circle trans-oceanic routes near volcanoes.

USGS map highlighting tectonic plate and active volcanoes

Proximity of air routes to active volcanoes

DoD recon of active volcano in Marianna Islands

Mt. Spurr eruption of '92 as observed by space shuttle

DC-10 on tarmac after Mt. Pinatubo eruption

FAA Aviation Safety Program

Potential Remote Sensing Solutions:

Low Earth Orbiting (LEO) Sensors

Pros:
- Good channel suite for detecting ash cloud and aerosols,
- Superior spatial resolution for defining ash areal extent,
- Frequent overpasses at high latitudes with large swath (2,000-3,000-km) sensors,
- Utilize R&D and operational sensors in near real-time.

Cons:
- Channels not optimized for this specific problem set,
- Data latency issues, especially for descending orbits,
- Multi-agency/country data sharing sometimes problematic.

NRL Digital Data Sets: AVHRR (5 sensors), OLS (5), MODIS (2), SeaWiFS

Geostationary Earth Orbiting (GEO) Sensors

Pros:
- Temporal sampling partially offsets channel and spatial resolution issues,
- Good view/resolution for many low-mid latitude volcanoes,
- Some volcanoes viewed by multiple GEO sensors,
- Newer GEO sensors with expanding channel suite.

Cons:
- Channel set less adequate than LEO sensors,
- View angle for many high latitude volcanoes problematic,
- Spatial resolution poor for many large satellite zenith angle volcanoes views,
- Data latency for foreign sensors sometimes a limitation.

NRL Digital Data Sets: GOES-East/West, MTSAT, Meteosat-9/7

NRL Volcano Monitoring Analogies

Process multi-platform satellite sensors upon near real-time data reception

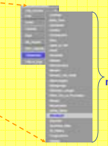
Tropical Cyclone (TC) web page:	Monitor global TCs [http://www.nrlmry.navy.mil/TC.html]
Satellite FOCUS web page:	"Focus" satellite images/products on specific DoD regions
Sensor suite available	Combined GEO/LEO satellites/sensors
Visible/IR/Water Vapor:	GOES/East-West, MTSAT, Meteosat-9/7, MODIS (2), AVHRR (5), OLS (5), SeaWiFS
Passive microwave:	SSM/I (3), SSMIS, TMI, AMSR-E, WindSat, AMSU (3), MHS (2)
Active microwave-	TRMM precip radar, CloudSat

Interact with volcanic ash advisory centers (VAAC, noted above) by enabling them to view near real-time multi-sensor data sets for both "fixed-static" sites as well as "turn-on/off" volcano views as interest rises/wanes for specific sites within their area of responsibility.

One Solution to Volcano Monitoring: NRL's NexSat Web Site

Incorporate both LEO/GEO near real-time data sets to monitor volcanoes world-wide:

Regions



Use research and operational sensors to demo future capabilities via NexSat.

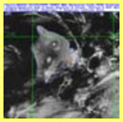
Ref: Miller et al., 2006(a)

26 volcanoes currently monitored and products posted as soon as processed

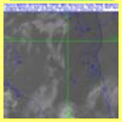
NexSat web site

http://www.nrlmry.navy.mil/NEXSAT.html

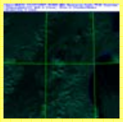
Kilauea Hawaii



Jabal-al-Tair: Red Sea



Kliuchevskoi: Kamchatka



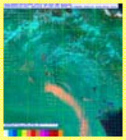
Channel 3 Fire Detection: Hot Spots

NRL Plume Detection: Algorithm & Examples

MODIS True Color Iraq/Persian Gulf region

- Dust/cloud coloration difference
- Airborne dust cooler
- Dust spectral signature
- Nine (9) vis/IR channel algorithm
- Separate water/land versions

Ref: Miller et al., 2006 (b)

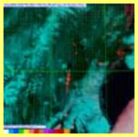


NRL Dust algorithm (pink –dust) with 19.5 m COAMPS mesoscale model forecast winds valid at image time.

Kliuchevskoi Volcano

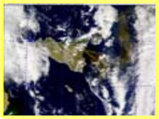
MODIS True Color

- Ash plumes often difficult to view due to faint separation from complex background scenes.
- Dust enhancement algorithm enables satellite analyst to extract plume areal extent.
- Data fusion with low-level NWP winds readily provides analyst with nowcasting knowledge.

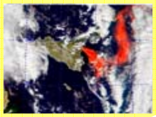


NRL Dust Alg with 19.5 m COAMPS winds

Mt. Etna Volcano



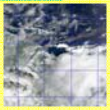
- Dust algorithm highlights plume well within partly cloudy scenes
- Thick plume provides strong signal that will not always be present

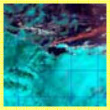


SeaWiFS Nov 7, 2002 1143Z

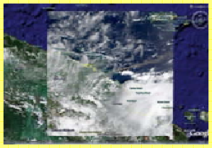
Satellite-derived Volcano Products

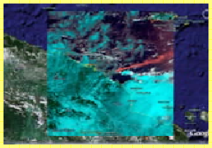
Manam PNG Volcano





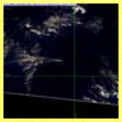
Dust algorithm identifies Manam (Papau New Guinea) ash plume well in spite of high clouds along plume boundary and does well even when plume density diminishes. Examples use MODIS true color on the left side of each comparison.



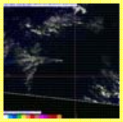


All NexSat volcano imagery, can be exported to Google Earth (GE) and readily viewed with the GE toolbox and thus manipulate the products with the full GE utility and potentially overlay other data sets (winds, warning areas, other plume detection aids).

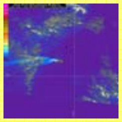
Anathan: Saipan



MODIS True Color



MODIS True Color with COAMPS 19.5 m Winds

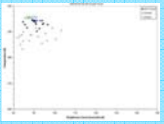


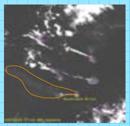
MODIS Aerosol Optical Depth (AOD)

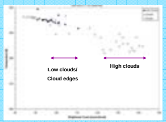
GOES-EAST Volcano Monitoring Product

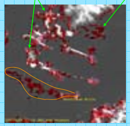
GOES EAST provides an exceptionally challenging situation for volcanic plume detection due to the loss of the split window 12 micron channel (Ellrod, 2004). However, the following equation has been shown to provide some operational applicability during daytime conditions (Ellrod and Schreiner, 2004).

Equation: $BT = 5 * [(DT) - 230]$ where BT is the brightness temperature of ash in degrees Kelvin where: $DT = (T2 - 1.5*T4 + 1.5*T6)$, T# = Brightness temp of channel #









GOES-East views of Soufriere Hills volcano plume (within orange outline) in the eastern Caribbean Sea on Feb 28, 2007 during the night (top) and day (bottom).

Cloud, ash and ocean pixels have been extracted manually from the IR/visible imagery to the left. The night time pass (top panel) does not provide a clear ash signal.

The resulting day time volcanic ash product (in red) does provide some signal. But low clouds/cloud edges generate false signals.

Reference: Ellrod, G.P, 2004 and Ellrod, G.P. and A. J. Schreiner, 2004.

Volcanic Detection/Emission Algorithms Under Consideration:

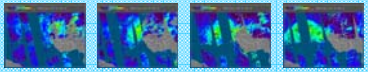
Reverse Absorption (Split Window technique): Reference: Prata, A. J., 1989 and Pavolonis et al., 2006

- Brightness temperature difference: (11 um - 12 um) with daytime complement using 4 channels (0.65, 3.75, 11 and 12 um)
- Discriminate ash clouds (negative temp difference) from meteorological clouds (positive temp difference)
- Four channel method more sensitive to volcanic clouds, less prone to false alarms and deals better with high tropical moisture.

Aerosol Optical Depth: Deep Blue: Reference: Hsu, et al., 2006

- Utilizes blue-wavelength radiance measurements from visible sensors to infer aerosol properties
- NASA algorithm provides aerosol optical depth (AOD) over both water AND land, major plus for potentially tracking volcanic plumes
- Applicable to SeaWiFS, MODIS(1, 3, 7, 8, 26, 31, 32, cloud mask and aerosol file) and upcoming VIIRS data sets.

MODIS true color composites for the NASA African Monsoon Multidisciplinary Analysis (NAMMA) field program [http://modis-atmos.gsfc.nasa.gov/deepblue/NAMMA/] highlighting a Saharan Air Layer (SAL) outbreak during 17-20 August 2007. Note the huge envelope of "dusty" air that progresses off the African coast and progresses westward over the eastern Atlantic.



MODIS Deep Blue (Hsu et al., 2006) aerosol optical depth (AOD) products at 500 nm (scale is from 0-1.5) valid during the same 17-20 August 2007 timeframe for the corresponding true color imagery above. Note the ability to monitor the beginnings of the dust envelope while over land (standard AOD algorithms are applicable to over-water only) and thus observe the dust event from genesis to advection well over Atlantic. The inclusion of valid over-land AOD values will benefit volcanic plume tracking efforts.

Three-band technique: Reference: Ellrod et al., 2003.

Satellite: GOES-11 or any other sensor that has 3.9, 10.7, and 12.0 um channels

Pros: Better discrimination of ash from clouds than using split-window method & best results in daytime and at night over ocean

Cons: Not useful if ash cloud is completely obscured in cloudy region

Cons: Some false detection during daylight in vicinity of cirroform clouds and not useful at night over non-ocean surfaces

Accuracy: In addition to pros/cons, Washington VAAC consensus is that it provided improved monitoring of ash, particularly in case of very weak eruptive activity (see reference).

SO_2 Detection: Reference: Watson, I.M., et al, 2004:

- MODIS retrievals at 7.3 micron (channel 28) and 8.6 um (channel 29)
- These channels are highly sensitive to SO_2 (11 & 12 um channels are not)
- 7.3 is not strongly affected by presence of either silicate ash or sulfate aerosol
- 7.3 application: mid-scale eruptions; disadvantage: high altitude required, some ice interference
- 8.6 application: mid-scale to passive degassing; disadvantage: strong ash and sulfate interference

Some Future NexSat Volcano Remote Sensing Data Sets:

METOP AVHRR 1-km: Gain access to global 1-km data set, versus GAC 4-km data.

DMSP OLS Fine & Night time visible: Fine resolution data to aid night time monitoring.

Locally received AVHRR/OLS data: Reduce data latency by incorporating descending passes that normally would take another orbit to reach readout stations.

NPP VIIRS: Take advantage of MODIS-like channel suite and superb spatial resolution (370-m) across the entire 3,000-km swath for both daytime and night time (day-night band) sensing in addition to Safety Net data latencies.

Oceansat-2: Potential to acquire a SeaWiFS type visible sensor data set.

Calipso: Lidar would see volcanic plumes, but only along narrow nadir track beam.

MERIS: Multiple-look visible sensor has potential, but data latency problematic.

References:

Ellrod, G.P.: Impact on volcanic ash detection caused by the loss of the 12.0 um "Split window" band on GOES imagers, Journal of Volcanology and Geothermal Research, 135, 2004.

Ellrod, G.P. and A. J. Schreiner: Volcanic ash detection and cloud top height estimates from the GOES-12 imager: Coping without a 12um infrared band, Geophysical Research Letters, 31, 2004.

Ellrod, G.P., B.H. Connell, and D.W. Hillger, 2003: Improved detection of airborne volcanic ash using multispectral infrared satellite data. J. Geophys. Res., 108 (D12), 4356, doi:10.1029/2002JD002802,

Hsu, N. C., S. C. Tsay, M. D. King, and J. R. Herman, (2006). Deep blue retrievals of Asian aerosol properties during ACE-Asia. /IEEE, Transactions on Geoscience and Remote Sensing/, 44, 3180-3195.

Miller, S. D., J. D. Hawkins, T. F. Lee, A. Kuciauskas, K. Richardson, J. Kent, R. Wade, C. Hoffman, 2006(a), NexSat: Previewing future NPOESS/VIIRS capabilities, Bull. Amer. Meteor. Soc., Vol. 87, 4, 433-446.

Miller, S. D., J. D. Hawkins, T. F. Lee, J. Turk, K. Richardson, A. P. Kuciauskas, J. Kent, R. Wade, C. Skupiewicz, J. Cornelius. J. O'Neil, P. Haggerty, K. Sprietzer, G. Legg, J. Henegar, and B. Seaton et al, 2006(b): MODIS Provides a Satellite Focus on Operation Iraqi Freedom, *Int. J. Rem. Sensing*, 27(7), 1285-1296, doi:10.1080/01431160500383772.

Pavolonis, M. J., W. F. Feltz, A. K. Heidinger, G. M. Gallina, 2006, A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash, J. Atmos. Oceanic Technol., 23, 1422-1444.

Watson, I.M., et al, 2004: Thermal infrared remote sensing of volcanic emissions using the moderate resolution imaging spectroradiometer. J. Volcano and Geothermal Res., 135, 75-89.

Prata, A.J., 1989: Observations of volcanic ash clouds in the 10-12 um window using AVHRR/2 data, Int. J. Remote Sens., 10, 751-761.

Acknowledgments:

The support of the research sponsor, the Federal Aviation Administration (FAA) Aviation Weather Research Program is greatly appreciated. The NexSat web site is sponsored by the NPOESS Integrated Program Office (IPO) to demonstrate next generation sensors using data fusion incorporating operational and research sensors. Special thanks to the NOAA-NASA Near Real Time Processing Effort (NRTPE) for the MODIS data, NOAA for access to the AVHRR data, the Fleet Numerical Meteorology and Oceanography Center (FNMOC) and the Air Force Weather Agency (AFWA) for MTSAT and Meteosat-9/7 data via NOAA, and the Naval Oceanographic Office (NAVO) for SeaWiFS data via Navy readout sites in Japan, Spain and Bahrain. Collaboration with these major satellite ingest and processing facilities permit NRL to carry out near real-time demonstrations with a relatively modest internal computing facility. Thanks also to David Scheider and Paul McCrone for providing volcano plume images.