MFE 659 Lecture 5b
The Inconvenient Truth about Vog

Outline

- Introduction: Vog and its Hazards (Motivation)
- Goals of Vog Measurement and Prediction (VMAP)
- Current Modeling Implementation and Web Server
- Model Validation
- Future work
- Summary

Geography of the Lava Flow Hazard

Volcanic emissions are greatest where the lava first reaches the surface.
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Formation of Vog

Vent emissions are composed primarily of water vapor, SO$_2$, CO$_2$ and various trace gases and metals. SO$_2$ rapidly mixes with water vapor to form gaseous sulfuric acid. A majority of the liquid sulfate also quickly converts to various sulfate compounds forming aerosols via:
- Nucleation
- Condensation onto existing aerosol

These sulfates form a layer of volcanic smog known as vog.

Monitoring VOG

Correlation Spectrometer (COSPEC) - COSPEC measures the amount of ultraviolet light absorbed by sulfur dioxide molecules within a volcanic plume. The Flyspec has largely replaced the COSPEC, being lighter, less expensive, with no loss in accuracy and precision.

Vehicle-based SO2 measurements are made downwind of the summit and east rift zone plumes on Crater Rim Drive and Chain of Craters Road during trade-wind conditions.

Proximity of Hazard to Volcano Village

2,231 Residents (2000 census).
4 miles north of Kilauea. 8 miles northeast of Pu’u O’o vent.
Can be exposed to SO2 levels as high as 2000 ppb
EPA’s regulation: 24 hour average from man-made sources
should not exceed 140 ppb SO2

Health Impacts from SO₂

In animal studies, high concentrations of SO₂ shows airway inflammation and hyper-responsiveness.

Studies on mild asthmatics that were introduced to SO₂ levels of 500 ppb showed increased airway resistance while exercising.

Study conducted by Reid Hoshide in Volcano Village from July 2006 to February 2007.

Spirometers used to determine Forced Expiratory Volume in one second and the Forced Vital Capacity.

6-8 spirometer measurements made per subject per visit.

Measured SO₂ with an Interscan monitor.

Conclusions of Volcano Village Study

Forced Expiratory Volume decreased significantly with increases in SO₂ up to a maximum concentration of 450 ppb.

Ratio of Forced Expiratory Volume/Forced Vital Capacity also decreased but not as statistically significantly in this exposure range.

Implications for public health: On high vog days stay indoors use air conditioning with a moist handkerchief.

Health Impacts from Sulfate Aerosols

Volcanic aerosol is of a size (0.1-0.5 µm) that can effectively reach down into the human lung, causing respiratory distress.

Epidemiological studies show that sulfates increase bronchitis, chronic cough, and chest illness.
Health Impacts from Sulfate Aerosols

“I’m seeing a 30 to 40 percent increase in vog-related symptoms,” said allergist and immunologist Dr. Jeffrey Kam on Oahu, “The main complaints associated with the vog are the increasing breathing difficulties. The worst one is obviously the asthma flare-up. They can have nasal congestion, wheezing, itchy and watery eyes and irritated throat.”

Vog Impact on General Aviation

Aerial photograph of Maui as aerosol obscures the lower slopes of Haleakala January 25, 2000, creating IFR conditions for pilots.

ACE1 Flight: Plume Characteristics

Impact of Vog on Agriculture

On August 11, 2010, the U.S. Department of Agriculture designated Hawaii County as a primary natural disaster area due to losses caused by ongoing vog conditions.

Crops impacted include coffee, corn, daikon (white radish), leafy vegetables, watercress, ginger, and cut flowers.

Recent cut flower damage occurred near Waimea/Kamuela on the northwest side of the island.

Payments are now being issued to ranchers who have lost fencing due to accelerated rusting.
Impact of Vog on Agriculture

There were 48 protea farmers in Ocean View on the Big Island in 2008. Today, because of the severe vog conditions, there are 3. While the federal government has offered low-interest loans to the farmers, requests for no-interest loans have been denied presumably because of the pervasive nature of the vog.

An Enhanced Threat from Vog

The recent increases in vog emissions have increased the importance of an accurate vog concentration forecasts for mitigation. Summit sulfur dioxide (SO2) emissions reaching record high levels in March 2008; a new vent opening in Halema’uma’u Crater; a small explosive eruption at Kilauea’s summit, the first since 1924; and lava flowing into the sea for the first time in over eight months.

Continued enhanced emissions have been catastrophic for nearby ecology and the SO2 concentrations in Volcano and Hilo under kona winds far exceed the EPA health standards requiring evacuations and other disruptions for the local population. Pu’u’O’o vent (right) is part of the east rift zone.

Kilauea SO2 Emissions (1984-2008)

Averaged SO2 emissions (metric tons per day) from Kilauea’s summit and east rift zone 1992 - 2008.
Increased Health Threat

EPA's regulation: 24 hour average from man-made sources should not exceed 140 ppb (red line).

Recent Kilauea SO₂ Emissions

Weekly averages of SO₂ emissions (metric tons per day) from Kilauea's summit and east rift zone from 26 October 2010 until present.

The Variable Threat from Vog

During the first two weeks of March 2011 emissions peaked at 11,000 metric tons/day associated with a new eruption along the Kamoamoa Fissure.

Dispersion of Vog

Heavily dependent on wind patterns and stability.
Predominantly tradewinds (from the northeast) from May to October.
More frequent periods of "Kona winds" from the south from November to April.
Effects Felt far Downstream

Vog plume impacting Oahu; compare visibility on clear day (lower left) with vog conditions.

Goals of VMAP

To mitigate the impact of post-eruptive plumes of volcanic gas and aerosol on respiratory health, aviation and agricultural interests.

Develop the capability to predict the concentration and dispersion of volcanic plumes of aerosol using numerical dispersion model approaches.

Initialize and validate the model using enhanced observations and satellite data.

Provide real-time forecasts via web for dissemination to State DOH, NPS, HVO, NWS, PDC, Civil Defense, and general public.

Halemaumau Vent

HYSPLIT
Hybrid Single Particle Lagrangian Integrated Trajectory Model

Vog plume impacting Oahu; compare visibility on clear day (lower left) with vog conditions.
HYSPLIT Model
Hybrid Single Particle Lagrangian
Integrated Trajectory Model Version 4.9
Developed by Roland Draxler (et al.) at NOAA-ARL

Components:
- Trajectory Simulation
  - Time integrated advection
- Dispersion
  - Vertical diffusivity profile and wind shear
  - Horizontal deformation of the wind field
- Pollutant Concentrations
  - Particles: Cell-averaged
  - Puffs: Calculated at a specific grid point
- Variable grid resolution
- Nested grid capability

Input for HYSPLIT

Enhanced Observations of Emissions

Proposed networked FLYSPEC array deployed around Halemaumau vent (red dot). Prototype array will consist of units S₀-S₅. Testing of first systems taking place at

Input from WRF

- Output from the Weather Research and Forecast (WRF) Advanced Research (AR) model provides input for the HYSPLIT model.
- 1-km output files are used for Island of Hawaii
- 3-km output is used for the domain covering the outer Hawaiian Islands.
- The temporal resolution is 1 hour.
- WRF fields passed to HYSPLIT include, P, T, RH, U, V, W, terrain, and turbulent fluxes of heat and momentum.
New Silicon Graphics Super Cluster operated by the Mauna Kea Weather Center with a 1-km grid over the Big Island and 3-km grid across all the main Hawaiian Islands w/ 40 vertical levels. See mkwc.ifas.hawaii.edu

Input for the WRF model is provided by
- NCEP GFS model output for initial and boundary conditions
- Local Analysis and Prediction System (LAPS), which assimilates satellite and local data sets.

In the HYSPLIT (Lagrangian particle) model, the source is simulated by releasing many particles over the duration of the release.

In addition to the advective motion of each particle, a random component to the motion is added at each step according to the atmospheric turbulence at that time.

A cluster of particles released at the same point will expand in space and time simulating the dispersive nature of the atmosphere.

In a homogeneous environment the size of the puff (in terms of its standard deviation) at any particular time will correspond to the second moment of the particle positions.
Dispersion Calculation

- A fixed number of particles are released and followed for the duration of the model run.
- Operational model uses 20,000 particles per time step in the initial release. Particles are lost due to deposition and passing the model boundary.
- Particles within the domain at the end of the previous run provide an initial condition for the subsequent run.
- Maximum number of particles allowed in model during the run is 500,000. This number is a compromise between the CPU needed to track particles and the accuracy of the model output at the edges of the domain at the end of the model run.
- The turbulent velocity variance is obtained from WRF’s TKE (turbulent kinetic energy field).
- Model uses Kanthar/Clayson vertical turbulence computational method.

Conversion Rate: SO₂ to SO₄

- Conversion rate of SO₂ to SO₄ (sulfate aerosol) in the model is set at a constant rate of 1% per hour.
- Dry deposition velocity for SO₂ = 0.48 cm/s
- Dry deposition velocity for SO₄ = 0.25 cm/s
- Trajectories follow isobaric surface with full reflection assumed at the surface.

2010 Model History

- July 23rd model began running in batch mode every 12 hours.
- August 15th, web products became available.
- September 5th, Isobaric replaced vertical field velocities to help eliminate specious pollutants sources.
- October 6th, 10 vertically stacked sources were used to better simulate plume height, with 90% of the emission released at the top most plume height.

VMAP Website
Observational Sites for Model Validation

Satellite Validation

6 October 2010

Satellite Validation

October 11, 2010

Satellite Validation

December 26, 2010
Current observations vs 12 hr forecast for Kona include all aerosols and do not discriminate between sulfate and non-sulfate aerosols.