Abstracts from the Vog Symposium

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Vog Overview and Background

Volcanic emissions from the Kilauea East Rift Zone are causing the most obvious air pollution problem in Hawaii today. On *Kona wind* days, volcanic haze is clearly visible hundreds of miles away on Oahu. The characteristics and dispersion patterns of volcanic emissions have been well-defined; however, studies on possible health effects are inconclusive.

Kilauea East Rift Zone has been erupting almost continually since January, 1983. Everyday the volcano produces more than 1,000 tons of sulfur dioxide. In fact, the U.S. Environmental Protection Agency reports the only recent violations of air quality standards for sulfur dioxide in the region were the result of naturally occurring volcanic emissions at the Hawaii Volcanoes National Park ("Breathing Easier: a Report by EPA on Air Quality in California, Arizona, Nevada and Hawaii").

Air quality monitoring data from other areas on the Big Island are very limited; however, data collected by the Department of Health suggest that state and federal ambient air quality standards are not being exceeded in Kona or other areas of the Big Island even under the worst conditions. Nevertheless, sulfur dioxide, fine particles in the air, and various pollutant mixtures, such as sulfates and acid aerosols may individually or in combination present a significant risk.

Of special interest is the possibility that sulfur dioxide and other sulfur compounds are combining with oxygen and water to form sulfuric acid mists. These acid mists can irritate the respiratory tracts of humans and animals. At present, there are no air quality standards to judge the degree of health risks posed by these pollutant mixtures.

Since 1983, the Department of Health has received hundreds of calls from residents and visitors concerned about respiratory problems associated with exposure to volcanic emissions (vog). Anecdotal reports by doctors also support the contention that these pollutants may affect breathing and aggravate existing chronic respiratory and cardiovascular diseases. Sensitive individuals may include asthmatics, individuals with bronchitis or emphysema, possibly children, and the elderly. Unfortunately, existing records have been found to be incomplete and inadequate to characterize health risks. Thus, studies completed to date have been largely inconclusive.

This special issue of the *Hawaii Medical Journal* includes abstracts of recent air quality and health studies conducted on vog, and they represent the current state of understanding of the subject. Although studies on health risks to date are inconclusive, all involved in the symposium agreed that further work is needed to better characterize health risks.

Obviously, nothing practical can be done to mitigate the source; however, it is important that the Department of Health and other agencies further define current risks so that appropriate intervention strategies can be developed. With a firm scientific foundation, we will be in a much better position to address public health concerns associated with vog.

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Airflow Over the Island of Hawaii

Pertubations induced by the airflow past single isolated mountains include a variety of phenomena: flow splitting and flow deceleration on the windward side, mountain wakes in the lee side, etc. In addition, the airflow is affected by the diurnal heating cycle. From July 11 to August 24, 1990, the Hawaiian Rainband Project (HaRP) was conducted over the island of Hawaii to study the mesoscale airflow around the island, and the dynamics of early morning rainbands offshore of Hilo. The mesoscale airflow over the island summarized in this report is based on the data collected from surface stations and aircraft observations during HaRP.

Island blocking as revealed by the mean surface airflow

The mean trade-wind sounding taken by aircraft over the ocean east of Hilo during HaRP exhibits east-northeast trade winds on the order of 6 to 9 meters per second. Along the windward coast, flow splitting occurs in the Hilo Bay area. The airflow moves around the island with northeasterlies along the northeastern coast and southeasterlies along the northeastern coast. In addition to northern and southern tips of the island, strong surface winds also are found in the Humuula Saddle between Mauna Loa and Mauna Kea and in the Waimea Saddle between the Kohala Mountains and Mauna Kea. In both regions, the airflow moves around the mountains and channels through the saddle. On the windward slope, the incoming flow is decelerated significantly as it approaches the island. In the lee side, the trade winds are completely blocked by Mauna Kea and Mauna Loa with calm winds.

Nighttime and daytime flow regimes

The surface airflow is strongly modulated by the diurnal heating cycle. At night, much of the island has a downslope wind component except in the high wind regions: northern tip, southern tip, Waimea Saddle, and Humuula Saddle. The flow direction along the northeastern and southeastern coasts shows that the trade winds are being forced to move around the island.

On the windward slopes west of Hilo, on the Kona coast and along the Waikoloa coast downstream of the Waimea Saddle, the wind direction of the daytime flow regime is about 180° out of phase with the nighttime flow regime. In these regions, the wind flow has a large upslope component during the day. Pronounced upslope flow also is observed at Mauna Loa Observatory, on the southeastern flank of Mauna Loa, and along the Kona coast as a result of solar heating.

Wake vortices

The wake consists of two elongated counterrotating quasi-steady eddies that give rise to a wide region of strong reverse flow along the wake axis. The reverse flow extends westward from the west coast of Hawaii a distance of about 200 km. A cloud line extends along the wake axis and sometime broadens considerably farther downstream. Aerosol concentration in the southerly eddy is elevated due to the entertainment of Kilauea plume. Strong shear zones, trailing westward from the northern and southern tips of the island delineate the accelerated trade winds and air trapped in the recirculating wake.

References

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Atmospheric Structure Around the Big Island and How It Affects Vog Flow

Relative to the size of the Earth, the thickness of the atmosphere is comparable to a sheet of Handiwrap covering a one foot diameter globe. Half of the Earth's atmospheric mass exists below 16,000 ft altitude. In short, the atmosphere is thin.

This thin layer of air is naturally divided into a number of discrete vertical regions like successive floors in a four-story building. The equivalent of the first floor within the atmosphere is called the boundary layer. In the atmosphere, air normally gets colder with height, but there are situations where the reverse is true, these regions are called temperature inversion layers. In Hawaii, the base of the boundary layer is at sea level and the top is generally in the region of 6,000 ft (~1 mile) above sea level at a strong (up to 6° C) temperature inversion. This inversion produces the top of the lowest cloud layer observed around the islands and separates the boundary layer from the free troposphere.

The free troposphere extends from the top of the boundary layer to another temperature inversion called the tropospause. The tropopause is usually observed at around 50,000 ft over Hawaii. Above the tropopause is the stratosphere.

The vog experienced in Hawaii is injected into the boundary layer and is for the most part trapped there. Vog, the same as clouds, is generally unable to penetrate the inversion layer; thus, the vog is carried along by the prevailing low-level trade winds from the northeast when blowing in strength. In the lee of Mauna Loa, eddies in the trade-wind flow are capable of carrying the vog along the Kona and Kohala coasts. Occasionally the vog is carried to Neighbor Islands when the boundary layer flow is other than the normal trades.

Under upslope conditions, whereby a thin layer of warm, moist boundary layer air flows up the side of Mauna Loa due to daytime heating of the dark lava, vog may be drawn into the free troposphere and carried up to Mauna Loa Observatory (11,400 ft). In so doing, the vog is pulled up the slopes from near sea level and drawn across areas not normally exposed to vog.

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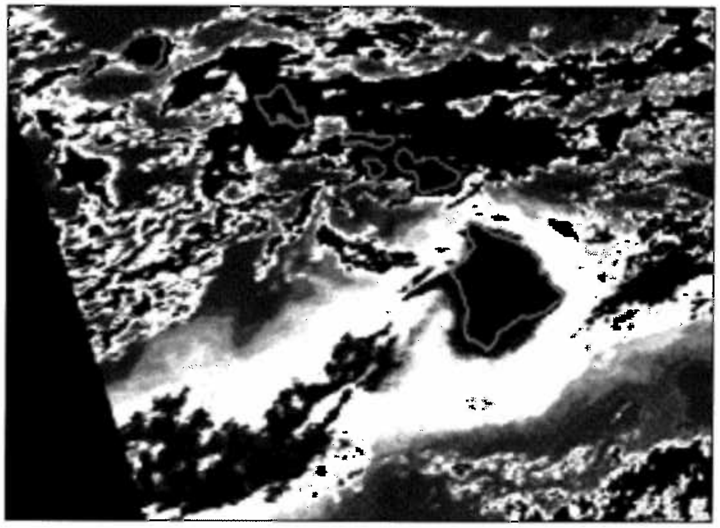
VOG Concentrations from Satellite



An AVHRR image (2/95) processed to obtain the aerosol optical concentration. In this image, island downslope nighttime winds have pushed some of the plume to the east while the majority is being carried to the southwest by the trades which are beginning to set in. The Kilauea Volcano plume is frequent but not always present in processed satellite images suggesting emissions are somewhat episodic. This image was collected by Pierre Flament and processed by John Porter (School of Ocean and Earth Science, University of Hawaii at Manoa).

Over the past few years we have developed algorithms that can derive aerosol optical depths from AVHRR satellites. These aerosol optical depths clearly show the Kilauea vog plume as it drifts downwind from the island of Hawaii. While the AVHRR satellite is useful for case studies, it is limited by the fact that it passes Hawaii only twice a day and often sun-glint conditions prevent the retrieval of the aerosol optical depth (particularly in the summer).

In the near future, the new GOES8 satellite will come on-line. This satellite will be improved (compared to previous GOES satellites) and will have sensor digitization similar to the AVHRR satellites (10 bits over 0 to 100% albedo). Therefore, this satellite will be useful for deriving the aerosol optical depth. A particular advantage of this satellite is the fact that it is geostationary, which means it will always be looking down on the Hawaiian Islands at the same viewing angle. Instead of taking images once or twice a day, it will provide images every hour and more frequently on occasion. If successful in obtaining funding, we will be providing aerosol optical depth images from an anonymous ftp (file transfer protocol) site where users could access the images freely.

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Vog Size Distributions, Optical Effects, and Spatial Variability

Vog is primarily a sulfate aerosol with a significant amount of associated water that varies with ambient relative humidity. It is usually mixed into the background aerosol and has a submicrometer size distribution with a mass peak near 0.35 µm. This size is particularly effective for scattering visible light, making light scattering measurements a rapid and reasonable surrogate for inferring the mass concentration of the vog aerosol. Light scattering measurements made every few seconds reveal marked variability in the vog structure over both horizontal and vertical scales. Factor of 10 changes in concentration were observed over time periods of less than one hour at the coastal site of Cape Kumukahi on the Big Island. Measurements from light aircraft reveal vertical gradients that can also increase by a factor of 10 between the surface and the tradewind inversion. Under appropriate meteorological conditions, these high concentrations aloft also can mix down to the surface. Temperature changes during the day vary relative humidity in ways that can result in changes in visibility for the same sulfate concentration. These factors must be considered when designing a sampling strategy or interpreting the results. In relation to potential health effects, during normal inhalation the hygroscopic growth of this vog, aerosol will grow in response to the near 100% humidity in the airways. Deposition determinations suggests that about one-third of the observed vog aerosol will be retained in the airways and lungs.

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Volcanic Emissions from Kilauea and Their Effect on Air Quality

Kilauea Volcano currently releases between 350 metric tonnes per day (T/D) of sulfur dioxide (SO_2) during eruptive pauses, and 1850 T/D during active eruption. Metric tonnes equal one metric ton or 1000 kilograms. Of this, between 90 T/D and 260 T/D are emitted from the summit and the balance from the East Rift Zone eruptive area. The volcano also directly releases water vapor, small particles, metals, and lesser amounts of other gases, including hydrogen sulfide, hydrogen chloride, hydrogen fluoride. This gas and particle mixture combines with air and sunlight to produce the hazy atmospheric condition known as vog: a combination of gases, sulfate aerosols including among others, sulfuric acid, ammonium sulfate, and ammonium hydrogen sulfate. Gas release of another form occurs at locations where lava enters the ocean. Molten lava (110° C) violently boils sea water to dryness and decomposes it, leading to a series of chemical reactions that produce a voluminous plume cloud containing a mixture of hydrocloric acid and concentrated seawater. This condition produces a localized atmospheric hazard known as lava haze or laze which can contain as much as 10 to 15 parts per million of hydrochloric acid. The geographic fate of this pollution is primarily a function of meteorology, especially wind speed and wind direction. Typically, northeasterly trade winds transport vog and to some extent laze plumes to the southern tip of the island where wind patterns wrap around, sending vog up the Kona coast. Here, vog becomes trapped by onshore/offshore winds, affecting populations in west Hawaii. During periods of Kona winds, primarily winter months, the eastern half of the island receives more of the vog.

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