GROUND-TRUTH MEASUREMENTS OF VOLCANIC SO₂ USING THE NEW UV CORRELATION SPECTROMETER “FLYSPEC”

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ABSTRACT

Utilization of the new ultraviolet correlation spectrometer, FLYSPEC, offers a potentially more accurate and cost-effective method for ground-truth measurement of atmospheric sulfur dioxide (SO₂) emissions in comparison to its older counterpart instrument, COSPEC. FLYSPEC was used at the Kilauea Volcano caldera to identify specific sources of volcanic emissions and to sample SO₂ emission rates from the volcanic plumes. Extensive data collection regarding SO₂ emission rates, topographical influences and atmospheric variables were used to understand spatial distribution, plume behavior, and the effects atmospheric conditions play on accuracy of data collection. Utilizing FLYSPEC on a continuous basis in a field-testing environment has validated the reliability of the instrument, its potential for extensive deployment, and shown the potential effectiveness as a ground-truth correlation tool for remote sensing systems for volcanic SO₂ emissions.

INTRODUCTION

Developed by the Hawaii Institute of Geophysics and Planetology, University of Hawai‘i at Manoa, FLYSPEC is a new ultraviolet (UV) correlation spectrometer designed for the detection of volcanic sulfur dioxide (SO₂) emissions. FLYSPEC is designed to replace its predecessor COSPEC, as an extremely lightweight, low-cost, and easy to operate instrument (Horton et al., in review). The cost effectiveness and ease-of-use of FLYSPEC, allows for the deployment of multiple instruments at a fraction of the cost, with minimal effort and resources. Acquiring SO₂ emission data with a UV correlation spectrometer no longer requires mounting a bulky instrument on an automobile, inside a manned airplane or mounted on a stationary tripod as has been necessary when operating the out-dated COSPEC (Horton et al., 2002). It is feasible for a single operator to carry multiple FLYSPEC instruments into the field, on foot with little or no effort. With these significant advancements in UV correlation spectroscopy technologies, FLYSPEC offers a large new potential of applications and abilities for a wider spectrum of users (Horton et al., 2003).

Information obtained with FLYSPEC has a broad potential and can be used as an SO₂ emission correlation tool for other means of volcanic plume analysis such as satellite (TOMS, MODIS, etc.) and ground-based remote sensing (LIDAR systems, etc). Unlike COSPEC, and although not demonstrated during this fellowship, FLYSPEC is able to acquire and analyze data real-time on multiple UV-absorbing gasses simultaneously. With this ability, FLYSPEC has further reaching potential than COSPEC in the analysis of volcanic emissions, emissions from industrial stacks, and for a variety of other environmental monitoring purposes (Horton et al., in review). FLYSPEC can be dispatched by multiple means, including low-cost unmanned aerial vehicles, mounting on a lightweight tripod for stationary measurements, fixed to a ground-based vehicle, or easily carried by a single person on foot into the field for remote location data collection. With this new found versatility, FLYSPEC can be used in coordination with other
SO₂ detection instruments for purposes of volcanic, industrial, and environmental monitoring with unprecedented ease of deployment.

BACKGROUND

Methods of detection for atmospheric SO₂ utilize incoming radiation from sunlight to evaluate atmospheric absorption of energy in the ultraviolet (UV) wavelengths. Sulfur Dioxide absorbs this UV light in specific wavelengths that can be detected using correlation spectrometer instruments such as COSPEC and FLYSPEC. Evaluating changing UV levels in the atmosphere to a known, calibrated reference, a path-concentration value of SO₂ can be calculated. When using COSPEC, it is imperative for data collection to occur during consistent sunlight levels in order to minimize errors due to changing light intensities. For example, a cloud moving past the sun during data collection would scatter incoming light and the signal received by COSPEC might be interpreted as a change in SO₂ concentration instead of signal intensity change. However, the software integrated into the FLYSPEC system evaluates incoming light signal using a slightly different technique than does COSPEC. Specific peaks and troughs in the UV spectrum, indicating absorption by SO₂, are monitored by the FLYSPEC software. Differences in those identified peaks and troughs are used to calculate an atmospheric path-concentration SO₂ value in ppm-m. (Horton et al., 2002; Galle et al., 2002)

Two primary objectives were established in order to evaluate FLYSPEC as a robust and reliable means of data collection in a true field testing environment. The efforts involved in achieving these objectives allowed for testing and development of FLYSPEC’s abilities and thus proving its superiority over COSPEC as a ground truth instrument.

Identifying specific sources of SO₂ emission is important to understanding volcanic plume behavior and characteristics. The first objective aimed to identify specific sources of SO₂ emissions and to produce a map displaying the identified sources within a well constrained geographic area... The second objective was to focus on the spatial relationships of SO₂ emissions relative to position, concentration of SO₂, atmospheric conditions and topographical influences. Identifying the influences of topography and atmospheric conditions on volcanic plume behavior is integral to understanding the spatial distribution of the SO₂ emissions from their source.

METHODS

The western edge of the Kilauea Caldera was selected for my project FLYSPEC testing area. It provided easy access to a known site of SO₂ emissions and relatively consistent wind conditions. The test area was accessed by motor vehicle using the Crater Rim Drive within Hawai‘i Volcanoes National Park; and SO₂ measurements using FLYSPEC were made on foot.

A general test area was established within the Kilauea Caldera in order to take initial SO₂ measurements using the FLYSPEC, identifying possible sources of volcanic emissions. Atmospheric SO₂ measurements were taken and the FLYSPEC data were evaluated using wind speed and direction information to determine the best location to establish a more defined area for data collection (Figure 1). SO₂ emission data were collected from February to November, 2003 with FLYSPEC. With the use of the integrated GPS device on FLYSPEC, the identified sources of SO₂ emissions were plotted using coordinate data recorded by the FLYSPEC software on ortho-rectified IKONOS satellite image. Data were collected during periods of wind conditions dominating from the northeast in order to maintain the most consistent conditions possible and allowing for the evaluation of the technique and instrument operation. Communication with the developers of FLYSPEC was established after each data collection session in order to assess any need for change in procedures. All data collected was forwarded to
Dr. Keith Horton at the University of Hawai‘i at Manoa for quality evaluation. Dr. Horton assisted in the creation of the source map for SO₂ emissions at the FLYSPEC field test site (Figure 2).

Using the newly created SO₂ emission source map, the traverse pattern used during data collection was changed slightly in order to better survey the areas within the Kilauea Caldera that radiate downwind from the identified SO₂ sources. GPS waypoints were used with a handheld GPS unit in order to maintain repeatability in traverse patterns during FLYSPEC data collection. Once again, the field test area was surveyed using FLYSPEC to collect atmospheric SO₂ concentration distribution data.

For the second term of data collection, heavy emphasis was placed on recording details regarding atmospheric conditions, including precipitation, humidity, wind-speed and direction, and sunlight intensities. Weather stations operated by the Hawaiian Volcano Observatory provided much of the wind and precipitation information used in this analysis. Field observations were made and recorded regarding any apparent changes in atmospheric conditions during the course of data collection.

One set of FLYSPEC data was collected concurrently with a vehicle mounted FLYSPEC unit performing multiple traverses along the Crater Rim Drive, further downwind from the FLYSPEC field test area. The two data sets were collected simultaneously in order to determine plume characteristics along a greater distance from the SO₂ emission sources and to determine SO₂ flux during the walking traverses.

The entire volume of FLYSPEC data collected was imported into a spreadsheet format for detailed analysis. SO₂ ppm-m values for each data set were displayed on an X-Y plot comparing SO₂ value vs. time. SO₂ values on the X-Y plot were used to identify patterns in SO₂ concentrations along the time scale. Data points representing SO₂ concentration peaks were extracted and comprised a new, reduced data set for further analysis (Figure 4).
The reduced data sets were converted to database files and imported into a GIS software system. Using the GIS software, the FLYSPEC data could then be displayed and manipulated to perform a variety of analyses. The first analysis involved overlaying each of the data sets, using the GPS location information recorded with each point recorded from the reduced FLYSPEC data. A unique, graded color was assigned to each data point corresponding to the ppm-m values in order to analyze spatial changes in SO2 concentration measurements over time. Each data point was tagged with information regarding date, time, location, etc. Any major changes in position of SO2 emission sources over time could be analyzed using the tagged information as well as the HVO archived weather station data for effect by variation in atmospheric conditions. Field notes of observations were included to provide more information for detailed analysis of observed change in spatial distribution of SO2 concentrations.

Spatially plotted data were superimposed onto a 1m resolution IKONOS satellite image to view data point location in relation to surface features of the FLYSPEC field test area. Combining the FLYSPEC data with the satellite image, identified SO2 emission sources could be analyzed with respect to physical location on the volcanic surface from which they are being emitted. In addition, overlaying ppm-m assigned data point over a satellite image, topographical influences on plume behavior could be evaluated.

RESULTS

Incorporating the numerous data sets with the IKONOS satellite image, a great deal of information was revealed. A first observation is that the SO2 emission sources exhibited very little change over the period of data collection. SO2 path-concentrations vary greatly as one moves further from the sources. However, the areas of highest concentration showed almost no migration. Comparing field notes with satellite incorporated data, it becomes evident that the primary source of SO2 emission comes from the southwest wall of the Halemaumau Crater. As one might assume, SO2 concentrations were highest at points corresponding with heavy sulfur deposits on the surface.

Data collected on November 20 utilized two FLYSPEC instruments collecting data simultaneously; one performing the standard foot-borne traverse while the second FLYSPEC was vehicle mounted scanning the perimeter of the test area in the standard HVO methodology. This data set provided valuable information regarding plume behavior as it moves across the caldera floor. Plotted data revealed that the plume follows the general trend of wind from the northeast. However, the gas tends to exhibit a pooling up and a behavior indicating spilling over the cliff face wall on the western edge of the caldera. These data indicated that SO2 concentrations build up at the caldera wall and then billow over with a gust of wind, lowering the concentration. Areas at the southern edge of the test area, with a less extreme elevation gradient, tend to maintain a relatively constant plume flow with only minor variations.

Evidently, wind direction and surface features that affect wind have the greatest influence on plume behavior, assuming a constant source. It is not apparent from these data whether precipitation or humidity might play a significant role in determining whether variations of SO2 output can be attributed to variations from specific sources. There was little variation in the position of emission sources during this project. Therefore, from these data, changes due to atmospheric conditions other than wind can not be evaluated effectively as contributors to SO2 emission system changes.

The final result in combining the FLYSPEC data collected from August to November was the creation of a false color snapshot of the SO2 plume in the test area (Figure 4). The image
represents the average ppm-m values of SO₂ in the FLYSPEC field test site. The image shows what plume conditions an observer could expect to experience at any given time in the experimental area.

CONCLUSIONS

Combining the information gathered from ten months of data collection with FLYSPEC, many conclusions can be made. Most importantly to the instrument developers, FLYSPEC endured a continuous campaign of data collection with no downtime due to instrument or software failure. Any problems encountered were typically due to operator error or adverse weather conditions.

This project is proof that FLYSPEC has broadened the potential for new applications utilizing new technologies for the atmospheric monitoring of UV absorbing gasses. Finally, FLYSPEC is easy to operate and provides a powerful tool for deployment as a ground truth instrument and for traditional volcano and industrial monitoring applications. The potential application of this type of low-cost instrumentation as an atmospheric groundtruth system has been demonstrated.

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REFERENCES


Figure 4 – Plume snapshot: average volcanic SO$_2$ concentration, Feb-Nov, 2003.