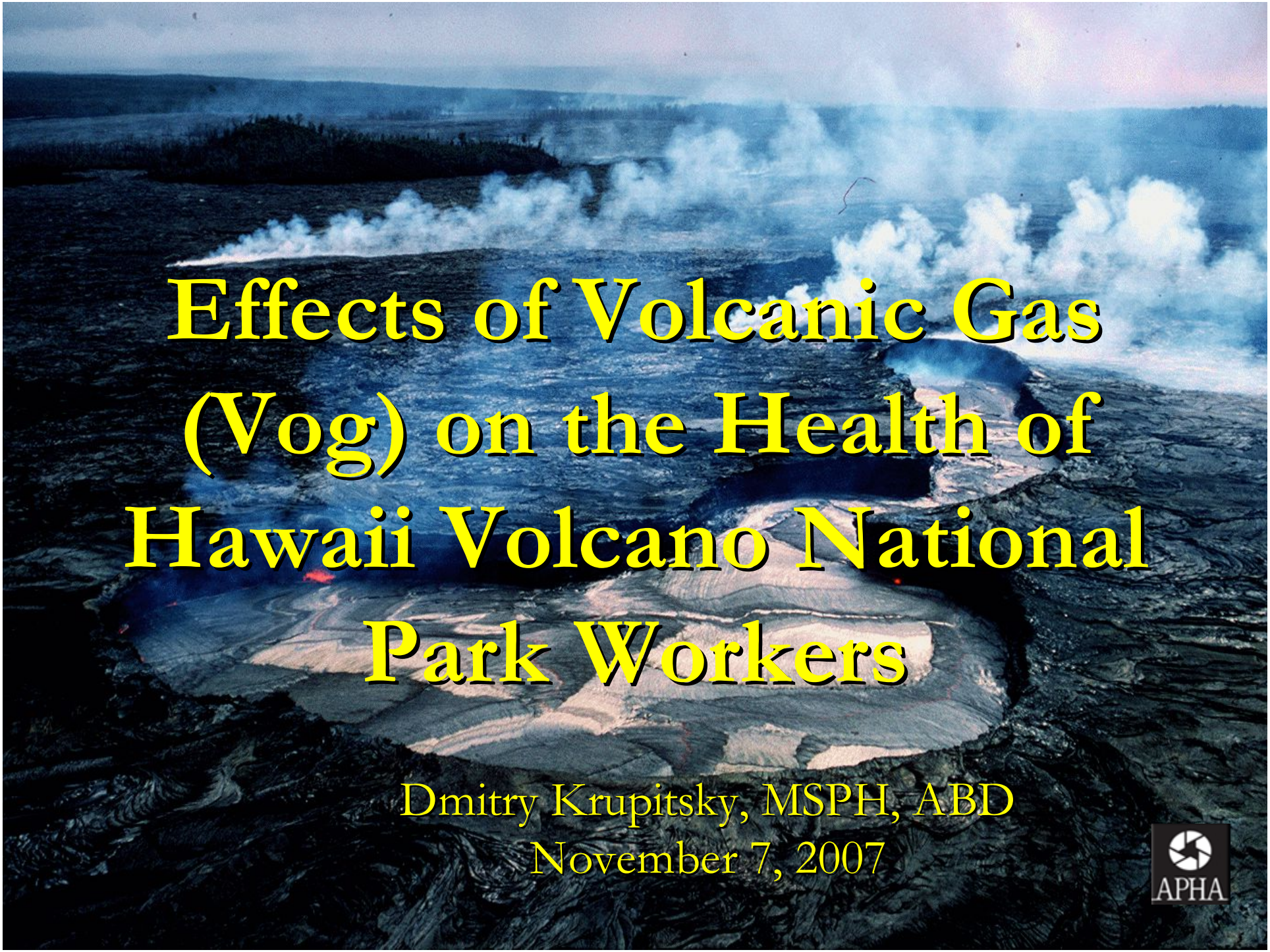

Effects of Volcanic Gas (Vog) on the Health of Hawaii Volcano National Park Workers

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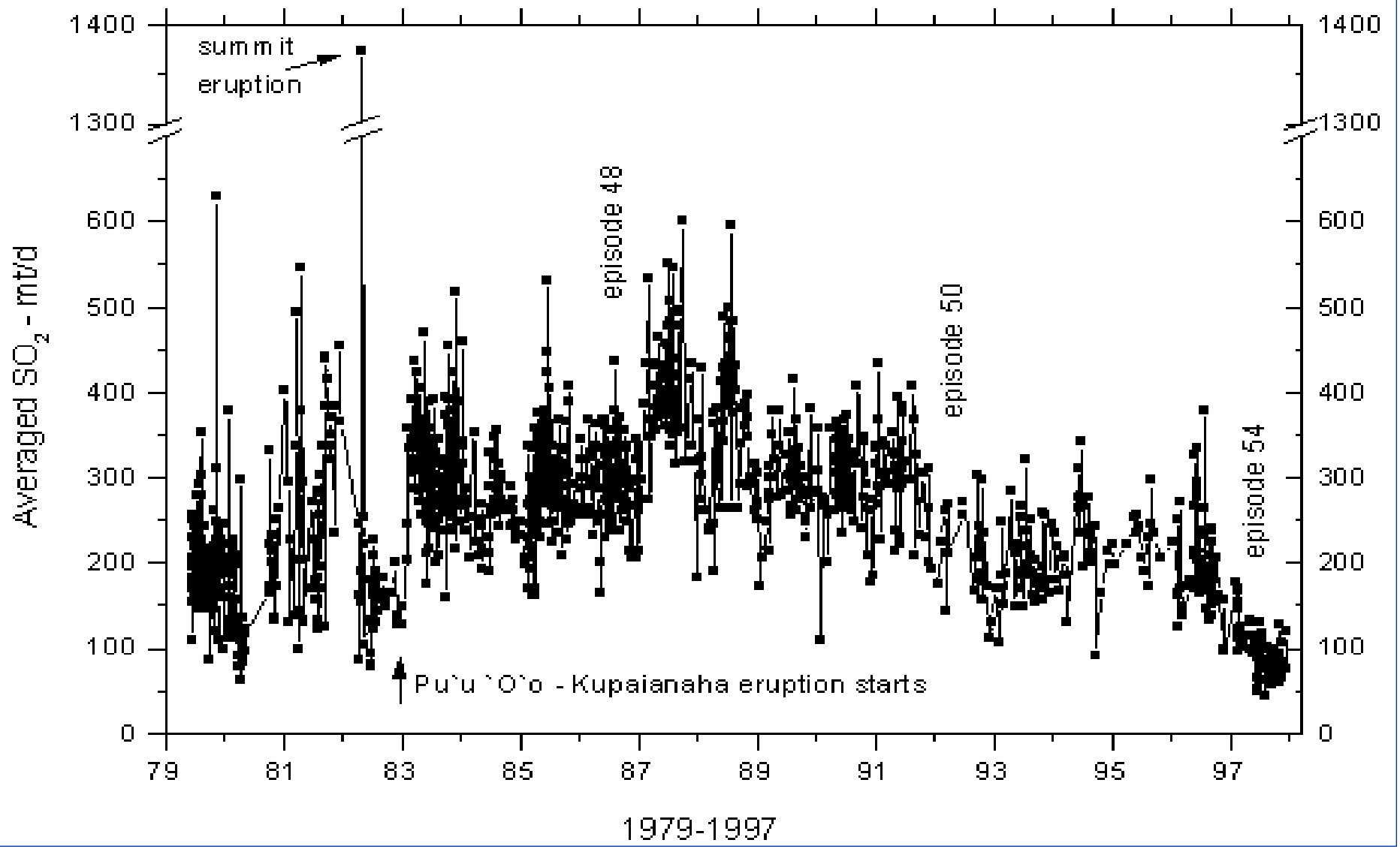
November 7, 2007

APHA

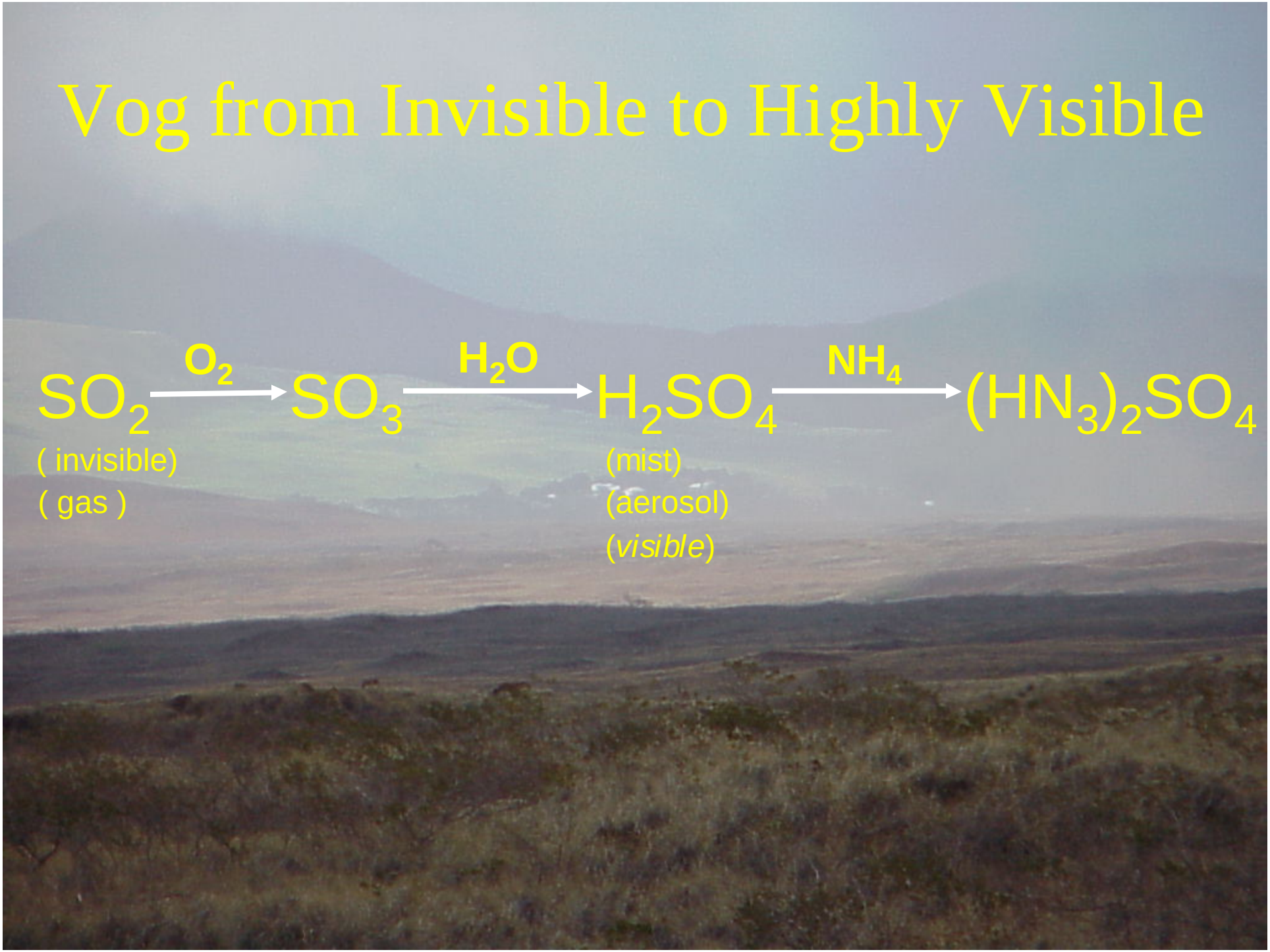
Kilauea Volcano

- Sulfur dioxide (SO_2), hydrogen sulfide (H_2S), Hg, ash, CO_2, and other gases are expelled in abundance from Kilauea Volcano during the eruptive phases.
- Since 1986, Kilauea Volcano has typically effused 1,000-2,000 tons per day of sulfur dioxide gas (SO_2) into the air over the Big Isle (Elias et al., 1998)
- Irregular eruptions beginning in 1983 became more continuous in 1986.
- Kilauea is the of the largest single source of SO_2 of the world

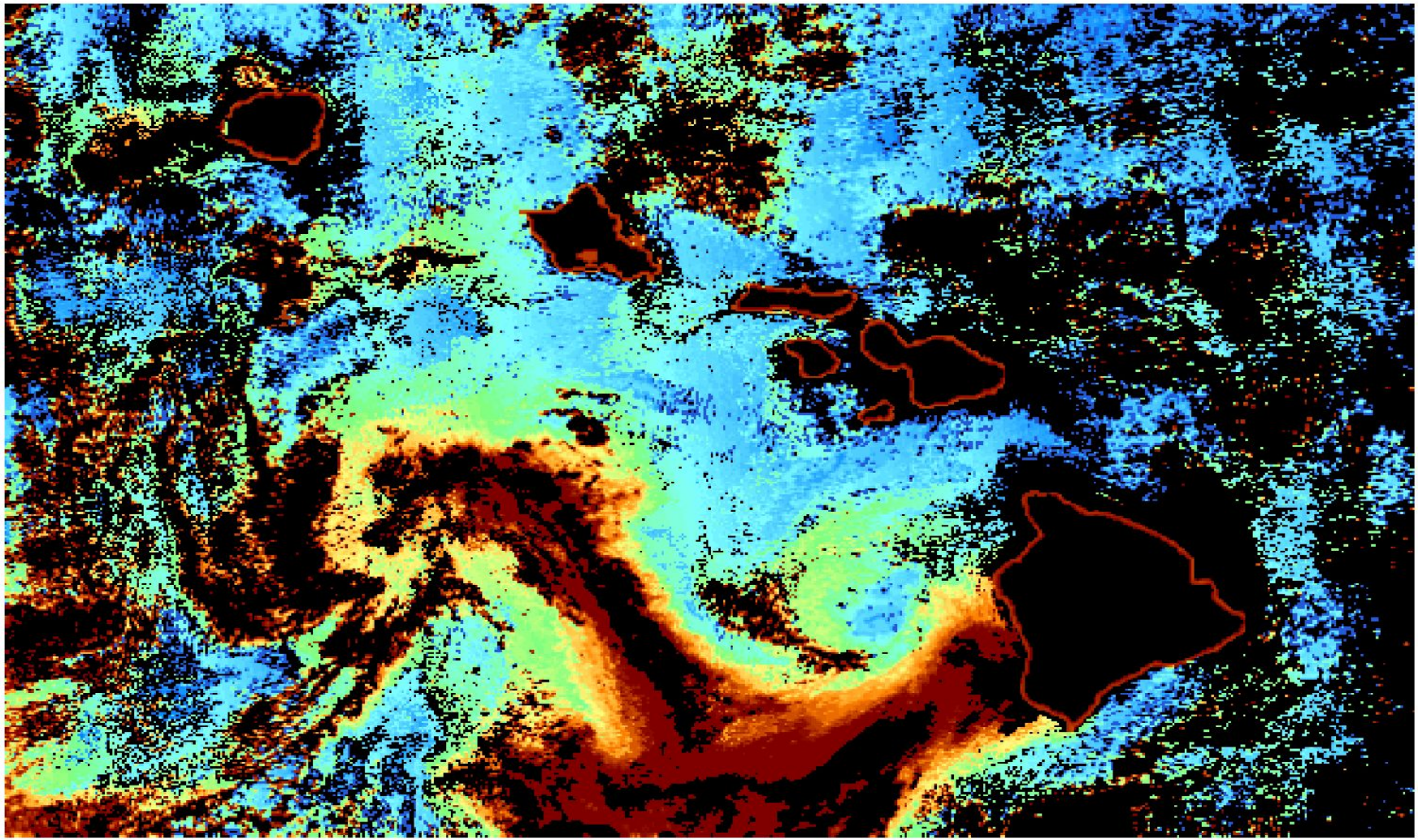
Kilauea Summit SO_2 1992-1997



Vog from Invisible to Highly Visible



View of Vog from Space



The aerosol was detected in Johnston Island and as far as 1000 km north from the Big Island. (Clarke and Porter 1991)

Public Concern

At times, vog makes the front pages news.

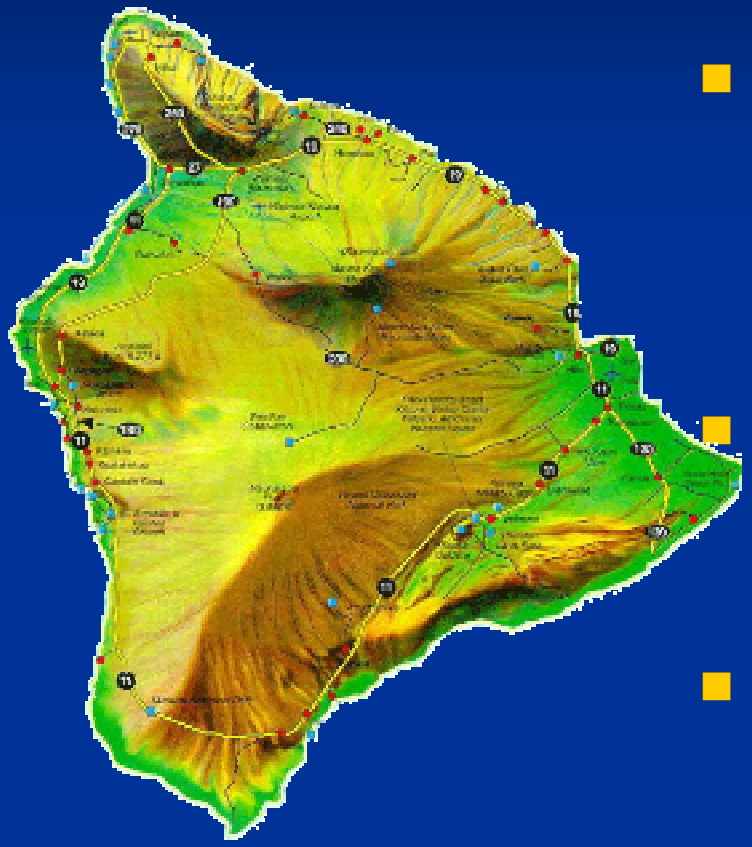
Anecdotal evidence, HVNP Visitors complain that vog triggers

- Headache
- Cough
- Asthma attack
- Allergic reaction
- Sinusitis
- Problem Breathing
- Eye Irritation

Douglas W. Dockery, C. Arden Pope, Xiping Xu, John D. Spengler, James H. Ware, Martha E. Fay, Benjamin G. Ferris, and Frank E. Speizer. An Association between Air Pollution and Mortality in Six U.S. Cities. New England Journal of Medicine. 329 (24):1753-1759 Dec 1993

- Estimated the effects of air pollution on mortality (prospective cohort study)
- Survival analysis was conducted with data from a 14-to-16-year mortality follow-up of 8,111 adults in six U.S. cities.
- Reported statistically significant associations between air pollution and mortality.
  - The adjusted mortality-rate ratio for the most polluted of the cities as compared with the least polluted was 1.26 (1.08-1.47).
  - Air pollution was positively associated with death from lung cancer and cardiopulmonary disease but not with death from other causes considered together.
  - Mortality was most strongly associated with air pollution with fine particulates, including sulfates.
- They suggested that PM is "associated with fine particulate matter, contributes to excess mortality in certain U.S. cities."

Mannino DM, Ruben S, Holschuh FC, Holschuh TC, Wilson MD, Holschuh T. Emergency department visits and hospitalizations for respiratory disease on the island of Hawaii, 1981 to 1991. Hawaii Med J. 55(3):48-54, 1996 Mar



- Examined ED visits and hospitalizations for Asthma and COPD 1981-1991

  Found that

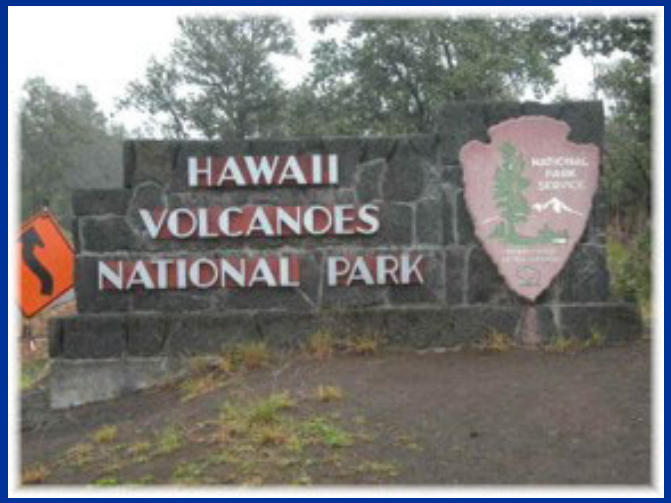
- Asthma visits in 1987-1991 are higher all over the Island of Hawaii than 1981-1986
- Hospitalization rates were higher for Kona than Hilo side
- During the weeks that winds were from the West, ED visits for asthma increased by 15%

Michaud JP, Grove JS, Krupitsky D. Emergency department visits and "vog"-related air quality in Hilo, Hawaii. Environ Res. 2004 May; 95(1):11-9.

Compared Asthma/COPD, cardiac, flu/cold/ pneumonia and gastroenteritis ED visits in Hilo, HI between 1/97-5/01 and air quality (PM1, SO2) with 0,1,2,3 days lag

- They found significant association with vog and all of the ED visits with exception of gastroenteritis
- Asthma/COPD was the strongly significantly associated with SO2 3 days lag and PM1.0 with 1 day lag
- However, month of the year was strongly associated with Asthma/COPD than air quality
- Most of the variation in Asthma/COPD ED visits are not explained by air quality

Michaud JP, Krupitsky D, Grove JS, Anderson BS. Volcano related atmospheric toxicants in Hilo and Hawaii Volcanoes National Park: implications for human health. Neurotoxicology. 2005 Aug;26(4):555-63



- Most of the PM1.0 is acidic sulfates aerosol
- SO2 is twice higher in HVNP than Hilo
- Air quality in HVNP is below the National Ambient Air Quality Standard
- HVNP firefighters could be exposed to twice higher $PM_{1.0}$ than voggy day in HVNP VC if HEPA masks are not frequently worn
- The lowest $PM_{1.0}$ in Hilo is 3:00 PM
- The lowest $PM_{1.0}$ in HVNP is 12:00 AM

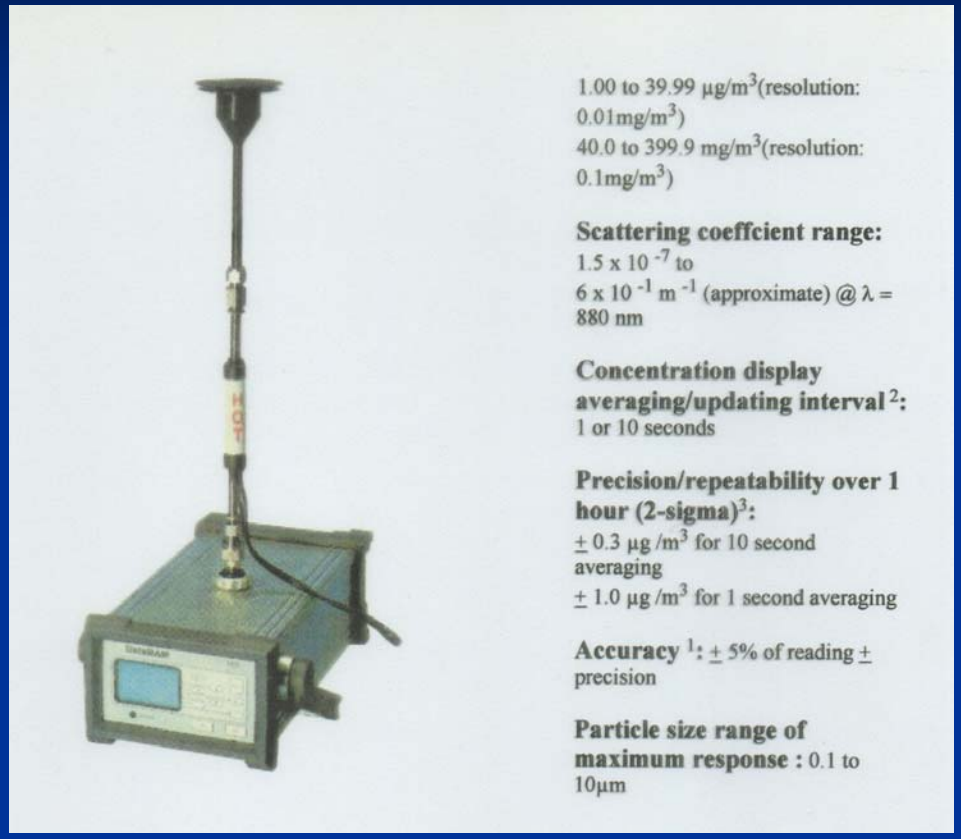
Research Questions

1. Investigate the relationship between the visually observed vog index and symptoms and lung function of the workers in the Hawaii Volcano National Park
2. Determine either the visually observed or instrument measured vog is the best predictor of worsen lung function and symptoms

Methods

- Air Quality Measurements
- Health Measurements
- Analysis

Air Quality :: Particular Matter



1.00 to 39.99 µg/m^3(resolution: 0.01mg/m^3)
40.0 to 399.9 mg/m^3(resolution: 0.1mg/m^3)

Scattering coeffcient range:
1.5 x 10 $^{-7}$ to
6 x 10 $^{-1}$ m $^{-1}$ (approximate) @ λ = 880 nm

Concentration display averaging/updating interval [2]:
1 or 10 seconds

Precision/repeatability over 1 hour (2-sigma)[3]:
± 0.3 µg /m^3 for 10 second averaging
± 1.0 µg /m^3 for 1 second averaging

Accuracy [1]: ± 5% of reading ± precision

Particle size range of maximum response : 0.1 to 10µm

The hourly $PM_{1.0}$ monitors were operated by Respiratory Effects in a Volcanic Environment (REVE) project.

PM_1 aerosol was measured by nephelometry (880nm)

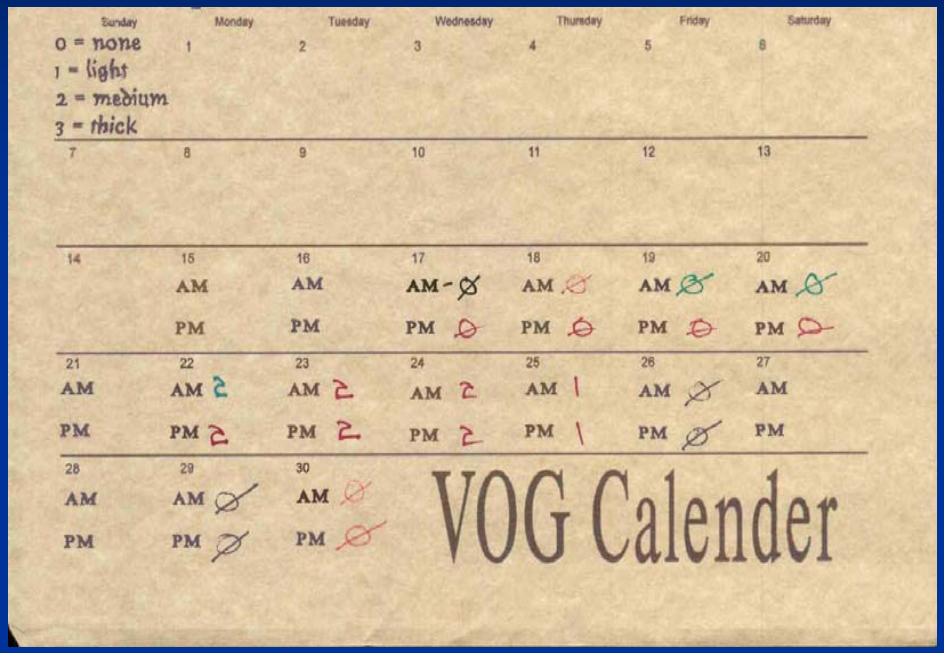
Daily PM_{10} and $PM_{2.5}$ will be obtained for Hilo, HI and HVNP if available

Air Quality :: Sulfur Dioxide

The hourly SO_2 was measured by pulsed fluorescence (model 43-C SO_2 monitor, Thermo Environmental Instruments, formerly Thermo Electron Corporation (TECO), Cheswick, PA, USA). These instruments were set up to auto calibrate once every 24 hours by EPA approved methods (span and zero gas and flow stream switching).

The instrumental operation utilizes the principle of "Pulsed Fluorescence" that is based on the fact that sulfur dioxide molecules absorb fluorescent energy, producing electronically an excited SO2 molecule with a known spectral decay rate to the ground state. The fluorescence emitted by the reaction is detected by a photo multiplier tube and the signal is a converter proportional to an electronic output signal. The signal is then processed to digital and analog outputs and captured by an ESC data logger located at each site.

Air Quality :: Monitored by Observers



- Vog presence was monitored by <u>four</u> observers independently
- Each observer recorded data in the individual calendar
- <u>All of them were park employees</u>
- None of them participated in the symptoms and lung function monitoring part of the study

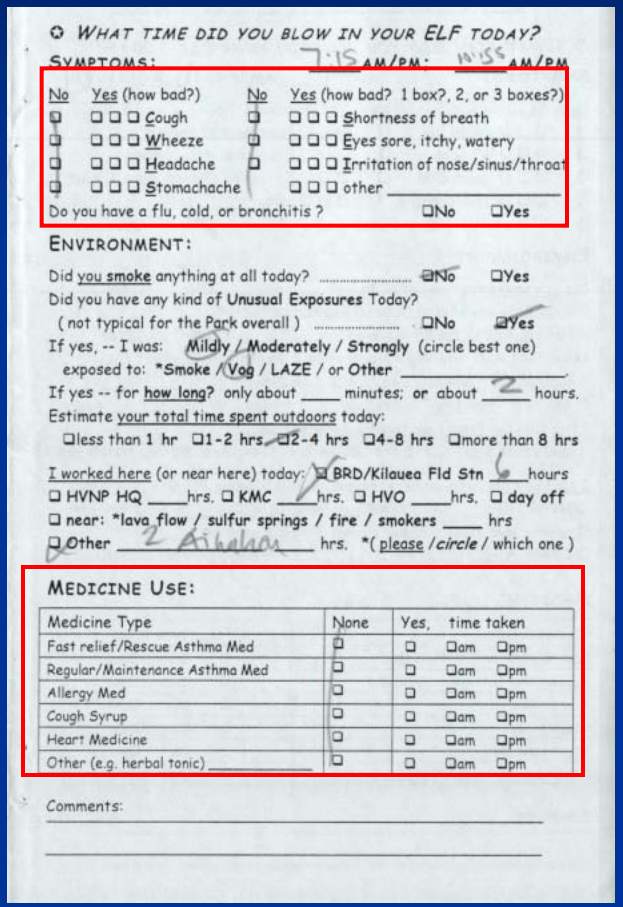
Methods

- Air Quality Measurements
- Health Measurements
- Analysis

Health Status Measures

- During two intervals of 3-4 months each, 121 subjects were enrolled.
- The working adults (18-65 years old) were recruited via public speaking engagements at HVNP and by participants voluntarily picking up enrollment forms from the Park Information Center.
- These adult populations were NOT recruited (nor excluded) for asthma, however, 'regular smokers' (>3x/wk, self-reported) were excluded.

Lung Function :: **Diary**



WHAT TIME DID YOU BLOW IN YOUR ELF TODAY?

SYMPTOMS: 7:15 AM/PM: 10:55 AM/PM

No	Yes (how bad?)	No	Yes (how bad? 1 box?, 2, or 3 boxes?)
☐	☐☐☐ Cough	☐	☐☐☐ Shortness of breath
☐	☐☐☐ Wheeze	☐	☐☐☐ Eyes sore, itchy, watery
☐	☐☐☐ Headache	☐	☐☐☐ Irritation of nose/sinus/throat
☐	☐☐☐ Stomachache		☐☐☐ other _____

Do you have a flu, cold, or bronchitis ? ☐No ☐Yes

ENVIRONMENT:

Did you smoke anything at all today? ☒No ☐Yes

Did you have any kind of Unusual Exposures Today?
(not typical for the Park overall) ☐No ☒Yes

If yes, -- I was: Mildly / Moderately / Strongly (circle best one)
exposed to: *Smoke / Vog / LAZE / or Other _____

If yes -- for how long? only about ____ minutes; or about 2 hours.

Estimate your total time spent outdoors today:
☐less than 1 hr ☐1-2 hrs ☐2-4 hrs ☐4-8 hrs ☐more than 8 hrs

I worked here (or near here) today: ☐ BRD/Kilauea Fld Stn 6 hours
☐ HVNP HQ ____hrs. ☐ KMC ____hrs. ☐ HVO ____hrs. ☐ day off
☐ near: *lava flow / sulfur springs / fire / smokers ____ hrs
☐ Other 2 Kilauea ____ hrs. *(please /circle / which one)

MEDICINE USE:

Medicine Type	None	Yes, time taken	
Fast relief/Rescue Asthma Med	☐	☐ ☐am	☐pm
Regular/Maintenance Asthma Med	☐	☐ ☐am	☐pm
Allergy Med	☐	☐ ☐am	☐pm
Cough Syrup	☐	☐ ☐am	☐pm
Heart Medicine	☐	☐ ☐am	☐pm
Other (e.g. herbal tonic) _____	☐	☐ ☐am	☐pm

Comments: _____

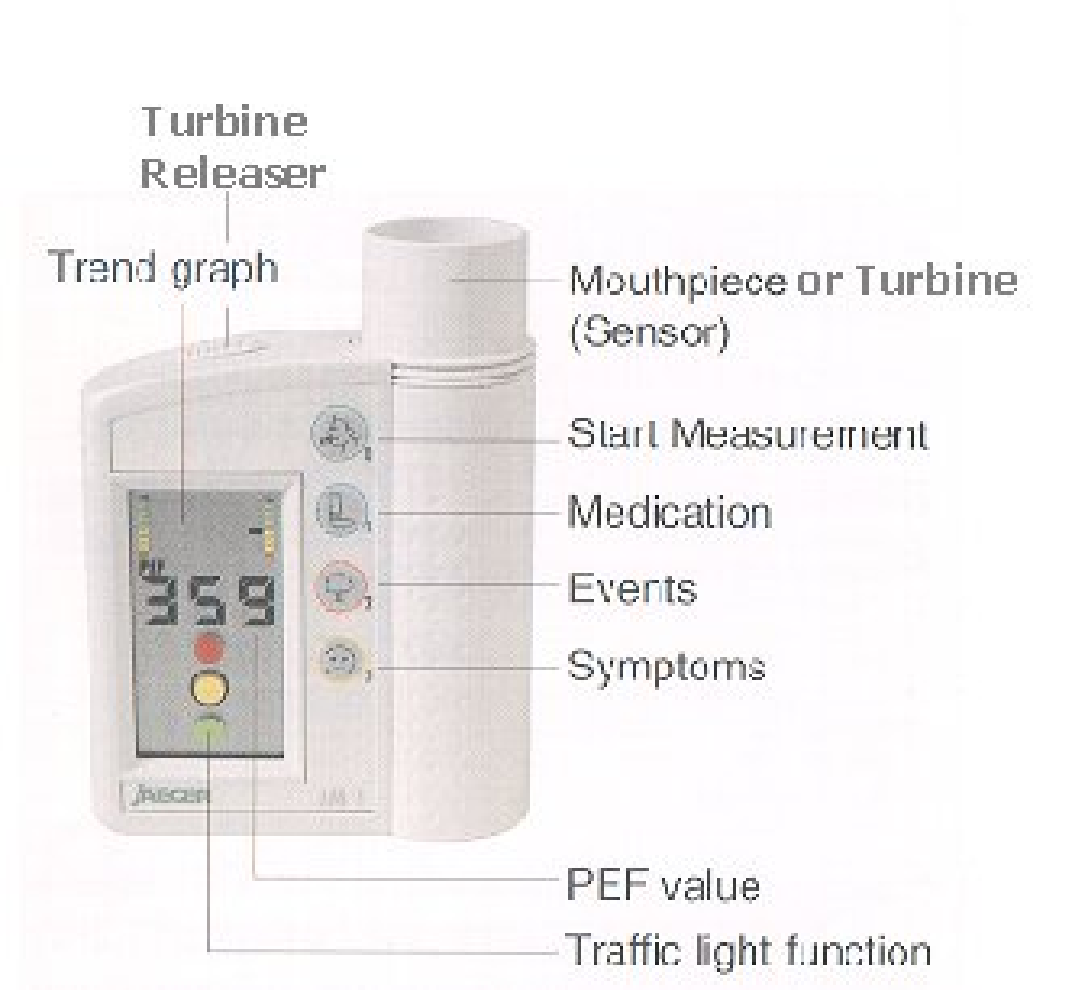
Symptoms were recorded by subjects daily and included cough; wheeze; headache; stomachache; shortness of breath; sore, itchy, watery eyes; irrational of the nose/sinus/throat, and specify other.

The severeness scale were assigned by the subjects and ranged form 0 to 3, where 0 is no symptoms and 3 is very severe.

Medication use including allergy and asthma were also recorded in the diary

Double key-punch of diaries were spot-checking against originals

Lung Function :: **AM-1 by Jaeger**



Accuracy of measurement:
Accuracy:
PEF ± 4% or 10 l/min
FEV1 ± 3.5% or 0.05 l
FVC ± 4% or 0.1 l
Deviations within a device:
PEF 3% or 10 l/min
FEV1 3% or 0.05 l
FVC 4% or 0.1 l
Deviations between several devices:
PEF ± 4% or 10 l/min
FEV1 ± 3% or 0.05 l
FVC ± 4% or 0.1 l

Measuring range:
Measurement Display
PEF 60 to 840 l/min 0 to 999 l/min
FEV 1 0.5 to 8 l 0 to 9,99 l
FVC 0.5 to 8 l 0 to 9,99 l
Resolution:
PEF from 1l/min to 20l/min over the entire range (resolution decreases from 1l/min in the lower flow range up to 20 l/min in the upper flow range).
FVC 15 ml
FEV 1 15 ml
Resistance: 7 Pa/l/s by 1l/s

Storage capacity: (E2PROM)
496 measurements (AM1)
(Standard setting: automatic determination of best measurement within 10 minutes)

Lung Function :: **AM-1 by Jaeger**

- PEF and FEV1 were self-collected with AM1. Subjects were trained to properly use the AM-1 monitor before the beginning of the study and were reminded a month later
- Subjects were asked to use them three times in the morning and in the evening within 10 minutes
- Data was examined for quality control

Accuracy of measurement:
Accuracy:
PEF ± 4% or 10 l/min
FEV1 ± 3.5% or 0.05 l
FVC ± 4% or 0.1 l
Deviations within a device:
PEF 3% or 10 l/min
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496 measurements (AM1)
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Lung Function :: **Spirometry**

Full effort Spirometry with (Spiro-232, Morgan Scientific) were collected by trained technicians at least once during the period of the study whenever possible.

Data Source Summary

- Air Quality Measurements (independent)
  - SO2 and PM1 measured at HVNP VC
  - Vog Index based on Observers' Calendar
- Health Measurements (dependent)
  - PEF and FEV1 from AM-1
  - Symptoms based on Diary

Methods

- Air Quality Measurements
- Health Measurements
- Analysis

Exclusions

- The day and three following days will be removed from analysis when subjects were exposed to unusual exposure such as
  - Fire Smoke
  - Paining
  - Sulfur Springs
  - Laze
  - Steam vents
  - Second hand smoke
  - Tobacco Smoke
  - Direct contact with lava

- Only those days will be excluded when subject
  - absent from work more than 3 days & not residing within park
  - Left the Big Island
  - Worked/Visited Chain Creator Road at any time of the day

Analysis

- Multiple regression models will be run using SAS 9.1 package
- Dependent variables will be examined: lung function (FEV1 from AM1 and PEF from AM1), symptom frequency
- Independent Variables will be examined Average Daily PM1 HVNP VC, SO2 HVNP VC, and Vog Index from Observers
- Individuals will be compared to their own baseline (non-exposed) health status measures to eliminate variations in genetics, etc.

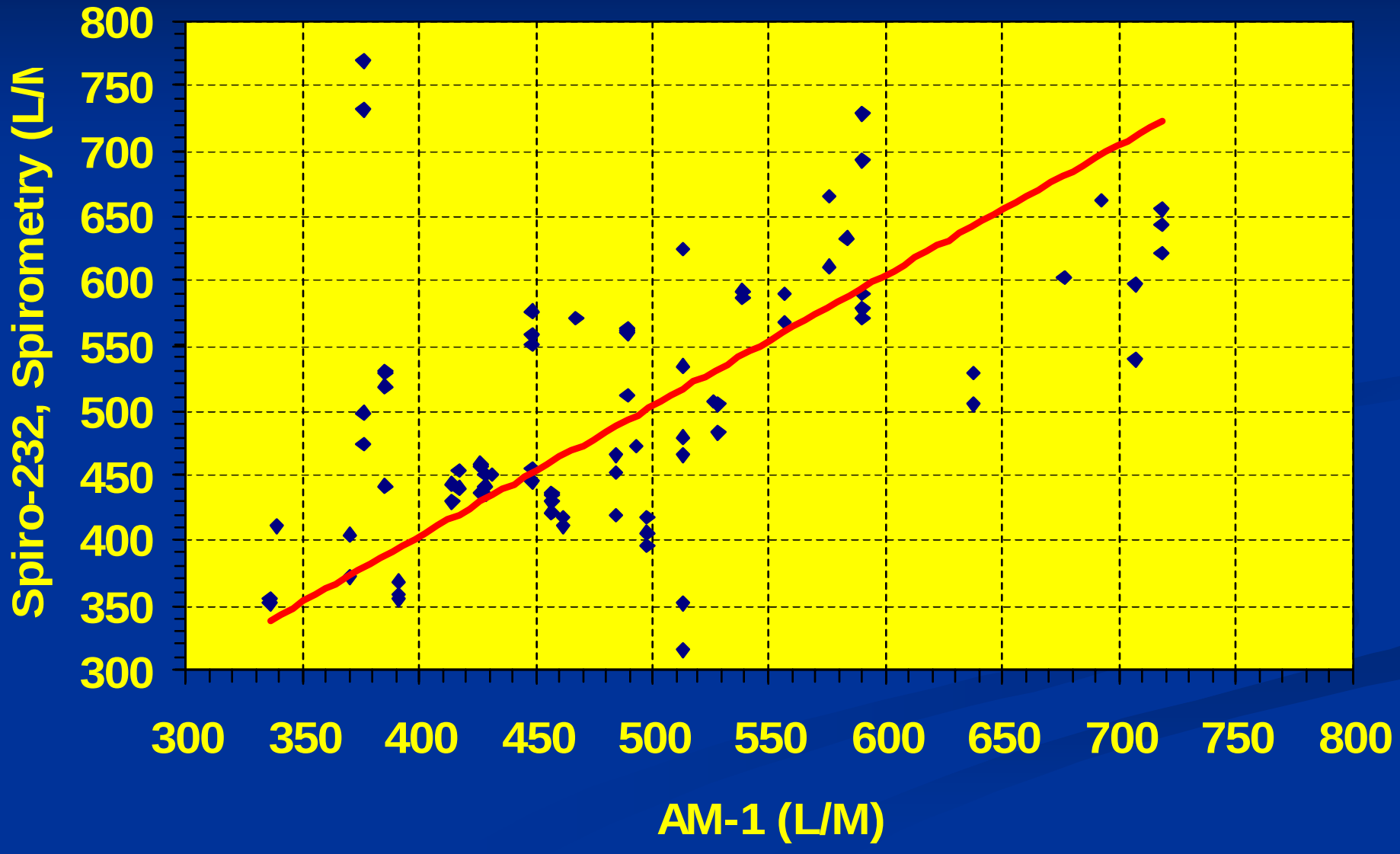
Analysis (continue)

- Models will be controlled for potential confounders such as: use of fast-acting and maintenance medication
- Time series analysis allows for a range of lag (same day, 1, 2, 3 days lag) times between changes in air quality and changes in respiratory health status; the physiological response to the episode trigger might be hours or days.
- Models will be tested for distribution and auto-correlation.

Descriptive Statistics: Daily Lung Function Measurements (AM-1)

Variable	Mean	Std Dev	Minimum	Maximum
Morning PEF (L/M)	481.2	129.3	145	963
Morning FEV1 (L)	3.058	0.685	0.6	6.5
Afternoon/Evening PEF (L/M)	478.6	121.3	184	963
Afternoon/Evening FEV1 (L)	3.012	0.668	1.3	5.4
Daily PEF (L/M)	490.8	126.5	145	963
Daily FEV1 (L)	3.094	0.678	0.6	6.5

FEV1(Spirometry) and FEV1 (AM-1) measurement for the same person/day



Visual Vog Index and SO_2

VVI	N	SO2 Mean (ppb)	Lower 95%	Upper 95%
0	122	11.5	7.3	15.8
1	31	35.8	23.1	48.5
2	15	61.9	36	87.9
3	4	38.9	-47.7	125.4

* ANOVA significance test: F- value = 17.14, p-value <0.0001

Visual Vog Index and PM_1

VVI	N	PM1 Mean (ug/m3)	Lower 95%	Upper 95%
0	110	1.6	1.3	1.8
1	28	2.1	1.6	2.6
2	12	4	2.8	5.2
3	1	7.4	.	.

* ANOVA significance test: F- value = 14.71, p-value <0.0001

MRM: FEV1 (L)

Independent	Estimate	95% Confidence Limits		Pr > |Z|
PM with log 0	0.0002	-0.0012	0.0016	0.77
PM with log 1	0.0007	-0.0008	0.0023	0.35
PM with log 2	-0.0003	-0.0017	0.0011	0.69
PM with log 3	0.0008	-0.0006	0.0021	0.26
SO2 with log 0	0.0000	0.0000	0.0001	0.08
SO2 with log 1	0.0001	0.0000	0.0001	0.01
SO2 with log 2	0.0000	-0.0001	0.0000	0.61
SO2 with log 3	0.0000	0.0000	0.0001	0.22
Visual Vog with log 0	0.0015	-0.0009	0.0039	0.21
Visual Vog with log 1	0.0026	0.0001	0.0050	0.04
Visual Vog with log 2	0.0005	-0.0019	0.0029	0.69
Visual Vog with log 3	-0.0007	-0.0026	0.0012	0.47

MRM: PEF (L/M)

Independent	Estimate	95% Confidence Limits		Pr > |Z|
PM with log 0	-0.0012	-0.0033	0.0009	0.27
PM with log 1	0.0014	-0.0007	0.0035	0.20
PM with log 2	0.0004	-0.0014	0.0022	0.67
PM with log 3	0.0008	-0.0011	0.0027	0.44
SO2 with log 0	0.0001	0.0000	0.0001	0.20
SO2 with log 1	0.0001	0.0000	0.0002	0.02
SO2 with log 2	-0.0001	-0.0002	0.0000	0.10
SO2 with log 3	0.0001	0.0000	0.0002	0.00
Visual Vog with log 0	-0.0012	-0.0042	0.0019	0.45
Visual Vog with log 1	0.0014	-0.0016	0.0044	0.37
Visual Vog with log 2	-0.0036	-0.0067	-0.0006	0.02
Visual Vog with log 3	0.0017	-0.0013	0.0048	0.26

MLR: Total Symptoms (Y/N)

Independent	OR	Lo 95% CI	Hi 95% CI	p-value
PM with log 1	1.091	1.043	1.141	0.000
PM with log 2	1.073	1.029	1.119	0.001
PM with log 3	1.038	0.987	1.091	0.144
SO2 with log 1	1.002	1.000	1.004	0.019
SO2 with log 2	1.001	0.999	1.003	0.459
SO2 with log 3	1.000	0.998	1.002	0.946
Visual Vog with log 1	1.152	1.066	1.246	0.000
Visual Vog with log 2	1.158	1.069	1.254	0.000
Visual Vog with log 3	1.087	1.021	1.158	0.009

Conclusion

- Visual vog index was the good predictor for instrument measured
- SO2 and PM1. SO2, PM1, and vog index were not good predictors for FEV1 and PEF after adjusting for variation between individuals and medication use.
- Adjusted Symptoms Index was significantly higher during voggy days (measured by SO2, PM1 and the visual vog) and the following day up to 3 day
- Visual vog index was the predictor for elevated symptoms overall.

Acknowledgment

- John Grove, PhD (UHM)
- Dewolfe Miller, PHD, MPH (UHM)
- Peter Holk, PhD (UHM)

SAS code

- proc genmod DATA = AM1;
- Class ID;
- model Symptoms = SO2/
- link=log dist=Poisson;
- repeated subject = ID / type=exch;
- run;