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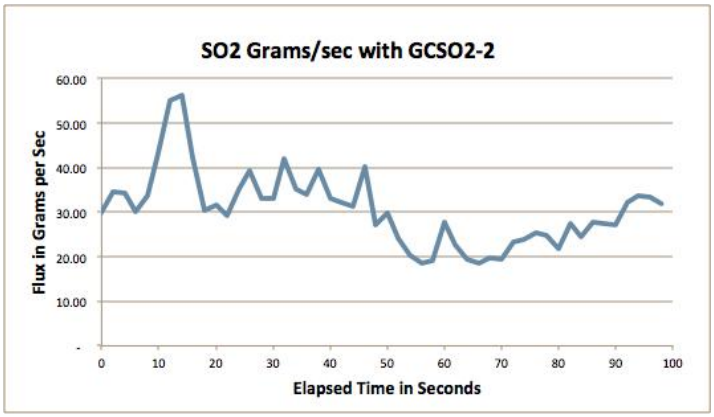
GCSO2-3 Gas Camera

The Resonance GCSO2-3 is a third-generation UV-sensitive camera that compares images in two spectral bands to produce concentration maps of SO2 plumes. This method is based on differential optical absorption spectroscopy (DOAS) for remote sensing of atmospheric gases (Refs 1-13). A unique feature of the GCSO2 cameras is that they simultaneously capture two images of the target plume in bands centered on 310 and 320 nm with only one CMOS UV camera. Offsets due to changes between two imaging chips or moving filters are eliminated. Another unique feature is the use of a mirror system which mirrors the two images about the optical axis of the camera. This configuration when combined with Resonance's powerful software eliminates the imbalances caused by distortion and edge dimming. Calibration across the entire field is obtained by use of a PC-controlled SO2 gas cell wheel. Field tests on volcanoes and smelter stacks have demonstrated that the concentration maps from GCSO series are highly specific to SO2 and are insensitive to changes in the spectrum of daylight due to solar elevation. The camera is delivered as a complete system ready to observe volcanoes or industrial stacks right out of the box. The third generation camera employs a lightweight housing with features that make the camera easier to use.

3rd Generation



Gas Camera at US Steel in Pittsburgh Pa. on June 2, 2017.

Features

- Produces quantitative images of SO2 in plumes from volcanoes and stacks that can be used to determine SO2-mass fluxes in tonnes per day.
- Captures simultaneous images at 310 and 320 NM.
- Single UV lens *for image stability*
- Single detector to eliminate *drift between 2 detectors*
- Mirror used to *cancel pincushion and barrel distortion*
- Calibration with COSPEC SO2 cells
- Automatic dark subtraction
- Uses Ratio-of-Ratios technique for calibrated ppm-m image map
- Alignment of mirror and lens focus adjusted in field
- Operates off of external battery pack, car battery or AC outlet
- Rainproof enclosure
- Camera with laptop, batteries and tripod weighs less than 4 kg.
- Can be backpacked to remote locations and operated for >8 hours.
- Laptop with high-brightness screen
- Batteries for > 6 hours continuous operation are allowable in carry-on luggage.

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Specifications

Dimensions/Mass/Power	
Housing dimensions	170mm x 135mm x 110mm
Camera Mass (excluding batteries)	700g
Tripod/Laptop/camera batteries Mass	1.9 kg/0.7kg/1kg
Capacity camera batteries	100 W/Hr minimum
Power Camera/Laptop	10W/20W

UV CMOS Camera	
Pixel	5.86 microns (square)
Interface	Ethernet and GPIO
Type	Back-thinned CMOS
Peak Quantum Efficiency	82%
ADC	12-bit
Readout method	Global shutter
Sensor format	1/1.2”
Megapixels	2.3
Single pixel width at plume with lens (4 km. distant)	2 meters

UV Multi-Element Lens	
F#	f/2.8
Focal length	12 mm
MTF	63 lp/mm (center)
Field of view (with CMOS camera) *Gas Image	15 x 22 degrees

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Optics	
Band-pass filters center wavelengths (nm)/FWHM(nm)/T	310 & 320/10 nm/ >70%
Calibration Cells SO2 ppm-m (nominal)	100/500/1500
Dark reference	Yes

Mechanics/Interface	
Interface	RJ45
Control	Arduino with ethernet input
Power average	<10W @ 12V

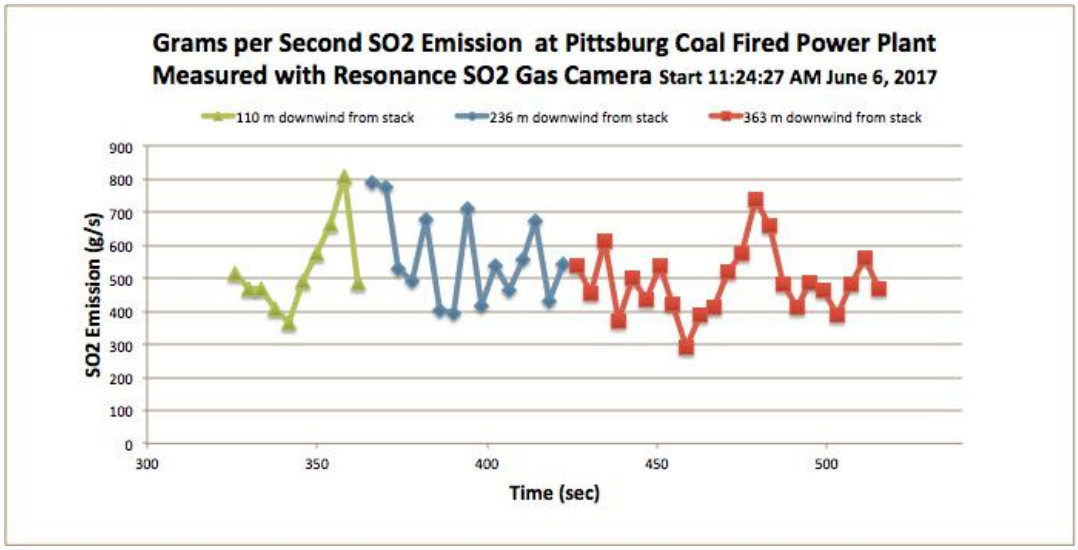
Electronics Interface	
Inside camera housing	Camera input power
Ethernet/USB 3.0 camera	Camera control and signal

PC and Camera Battery	
Laptop with preinstalled software	I5, with Solid State Drive
Spare battery	>60 Whr >6 hrs operation

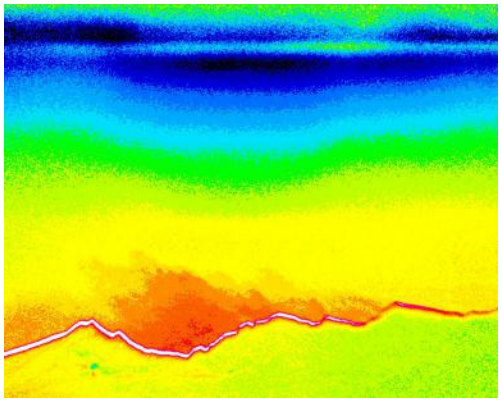
Software
Real-time display of signals and concentration maps
Saves data in standard editable formats
Settings (ini) file for holds calibration configuration
Controls for calibration with S02 and dark
Control screen can be viewed/controlled over internet
Analysis tools for profiles, plume velocity and plume flux (T/day)

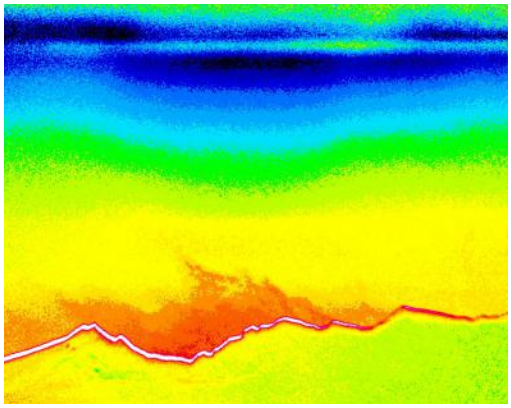
Housing
Camera interfaces for mounting to tripod and mounting accessory cameras
Top door allows user to adjust mirror alignment without opening main box

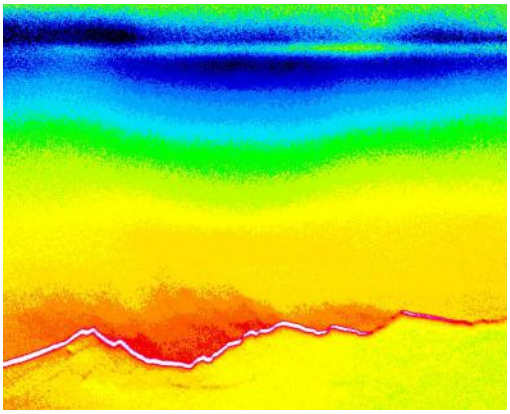
In the Box (RTU)
GCSO2-3 Gas Camera
GCEI-3 Electronic interface and manual and SW on disk
GCL-3 laptop with spare battery, installed SW
GCT-3 Tripod
GCSW-3 Software
GC-3-SWU 2-year software upgrades
GC-3-T 3 days on-site training
GCW-3 1 year replacement warranty and 3 year parts replacement warranty
Also includes: cables, power supplies, carrying case and complete calibration

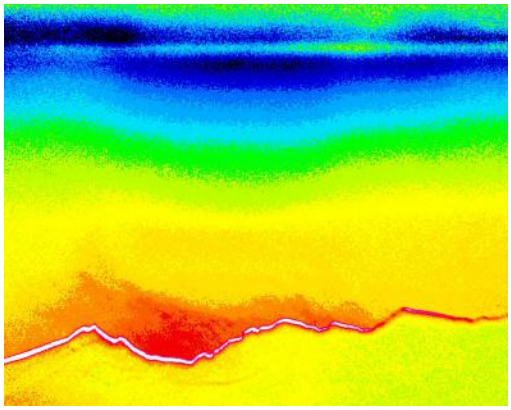


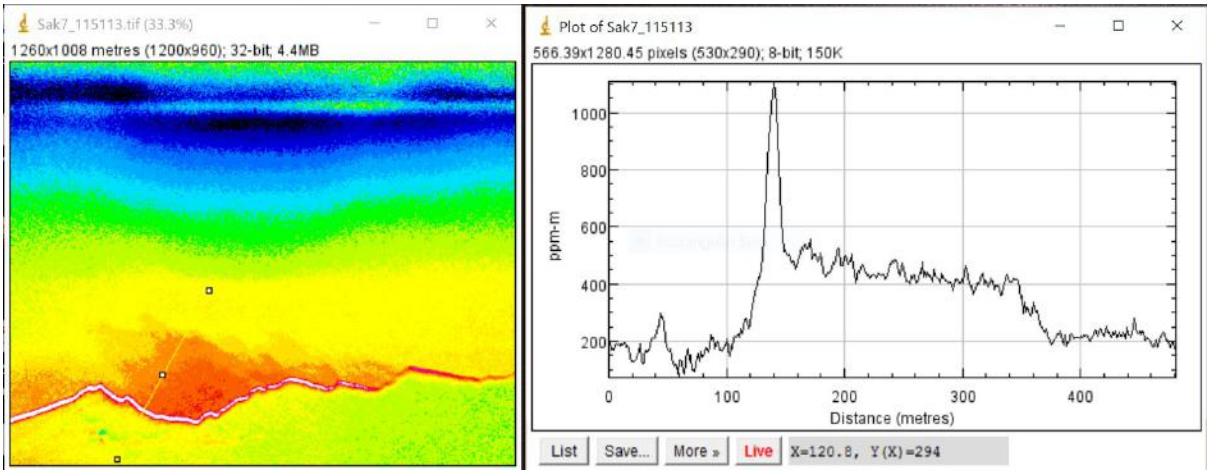
SO2 captured under good conditions at Sakurajima on March 24,2016 Four time lapse images of SO2 45 seconds apart.





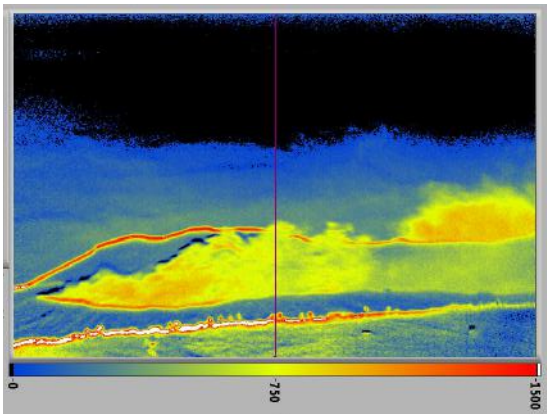


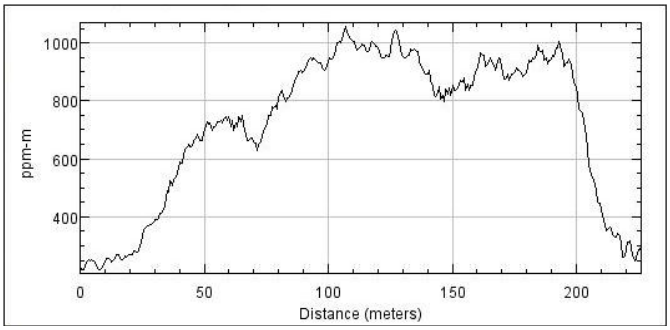




Quantitative profile normal to plume velocity

Profile of Aso plume from GC Image 15:07:34 March 24 2016





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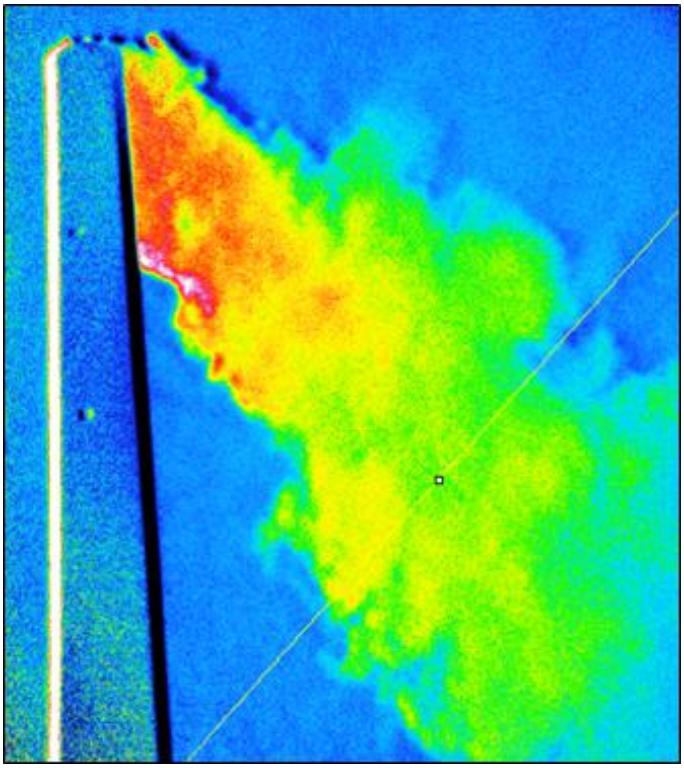
Resonance Gas Camera image of SO2 at Vale Super Stack, Sudbury Ontario.



Resonance Gas Camera at Sakurajima, March 2016 *previous version

Resonance Gas Camera at Unzen, March 2016 *previous version

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GCS02-3

Developments, Field Trials and Software - **Update Nov. 2018**

New Developments

1. **Improved field uniformity obtained with better baffling and better mirrors**
2. **Software for real time plume flux**
3. **Software for determining plume velocity**
4. **Software for fine tune digital alignment**
5. **Lighter case with handle, viewfinder and optics door for ease of focus adjustment in field**
6. **Improved frame rate**
7. **Improved flat field with larger gas cells**
8. **Validation with very low fluxes <10g/sec**
9. **Development of NO2 camera**
10. **Prototype Design for Drone version of Gas Camera**
11. **Prototype Design for Active Gas Camera remote sensor for H2S and other gases**
12. **Increased field of view**
13. **Reduced weight and dimensions**

Dec 2016

Power Plant and Shipping plumes in Rostock Germany and Etna Volcano in Sicily, Italy
First Field trials with NO2 filters

June 2017

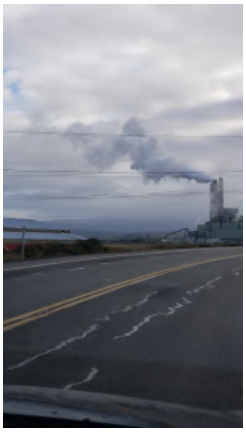
3 Steel processing plants and one coal generating station in the US (Pittsburgh)

Nov. 2017

Shanghai MAX DOAS with Gas Camera

Nov. 2018

Washington State, Centralia Power Plant



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Quick Comparison

	Gas Camera Previous Generation	Gas Camera 3rd Generation (Latest Version)
Housing Dimensions	284 x 182 x 188	170 x 135 x 110 mm
Camera Mass (excluding batteries)	3.5 kg	700 g
Tripod/Laptop/camera batteries mass	1.9 kg/2.5 kg/1.0 kg	1.9 kg/0.7kg/1.0 kg
Interface	Ethernet and GPIO	Ethernet/USB 3.0
Single Pixel Width at Plume with Lens (4 km. distance)	1 meter	2 meters
Focal Length	24 mm	12 mm
Field of View (with CMOS camera)	12.5 x 16 degrees	15 x 22 degrees
Motorized Calibration Wheel	Hall-sensor servo	N/A

The latest gas camera GCSO2-3 has been re-designed to reduce weight and size for greater portability in the field. To achieve this we modified the optical design and externalized the calibration to reduce mass and size. These changes allows us to utilize the GCSO2-3 gas camera on an aerial platform such as quad/octo-copter drones.

GCSO2-3 Latest Design

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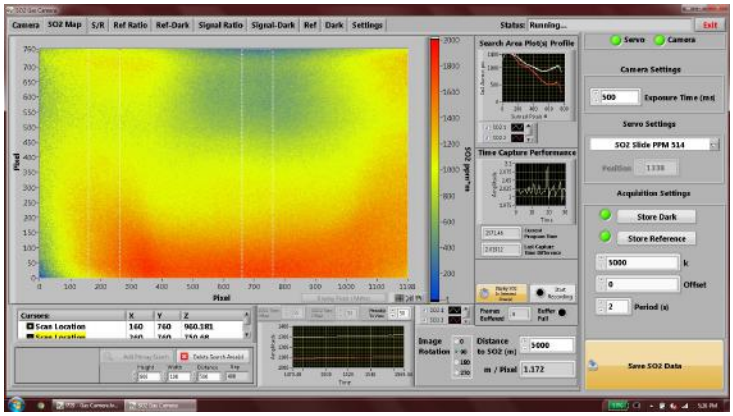
GCSWU_072616 A1 Software Features (alpha version released July 26, 2016):



Recording time lapse SO2 image data: Time lapse data stored in an Excel and Matlab compatible format for later analysis and presentation. This data will facilitate later refined analysis of plume dynamics for velocity determination using DW-CWT or Farneback algorithms.

Raw data capture: Recording of Raw Reference, Dark and Signal frames as aids for future data analysis.

Alignment cursors: Symmetric cursors to allow quick fine tuning optical alignment.

Filter correction: Corrects for transmission profile shifts in Bandpass filters caused by variation of field angle with correction matrices derived from frames taken through gas cells.

Scan box integration: Collects Profile data PPM-M vs. x or y in N user-defined boxes. This time-stamped data is stored in a matrix with meta data for later analysis.

Profile display and capture: Profiles are displayed as a function of distance and saved.

Scan box averages display and capture: This integrated profile data is displayed a time series and saved.

Real time plume flux estimates: Uses cross-correlation plume velocity measurements and plume profiles to produce approximate SO2 fluxes in real-time.

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