GHAPS: A new Green House And Pollutant gas column Sensor

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A Proposed Solution to Global Monitoring of Air Quality

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Abstract – Overview

Advances in detector arrays, communication, global positioning and gas filter correlation radiometry (GFCR) are combined to produce a small, simple, inexpensive, accurate, autonomous long lived gas column sensor. This fills a gap in air quality monitoring. We describe a miniature gas correlation sensor that can be placed wherever solar or lunar observations can be made. For example, the sensor could provide simultaneous gas column measurements of CH_4, CO_2, N_2O and CO from ground-based platforms or orbit based platforms observing the sun. Envisioned is an 8x10x20 cm size device, that is a low cost solution to monitoring the atmospheric abundance of key greenhouse and pollutant gases, including fluxes of gas emanating from areas surrounded by such sensors. The measurement concept, implementation strategy and performance estimates follows.

***Keywords:** Instruments and techniques, Pollution: Urban and regional, Sensors web, Instruments useful in three or more fields*

The Problem

The world needs energy. The energy demands require the production and use of fossil fuels, which affect the atmosphere through greenhouse and pollutant gas emissions. To thoroughly understand the impact of energy consumption, the atmosphere must be monitored on a global scale.

The problem is being addressed with two main categories of sensors, in situ and remote. In situ, basically air sample analysis systems, work well but have the obvious limitation of location. They must be placed or ported to the air being sampled. Nevertheless, they provide an increasing wealth of data as the technology simplifies and platforms of opportunity, such as commercial airliners and UAVs, are exploited.

Remote sensors typically measure column abundances between sensor and light sources. Active sensors such as lidars and radars can obtain profiles along the lines of sight, but are limited in range and prohibitively expensive to deploy on a global scale. Table 1 is a simple (and admittedly subjective) listing of the limitations encountered with current approaches when applied to the global monitoring problem.

Needed is the ability to sense the full atmospheric column of key gasses on a fine global grid, and with good temporal resolution. Ground-based high-resolution spectrometers have demonstrated the necessary quality of measurements (ex. the TCCON network[1]), but are prohibitively expensive to deploy and operate in a very high density global grid. Satellite instruments solve the coverage problem, but spatial resolution, temporal resolution and accuracy are challenging, and typically marginal at best. What is needed is an inexpensive, simple, small, low-power, autonomous ground-based spectrometer that is economically feasible to deploy in high numbers.

GHAPS: A GFCR solution

Thanks to modern uncooled detector technology (ex. Hecht[2]), remote communication, solar cell panels, cheap miniature processors, small inexpensive pointing systems and a novel GFCR design, a simple solution is possible.

GFCR has a successful history, but mostly in orbit. The first was on Nimbus 6 in 1975 using pressure modulation radiometry[3]. This was followed by SAMS[4] and ISAMS[5] on the Nimbus 7 and UARS satellites respectively. A nadir viewing GFCR, MOPPIT[6] on the Aqua satellite included length modulation. HALOE[7] (Fig. 1), also on UARS, used a dual beam approach that simplified the system (i.e. no cell modulation) and increased the GFCR signal because of the larger spectral difference. The steady source, large signal, and calibration advantages of solar occultation allowed a dual beam approach for HALOE. Though highly successful, HALOE was optically complex and large. However, HALOE demonstrated the ability to make measurements with a GFCR approach that achieved very high effective spectral resolution (resolving power > 100,000) with a static system and a low data rate intrinsic to GFCR.

We can now reduce the $20M HALOE to a less than $10K GHAPS by implementing a Pupil Imaging Gas Correlation approach (PIGC, like HALOE) with new technology. Figure 1 shows the projected relative size. Figure 2 is a conceptual block diagram of GHAPS and figure 3 is what GHAPS might look like on a commercial pointing system. Power requirements are expected to be less than demanded by a typical cell phone. Table 2 gives sensitivity estimates for some measureable gases.

Deployment options are many. Perimeter monitoring could occur around energy production sites, as depicted in figure 3, or using moving vehicles if mounted on a motion stabilization gimbal ($150 from the Tarot company) as depicted in figure 4. Constellations could be deployed on cubesats for upper atmosphere monitoring (Fig. 5), with HALOE-quality observations, but at tiny fractions of the cost. Low data rate measurements are automatically phoned into analysis centers, for nearly real-time estimates of key gas concentrations and source location.

Conclusion

Technology advances, driven by commercial markets, have provided a major opportunity to improve atmospheric monitoring on a global scale. These advances (and market sources) include uncooled detectors (thermal imaging market), low-cost processing, communication, imaging and solar cell rechargers (cell phone market), and low-cost pointing systems (entertainment industry, including products serving cameras such as GoPro). These are all potential GHAPS subsystems that can be combined with a novel implementation of GFCR to produce a small low-cost simple instrument for gas column measurement.

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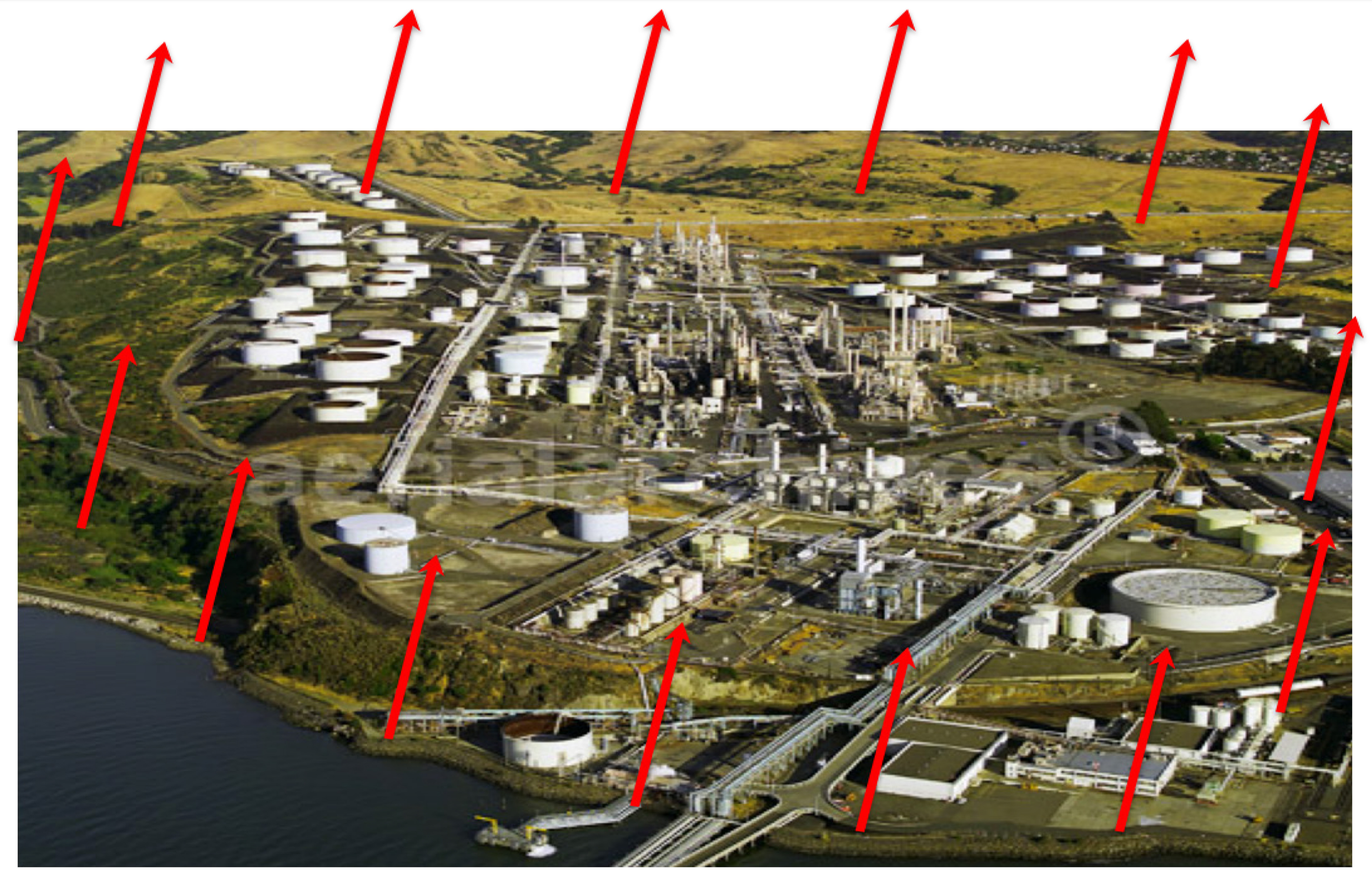

Figure 3. A GHAPS Wide Area Monitoring System. Autonomous GHAPS sensors can form perimeter monitoring systems. Red arrows illustrate placement of GHAPS instruments monitoring emission from refinery.

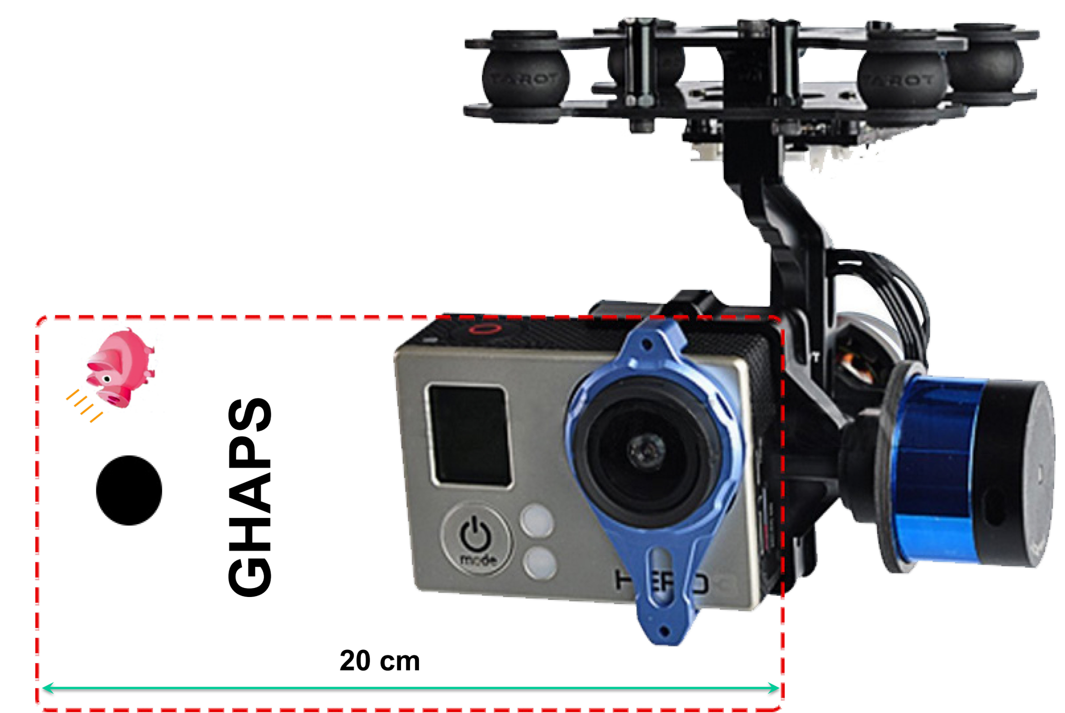

Figure 4. Inexpensive gimbal systems are readily available, such as the pictured Tarot company Tarot 2 Axis Brushless Camera Gimbal With Gyro TL68A00 system that supports a GoPro camera. The red dotted line shows the projected outline of a GHAPS

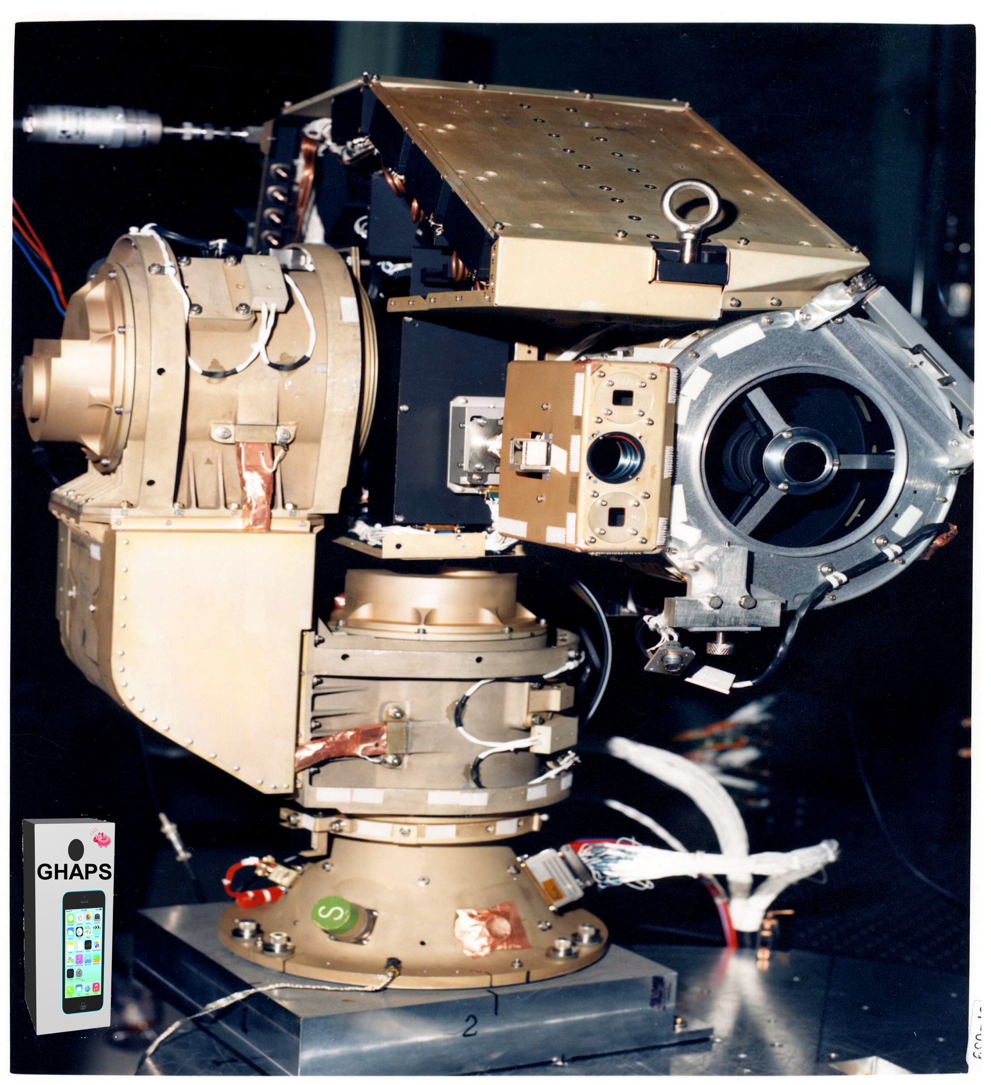

Figure 1. The measurements of a $20M HALOE instrument can now be performed by a <$10K GHAPS Instrument. The projected size is illustrated with an embedded cell phone, next to the HALOE instrument.

Table 1.

Air Quality Monitoring Factors

Instrument Type & Strategy	Coverage: Local (Spatial Resolution)	Coverage: Global (% of Globe)	Coverage: Vertical Column	Coverage: Temporal	Implementation & Operation: Cost	Implementation & Operation: Complexity & Maintenance
In Situ Fixed	Must be strategically placed	Can be located nearly anywhere		Excellent. Effectively continuous for "sniffers"	Varies. Depending on technique.	Varies
Aircraft & balloons In Situ	Good Resolution	UAVs and commercial platforms make it possible	Must fly at various altitudes. Not practical for most aircrafts	Limited by flight frequency	Commercial Airliner "sniffers"	
Aircraft Remote	Good Resolution	UAVs make it possible, but ocean coverage problematic	Look up and down	Typically limited to special missions	High cost but drone potential may improve	Improving but typically complex
Satellite	Limited footprint	Orbit limitation could require a constellation	Variation in surface and atmosphere scatter thwarts accuracy	Cloud cover severely limits regular repeat	Expensive to develop and operate	Complex but good heritage
Ground Remote (existing)		Possible but prohibitively expensive to implement	Measures atmospheric column, so senses upper layers	Sun or Moon must be identifiable. Requires moderate overcast or better.	Typically >$100K/ Instrument and requires thousands.	Varies, but typically formidable
GHAPS Surface, Fixed or Mobile	Must be strategically placed	Autonomous, low maint-enance & solar powered	Measures atmospheric column, so senses upper layers	Sun or Moon must be identifiable. (Moderate overcast or better)	<$10K Instrument	Autonomous, continuous, self calibrating

	Good horizontal Resolution	Possible	Senses entire column	Daily or better	Good	Good
	Limited	Unlikely without a constellation	Possible with effort	Limited by significant cloud cover	Moderate	Proven heritage
			Not possible	Limited by flight hours	Cost driven by instrument or flight frequency	

Table 1. Subjective comments on various approaches. To frequently and accurately measure full atmospheric columns of targeted gases, a grid of fixed ground based sensors are needed. GHAPS is an economical solution to that problem.

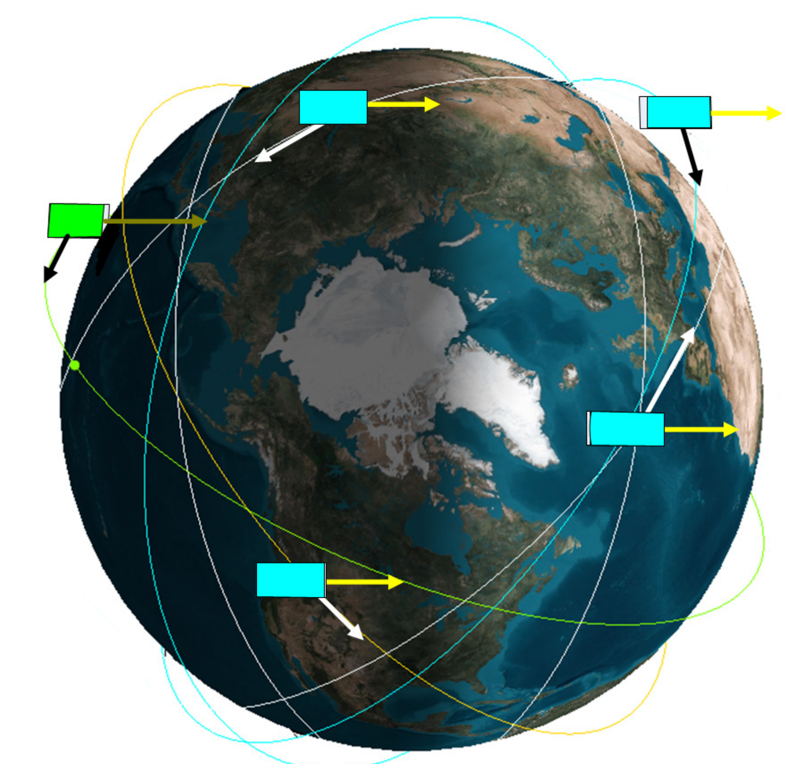

Figure 5. A constellation of GHAPS sensors making solar occultation observations would provide global coverage and trends of upper atmosphere temperature, key chemical species and aerosols at unprecedented low cost. It would consist of small satellite pointing continuously along the solar vector.

Conceptual Block Diagram of the GHAPS Instrument

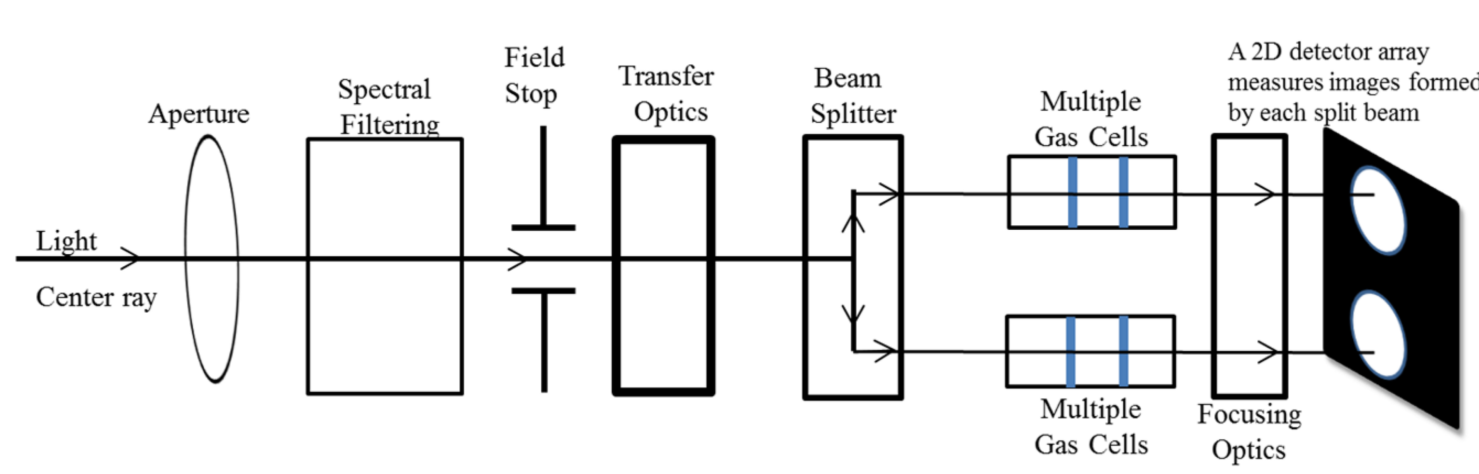

Figure 2. GHAPS is an instrument that produces multiple GFCR channels, but requires splitting the beam just once. Using a light source, such as the sun, low power uncooled detector arrays can be employed. GHAPS is an implementation of the HALOE Pupil Imaging Gas Correlation (PIGC) technique, using modern detector array technology, a patented filtering scheme and proprietary beam-splitting approach.

Column Sensitivity

Target Gas	Sensitivity atm-cm [ppm-m]	Sensitivity (% of ambient atmospheric column)	Notes
CH_4	0.0006 [6.0]	0.05	
CO	0.00009 [0.9]	0.1	
CO_2 ($^{13}CO_2$ proxy)	0.2 [2000.0]	0.1	$^{13}CO_2$ is measured
N_2O	0.00007 [0.7]	0.03	
SO_2	0.0001 [1.0]	NA*	
NH_3	0.0004 [4.0]	NA	
H_2O (HDO proxy)	0.9 [9000.0]	0.05	HDO is measured
H_2S	0.005 [50.0]	NA	

*No appreciable ambient, so not applicable.

Table 2. Sensitivity of GHAPS solar measurements for a few key gases.