Development of the Global Ozone Lidar Demonstrator (GOLD) for the Global Hawk

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ABSTRACT

A compact ozone (O_3) and aerosol lidar system is being developed for conducting global atmospheric investigations from the NASA Global Hawk Uninhabited Aerial Vehicle (UAV) and for enabling the development and test of a space-based O_3 and aerosol lidar. GOLD incorporates advanced technologies and designs to produce a compact, autonomously operating O_3 and aerosol Differential Absorption Lidar (DIAL) system for a UAV platform. The GOLD system leverages advanced Nd:YAG and optical parametric oscillator laser technologies and receiver optics, detectors, and electronics. Significant progress has been made toward the development of the GOLD system, and this paper provides an overview of this program with a focus on the American Recovery and Reinvestment Act (ARRA) funded tasks that will enable the GOLD system for flight on the NASA Global Hawk..

1. INTRODUCTION

Global ozone measurements are needed across the troposphere with high vertical resolution to enable comprehensive studies of continental and intercontinental atmospheric chemistry and dynamics which are affected by diverse natural and human-induced processes. The development of a UAV-based GOLD system is an important step in enabling a space-based O_3 and aerosol lidar and for conducting unique UAV-based large-scale atmospheric investigations.

The GOLD system incorporates advanced laser technology developed, in part, under the NASA Laser Risk Reduction Program (LRRP) to produce a compact, autonomously operating O3 and aerosol DIAL system. This system also leverages advanced receiver optics, detector electronics, and DIAL control system technologies developed by NASA LaRC, ITT industries, and Welch Mechanical Designs.

The development of the GOLD system was initiated as part of the NASA Earth Science Technology Office (ESTO) Instrument Incubator Program (IIP) in December 2005, and great progress has been made towards completing and demonstrating the GOLD system. Development of optical parametric oscillators (OPO) and nonlinear mixing crystals, collectively called Nonlinear Optics Module (NLO), for generating the O_3 DIAL wavelengths of 290 and 300 nm and the aerosol visible wavelength at 532 nm have been built and lab tested. A new and compact high speed data acquisition system has been implemented. Welch Mechanical Designs designed and developed a compact, lightweight, and efficient telescope. These lidar subsystems are designed to be integrated into a pressure controlled enclosure that fits into the lower compartment of the NASA Dryden Global Hawk.

To enable a flight demonstration of the GOLD system, additional developments are required for both the instrument and the Global Hawk platform based on the results from the IIP program. For the instrument, four tasks will be supported through the ARRA funding: (1) a robust and environmentally tested Nd:YAG pump laser designed by Fibertek will be built and integrated with the NLO module, (2) the NLO module optical mounts and its enclosure will be upgraded to improve mechanical stability and to mate to the new pump laser, (3) the opto-mechanical components for the transmitter optics and the instrument frame will be configured to match the changes in the laser, (4) integration and ground tests of the new laser with the GOLD system will be conducted. In addition, four tasks are supported to integrate the instrument onto the Global Hawk: (1) a liquid cooling system for the lasers will be developed and integrated onto the lower compartment of the Global Hawk, (2) a deep fairing (AESA) will be fabricated and matched to the 16 inch clear aperture telescope, (3) the design, analysis, and fabrication of the mounts for the GOLD instrument pressure housing into the lower compartment will be completed, (4) and a structural analysis and airworthiness report will be performed for the GOLD instrument.

Science objectives for the GOLD system, details of the GOLD system design and development, highlights of the additional tasks funded under ARRA, and initial atmospheric ground tests conducted under the IIP program are discussed in the following sections.

BACKGROUND FOR THE DEVELOPMENT

1.1 Enabling Global Atmospheric Science Investigations

The development of the GOLD system is a revolutionary step toward conducting global atmospheric research with UAV platforms, and it is an enabling step in the development of a space-based O_3 and aerosol lidar system. Both of these steps are important contributions to the long-range objectives of NASA's Earth System Science Research Program.

A UAV-based lidar such as GOLD, will be able to conduct large-scale atmospheric science investigations that will complement and extend those currently conducted from the Aura satellite by providing high vertical resolution O_3 and aerosol measurements that can be used to validate measurements from Aura and to observe atmospheric features and processes that take place on vertical scales that are too small to resolve with current passive sensors. In addition, the simultaneous measurements of O_3 and aerosols can provide insights into atmospheric composition, dynamics, and source/sink processes that are unavailable to the passive satellite instruments. A UAV-based O_3 DIAL system will provide a greater opportunity to study global tropospheric and stratospheric O_3 processes, including stratosphere-troposphere exchange, than can be accomplished through infrequent, major airborne field experiments using large platforms, such as the NASA DC-8 aircraft.

Tropospheric chemistry is considered to be the ‘next frontier’ for atmospheric chemistry, and understanding and predicting the global influence of natural and human-induced effects on tropospheric chemistry will be a major challenge for atmospheric research over the next couple of decades. In particular, obtaining the global distribution of tropospheric O_3 with high vertical resolution (1-3 km) would greatly enhance the understanding of atmospheric processes related to transport, dynamics, O_3 production and loss, atmospheric radiation balance, and photochemistry [1]. The simultaneous high vertical resolution (100 m) measurements of aerosol and cloud distributions along with the O_3 measurements provide important complementary information about air mass types and their origin, evolution, chemistry, and transport as has been demonstrated in many NASA Global Tropospheric Experiment (GTE) field missions (see e.g., [2-5]).

1.2 Advancing Airborne Ozone Lidar Technology

The GOLD system uses the DIAL technique for the measurement of atmospheric O_3 profiles and the standard backscatter lidar technique for simultaneous measurement of aerosol scattering ratio profiles [6,7]. The capability of the DIAL technique for atmospheric O_3 and aerosol profiling has been demonstrated with NASA Langley’s Airborne UV DIAL System over the past 29 years (see e.g., [2-9]). An example of the measurement capability of this method for O_3 profiling is shown in Fig. 1. This distribution represents a vertical cross section of O_3 measurements obtained from our current airborne UV DIAL system operating simultaneously in the nadir and zenith modes from the NASA DC-8 aircraft flying from California to Costa Rica during the Tropical Composition, Cloud, and Climate Coupling (TC4) Mission conducted during July-August 2007. This figure illustrates the complex combination of dynamics and chemistry that contributes to the O_3 budget in the troposphere and that varies dramatically with latitude and altitude. The transition from mid-latitudes into the tropics across the Intertropical Convergence Zone near 15°N is clearly observed

A complete latitudinal cross section of O_3, such as the one shown in Figure 1, covering over three times the latitudinal range can be realized with the GOLD system deployed on the Global Hawk from a single flight without data gaps at the aircraft altitude.

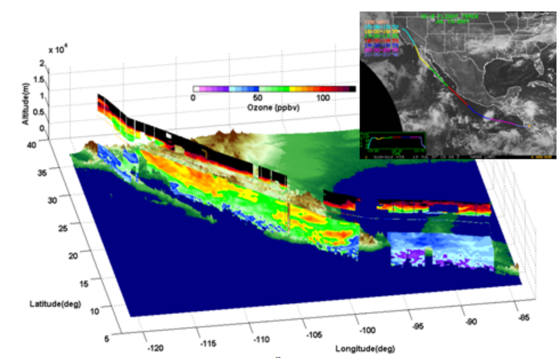

Figure 1. Average O_3 distribution measured from LaRC airborne DIAL covering from California, US to San Jose, Costa Rica during the NASA TC4 mission. The inset shows the GOES visible image and the flight ground track.

2. GOLD INSTRUMENT DESCRIPTION AND STATUS

2.1 GOLD Overall Characteristics

The objectives for the GOLD system are to 1) use the latest technology available to demonstrate the science capability of an O_3 DIAL lidar from a UAV platform, 2) demonstrate a compact, autonomously operating O_3 DIAL system as a precursor to a space-based DIAL system, and

3) evaluate new laser technologies for DIAL measurements as they are developed.

2.2 Description of Key Technologies

The main GOLD lidar parameters are listed in **Error! Reference source not found.** for the telescope and laser. A 3-D model of the GOLD instrument is shown in Figure 2 showing the tightly integrated design of the telescope, receiver optics module that includes compact analog detectors and electronics, laser transmitter, and laser beam conditioning and steering optics. ITT Industries developed a nonlinear optics module that includes OPO and mixing crystals that will be integrated with the Fibertek Inc. Nd:YAG laser to produce the airborne wavelengths of 290 and 300 nm. The Fibertek pump laser is being developed under the ARRA program. In addition, the 532 nm second harmonic wavelength of the Nd:YAG laser is used for aerosol profiling; three wavelengths are transmitted in total. An all-metal 40-cm diameter by 40-cm tall telescope has been specifically designed and implemented for the receiver to enable integration into the limited height of the Global Hawk external fairing.

The receiver optics module includes a narrowband grating to simultaneously separate the two UV transmitted wavelengths and narrowband interference filter to reduce solar background light. Also, compact detectors modules that incorporate custom amplifiers, digitizers and data acquisition electronics are integrated into the receiver module. The transmit optics module includes beam expanders, Risley prisms for beam steering, energy monitors, shutters, and optics to set and control the laser output polarization and will be reconfigured to mate to the laser being built under ARRA funding. The dimension of the instrument head shown in Figure 2 is approximately 72x57x49 cm.

Table 1. Basic Lidar System Parameters. These parameters are provided for the Fibertek Inc. pump laser and ITT NLO developed under the ARRA funds.

Parameter	Value
Manufacturer	Fibertek, Inc., ITT Industries
Type	Custom Seeded Nd:YAG/OPO
Laser Repetition Rate	200 Hz (1000 Hz for ITT pump laser)
Wavelengths	355, 532, 1064 nm
Energy	45 mJ @ 355 nm
	35 mJ @ 532 nm
	100 mJ @ 1064 nm (OPO pump)
	5 mJ @ 290 nm, 3 mJ @ 300nm
Polarization @ 532nm	Linear (>100:1)
Pulse Width	15 ns
Telescope Dia.	40 cm
Full Field of View	1 mrad

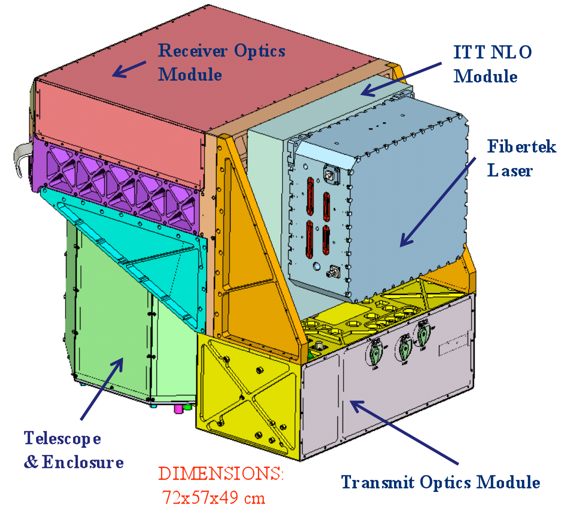

Figure 2. Drawing of the GOLD instrument showing the laser, telescope, receiver optics module, and the transmit optics module.

2.3 Integrated GOLD system on the Global Hawk.

The GOLD system is designed to be integrated into the lower compartment of the NASA Global Hawk. A drawing for the layout of the GOLD system integrated into the Global Hawk lower compartment is shown in **Error! Reference source not found.**. To incorporate the instrument with it given height into the lower compartment, an existing design from Northrop Grumman Corporation (NGC) for a deep fairing (AESA design) will be purchased and modified under ARRA funding to include the view port in the bottom, and the inlet and exhaust ports for an air-liquid liquid cooling system. In order to provide cooling to the lasers, an air-liquid LCS, also designed by NGC, will be certified,

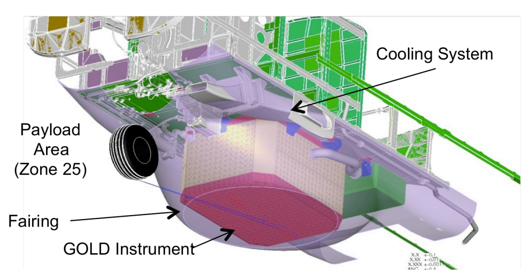

Figure 3. Layout of the GOLD system on the Global Hawk showing the pressure housing in relation to the aircraft fairing and fuselage.

integrated, and flight tested on the NASA Global Hawk with ARRA funds. The GOLD transmitter, receiver, and electronics are housed in a thermally controlled pressure box which is 112x84x63 cm in size. For comparison, the overall system parameters for the GOLD instrument and current airborne DIAL systems are listed in **Error! Reference source not found.** showing a significant reduction in the main system parameters without a loss in performance. The design, structural analysis, and fabrication of the mounts for GOLD pressure housing will be completed under a ARRA task.

Table 2. Comparison of the NASA LaRC airborne UV DIAL system and GOLD system parameters and measurements.

	UV DIAL	GOLD
Weight (lbs)	2521	780 (926 with pressure boxes)
Power (kW)	10.1	2.6
Volume (m^3)	3.95	0.68
Measurements:	nadir/zenith DIAL ozone aerosol (532/1064) depolarization (532)	nadir DIAL ozone aerosol (532) depolarization (532)

3. INITIAL GOLD GROUND TESTS

Initial up-looking ground tests have been performed during July and August 2009 at NASA LaRC. Ozone, estimated O_3 uncertainty, and aerosol attenuated backscatter data taken on 1 July 2009 over approximately 5 hours are presented in 0. The O_3 was calculated with a 315 m vertical range and 3-minute time resolution. The estimated uncertainty in the ozone was found to be less than 10% for altitudes less than 6-7 km during this period. A more quantitative comparison with a local ozonesonde measurement on August 17, 2009 is shown in **Error! Reference source not found.**. The GOLD results show good agreement with the consistency in the overall features but a slight bias of ~5 ppbv (<10%) in the lower troposphere.

As mentioned previously, the simultaneous measurements of O_3 and aerosols can provide insights into atmospheric composition, dynamics, and source/sink processes. The aerosol backscatter data at 532 nm is shown in 0
and was derived using 15-m vertical range and 10-second time average. The low aerosol loading in the upper troposphere with enhanced ozone is consistent with stratosphere-tropospheric exchange events. In addition, the aerosol scattering shows a thin aerosol layer at 16 km with low aerosol depolarization (not shown), which can possibly be attributed to volcanic plumes from the Sarychev Peak in the Kuril Islands that was active in the latter half of June. These data provide ground based results that demonstrate the initial performance of the GOLD system, which is similar to our current UV DIAL system but with significantly reduced system parameters.

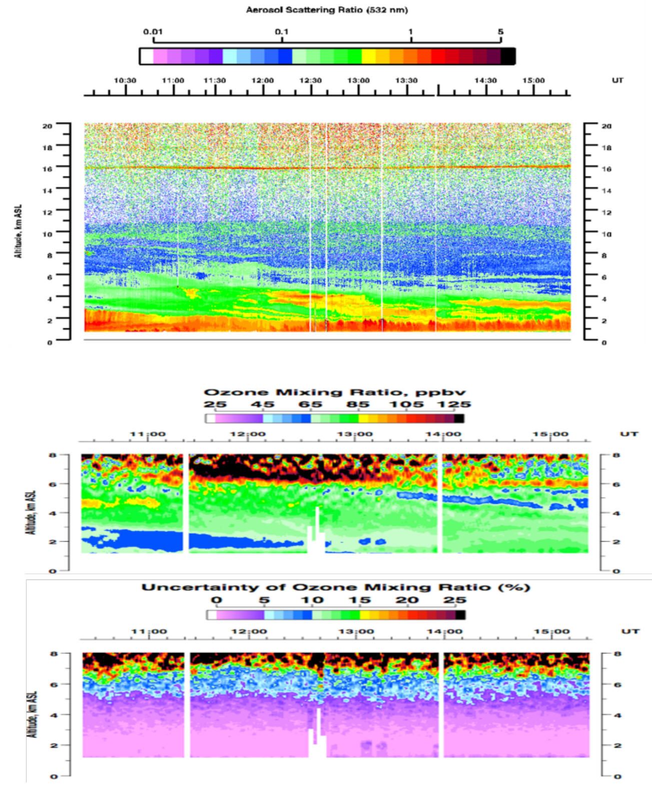

Figure 4. 1 July 2009 GOLD measurements of attenuated aerosol scattering backscatter ratio, ozone, and ozone uncertainty for a 5 hr period from ~10:30 – 15:30 local time in Hampton, Virginia.

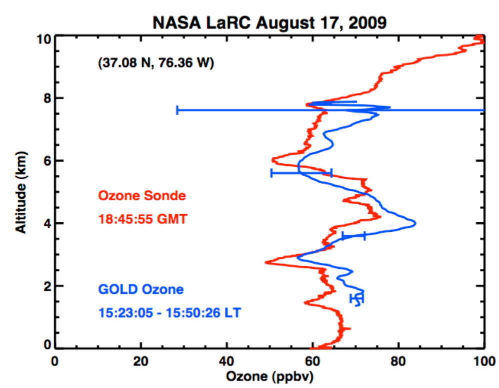

Figure 5. Comparison of co-located and near-time-coincident ozone profiles on 17 August 2009. GOLD measurements ozone (blue), and ozonesonde measurements (red).

4. SUMMARY

This paper summarizes the current status of the GOLD instrument and outlines the developments conducted under the ARRA program. The main objectives of the ARRA tasks are to increase the stability of the laser modules, finalize integration of the instrument into the pressure housing, and integrate the liquid cooling system and a new fairing onto the Global Hawk to enable the first flight demonstration of an UV DIAL ozone lidar on a the NASA Global Hawk aircraft.

ACKNOWLEDGEMENTS

We acknowledge our industry partners for their important contributions to the GOLD project. ITT Industries in Albuquerque, NM developed the first version of the GOLD pump laser and the nonlinear OPO laser under the ESTO IIP program. They also designed and built the grating based filter system used in the receiver. Fibertek Inc. is currently developing a second generation pump laser based on a separate ESTO IIP project that is currently being implemented into the GOLD system. Welch Mechanical Designs in Belcamp, Maryland provided the mechanical engineering support for the program and designed and built the telescope. We also thank Anne Thompson and her team at Penn State University for providing the ozonesonde data launched from NASA LaRC. Northrop Grumman Corporation working with DFRC has provided engineering support for integration of the GOLD instrument onto the Global Hawk. This work was funded by NASA Earth Science Technology Office under the Instrument Incubator Program and NASA ARRA.

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