Development of a quantum cascade laser spectrometer for rapid, accurate, measurements of atmospheric CO, CH_4, N_2O, and CO_2 from HIAPER

First semi-annual progress report

Instrument descriptions

There are two components to the HAIS tracer instrument.

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Quantum Cascade Laser CO_2 Analyzer

Instrument: Quantum Cascade Laser CO_2 Analyzer
Principal Investigators: Steven C. Wofsy* and Mark S. Zahniser
Co-Investigators: David D. Nelson, J. Barry McManus, Rodrigo Jimenez*, Bruce Daube*

Organizations:

Aerodyne Research Inc.
Billerica MA 01821

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Measurement Description: Fast response CO_2 instrument measures CO_2 concentrations in situ using a thermoelectrically cooled pulsed-quantum cascade laser (QCL) light source, gas cells, and liquid nitrogen cooled solid-state detectors. These components are stabilized along the detection axis, vibrationally isolated, and housed in a temperature-controlled pressure vessel. Sample air enters a rear-facing inlet, is preconditioned using a Nafion drier (to remove water vapor), then is reduced in pressure to 60 mbar using a Teflon diaphragm pump. A second water trap, using dry ice, reduces the sample air dewpoint to less than –70C prior to detection. The CO_2 mixing ratio of air flowing through the sample gas cell is determined by measuring absorption from a single infrared transition line at 4.32 microns relative to a reference gas of known concentration. In-flight calibrations are performed by replacing the air sample with reference gas every 10 minutes, with a low-span and a high-span gas every 20 minutes, and with a long-term primary standard every 2 hours. The long-term standard is used sparingly and serves as a check of the flight-to-flight accuracy and precision of the measurements, augmented by ground-based calibrations before and after flights.

Accuracy: ±0.1 ppm
Precision: ±0.05 ppm
Weight: 70 lbs.
Power: 675W typical, 1400W maximum (combined for both QCL instruments)
Response Time: 1 seconds
Location: Shares HIAPER rack mount with dual-QCL for CO and CH_4

Dual Quantum Cascade Laser CO-CH_4-N_2O Analyzer

Instrument: Dual Quantum Cascade Laser CO-CH_4-N_2O Analyzer
Principal Investigator: Steven Wofsy* and Mark S. Zahniser
Co-Investigators: David D. Nelson, J. Barry McManus, Rodrigo Jimenez*, Bruce Daube*

Organizations:
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Measurement Description: Fast response instrument simultaneously measures CO, CH_4 and N_2O concentrations in situ using two thermoelectrically cooled pulsed-quantum cascade lasers (QCL) light sources, a multiple pass absorption cell, and two liquid nitrogen-cooled solid-state detectors. These components are mounted on a temperature-stabilized, vibrationally isolated optical bench with heated cover. The sample air is preconditioned using a Nafion drier (to remove water vapor), and is reduced in pressure to 60 mbar using a Teflon diaphragm pump. The trace gas mixing ratios of air flowing through the multiple pass absorption cell are determined by measuring absorption from their infrared transition lines at 4.59 microns for CO and 7.87 microns for CH_4 and N_2O using molecular line parameters from the HITRAN data base. In-flight calibrations are performed by replacing the air sample with reference gas every 10 minutes, with a low-span and a high-span gas every 20 minutes, and with a long-term primary standard every 2 hours. The long-term standard is used sparingly and serves as a check of the flight-to-flight accuracy and precision of the measurements, augmented by ground-based calibrations before and after flights.

Accuracy: CO $\pm$ 1 ppb; $CH_4 \pm$ 15 ppb; $N_2O \pm$ 2 ppb
Precision: CO $\pm$0.5 ppb; $CH_4 \pm$ 2 ppb; $N_2O \pm$ 0.3 ppb
Weight: 120 lbs.
Power: 675W typical, 1400W maximum (combined requirement QCL instruments)
Response Time: 1 seconds
Location: Shares HIAPER rack mount with QCL CO_2 instrument
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The contract milestones for the project are given as follows (listed as *month of 2005*):

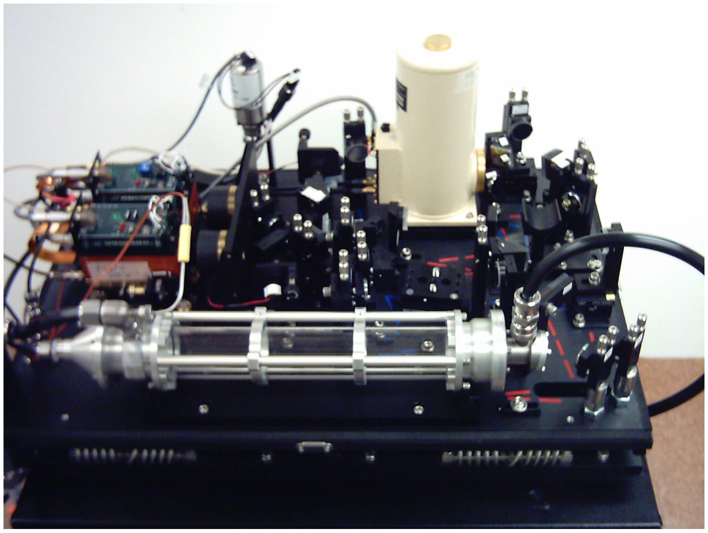
	1 -3	4- 6	7-9	10-12	13 -15	16-18	19-21	22-24
Start project, procure components	xxx							
Design of integrated instrument	xxx							
Build optical module	xxx							
Design & build electronic components	xxx							
Evaluation & testing of optical module	xxx							
Final design on instrument configuration								
Engineering of components adapted from MRI & STTR instruments		xxx	xxx					
Fabricate and assemble instrument & test the sub-assemblies			xxx	xxx				
Laboratory testing of instrument (includes environmental chamber & inter-comparison studies)					xxx			
Final packaging and flight certification						xxx		
Integration & flight testing on HIAPER, training of NCAR-ATD staff							xxx	xxx

Progress on each element is summarized below.

1. *Start project, procure components.* Procurement of all major and long-lead-time components is almost complete, including pressure housings and optical tables, optical components, laser housings and drivers, re-designed long-path and short dual-path gas cells, and gas-handling systems, pressure- and temperature-controllers. Lasers for CO, CH_4 and N_2O are in hand and have been characterized, with excellent results. Only two significant items have not yet been procured: *(a)* Alpes has yet to deliver on the CO_2 laser order. We understand that they have recently delivered these lasers to other customers and expect ours soon. *(b)* We await new, compact, DC-powered thermo-electric liquid cooling elements, which the company has said will be delivered in July/August 2005. Older-model chillers can be used instead if needed, but these require 60-hz AC power which we prefer not to use.
2. *Design of integrated instrument.* The entire flight instrument has been designed, optical and gas-handling elements, cells, computer architecture, etc. The only element as yet incomplete is the power supply and associated housing.
3. *Build optical module:* The optical module has been assembled and is currently being tested, including laser mounts, laser drivers, cooling circuits, gas flow elements, sample cells, and external housing. This is flight hardware (see photographs at the end of this report).
4. *Design & build electronic components:* completed except for power supplies.
5. *Evaluation & testing of optical module;* in progress.
6. *Final design of instrument configuration;* completed.
7. *Engineering of components adapted from MRI & STTR instruments:* completed.
8. *Fabricate and assemble instrument & test the sub-assemblies:* flight hardware is assembled, and is being tested.
9. *Laboratory testing of instrument (includes environmental chamber & inter-comparison studies);* preliminary stages are in progress. Performance of the CO_2 module appears to exceed specifications. We expect this to be true also for the long-path system but tests are not complete.
10. *Final packaging and flight certification:* We have defined the process with various Designated Engineering Representatives (DERs), and we are awaiting instructions as to whether this will be done by us with a budget supplement from NCAR (**NB!**), or by NCAR as indicated in the Investigator's Handbook. We are assuming that the procedure involves delivering paperwork (and possibly test results) needed for obtaining one or more "Engineering Authorizations" from the DERs, under Part 25 for the G-5, obtaining a Form 337 ("alterations") from the FAA, and then final certification when installed. However NCAR has not yet instructed us as to the applicability of Form 337.
11. *Integration & flight testing on HIAPER, training of NCAR-ATD staff:* not started yet.

We expect to deliver a flight—ready instrument for deployment in the T-REX program in March—April 2006. Our QCL has been requested for this program. We expect to deploy in T-REX to obtain both test flight and science data.

Photos of the instrumentation are attached.



(*Above*) **Long-path, dual laser, CO_CH_4_N_2O sensor.**
Flight hardware with the long-path cell, dual laser assemblies (upper left), dual detectors (in one housing), etc., on the shock-mounted optical bench.

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(*Below*) **CO_2 HAIS sensor.**
Left: Flight hardware of the optical module showing (1) dual detector, (2) dual 4 cm cells, (3) QCL laser assembly. *Right:* Assembly showing the purged pressure housing.