Passive Measurement of CO_2 Column from an Airborne Platform

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***Abstract*--We present results from flight testing of a new instrument intended for very precise measurements of atmospheric carbon dioxide and oxygen**

I. Introduction.

We are in the third and final year of our IIP funding to develop a sensor for very precise determination of the CO_2 column. Global measurements of this sort from a satellite platform are needed to improve our understanding of the global carbon budget. In previous reports to this meeting we have described the method by which this system operates and presented data taken during ground based tests of the instrument.

Figure 1. The flight unit optics package

Work in the final year has concentrated on building the flight hardened version of the instrument that will be used in our field trials on the Dryden DC-8. The flight unit represents an integration of three channels into a single instrument. These three channels are the CO_2 channel, the oxygen pressure sensing channel, and the oxygen temperature sensing channel. Integration of the three channels into a single unit significantly decreases the size of the instrument. The flight unit also employs more rugged optical mounts and integrated optical shielding. Figure 1 shows the flight unit during final assembly in the lab. Light enters the instrument from below first striking the right angled mirror shown extending over the edge of the platform. The light is then focused through a pinhole to define the instrument field of view, chopped and recollimated. Dichroic mirrors are used to separate the CO_2 wavelength from the O_2 wavelength and that light is further divided by a 50-50 beamsplitter between the 2 oxygen channels—the pressure channel and the temperature channel. The six white boxes contain the detectors for each of the three channels. The detectors on the left in the photo serve the reference channels and the detectors on the right are for the Fabry-Perots. CO_2 is measured by the pair of detectors farthest from the viewer. Pressure via O_2 is detected by the central pair of detectors. The closest pair is used to determine temperature via O_2.

II. Instrument Design

We have described the operation of the CO2 channel of the instrument in previous presentations to ESTO. Basically the Fabry-Perot (FP) transmission fringes are aligned with multiple absorption features of the CO_2 molecule. Light transmitted by the FP is very sensitive to changes in CO_2. We had planned to build the oxygen channels in a similar fashion although the oxygen lines are doublets rather than evenly spaced lines. Modeling of the instrument showed that lining up individual fringes with each line in a doublet pair would be inefficient. Moreover the oxygen A-band lines in the atmosphere are so strong that their peaks are completely saturated—changing amounts of O2 makes no change in the amount of light coming through the atmosphere at the peak wavelength. Larger changes occur in the valleys between the lines. For these reasons we designed the main oxygen channel to operate as shown in Figure 2. An etalon with a large free spectral range is temperature tuned so that the absorption peak lies between the 2 branches of the oxygen A-band. A bandpass prefilter is used to restrict the light to a single transmission fringe of the Fabry-Perot.

The red curve in Figure 2 illustrates how the prefilter confines the observations to a single passband of the FP. When the atmospheric O_2 concentration changes the light passed by the prefilter changes more than the light passing through the prefilter and the FP combined because the latter is tuned to a region where O_2 absorbs only weakly. This channel has a very strong response to changes in atmospheric O_2 but the ratio of the FP channel to the reference channel increases for increasing O_2 rather than decreasing with increasing abundance as the CO_2 channel

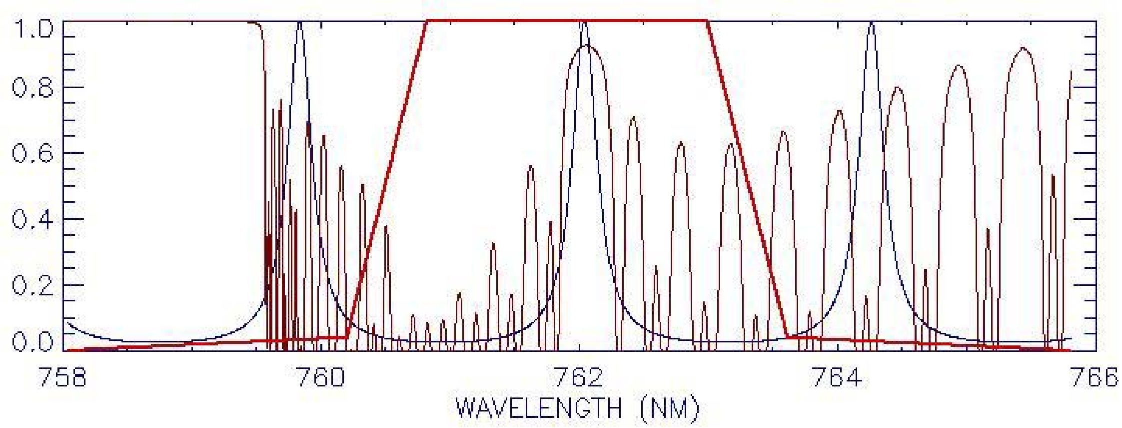

Figure 2. A theoretical depiction of the operation of the O2 sensing channel.

A second O_2 channel operating on weaker O_2 lines near 768 nm has been built using the FP on the line peaks just as with the CO_2 channel. Because the strength of these lines is very temperature dependent we hope to be able to obtain information about atmospheric temperature using this channel.

In order to evaluate the performance of these instruments we have initiated a field campaign operating the instrument on NASA Dryden's DC-8 aircraft. Figure 3 show the instrument installed over the aft, right side down looking port of the aircraft. The instrument is located in the green box in the foreground and the system

Figure 3. The instrument mounted on the cabin floor of the DC-8.

electronics are mounted in the rack just behind the box.

III. Results

We have performed calibrations in the field for the instrument by introducing direct sunlight into the instrument and monitoring the change in the FP to REF ratio as the sun rises changing the path length for the absorbing gas. A curve for the CO_2 channel is shown in Figure 4. The response to changing airmass is not linear because the CO_2 lines are so strong the absorption at the peaks is saturating. The curve shows that the ratio changes about 10% for 6 airmasses although additional work at smaller total columns shows about 2% change per airmass in the 1-2 airmass region.

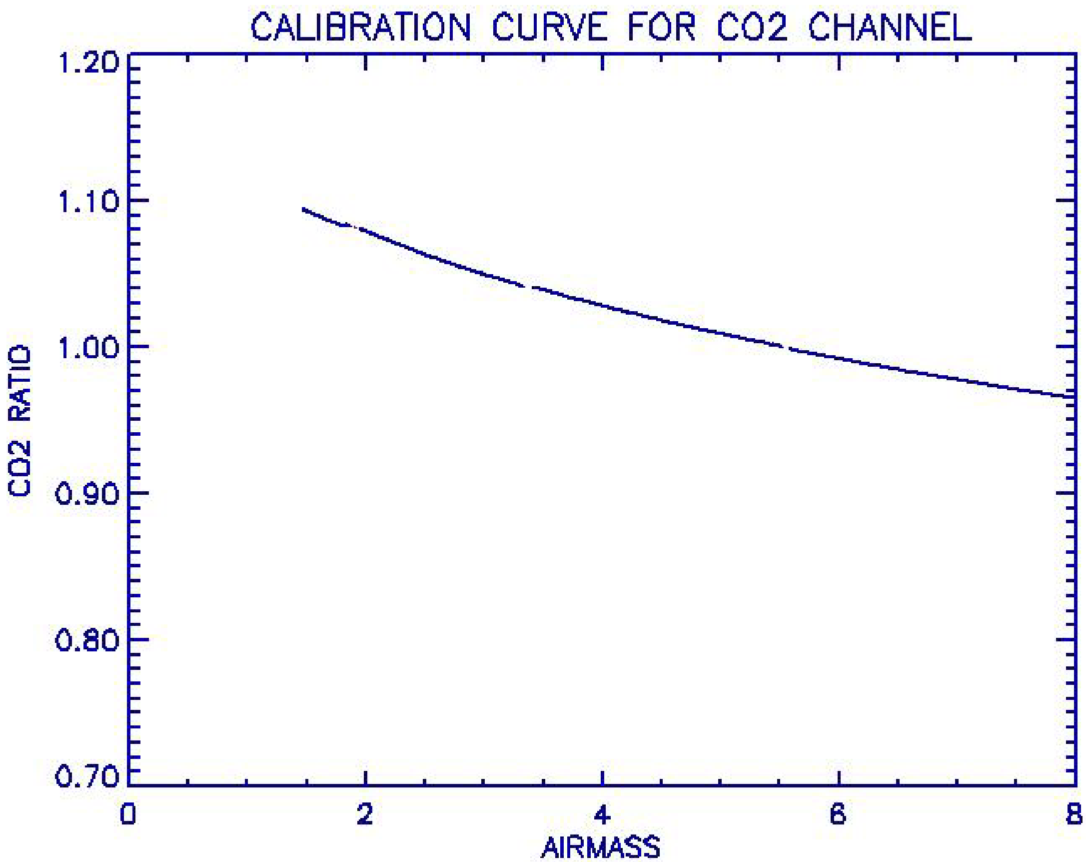

Figure 4. Plot of CO_2 ratio change per airmass yields a calibration for the CO_2 channel.

Figure 5 shows a highly magnified portion of figure 4 permitting an evaluation of the noise levels of thechannel. These data are taken at one second intervals with an instrument integration time of 0.1 seconds. The red curve shows the result of averaging 10 data points. For the red curve the noise appears to be roughly plus or minus .0001 of the ratio which is equivalent to about .002 of an airmass. Since the column average for CO_2 is about 370 ppm this noise level represents an intrinsic ability of the instrument to detect changes smaller than 1 ppm of CO_2 in one second.

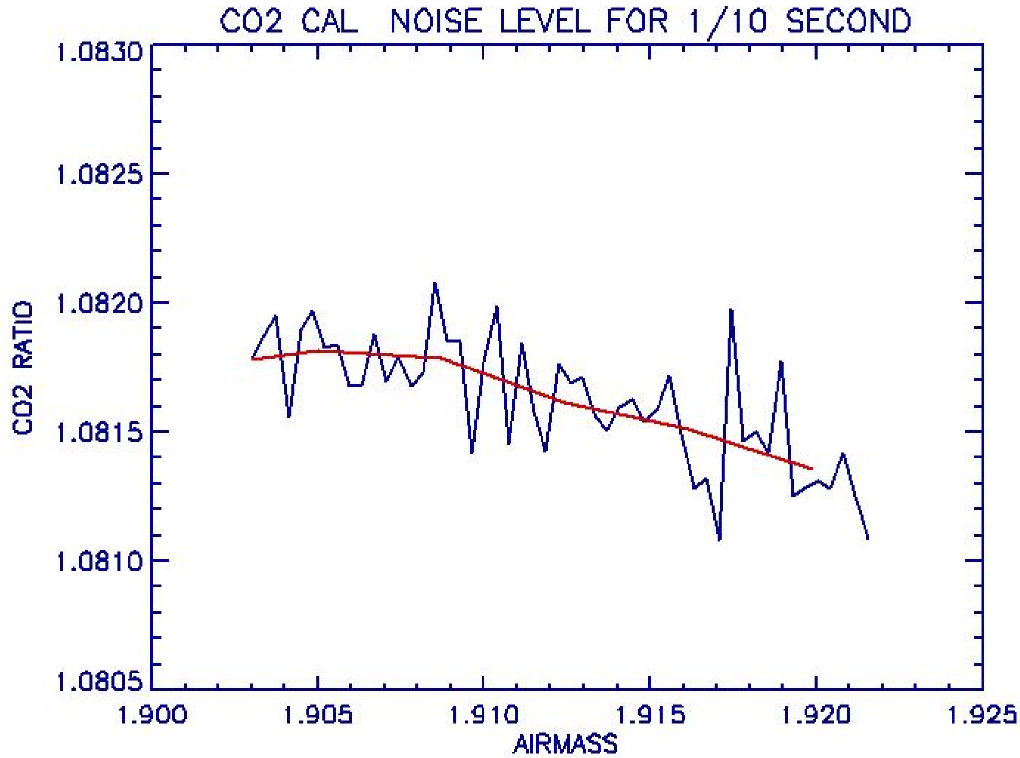

Figure 5. Sample showing noise for the CO2 channel

Figure 6 shows the change in the O_2 ratio with airmass. Note that the O_2 ratio changes by almost a factor of 2 for a change of 6 airmasses. An evaluation of the noise in this channel similar to that conducted for the CO_2 channel implies that the instrument has an instrinsic ability to detect changes in surface pressure on the order of 1 mB in one second of integration.

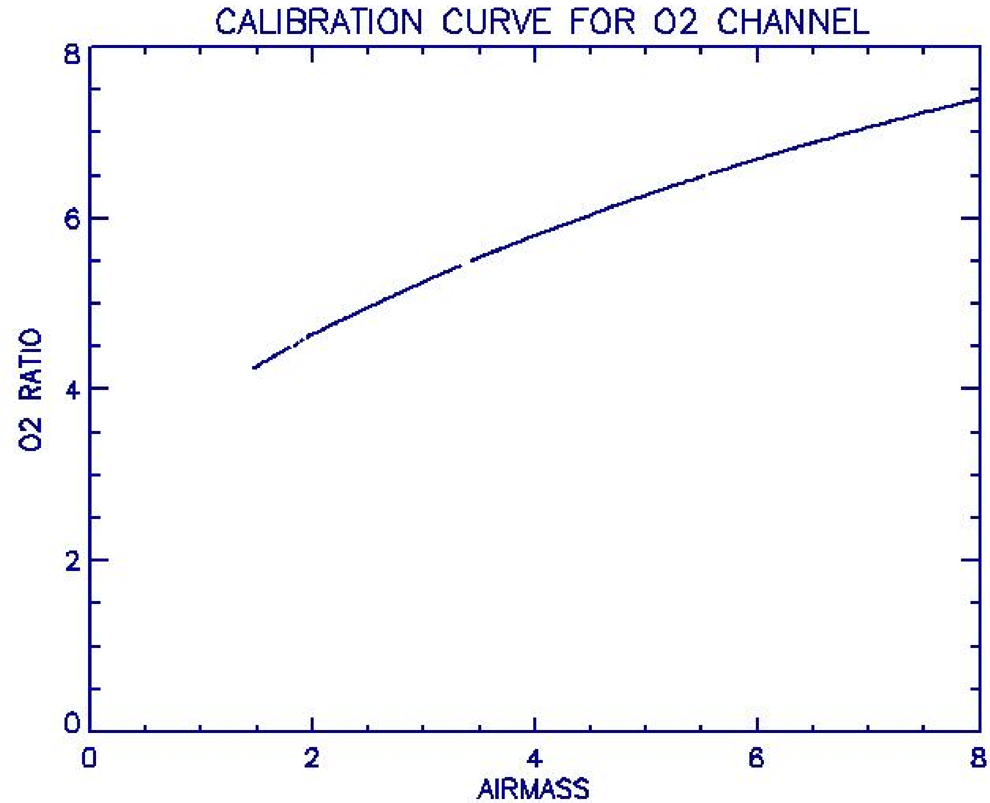

Figure 6. The O2 ratio versus airmass.

Of course measuring column absorption reflected off the ground or water is very from a moving platform employing light different than measuring direct sunlight.Variations in the measured ratio can be introduced by aircraft pitch and roll, changing terrain height, changing scene albedo and most significantly changing atmospheric scattering conditions.

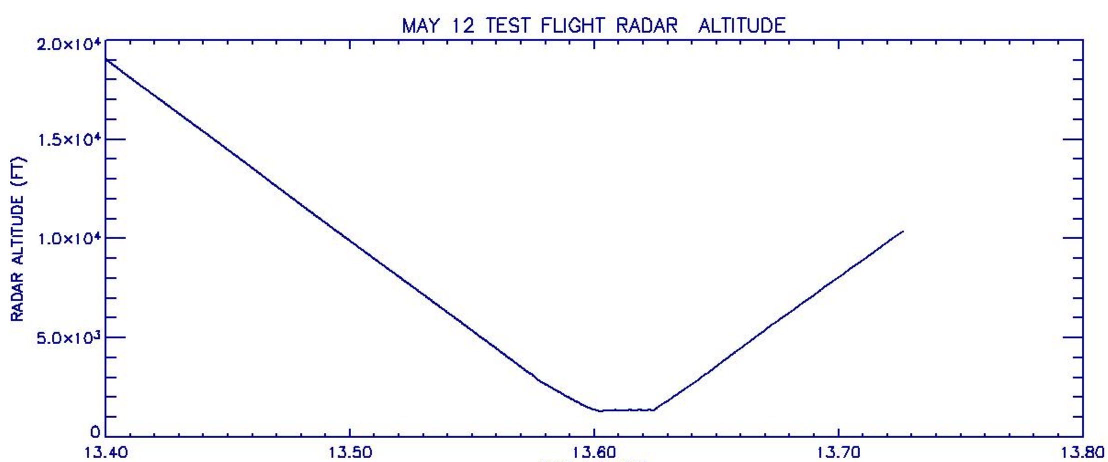

Figure 7. Radar altitude of aircraft for a short portion of the flight on May 12.

Figure 7 and 8 show a brief result from a DC-8 test flight conducted on Wednesday, May 12. Flying south over the San Joaquin valley of central California the aircraft slowly descended from 20000 feet to 1000 feet MSL and then began to climb back up. Figure 7 shows the height above the ground measured by the radar altimeter on board the aircraft. Figure 8 shows the change in the ratio of the CO_2 channel during this descent and slow reascent

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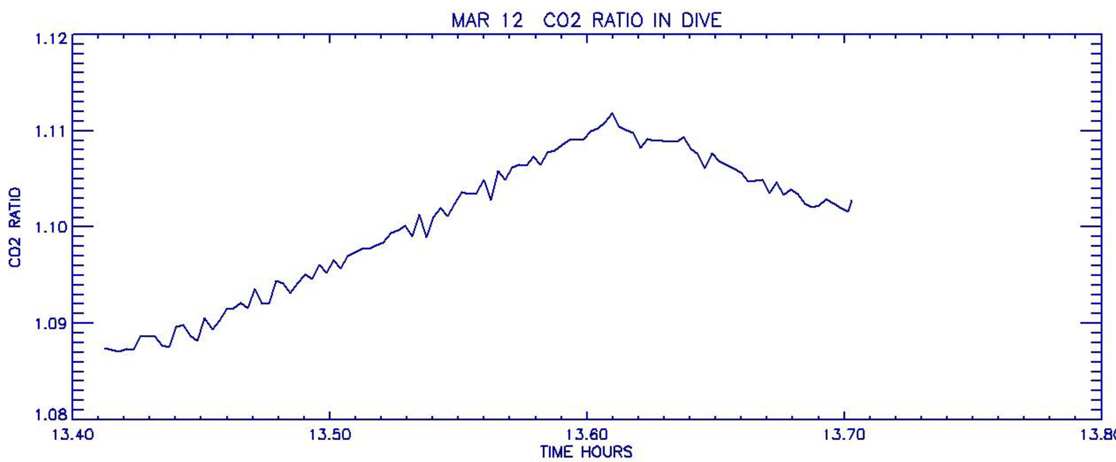

Figure 8. The change in the CO2 ratio in response to a change in aircraft altitude

The absorbing path length gets shorter as the aircraft nears the ground. Less absorption by CO_2 increases the signal in the FP channel so the CO_2 ratio increases. The ratio shown in the figure employs 10 second averaging but clearly the noise on the plot is too large to enable the resolution of 1 ppm of CO_2 (which is approximately equivalent to 80 feet of altitude).

IV. Conclusions

We have demonstrated the construction of an instrument with great sensitivity to changes in atmospheric levels of carbon dioxide and oxygen. This represents a significant step in the quest to make such measurements from space. The principle difficulty appears to be that of properly accounting for variability of atmospheric scattering. It is hoped that the simultaneous measurements of carbon dioxide and oxygen will help untangle the effects of scattering enabling resolution of smaller changes in CO_2 column but the answer to that question awaits more detailed analysis of the data.