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Development and Preliminary Tests of an Open-Path Airborne Diode Laser Absorption Instrument for Carbon Dioxide

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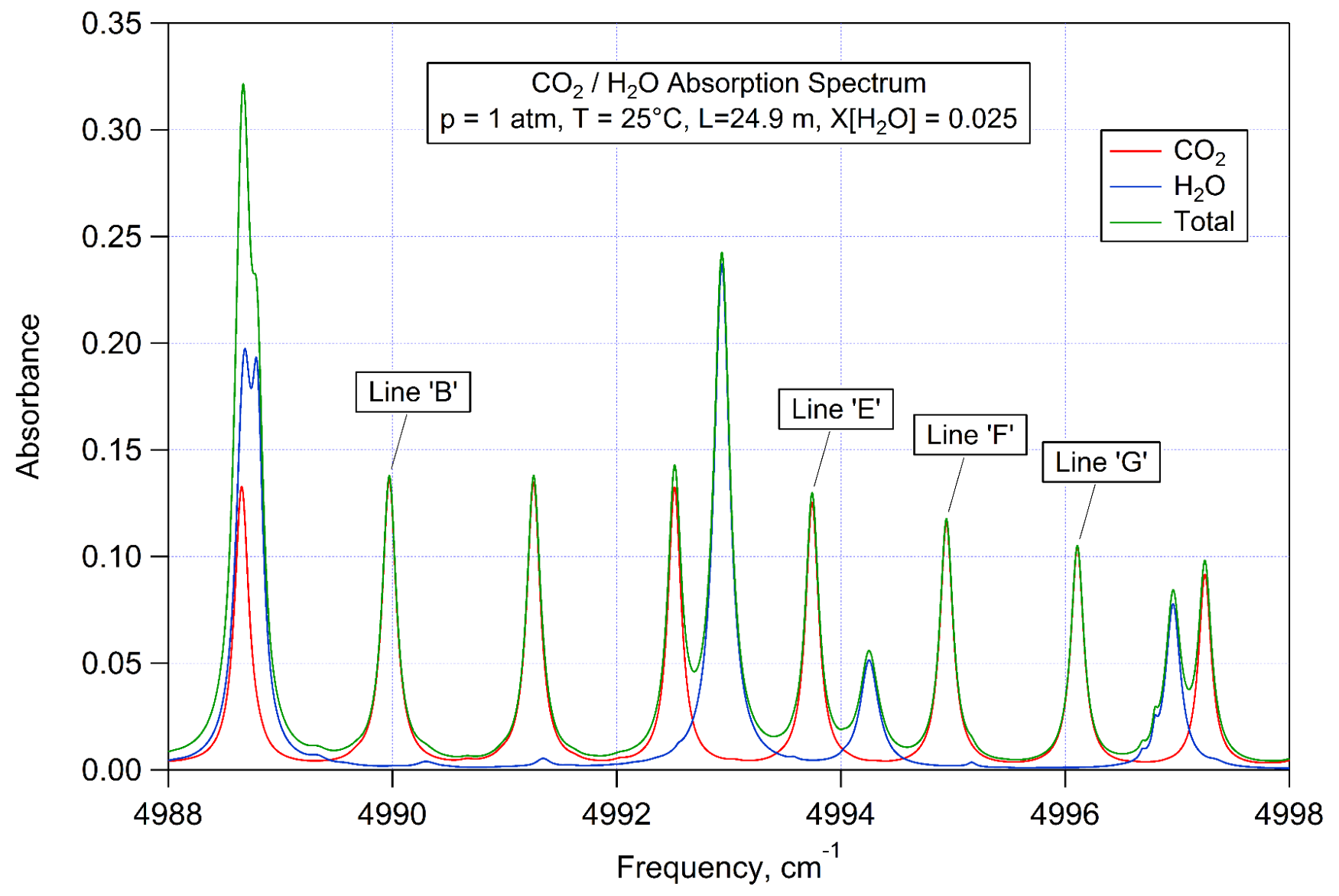
ABSTRACT

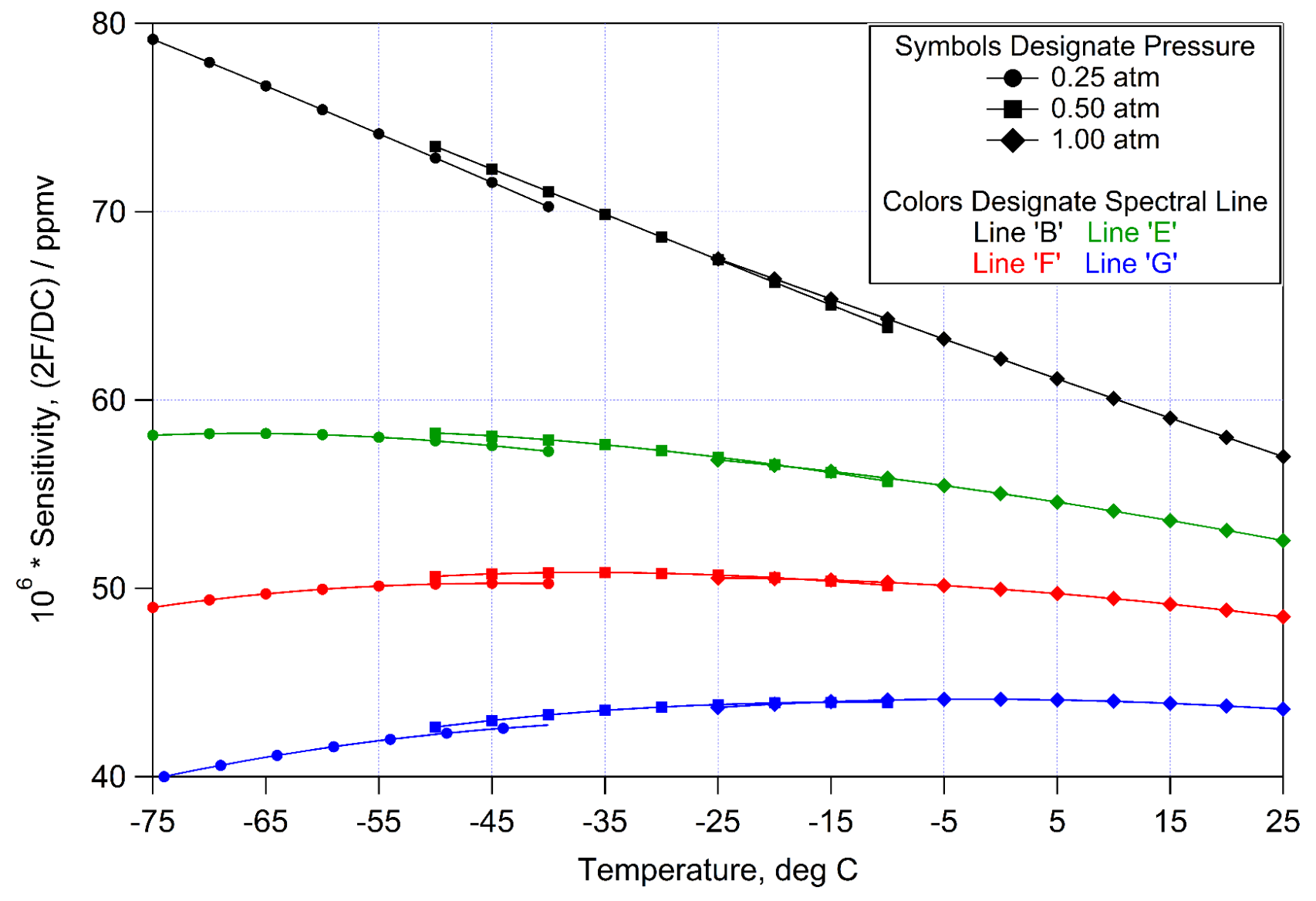
Carbon dioxide (CO_2) is well known for its importance as an atmospheric greenhouse gas, with many sources and sinks around the globe. Understanding the fluxes of carbon into and out of the atmosphere is a complex and daunting challenge. One tool applied by scientists to measure the vertical flux of CO_2 near the surface uses the eddy covariance technique, most often from towers but also from aircraft flying specific patterns over the study area. In this technique, variations of constituents of interest are correlated with fluctuations in the local vertical wind velocity. Measurement requirements are stringent, particularly with regard to precision, sensitivity to small changes, and temporal sampling rate. In addition, many aircraft have limited payload capability, so instrument size, weight, and power consumption are also important considerations.

We report on the development and preliminary application of an airborne sensor for the measurement of atmospheric CO_2. The instrument, modeled on the successful DLH (Diode Laser Hygrometer) series of instruments, has been tested in the laboratory and on the NASA DC-8 aircraft. Performance parameters such as accuracy, precision, sensitivity, specificity, and temporal response are discussed in the context of typical atmospheric variability and suitability for flux measurement applications. On-aircraft, in-flight data have been obtained and are discussed as well. Performance of the instrument has been promising, and continued flight testing is planned during 2016.

Instrument Design Considerations

- **Built on framework developed for Diode Laser Hygrometer**
  - **Common hardware, control methodology**
  - **Wavelength Modulation with Multi-Harmonic Detection**
  - **Line-locked to absorption feature of interest**
  - **Line-switching, modulation-switching**
  - **Primarily operates in automated mode, but operator can intervene**
  - **Long external path samples relatively undisturbed air**
  - **In situ calibration not possible, but in-flight characterization improves instrument model**
  - **Wavelength is 2.0 µm, to probe appropriate CO_2 absorption features**
- **Native data rate nominally 100 Hz, optically**
  - **Measurement geometry and aircraft velocity limit response to ~20 Hz**
  - **Target temporal response to enable measurements of flux using eddy correlation technique**

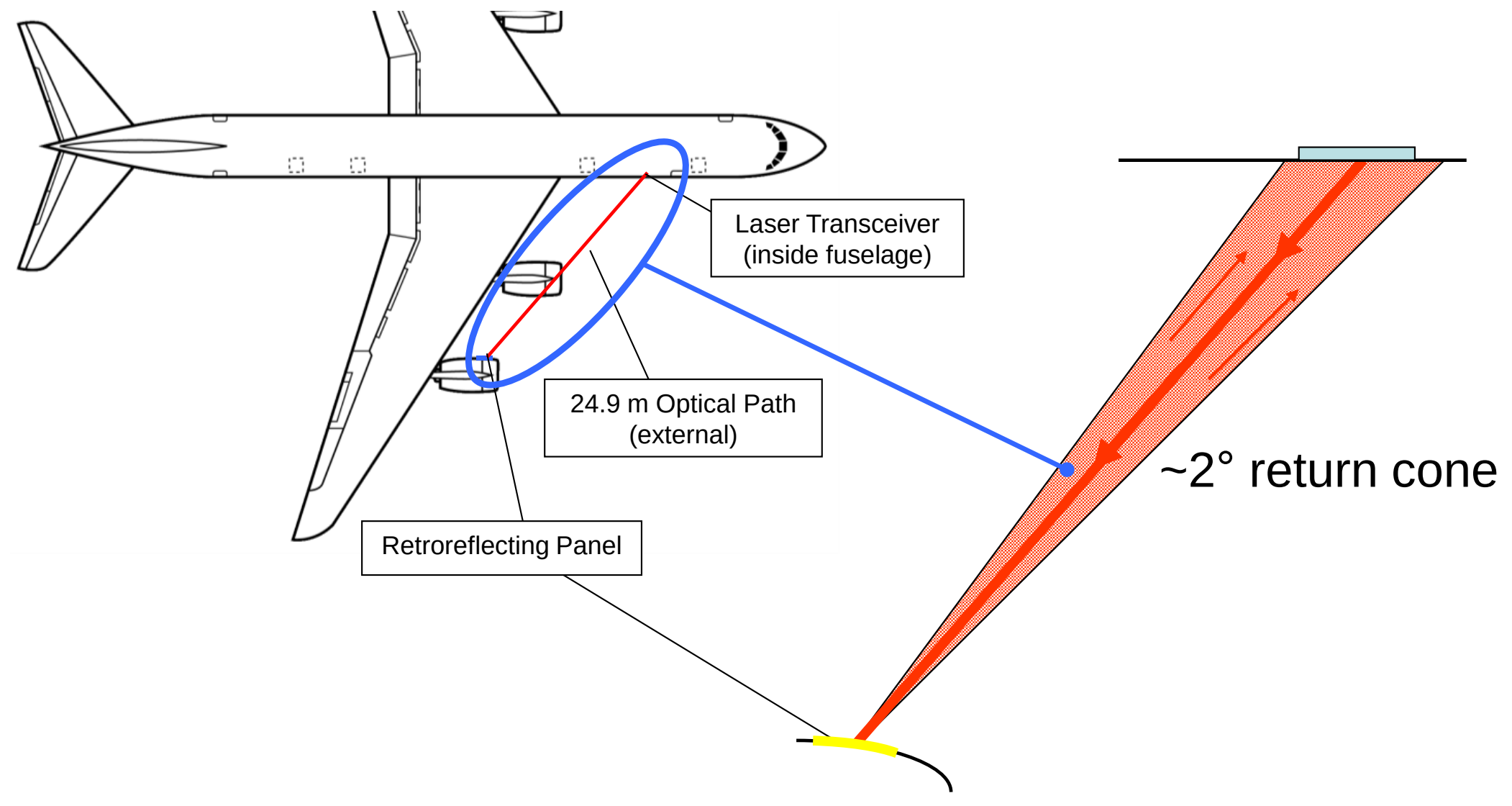




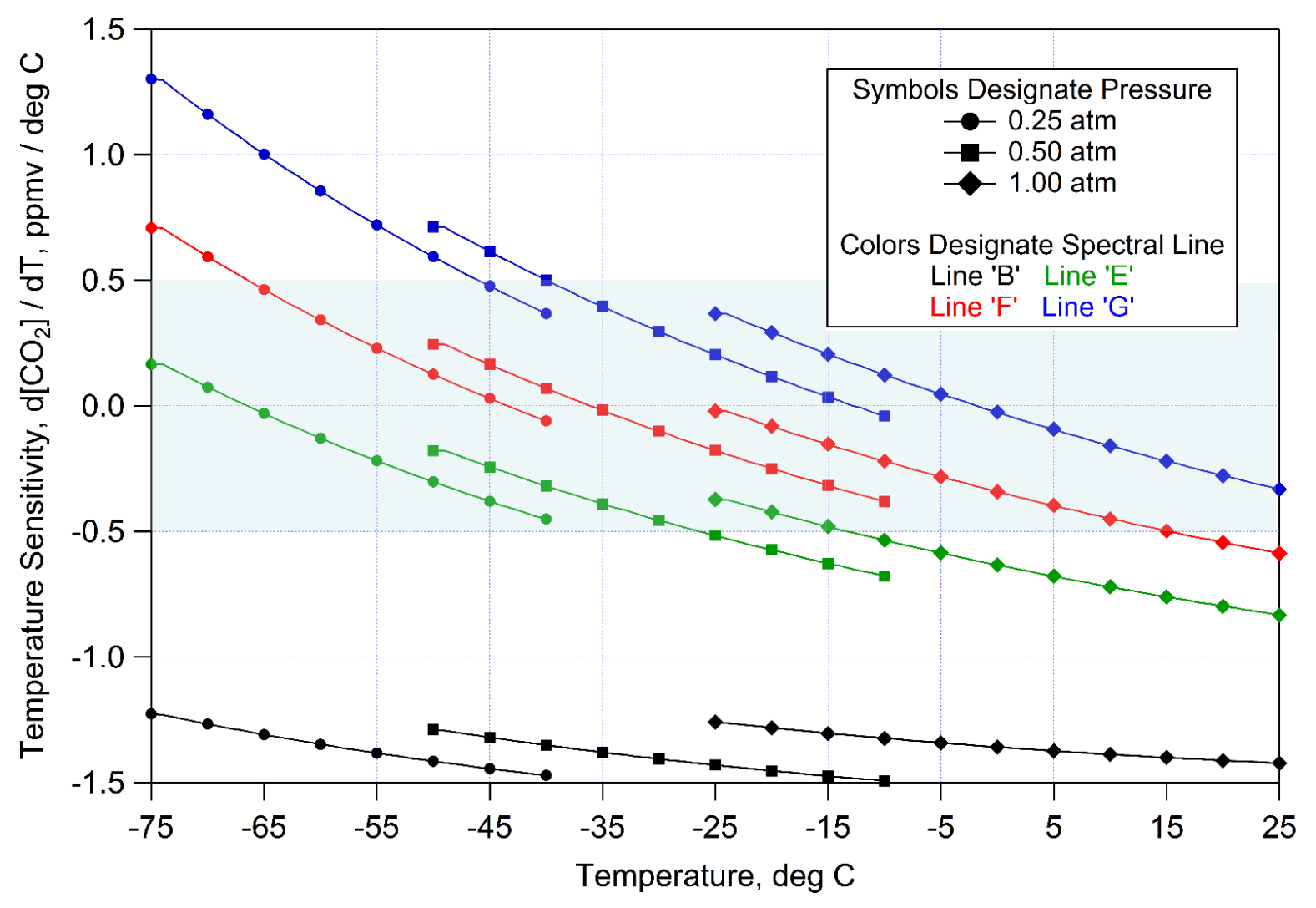
CO_2 Measurement Considerations

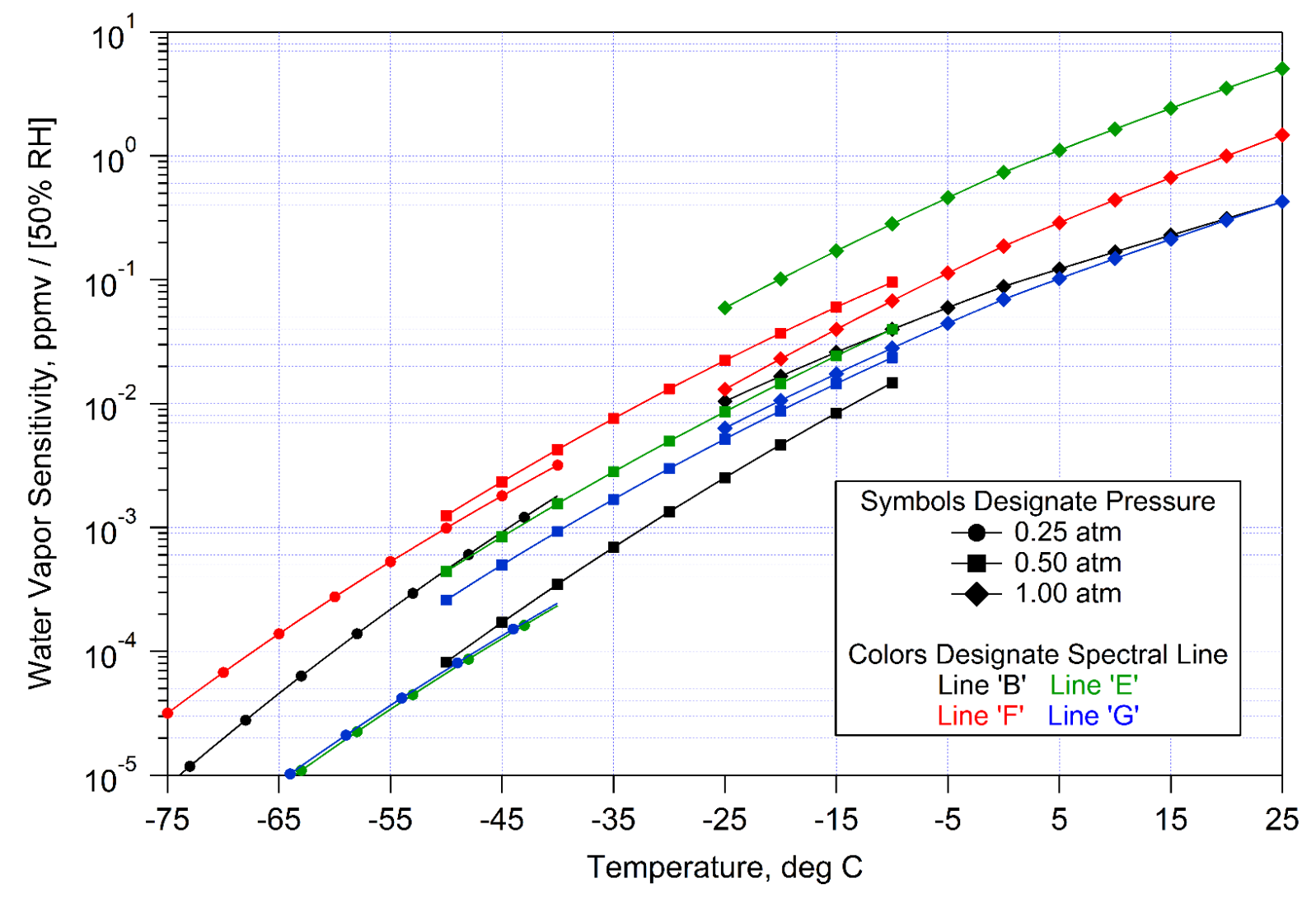
- **Measurement accuracy and precision requirements more stringent than for H_2O**
  - **In near-term, tie measurement to recognized standard through in-flight intercomparisons**
  - **Precision goal < 0.1%, 1 σ, in 1 s**
- **CO2 dynamic range is much more limited than H_2O**
- **Instrument design must minimize sensitivities to:**
  - **Ambient pressure, temperature, water vapor**
  - **CO_2 located within internal path**

Instrument Layout on NASA DC-8 Aircraft

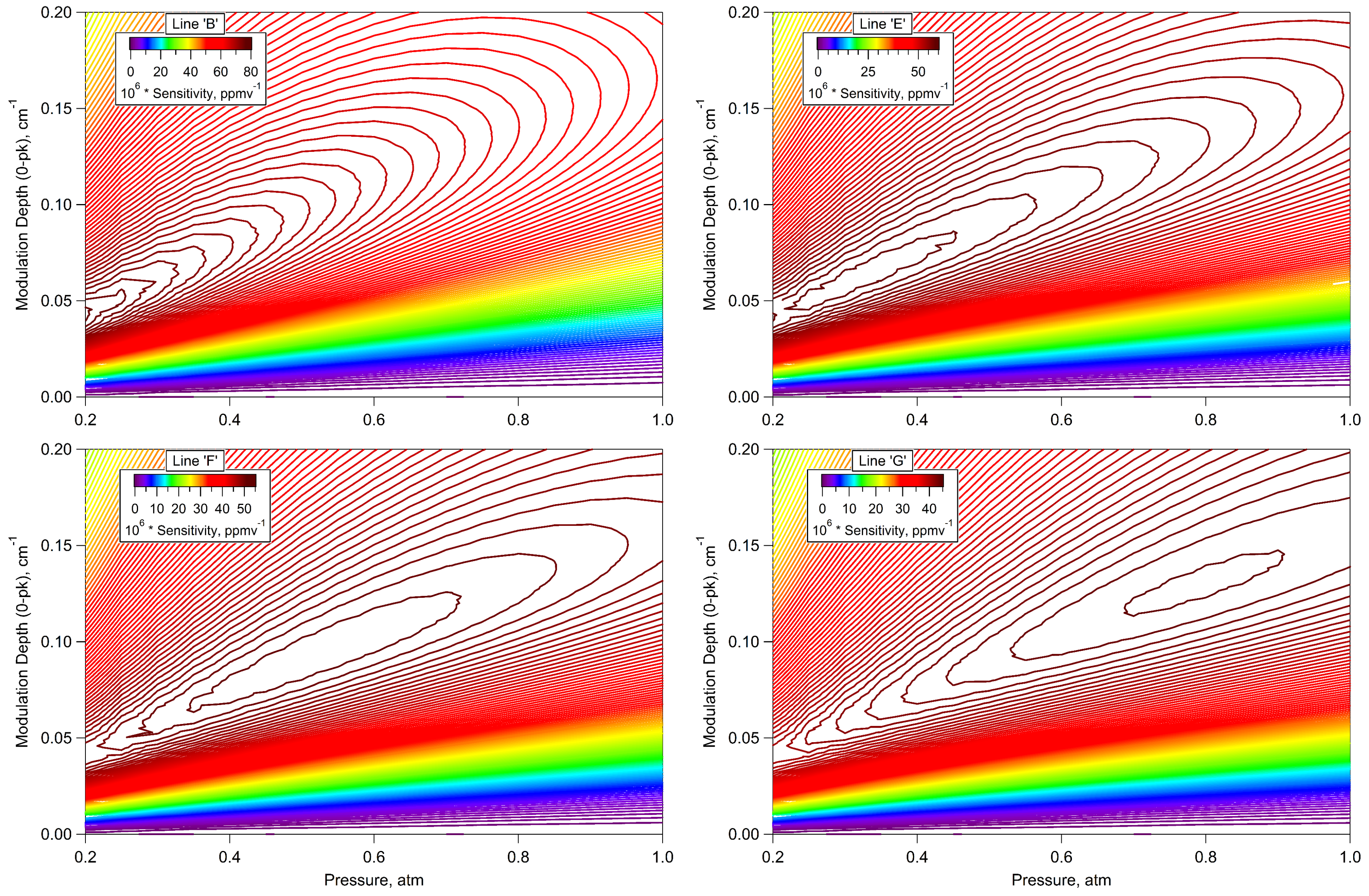


Minimizing Sensitivities to Temperature and Pressure





Determining the Optimum Modulation Depths



Flight Testing

- **Instrument was flown on DC-8 as a piggyback during three flights in Sept-Oct 2015**
  - **Signal power severely limited due to non-optimized components**
    - **Optical fiber and fiber components, solar-blocking filters**
  - **Damaged collection optic caused excessive scatter**
  - **Stabilization detector had large thermal drift**
- **Obtained useful data on all three flights**
  - **Experimental characterization data obtained for all lines at multiple altitudes**
  - **Signal precision nearly met goal, σ ~ 0.2% in 1 sec**

Ongoing and Future Work

- **Higher-performance components**
- **Replacement of stabilization detector, collection optics, fibers and components**
- **Improvement of Selected Operational Parameters**
- **Additional flight tests planned for 2016**

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