Title: NCAR AO2 Data Set

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1.0 Data Set Overview:

This data set includes measurements of O_2 and CO_2 concentration, with O_2 reported as deviations in the O_2/N_2 ratio, made by the NCAR Airborne Oxygen Instrument (AO2) on one or more of 13 campaigns during the 2008-2018 period. These campaigns include ACME-07 on the Wyoming King Air; START-08, HIPPO1-5, and ORCAS on the NSF/NCAR GV; ARISTO-2015 on the NSF/NCAR C-130; and ATom1-4 on the NASA DC-8. The instrument and data processing are described in detail in Stephens et al. (2021).

Please keep Britton Stephens updated if you are using these data in your analyses, so that he may provide input on their interpretation and apprise you of any data quality issues or updates.

2.0 Instrument Description:

The NCAR Airborne Oxygen Instrument (https://www.eol.ucar.edu/instruments/airborne-oxygen-instrument) measures O_2 concentration using a vacuum-ultraviolet absorption technique. AO2 is based on earlier shipboard (Stephens et al, 2003) and laboratory instruments using the same technique, but has been designed specifically for airborne use. To achieve the high levels of precision needed, AO2 switches between sample gas and air from a high-pressure reference cylinder every 2.5 seconds. Atmospheric O_2 concentrations are typically reported in units of one part in 1,000,000 relative deviations in the O_2/N_2 ratio, which are referred to as "per meg." AO2 has a nominal 1-sigma precision of ± 2.5-4 per meg on a 5 second measurement, depending on aircraft motion.

The instrument includes an internal single-cell CO_2 sensor (LI-840) which is used to correct the O_2 measurements for dilution by CO_2 and for scientific purposes. The CO_2 measurement has a 1-sigma precision of 1 ppm on a 1 second measurement.

To minimize inlet surface effects, the pressure in the inlet line is actively controlled at the aircraft bulkhead. The sample air is cryogenically dried in a series of electropolished stainless steel traps immersed in a dry ice Fluorinert slurry.

The AO2 system consists of a pump module, a cylinder module, an instrument module, the inlet assembly, a line-purge cylinder, and a dewar.

Figure 1. The AO2 system as used during HIPPO flights on the NSF/NCAR GV. The instrument module is on top, the pump module in the middle, and the cylinder module on the bottom. The dewar, line purge cylinder, and inlet pressure controller are not shown.

3.0 Data Collection and Processing:

The instrument includes a PC104 based PC running Windows XP. Instrumentation control is with Visual Basic and communication is via ethernet. Data are recorded by the instrument, transferred from the aircraft after flights, and merged into scientific data products after the standard processing is complete. Processed data and diagnostic plots are available at https://archive.eol.ucar.edu/homes/stephens/AO2.

Four high pressure reference cylinders are carried inside the instrument for calibration. High span and low span gases are analyzed for 2.5 min each every 50 min for calibration. Every other calibration cycle includes a third calibration gas used to establish the non-linear response of the CO_2 sensor, and every third calibration cycle includes a long-term surveillance cylinder. A fifth Line Purge cylinder, used to avoid wet and polluted air during pre and post flight, is introduced by a manual 3-way valve at the aircraft bulkhead. Values on the Scripps O_2 and CO_2, and WMO CO_2 scales are assigned to these field cylinders by the NCAR O_2 / CO_2 Calibration Facility (https://archive.eol.ucar.edu/homes/stephens/CALFAC).

The surveillance gas measurements are used to evaluate calibration scale and tubing surface humidity effects. AO2 measurements are further evaluated for inlet fractionation, calibration offsets, surface effects, and other sources of bias by comparison to whole air samples collected by the NCAR/Scripps Medusa flask sampler and analyzed at the Scripps Institution of Oceanography.

4.0 Data Format:

The archived AO2 data are in 1 flat ascii text file per flight. Each file contains 1 Hz interpolated values (of the original ~ 2.5-second data) matching the times in the RAF data files. The reported times have been adjusted for inlet delays and correspond to when the air entered the inlet (see below). The files are in NASA Ames 1001 format.

Prior to ATom, the archived files are in an approximation of the NASA Ames format that was used during HIPPO. The files are space delimited, have file names of the format:
AO2_YYYYMMDD_RF##_190520a.GV (or *.C130, where the ## indicates flight number),
have variable names:
UT, CO2_AO2orig, O2_AO2orig, APO_AO2orig, CO2_AO2, O2_AO2, and APO_AO2
and use 9999.99 for missing data.

For ATom, the archived files are in NASA Ames format. The files are comma delimited, have file names of the format:
AO2_DC8_YYYYMMDD_R#_a.ict (where the # represents revision number),
have variable names:
Start_UTC,CO2raw_AO2,O2N2raw_AO2,APOraw_AO2,CO2_AO2,O2N2_AO2,APO_AO2
and use -99999 for missing data.

Data Columns:

UT = Start_UTC = Seconds since 0000 UTC on day of takeoff

CO2_AO2orig = CO2raw_AO2 = Dry air mole fraction in units of ppm on the WMO X2007 scale

O2_AO2orig = O2N2raw_AO2 = O_2 to N_2 ratio in units of per meg on the Scripps O_2 scale as defined on 16 March 2020

APO_AO2orig = APOraw_AO2 = atmospheric potential oxygen in units of per meg, calculated as APO_AO2orig = O2_AO2orig + 1.1*(CO2_AO2orig - 350)/0.2094

or APOraw_AO2 = O2N2raw_AO2 + 1.1*(CO2raw_AO2 - 350)/0.2094

CO2_AO2 = Dry air mole fraction in units of ppm on the WMO X2007 scale, adjusted to match Medusa with linear time of flight plus constant offset fit

O2_AO2 = O2N2_AO2 = O_2 to N_2 ratio in units of per meg on the Scripps O_2 scale as defined on 16 March 2020, adjusted to match Medusa with linear time of flight plus constant offset fit

APO_AO2 = atmospheric potential oxygen in units of per meg, calculated as

APO_AO2 =O2_AO2 + 1.1*(CO2_AO2 - 350)/0.2094 or

APO_AO2 = O2N2_AO2+1.1*(CO2_AO2 - 350)/0.2094

ATom data files in the same file format as previous campaigns are available at https://archive.eol.ucar.edu/homes/stephens/AO2

5.0 Data Remarks:

O_2 Data:

The raw AO2 O_2 measurements on various campaigns have exhibited systematic offsets relative to Medusa flask samples owing, we believe, to inlet fractionation, surface interactions on tubing or trap surfaces, and photochemistry of residual water vapor in the sample cell. Detailed discussion of the potential causes for these offsets, descriptions of our methods for empirically correcting or filtering them, and their magnitudes before and after correction are presented in Stephens et al. (2021).

CO_2 Data:

The CO_2 sensor in AO2 is intended to provide a dilution correction for the O_2 measurements and has relatively coarse precision. AO2 CO_2 data should generally not be used for scientific analyses without a detailed understanding of their limitations. The AO2 CO_2 data have a precision of 0.7 ppm (1-sigma) for the original 2.5-second data, and 0.3 ppm on 10-second medians. Average offsets with respect to Medusa flask samples are typically several tenths of ppm. We make similar empirical corrections for CO_2 as for O_2, based on comparisons to Medusa, as described in Stephens et al. (2021).

Inlet delays:

The inlet delay is empirically calculated from the response to switching the inlet Line Purge valve, with a small pressure dependent adjustment for the inlet itself. Our inlet delay time calculations do not allow for mixing in traps or due to tubing shear, which spread step changes by approximately $\pm$ 10 seconds. A perfect inversion of measured to inlet concentration time series is not possible. Therefore, comparisons of high-rate variables to AO2 data should be done after smoothing the high rate data with approximately a 20-sec running mean.

6.0 References:

Stephens, B.B., R.F. Keeling, and W.J. Paplawsky, Shipboard measurements of atmospheric oxygen using a vacuum-ultraviolet absorption technique, Tellus Series B, 55, 857-878, https://doi.org/10.3402/tellusb.v55i4.16386, 2003.

Stephens, B. B., Morgan, E. J., Bent, J. D., Keeling, R. F., Watt, A. S., Shertz, S. R., and Daube, B. C.: Airborne measurements of oxygen concentration from the surface to the lower stratosphere and pole to pole, Atmos. Meas. Tech. (accepted), https://doi.org/10.5194/amt-2020-294, 2021.