A Study of Stratosphere-Troposphere Exchange Associated with Tropical Storms

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Abstract

We propose to fly in situ ozone and water vapor instruments on board the ER-2 during CAMEX-4 flights over severe tropical convection. The aim of these measurements is to examine stratosphere-troposphere exchange (STE) processes over hurricanes in the Atlantic. The purpose is to determine whether significant lofting of upper tropospheric air into the stratosphere occurs under such situations. Such transport affects the chemistry of the lower stratosphere. Concomitant transport of lower stratospheric air into the upper troposphere also occurs; this may impact tropical storm formation or evolution. Data will be analyzed to assess frequency and location of STE and its impact on the stratosphere and on tropical storm evolution.
Scientific Questions:

1) How is air transported from the troposphere to the stratosphere?

2) What role does convection play in dehydrating air to the low mixing ratios observed in the stratosphere?

3) Does transport of high PV stratospheric air into the upper troposphere affect tropical storm formation and/or evolution?

Measurements:

*In situ* ozone and total water on the ER-2

Instruments:

Dual-Beam UV Absorption Ozone Photometer

Lyman-α Total Water Hygrometer
NOAA Dual-Beam UV Absorption Ozone Photometer

Ozone is measured using a photometer consisting of a mercury lamp, two sample chambers that can be periodically scrubbed of ozone, and two detectors that measure the 254-nm radiation transmitted through the chamber (Proffitt et al. [1983]). The ozone number density is calculated using the ozone absorption cross-section at 254 nm. At a one-second data collection rate, the minimum detectable concentration of ozone (one standard deviation) is $1.5 \times 10^{10}$ molecules/cm$^3$ (0.6ppbv at STP).

Accuracy: 3% + precision
Precision: $1.5 \times 10^{10}$ molecules/cm$^3$
Weight: 24 kg
Data rate: 1 second
NOAA Lyman-α Total Water Hygrometer

Total water is as vapor with a Lyman-α hygrometer (Kelly et al. [1989]). Lyman-α light (121.6 nm) photodissociates water to produce an excited OH radical. The fluorescence from this radical at 309 nm is detected with a phototube and counting system. The Lyman-α radiation produced with a DC-discharge lamp is monitored with an iodine ionization cell that is sensitive from 115 nm to 135 nm. Calibration occurs in flight by injecting water vapor directly into the ambient sample flow.

Detection System:

- Molecular Iodine Cell
- Photodiode
- Outlet
- 121.6 nm Source
- 121.6 nm Cutoff Filter
- Sphere Exhaust
- PMT
- Calibration
- 309 nm Filter
- H₂O Injector
- Inlet
- Air Sample
- Black Glass Chamber
- Black Glass Cube
- Retroreflecting Corners
- Externally Pumped

Accuracy: 10%
Precision: 5%
Data rate: 1 second
Weight: 29 kg
Data files for both the ozone and water instrument have been submitted to the CAMEX-4 data archive.

Ozone data is complete for all flights.

Water data is complete for all but 3 flights. Flights with missing water data include:

1) Gabrielle flight (lost ~30% of the data due to a flash card failure)
2) Humberto flight on Sept. 24 (lost ~40% of the data due to a stuck calibration valve)
3) Transit flight to Dryden (calibration valve unstuck midway in flight, have data for ~50% of the flight)

All files are in ASCII, and consist of two columns, UT seconds in flight and mixing ratio.
Prior to the CAMEX-4 flights, we have NOAA O$_3$ and H$_2$O data from 3 storms.

1) 1987, STEP-Darwin, ER-2 flew over Cyclone Jason.

2) 1994, ASHOE/MAESA, ER-2 flew near Typhoon Usha.

3) 1999, ACCENT, WB-57F flew over Hurricane Floyd.
This shows low O₃ in the 70-80 hPa layer above Jason, likely due to upward transport of tropospheric air. Larger values of ozone in the 90-100 hPa layer may be due to downward transport of stratospheric air.
Hurricane Floyd overflight profile (red diamonds) compared with a vertical profile in the same area taken 2 days earlier (blue diamonds). Measurements were taken from the NASA WB-57F during the second deployment of the ACCENT experiment in September 1999. Points plotted (volume mixing ratio versus pressure) are 1 minute averages.

This shows possible dehydration over the storm, and lofting of O₃ poor air ~80 hPa over Hurricane Floyd.
Key point: Based on these previous flights, the signal we were interested in sampling appears to be between the tropopause and 70 hPa. In particular, we wanted level flight legs over the tropical storms between 100 and 70 hPa, or 55-65 kft.

Histogram of CAMEX-4 sampled pressures
Since we clearly didn't get flights at the levels of interest for our proposed study, we are now assessing what we can do with the in situ data collected.

Initially, we're looking for evidence of gravity wave propagation above the tropical storms. This will involve collaboration with Joan Alexander (at CORA) and M. J. Mahoney (at JPL) using the MTP data once it is in final form.

We are also trying to simulate the storms sampled with MM5 runs to look at mixing processes and gravity wave propagation above the tropopause. (Eric Ray, AL)
Summary of data collected

CAMEX-4 Ozone, all flights except transits

CAMEX-4 Water, all flights except transits
CAMEX-4 storm flights, 45-65 mb

CAMEX-4 non-storm flights, 45-65 mb
What next?

1) Try to characterize storm and non-storm vertical profiles of ozone and water vapor.

2) Look for evidence of wave propagation up to ER-2 altitudes in both MTP and ozone data.

3) Attempt to model STE and lowermost stratosphere mixing processes above the storms sampled during CAMEX-4.

4) Acquire the high resolution TOMS data and look for total ozone signatures (a la Rodgers et al. [1990] and Stout and Rodgers [1992]).

5) Attempt to get an ozone instrument on the NOAA G4 for next hurricane season. (One is currently flying on the G4 this winter.)