Ozone Measurements from Eyewall Transects of Two Atlantic Tropical Cyclones

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ABSTRACT

Measurements of ozone (O₃) concentrations obtained during aircraft eyewall crossings of Tropical Cyclones Floyd (September 1999) and Georges (September 1998) by NOAA P-3 hurricane research aircraft showed marked changes between the intensifying and weakening stages of the storms’ life cycles. Renewed deepening appeared to be underway near landfall of both storms. During intensification, ozone levels indicated that air either descended from an altitude <1 km above flight level or was strongly diluted with low-O₃ eyewall air. During weakening, ozone concentrations were low throughout the eye and eyewall, consistent with the eye’s being filled with boundary layer air.

1. Introduction

Tropical cyclone (TC) eye dynamics and thermodynamics have been the subject of several recent investigations (Kossin et al. 2000, 2002; Kossin and Eastin 2001; Dodge et al. 1999; Willoughby 1998; Emanuel 1997). These studies have clarified the structural changes that accompany TC evolution: in intensifying storms, air in the eye above a descending inversion layer is warmer and dryer than the surrounding air; in a weakening storm the air becomes cooler and wetter, and the inversion layer ascends. The transition between the two modes may be rapid (Kossin and Eastin 2001).

These investigations have not exploited chemical tracers other than humidity. Clearly, the possible movement of marine boundary layer (MBL) gases upward as high as 15 km and redistribution over a large horizontal area suggests that chemical measurements should provide insight into hurricane eye dynamics. They may, for example, resolve issues of mixing at the eyewall boundary and lifetime of air within the eye (Willoughby 1998).

Only a few tropical cyclones have been subjected to extensive chemical sampling. The first ozone measurements were made in Hurricane Ginny in 1964; elevated ozone concentrations were observed in the eye (Penn 1965). The most thorough study is the large suite of measurements from Supertyphoon Mireille investigated during the (Pacific Exploratory Mission) PEM-West A campaign in the Pacific in 1991 (Newell et al. 1996). The measurements were obtained from an altitude of almost 12 km, about 4 days after the cyclone passed maximum intensity and just before landfall on Kyushu, Japan [Joint Typhoon Warning Center (JTWC); http://www.npmoc.navy.mil]. The storm was mature, close to land, and weakening rapidly. The measurements revealed that NO, H₂O₂, CH₃OOH, and SO₂ were elevated episodically in the region of the eye, but offered no evidence of stratospheric air intrusion. The results were interpreted as evidence of entrainment of boundary layer air into the eye, and an active photochemical environment at high altitudes relative to the background. Elevated concentrations of nitric oxide (see following discussion) occurred in the outflow regions. These intriguing results prompted us to initiate a modest, but sustained, program to constrain conceptual models of tropical cyclone dynamics with observations of key chemical species.

Ozone is photodissociated by light of wavelength λ < 320 nm (Hartley band) (Warneck 1988). The resulting O(¹D) may be collisionally deactivated in air to O(³P) (which usually reacts rapidly with oxygen to reforming ozone) or react with H₂O to form the hydroxyl radical. The hydroxyl radical is the chief oxidizing species in the troposphere. Thus, when water is present photodissociation is an important sink for ozone that has implications for photochemical activity in hurricanes as well as

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for the lifetime of ozone in the MBL. Additional known loss reactions of ozone with hydroxyl and hydroperoxide are probably less significant because of these species’ low concentration in the pristine marine troposphere. Photochemical sources of ozone in the troposphere depend on the presence of hydrocarbon precursors and on NO and NO₂ (Crutzen 1979). It seems possible that hydrocarbon gases dissolved near the oceans’ surface could be outgassed by the high wind speeds and low atmospheric pressures of a hurricane, at least in biologically productive waters, and lofted to the tropopause; however, the concentration of reactive nitrogen gases in the remote marine troposphere is probably low (Logan 1983). Lightning is a significant source of nitrogen oxides in remote regions (Martin et al. 2000), and some hurricanes exhibit electrical activity (Black and Hallett 1999), which may result in elevated nitrogen oxide concentrations (as in TC Mireille; New- ell et al. 1996). However, electrical activity is quite variable in Atlantic tropical cyclones (Molinari et al. 1999) and was not observed in either storm considered here.

Thus, the air inside the eyes of Atlantic hurricanes is expected to resemble the remote marine troposphere, with low concentrations of ozone precursors and water vapor before the filling stages. In lieu of supporting measurements to support an exact computation of production and loss reactions for ozone, it may be approximated using the empirical relationships of Davis et al. (1996), which were derived from observations in the North Pacific (see below). A more quantitative investigation of the photochemical environment within Atlantic hurricanes will require additional chemical and actinic measurements.

2. Experimental procedure

Ozone measurements were obtained from National Oceanic and Atmospheric Administration (NOAA) N43RF (P-3) aircraft during the 1998 and 1999 hurricane seasons, as part of NOAA/Atlantic Oceanographic and Meteorological Laboratory Hurricane Research Division’s annual campaign of airborne research. The ozone instrument employed was an Environics Models 300 B Ozone Analyzer (Environics, Inc., Tolland, Connecticut). The instrument was located near the center of the aircraft fuselage. Teflon lines [0.635-cm (1/4) outside diameter (OD), each ~10 m in length] ran from the instrument’s inlet and outlet connections through the aircraft’s skin; transit time for air into the instrument was <1 s. The sample line was maintained at ambient (outside) atmospheric pressure. The output of the instrument (voltage) was recorded every 5 s on the aircraft’s digital data recording system. Postflight processing of the data included a correction for atmospheric air pressure, since the pressures experienced during the flight exceeded the range of the instrument’s automatic pressure correction, which was disabled during data collection. The sampled air was assumed to reach thermal equilibrium with the interior of the aircraft; thus, no temperature correction was required. A ~70 s delay in the response of the instrument to changes in ozone, determined using a calibrated ozone source, was applied to the measurements. The instrument itself was calibrated by the Dade County Department of Environmental Resources Management in Miami, Florida, using Environmental Protection Agency (EPA) protocol, at the start of each field season. It was found to be accurate to <2%, with a precision of <1% relative standard deviation (rsd) at 100 ppb. A percent relative ozone (\%O₃) was computed by assigning an average ozone concentration near but outside the eye region (vicinal ozone) as 100%. Decreases or increases in ozone concentration were expressed as a percentage of that concentration.

3. Results and discussion

Ozone was measured in aircraft flights during flights into Hurricanes Floyd (1999) and Georges (1998; Table 1). In addition to ozone, the aircraft also measured its standard suite of thermodynamic and kinematic variables as described by Jorgensen (1984; and online at http://www.aoml.noaa.gov/hrd/). The aircraft was usually flown through the eye at a fixed pressure, equivalent to a geometric altitude of 2–6 km. The instrument operated throughout the entire flight; however, here we are concerned with measurements made near the eye. The eye center was readily found in the data as minima of wind speed, geopotential height at fixed pressure, and dewpoint, coincident with maximum temperature.

a. Hurricane Floyd

The precursor of Hurricane Floyd formed over western Africa on 2 September 1999 (all times and dates are UTC unless otherwise noted). The system developed a center of circulation on the 5th, became a tropical depression on the 7th (Lawrence et al. 2001), a tropical storm on the 8th, and a hurricane at 1200 of the 10th (19.3°N, 58.8°W), east of the Leeward Islands. By 12 September, the eye was well formed and clear down to the sea surface. On the morning of the 13th, Floyd attained its maximum strength, just short of category 5 on the Saffir–Simpson hurricane scale (Simpson 1974) with surface winds of 69 m s⁻¹ and a pressure of 921 hPa at 1200 UTC (Lawrence et al. 2001). Floyd was thus a very large and intense storm with a well-defined, cloud-free eye of 37–46 km in diameter. A strong rainband 90–100 km from the eye center had become a secondary eyewall. An eyewall replacement had begun. By 14 September, near Eleuthera, Bahamas, the outer convecive ring became the primary eyewall, and the storm had weakened somewhat. Aircraft-observed winds showed a eye diameter of 119 km at 2020 UTC. The eye was cooler than the previous day, and dropsondes no
longer reported an inversion layer. Floyd, by then a category 2 hurricane, was losing its eyewall structure as it made landfall at 0630 on the 16th, near Cape Fear, North Carolina. It continued across New England and departed into the North Atlantic on the 19th.

N43RF sampled Floyd from 9 to 16 September. Flights with ozone measurements occurred on 13, 14, and 15 September (day numbers 256, 257, and 258). Sampling occurred at fortuitous times during the evolution of the storm, from near the time of maximum intensity to more than two and a half days later, after filling of the eye and an eyewall replacement. Table 1 summarizes the sorties into Floyd.

The aircraft flight path for the 13 September flight is shown in Fig. 1. The aircraft is seen to employ “figure four” patterns to obtain the four eye crossings following the transit to the vicinity of the hurricane, which was located near 24.2°N, 73.2°W and heading west-northwest. Data obtained during the entire flight are shown in Fig. 2. The dataset begins with the transit portion at ~5 km (~565 hPa); there, the air was cooler, drier, with elevated ozone expected for the mid troposphere. The aircraft then descended to ~644 hPa (3.7 km) at a position due south of the storm and began the four eye transects; these are denoted 1–4 in Figs. 1 and 2. Because it flew on a constant pressure surface, the aircraft descended ~0.5 km during each eye passage. The air in the eye is significantly warmer and drier than

![Diagram](http://journals.ametsoc.org/mwr/article-pdf/133/1/166/4215141/mwr-2844_1.pdf)
the surroundings. At the center of the eye, as determined by true tangential wind speeds (not shown) near zero, temperature increases of \(\sim 15^\circ\)C and relative humidity decreases to \(\sim 30\%\) were observed. The ozone profile across the eye exhibited a “w” pattern just inside the eyewall, as discussed below.

Transits between eye crossings were often characterized by regions of elevated or depressed ozone. Features A–D in Figs. 1 and 2 (days 13.866, 13.902–13.926, 13.964, and 13.993) have elevated ozone and are warm and dry, consistent with subsiding air. We interpret these features as dry mesoscale downdrafts (Marks and Houze 1987). Upper-troposphere air can be entrained into downdrafts near the 0°C isotherm (Betts 1982; Betts and Silva Dias 1979) and forced by melting and evaporation of hydrometeors. The entrained air will have elevated ozone relative to air derived solely from the boundary layer. This pattern is distinct from that at position E (at 2331 UTC), which has lower ozone mixing ratio but nearly 100% RH. Nearly simultaneous radar reflectivity fields (recorded 2300–2329 UTC; not shown) suggest the aircraft was then crossing a rainband where moist, low-ozone air would be expected.

We begin by examining the transect 2 of Hurricane Floyd, which occurred on 2113 UTC 13 September (Figs. 1 and 2). Measurements of air temperature, humidity, tangential wind velocity, and ozone from this transect are shown in Fig. 3. The ozone trace exhibited a w pattern, with lower concentrations adjacent to the eyewall and elevated concentrations around the center of the eye. Ozone concentration measured at transect altitude (\(\sim 3.2\) km) away from the eye (“vicinal” ozone) was about 16.4 ppb in this pass. In the western eyewall, the ozone was depressed by about \(\sim 2.5\) ppb, or \(\sim 15\%\) relative to the vicinal concentration, and in the eastern eyewall, \(\sim 2\) ppb or about \(12\%\) (Fig. 3). The eye showed some asymmetry, noted previously. In the center of the eye, ozone was elevated to \(\sim 17\) ppb, slightly above the vicinal concentration. To the east of the eye, a second eyewall had formed; this feature appears in Fig. 3 at about \(72.5^\circ\) longitude and was characterized by humid, warm air with decreased ozone concentration.

The flights on 14 September included two passes through the eye, a north-to-south pass with a wind speed minimum at 1442 UTC, and an east-to-west with a minimum at 2029 UTC, at an altitude of \(\sim 4.0\) km. The pass data were very similar; here we describe the latter pass because the former aircraft flight path extended only \(0.7^\circ\) north of the eye, not far enough to provide a complete description (Fig. 4). A major eyewall replacement process was then complete, and the eye diameter had doubled from \(\sim 37\) to \(\sim 70\) km. The composition of the eye had substantially changed; the w pattern from the previous day has been replaced by cool (11.5°C), moist (\(\sim 80\%\) RH) air with ozone of nearly constant lower mixing ratio (\(\sim 16\) ppb) from eyewall to eyewall, in contrast with the vicinal concentration away from the eye (\(\sim 17.8\) ppb). The hurricane had weakened from the previous day because of combined effect of low-level entrainment of drier air from the northwest and increasing south-southwesterly vertical shear (Lawrence et al. 2001).

The final sortie on 15 September included four eye transects, at 2058, 2223, 2340, 0109, 0229, and 0342 UTC (the latter three on 16 September). The transects were
flown at lower altitude (~2 km) (Table 1). Data from the 2340 UTC transect are shown in Fig. 5. Floyd was then a category 2 hurricane, with maximum surface winds of \(46 \text{ ms}^{-1}\) It made landfall near Cape Fear some 7 h later. The eye, which had been at 90% humidity as the storm weakened before 1408 UTC 14 September, became notably drier (60%–80% RH) after the eyewall replacement was complete.

Marked changes in the radius of maximum wind suggest that Floyd underwent two eyewall replacements. The first was complete before 1731 UTC 11 September and was preceded by a divergence of \(T\) and \(T_d\) that was most pronounced at 0907 UTC 11 September. The second replacement ended near 0600 UTC 14 September, just after Floyd’s maximum intensity at 1200 UTC 13 September. It was also heralded by the large downdraft depression, a rapidly sinking inversion layer, and elevated ozone concentrations. Following this replacement that moistened the eye was an 11-h period of increasing wind speed during which the eye remained moist and cloudy. As the storm approached land late on 15 September, a third period of drying inside the eye was observed, as the storm’s dynamic tendency to reintensiﬁcation was aborted by dry air entrainment and shear. This period was also characterized by decreasing eye radius and the reestablishment of an inversion layer. Landfall occurred on day 0629 16 September.

The foregoing results record the complex evolution of Floyd’s eye on 10–17 September (Fig. 6). These data, along with downdraft depression and ozone concentrations, appear to support the model of Kossin and Eastin (2001, hereafter referred to as KE), in which two distinct regimes exist within the eye. The first, which we denote as KE regime 1, occurred during intensiﬁcation and was characterized by a warm, dry eye with low equivalent potential temperature. The second, denoted KE regime 2, was characterized by a cooler, wetter eye and elevated potential temperature. Jordan (1961) also noted the two regimes, which he described as “filling”
and “deepening.” A transition between the regimes was noted at or near maximum intensity. However, the results reported here suggest there can be an alternation between the regimes. The alternation may reflect competition between descent driven by eyewall heating (Willoughby 1998) that draws warm, dry, high-ozone air down toward the bottom of the eye as the eye radius contracts, and an episodic flooding of the eye driven by barotropic instability due to a maximum in absolute vorticity just inside the radius of maximum wind (e.g., Schubert et al. 1999). During the intensifying phase this instability is stabilized by diabatically driven axisymmetric ascent in the eyewall (Nolan 2001).

Although ozone was not measured on every flight, the data are consistent with the above changes. Elevated ozone in the center of the eye on 13 September (Fig. 3) coincides with a KE regime 1 eye. The transition to KE regime 2 on 14 September (Fig. 4) resulted in reduced ozone concentration throughout the eye and an inversion layer at or above aircraft altitude. Finally, on 15 September (Fig. 5), elevated ozone in the center of the eye provides strong evidence that the reestablishment of a KE regime 1 structure was underway before landfall on 16 September.

A telling characteristic of the KE regime 1 is descending air in the eye. We may estimate the amount of subsidence from the temperature increase within the eye. During the 13 September flights the eye was about 14°C warmer than the surrounding air (Fig. 3); the environmental lapse rate above the inversion, as measured by a dropsonde (983410038 at 1941:42) was \(-2.8\,^\circ\text{C} \text{ km}^{-1}\). The estimated amount of descent is then 
\[
(14^\circ\text{C})/(9.8^\circ\text{C} \text{ km}^{-1} - 2.8^\circ\text{C} \text{ km}^{-1}) = \approx 2 \text{ km}.
\]
However, arriving at an accurate temperature elevation is not straightforward; nor is it clear that the descent would be entirely adiabatic. Radiational cooling of the descending air or evaporation of moisture mixed into the eye would reduce the temperature excess and lead to a smaller thermodynamically estimated descent. Indeed, a skew T thermodynamic diagram of the dropsonde data (not shown) indicates that the air at \(-2 \text{ km}\) above the aircraft would have been at or near saturation.

Ozone measurements provide an additional method of determination. On 13 September, the elevated ozone in the center of the eye is strongly suggestive of descent from above flight level, but no measurements of ozone from that altitude are available. However, we may estimate the vertical gradient of ozone concentration from the ascending and descending portions of the aircraft track (Fig. 7). During the ascent, ozone increased with altitude at a rate of 2.07 ppbO3 km\(^{-1}\) (intercept = 6.5 ppb); during the descent the slope was 2.92 ppb km\(^{-1}\) (intercept = 7.7 ppb, reduced major axis regression). Those profiles are reasonably similar and consistent with published results for similar environments (e.g., Logan 1999). We may compute an altitude corresponding to the ozone concentration in the center of the eye; this altitude is less than a kilometer above the flight level. Thus, as a first approximation, the air at the eye center can be viewed as ambient tropospheric air that has subsided a kilometer or less above flight level.

A more accurate estimation can be made by including the effects of photochemistry. If we use the vertical profile of ozone described above, and an approximate tropopause height of 14 km, we compute an ozone concentration at that altitude of 42 parts per thousand (ppt; a very conservative value; see Logan 1999). The photochemical loss that would occur during the time of descent can be approximated using the empirical relationships of Davis et al. (1996), assuming a NOx concentration of 25–50 ppt (Logan 1999), to be \(-1–2 \text{ ppb day}^{-1}\), with a descent rate of 1 cm s\(^{-1}\) (Table 1; Willoughby 1998). While vertical velocities were measured on the aircraft (Table 1), the results were always near zero and near or below the instrumentation limitations. If the air within the eye at a particular altitude is a mixture of air from the eyewall and air from the upper troposphere (ut), the O3 concentration is

\[
O_3(\text{aircraft}) = X \times (O_3[\text{ut}] - D) + (1 - X) \times O_3[\text{wall}],
\]

where \(D\) represents the loss of ozone during the time of descent, and \(X\) is the fractional contribution of upper-troposphere air. We apply this equation to the three transects of 13 September, using a destruction rate of 1 ppb day\(^{-1}\). The results are given in Table 1; clearly, only 10%–20% of the air at the aircraft could be attributed to the tropopause (even less with a destruction rate of 2 ppb day\(^{-1}\)). These observations do not support the view that the air within the eye has descended essentially unchanged from the tropopause (which would result in much higher ozone concentrations than were observed), nor relatively rapid cycling of boundary layer air through the eyewall into the eye region (which

![Fig. 7. Ozone mixing ratios measured from the aircraft vs aircraft altitude for the entire 13 Sep sortie. The major ascending (1) and descending (2) segments are indicated.](http://journals.ametsoc.org/mwr/article-pdf/133/1/166/4215141/mwr-2844_1.pdf)
could not result in an ozone maximum at the eye center). The picture that emerges is of air slowly descending within the eye, derived primarily from the eyewall and to a much smaller degree from the tropopause, the latter contribution considerably reduced by photochemical destruction at 1–2 ppb day$^{-1}$ during the 10–12 days of descent.

The reciprocal relationship between ozone and relative humidity stems from their contrasting sources: the marine surface for humidity, and above the tropopause for ozone. Figure 8 is a scatterplot of those quantities during the 2113 transect of Floyd on 13 September. The eye is characterized by negative correlation, as descent advects air with higher ozone concentration and low humidity. The eyewall is characterized by the low, nearly constant ozone concentration, and elevated humidity near the convective updrafts. Similar variations occurred in the other transects of Floyd on 13 September.

Figure 9 shows the maximum ozone concentration and relative humidity in the center of the eye during 2 days around the time of maximum intensity. Following a consistent decrease, the humidity began to increase rapidly after 2236 on 15 September. Floyd's maximum intensity was almost 2½ days earlier. The subsequent rate of increase in relative humidity inside the eye was about 6% per hour (dashed line in Fig. 9). Coincident with this dramatic moistening was the decrease in the ozone concentration in the center of the eye. Apparently, the ozone concentration in the center of the eye had been higher previously, possibly reaching a maximum at the time of the storm's highest intensity.

The situation was dramatically different at 4 km on 14 September, well past the collapse of the eyewall and emergence of KE regime 2 structure. However, by 16 September, the ozone maximum was unambiguously reestablished at 2.08 km in the center of the eye (Fig. 5). This feature could only be derived from air descending from above flight level and represents reemergence of a KE regime 1 eye. The process never attained completion due (apparently) to weakening near landfall. The humidity within the eye reached a minimum of only ~65% at 1017 on 15 September (Fig. 9) before it began to increase. The ozone measurements were obtained subsequent to 1017, as on 13 September; however, on 15 September the ozone concentration in the center of the eye continued to increase even as the eye filled with moist air. Again, the effects of landfall may have perturbed the sequence.

b. Hurricane Georges

Similar variations of maximum wind, radius of maximum wind, temperature, and dewpoint unfolded in Hurricanes Luis (1995), Danielle (1998), Andrew (1992), Mitch (1998), and Georges (1998). Here we briefly examine only the last of the three. Georges (15 September–1 October 1998) was a very strong (category 4) hurricane that caused extensive damage as it made seven distinct landfalls in the Caribbean and the
United States (Pasch et al. 2001). Although the storm was investigated extensively by aircraft, ozone sampling occurred only on 19 and 28 September.

On 19 September, the hurricane was nearing maximum intensity (which occurred at 0600 on 20 September). It was somewhat asymmetric, with higher wind speeds and stronger convection to the north. The eye was warmer than the surrounding air and dry, with maximum winds just outside the eyewall. A dropsonde in the eye at 0517 UTC found the inversion at 891 hPa (979 hPa). Ozone measurements found reduced concentrations in the eyewall, nearly 11% below the vicinal concentration (18.2 ppb) in the northern eyewall, but near vicinal levels around the center of the eye (Fig. 10; the ozone spike at 15.25°N is probably instrument error). This “w” pattern is analogous to that in Floyd on 13 September 1999. The profile during ascent between 2038:20 and 2043:20 as the aircraft left the storm shows that ozone increased with altitude at a rate of 4.9 ppb km⁻¹. Using the model previously described for Floyd, we again find that essentially all of the air was derived primarily from the eyewall from a few kilometers above the aircraft, with a small (~5%) upper-tropospheric component (Table 1). Georges was fortunately sampled just before it reached maximum intensity. The eye was becoming dryer, and ozone concentration was increasing rapidly (Fig. 10), a KE regime 1 structure. Subsequent flight data (not shown) demonstrate that the eye became cooler and more moist after it passed maximum intensity (KE regime 2).

By 28 September, the storm was 11 days past its maximum strength and approaching landfall near Biloxi, Mississippi (at 1130 UTC). Significant weakening had occurred so that surface winds were 46 m s⁻¹, and minimum sea level pressure was 965 hPa. The eye was moist and only ~3°C warmer than outside the eye.

The inversion layer was apparently above flight level. Another complication in the comparison of the two datasets was the difference in altitude—4.3 km on the 13th and 1.9 km on the 28th. Examination of the relative humidity within the eye (Fig. 11) shows that it reached a minimum around noon on the 15th. Ozone data from the 28 September sortie—for example, the 1134 transect (Fig. 11)—clearly indicates the presence of descending air and a partial return to a KE regime 1 structure. The transect occurred at 0734 eastern daylight time (EDT), so that sunlight probably had not penetrated the eye significantly, minimizing photochemical destruction of ozone in the eye’s center. Examination of the ozone and relative humidity changes during that time (Fig. 12, lower panel) shows a decrease in eye ozone with time, as the humidity increased, indicating that the maximum KE regime 1 character had occurred earlier.

4. Summary and conclusions

Examination of ozone measurements during eyewall transects of Hurricanes Floyd of 1999 and Georges of 1998 provide insight into rapid changes taking place within the eyes of both storms. During intensification, ozone concentration in the eyewall was lower by as much as 20% compared with the vicinal concentrations measured near the sampling altitude outside the eye, but was elevated at the center eye so that it was comparable with or even exceeded the vicinal concentration. The ozone profiles were generally anticorrelated with dewpoint, as ozone increased with altitude while humidity decreased. Temporal changes in the ozone concentration inside the eye were interpreted in terms of cycling between regime 1 and 2 structures as described by Kossin and Eastin (2001). In addition, the concentrations of ozone observed in both hurricanes...
indicate that air within the eye was primarily eyewall air. The elevated concentrations at the center of the eye are consistent with origin of the air < 1 km above flight level and gradual descent in the face of photodissociation and dilution by eyewall air.

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