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Elevated middle and upper troposphere ozone observed downstream of Atlantic tropical cyclones

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HIGHLIGHTS

- . Ozone profiles are taken downstream of 5 tropical cyclones during the GRIP field campaigns in 2010.
- Elevated ozone mixing ratios are found in the mid-troposphere, with dry air and warming.
- Hurricanes Danielle and Igor show the largest increases in ozone mixing ratio.
- Lighting produced NOX is suggested as the primary source of elevated ozone mixing ratios.
- ozone enriched air is transported ahead of the tropical cyclone in the mid-troposphere.

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ABSTRACT

During the peak period of hurricane activity in the summer of 2010, vertical profiles of ozone using ozonesondes were taken downstream of tropical cyclones in the Western and Eastern Atlantic Ocean basin at Barbados and Cape Verde. Measurements are taken for tropical cyclones Danielle, Earl, Fiona, Gaston, Julia and Igor. The measurements show an increase in ozone mixing ratios with air originating from the tropical cyclones at 5–10 km altitude. We suggest that observed lightning activity associated tropical cyclones and the subsequent production of NO_X followed by upper level outflow and subsidence ahead of the tropical cyclones and aged continental outflow from West Africa thunderstorms produced observed increases in ozone mixing ratios. Hurricane Danielle showed the largest changes in ozone mixing ratio with values increasing from 25 ppb to 70 ppb between 22 and 25 August in the middle troposphere, near 450 hPa; warming and drying in the middle and lower troposphere. Measurements of ozone mixing ratios in Cape Verde show higher ozone mixing ratios prior to the passage of tropical storm Julia but low ozone mixing ratios and high relative humidity up to 300 hPa when the storm was in close proximity. This is due most likely the vertically transported from the marine boundary layer.

1. Introduction

Continental landmasses in the tropics serve as the primary source of anthropogenic (biomass burning, industrial, transportation, cooking) or natural (lightning (LNO_X), biogenic soil NO_X) emissions of ozone precursors leading to the production of ozone in the troposphere. Tropical oceans in contrast serve as a significant sink of ozone in the marine boundary layer through surface deposition, chemical transformation or destruction (Read et al., 2008). Hence, low tropospheric column ozone (TCO) values are found over the tropical oceans, except for the Tropical Southern Atlantic, where ozone precursors from biomass burning, biogenic soil emissions and LNO_X and the resultant ozone from South America and Africa can be transported towards the tropical South Atlantic and undergo subsidence, producing the observed Wave-1 zonal pattern from September–November (Thompson et al., 2003; Ryu and Jenkins, 2005). Oceanic regions, such as the Tropical Pacific or Western Atlantic, that are distant from biomass

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burning or continental lightning sources have low observed TCO values and lower mid-tropospheric mixing ratios (Thompson et al., 2003; Ziemke et al., 2011; Jenkins et al., 2013).

Increases in observed tropospheric ozone mixing ratios over the Northern Tropical Atlantic are due to either the long-range transport from continental areas or through the secondary production of ozone by lightning (LNO_X) from convection. Lightning is estimated to produce 2–8 Tg of nitrogen (N) annually (Martin et al., 2007) with some uncertainties related to the LNO_X production per flash for intra-cloud (IC) verses cloud to ground flashes (CG). Bucsela et al. (2010) show NO_X mixing ratio enhancement of 1.74–2.35 from lightning activity and 174 mol LNO_X per flash based on aircraft

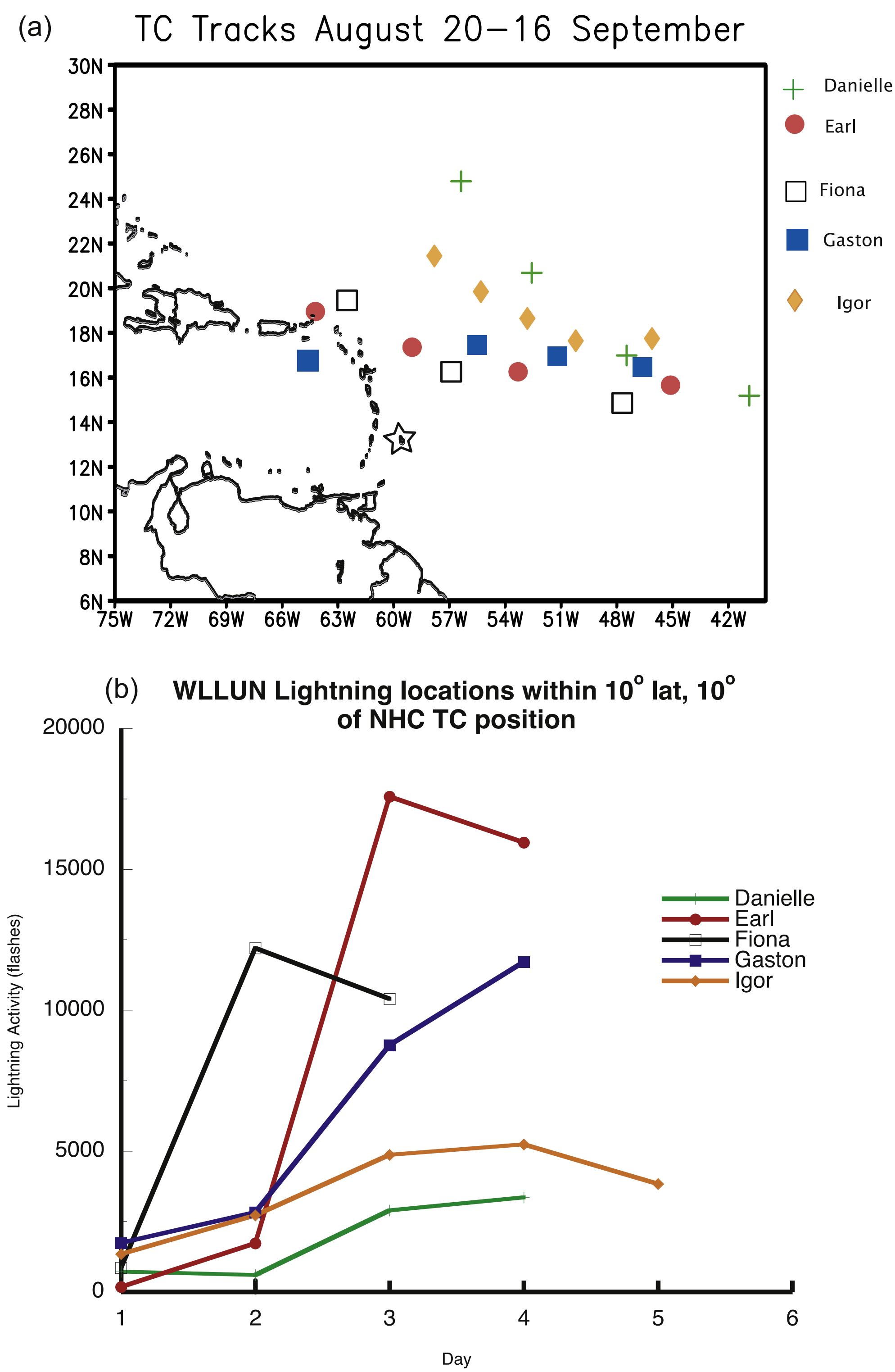

Fig. 1. (a) Locations of tropical disturbances based on NHC best track data; (b) lightning activity associated within a 1–5 day locations in (a) for the tropical disturbances. Name of tropical disturbances denoted by the letters D (Danielle), E (Earl), F (Fiona), G (Gaston), I (IGOR).