PICTURE OF THE MONTH

A Mesoscale Low-Level Thunderstorm Outflow Boundary Associated with Hurricane Luis

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24 January 2000 and 1 March 2000

ABSTRACT

A large, low-level thunderstorm outflow boundary was observed as it exited from beneath the cirrus canopy of Hurricane Luis following a period of intense convection in the storm's eyewall. A description of the feature and a short summary of its behavior are presented.

1. Introduction

Low-level thunderstorm outflow (LTO) boundaries can play critical roles in the life cycles of midlatitude severe and tornadic thunderstorms (Magor 1959; Purdom 1976; Weaver 1979; Maddox et al. 1980; Weaver and Nelson 1982; Wilson et al. 1992; Przybylinski et al. 1993; Weaver et al. 1994; Browning et al. 1997; Markowski et al. 1998). LTO-stabilized air masses can also have negative effects on convection, particularly if a preexisting storm moves out over a large, stable thunderstorm-modified air mass (e.g., Weaver et al. 1994; Weaver and Purdom 1995; Markowski et al. 1998).

In tropical regions, LTO boundaries can also act to stabilize the normally unstable boundary layer, thereby weakening convection. As in midlatitudes, the tropical precipitation process can produce strong downdrafts through both precipitation loading and the evaporation of rain into a dry midlevel environment (Young et al. 1995; Johnson and Nicholls 1983). Mean boundary layer recovery times for tropical mesoscale convective systems can be 12 h or more (Saxen and Rutledge 1998; Young et al. 1995). This boundary layer stabilization process most often occurs with rainband convection in tropical cyclones, where the difference between the surface and midlevel θ_e is as much as 12°C (Barnes et al. 1983). Rainband-generated downdrafts can stabilize the boundary layer to a point that in most cases the air mass cannot recover before it is ingested into the hurricane eyewall (Powell 1990). As that author states, ''Any mechanism that can act to lower θ_e, if acting on large enough scales to modify a significant portion of the inward flowing boundary layer, should also be able to affect storm intensity.'' That is to say, the central convection of a tropical storm might be expected to weaken somewhat following periods of strong rainband convection, especially if associated downdraft activity lowers the equivalent potential temperature values of the air being ingested into the eyewall.

Strong downdrafts are not limited to rainband convection alone. Implicit in Simpson and Riehl (1958) is the fact that for cases of large cross-storm ventilation, where drier air intrudes all the way into the eyewall region of the storm, the eyewall convection can produce cooler and more intense downdrafts. The objective of this paper is to illustrate an unusually large LTO boundary associated with eyewall convection that later appears to affect the intensification trend of Hurricane Luis.

2. Hurricane Luis: 6–7 September 1995

Hurricane Luis was a category 4 (Simpson 1974) hurricane that crossed the northernmost islands of the Lesser Antilles on 5 September 1995, then curved north of Puerto Rico over the next two days. Following a short period of weakening due to vertical wind shear (values ranging from 8.8 to 9.3 m s^{-1}) and to a dry midlevel

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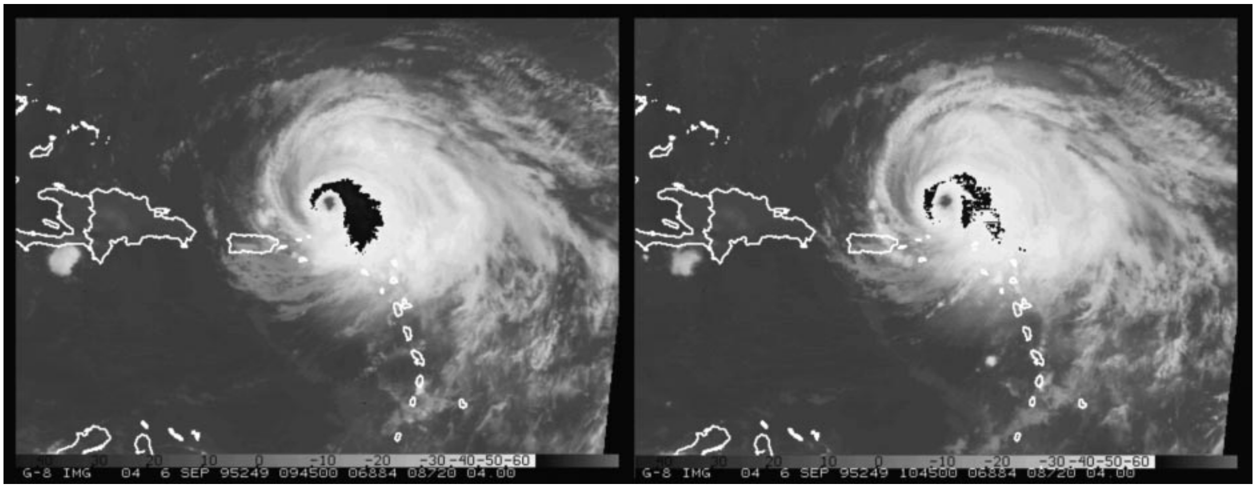

FIG. 1. GOES 10.7-μm infrared imagery of Hurricane Luis on 6 Sep 1995 at (a) 0945 and (b) 1045 UTC. Images show the rapid decay of deep convection located on the north side of the eyewall. Temperature bar wraps back to black at -70°C.

air intrusion into the storm's center,[1] the hurricane developed new eyewall convection on its northeastern side. The coldest cloud tops during this period occurred between 0945 and 1015 UTC (Fig. 1a). The new eyewall convection did not last long. Dry environmental air at mid- and upper levels, and moderate vertical wind shear (8.8 m s^{-1}) in the environment, continued to disrupt storm intensification. Over the next hour, there was a significant warming of the cloud tops near the center (Fig. 1b), indicating a continuation in the weakening trend.

As the convection collapsed, a large LTO boundary emerged from beneath the cirrus cloudiness on the northwest side of the storm (Fig. 2). Cloud-top temperatures averaged 22°C over the arc cloud, which is consistent with temperatures found near the top of the tropical cyclone boundary layer. Although first seen in the visible imagery at 1600 UTC, the extensive spatial coverage of this LTO boundary was not obvious until 1700 UTC (Fig 2a). Throughout the day, a meso-α-scale arc cloud line expanded northwestward at 14–17 m s^{-1}, persisting in the visible (Fig. 2), and then in the 3.9-μm channel (not shown), well into the nighttime hours. Since the storm was traveling toward the northwest at this time, the LTO boundary, and the region of stable air associated with it, were being positioned just ahead of the storm's center. When the hurricane's core crossed into the area where this outflow air had spread, the stable air appeared to have had a strongly negative influence on the eyewall convection.

For several hours, as the center of Hurricane Luis slowly approached the LTO-stabilized air, it was still

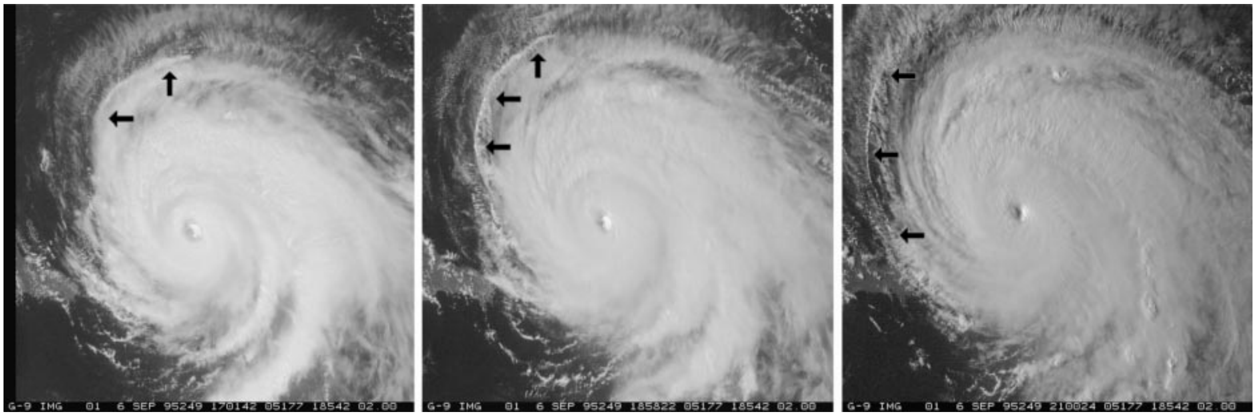

FIG. 2. GOES visible imagery of Hurricane Luis on 6 Sep 1995. The images show the evolution of a large arc cloud line to the northwest of the storm associated with low-level thunderstorm outflow. Image times are (a) 1700, (b) 1900, and (c) 2100 UTC. The feature is moving outward from its origin between 14 and 17 m s^{-1}.

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[1] Vertical wind shear values were computed using both Aviation Model output and satellite-derived cloud drift winds. The intrusion of dry mid-level air into the storm's center was identified using Geostationary Operational Environmental Satellite (GOES) water vapor imagery.

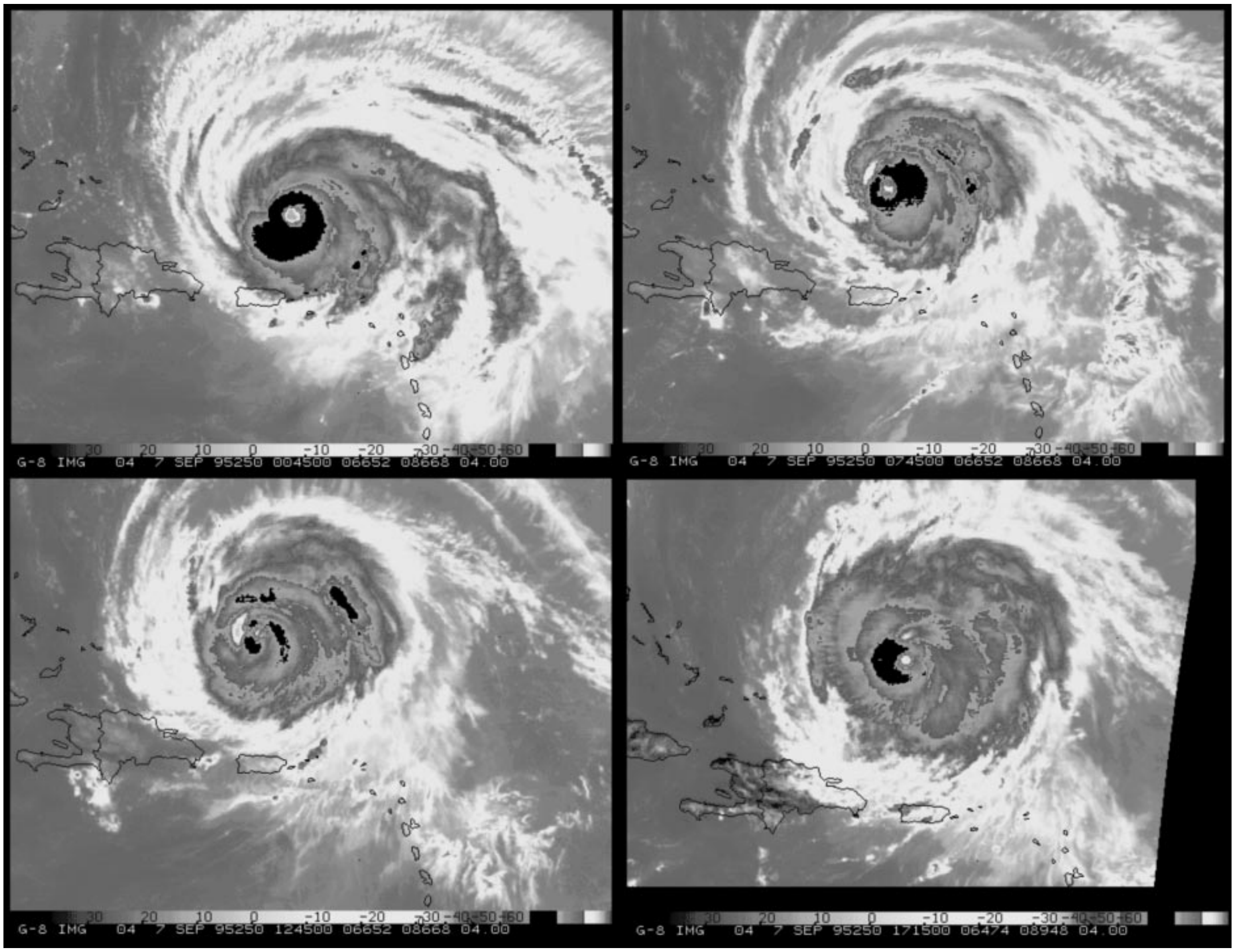

FIG. 3. GOES 10.7-μm infrared imagery of Hurricane Luis on 7 Sep 1995 as the storm begins to encounter the low-level stable air produced the previous day. Images show (a) 0045 UTC, a reorganizable Hurricane Luis with a ring of very cold tops surrounding the eye wall; (b) 0745 UTC, eyewall convection begins to diminish; (c) 1245 UTC, eyewall convection collapses; and (d) 1715 UTC, storm begins to reintensify. Temperature bar wraps back to black at −70°C.

ingesting unstable air in at least three quadrants. The storm actually became better organized during this period (Fig. 3a), and the vertical wind shear appeared to remain moderate to low (7.2 m s^{-1}). Eventually, however, the eyewall region moved over the LTO-stabilized boundary layer region. The convection suddenly became less well defined, and the area of the cold cloud tops decreased with time (Figs. 3b and 3c). Although there was no significant weakening of maximum winds, or increase of mean sea level pressure, this disruption of the eyewall structure did appear to interrupt the intensification trend the storm was experiencing at 0000 UTC. This interruption of central deep convection and short-term intensification is not unexpected. As Willoughby (1998) points out, it is the inflow above the boundary layer that is important for maintaining circulation outside the eyewall region. It is also interesting that after the storm passed beyond the area of more-stabilized boundary layer air, it once again began to become better organized and resumed its intensification, while the vertical wind shear remained nearly constant at 7.2 m s^{-1} (Fig. 3d).

The sequence of events observed in this case is consistent with results from several tropical cyclone boundary layer studies, including Powell (1990), Barnes et al. (1983), Fitzpatrick (1996), and Cione et al. (2000). Those studies imply that changes in boundary layer conditions outside the inner core region of the storm may not be able to fully recover before the modified air is ingested into the eyewall, potentially affecting tropical cyclone intensity change.

3. Summary

Tropical cyclones produce LTO boundaries when drier air is present aloft. These outflows can frequently be seen in satellite imagery, but on the limited spatial scale of the rainbands producing them. Outflow boundaries as large as the one shown in Fig. 2 are associated with eyewall convection and are much less frequently observed. This is because eyewall convection is normally shielded from the dry midlevel conditions of the tropical atmosphere. This does not appear to be the case here. Based on vertical shear estimates, on 6.7-μm water vapor imagery, and on published works cited in this paper, the time evolution of Hurricane Luis during the period illustrated is assumed to be the result of the following process: 1) a period of moderately intense wind shear and dry air intrusion caused the eyewall convection to ingest dry midlevel air and weaken, 2) the collapsing convection produced a very stable LTO air mass ahead of itself, 3) the convection near the center of the hurricane passed over this stable, low-level air mass and weakened, and 4) once out of this region, the storm reintensified. Recognition of this short-term change in storm behavior might have useful application in the nowcast time frame.

Acknowledgments. The authors would like to thank Drs. Ray Zehr and Mark DeMaria for their comments on this work as well as the three anonymous reviewers for their helpful comments. Funding for this paper were provided by NOAA Grant NA67RJ0152.

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