These conditions are consistent with the strong climate link that occurs on multidecadal time scales between Atlantic hurricane activity and the strength of the West African monsoon (Bell and Chelliah 2006). Specifically, the current Atlantic high-activity era (Fig. 4.17b) has featured an enhanced monsoon with total OLR values below 240 W m^{-2} in the Sahel region, whereas the low-activity period of the 1980s and early 1990s featured a weaker monsoon with OLR values in the Sahel region often well above 240 W m^{-2} (Fig. 4.21d). These multidecadal fluctuations in monsoon strength coincide with opposing phases (warm and cold, respectively) of the Atlantic Multidecadal Oscillation (AMO; Enfield and Mestas-Nuñez 1999; Bell and Chelliah 2006).

SIDEBAR 4.1: HURRICANE MICHAEL: A FLORIDA PANHANDLE RECORD-BREAKING LANDFALL—P. J. KLOTZBACH

The 2018 Atlantic hurricane season was perhaps best known for two significant hurricanes—Florence and Michael—that brought death and destruction to the continental United States. This sidebar focuses on Michael, which was first named on 7 October and became only the fourth continental U.S. landfalling Category 5 hurricane on record just three days later (Beven et al. 2019). Michael's meteorological history is discussed, followed by a discussion of the many meteorological records the storm set in its relatively short lifetime. Historical landfall records from 1851–present are taken from the National Hurricane Center/Atlantic Oceanographic and Meteorological Laboratory archive located at: www.aoml.noaa.gov/hrd/hurdat/All_U.S._Hurricanes.html.

Michael was first noted as a potential TC on 6 October. The tropical disturbance that spawned Michael brought heavy rainfall to Central America and resulted in 15 fatalities. Michael's initial development was hampered by strong vertical wind shear from an upper-level trough located in the Gulf of Mexico. However, despite continuing to encounter relatively strong vertical wind shear, Michael intensified into a tropical storm the following day. While statistical and dynamical model guidance called for relatively slow strengthening due to persistent westerly vertical wind shear from the upper-level trough in the central Gulf of Mexico, Michael deepened much faster than anticipated, reaching hurricane strength less than 24 hours after being named. Michael's intensification despite persistent wind shear may have been due to the trough in the central Gulf of Mexico generating upper-level difluence that somewhat counteracted the strong shear. In addition, another upper-level trough to the east of Michael likely aided its upper-level outflow (Beven et al. 2019). While Michael's peak rapid intensification rate never exceeded 40 kt (21 m s^{-1}) 24 h^{-1}, it intensified at a rate of 20–40 kt (10–21 m s^{-1}) 24 h^{-1} from the time that it was named until the time it made landfall near Mexico Beach, Florida.

While the dynamic environment in the western Caribbean was only marginal for Michael's development, the thermodynamic environment was much more conducive than normal. SSTs averaged 1°–2°C warmer than normal, with anomalously high levels of upper ocean heat content along Michael's track (see Fig. SB4.3). Vertical wind shear impinging on Michael also weakened considerably as the storm tracked northward from the western Caribbean into the Gulf of Mexico.

As noted earlier, Michael underwent moderate-to-rapid intensification throughout its lifetime as a named storm, reaching major hurricane strength on 9 October. Unlike most recent major hurricanes making landfall along the northern Gulf Coast that weakened in the 24 h prior to landfall (e.g., Rita and Katrina 2005; Ivan 2004; Opal 1995), Michael continued to intensify up until its landfall in Florida (Fig. SB4.1). Michael's landfall intensity of 140 kt was the fourth strongest for any continental U.S. hurricane landfall on record (since 1851), trailing in order from the strongest: Labor Day (1935), Camille (1969), and Andrew

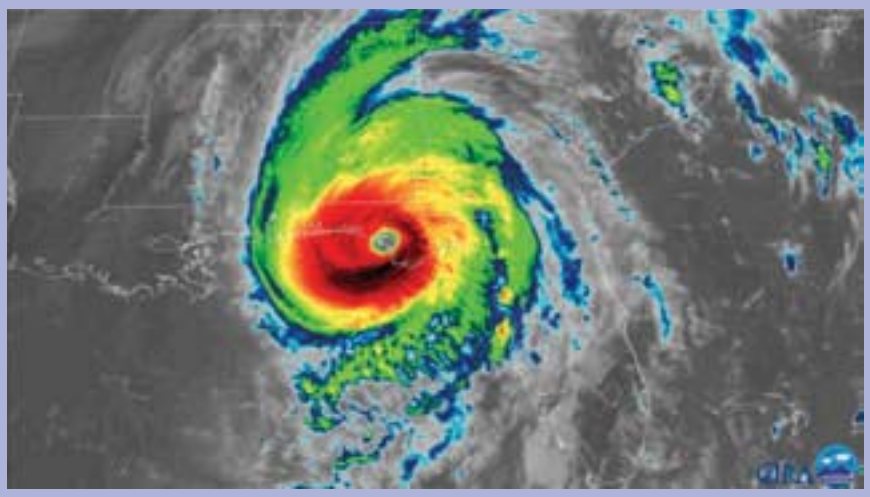

Fig. SB4.1. GOES-16 infrared satellite image of Hurricane Michael making landfall at 1800 UTC on 10 Oct (from RAMMB CIRA; http://rammb.cira.colostate.edu/).

CONT. SIDEBAR 4.1: HURRICANE MICHAEL: A FLORIDA PANHANDLE RECORD-BREAKING LANDFALL—P. J. KLOTZBACH

(1992). Michael's central pressure of 919 hPa at landfall was the third lowest for a continental U.S. landfalling hurricane on record, trailing in order from the strongest: Labor Day (1935) and Camille (1969).

Michael also was the first storm of greater-than-Category 3 intensity on record to make landfall in the Florida Panhandle. The prior strongest Florida Panhandle landfalls were 110 kt: Pensacola (1882) and Eloise (1975). Opal's landfall central pressure of 942 hPa was the lowest previous central pressure for a Florida Panhandle landfall. Michael shattered both of those marks (140 kt and 919 hPa). It was also the first Category 5 hurricane on record to make landfall in Florida in October.

After its landfall, Michael only slowly weakened. It was still a Category 2 when it crossed the border from Florida into Georgia (Fig. SB4.2), becoming the first hurricane to bring sustained Category 2 winds to Georgia since Hurricane David in 1979. Michael continued to weaken as it tracked across the southeastern United States but began to restrengthen as it emerged off the mid-Atlantic coast. It underwent extratropical transition and became a powerful extratropical cyclone on 12 October.

Given these superlatives, it is no surprise that Michael caused tremendous devastation near the point of its landfall, with exceedingly strong winds and high levels of storm surge being the primary drivers of the damage. Nearly all structures in Mexico Beach were damaged or destroyed, with significant wind damage extending through a large portion of the Florida Panhandle and into Georgia, where there was widespread timber loss and significant damage of the pecan and cotton crops.

Michael's relatively brisk forward speed prevented rainfall amounts from becoming too extreme near where it made landfall (100–150 mm), although small areas recorded over 300 mm. Terrain interactions drove higher rainfall totals (200–300 mm) over portions of the Appalachian Mountains. The highest point rainfall total from Michael in the continental United States was 330 mm in Black Mountain, North Carolina. Michael was responsible for 16 direct and 43 indirect fatalities in the United States, with a current damage estimate of $25 billion (U.S. dollars; Beven et al. 2019).

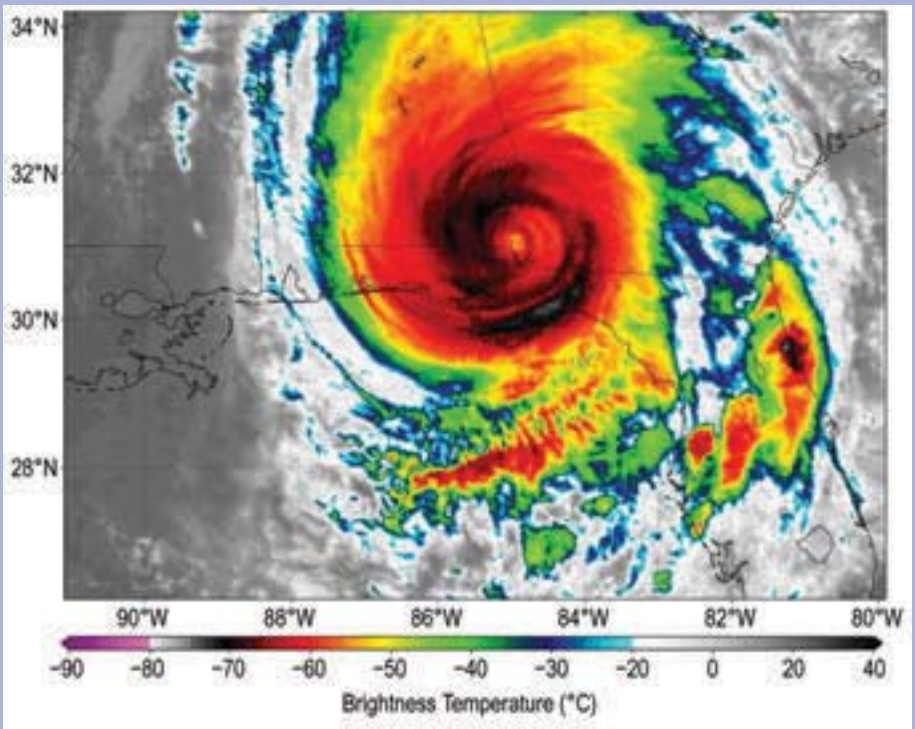

FIG. SB4.2. GOES-16 infrared satellite image of Hurricane Michael entering southwest Georgia at 2128 UTC on 10 Oct (from Tropical Tidbits; tropicaltidbits.com).