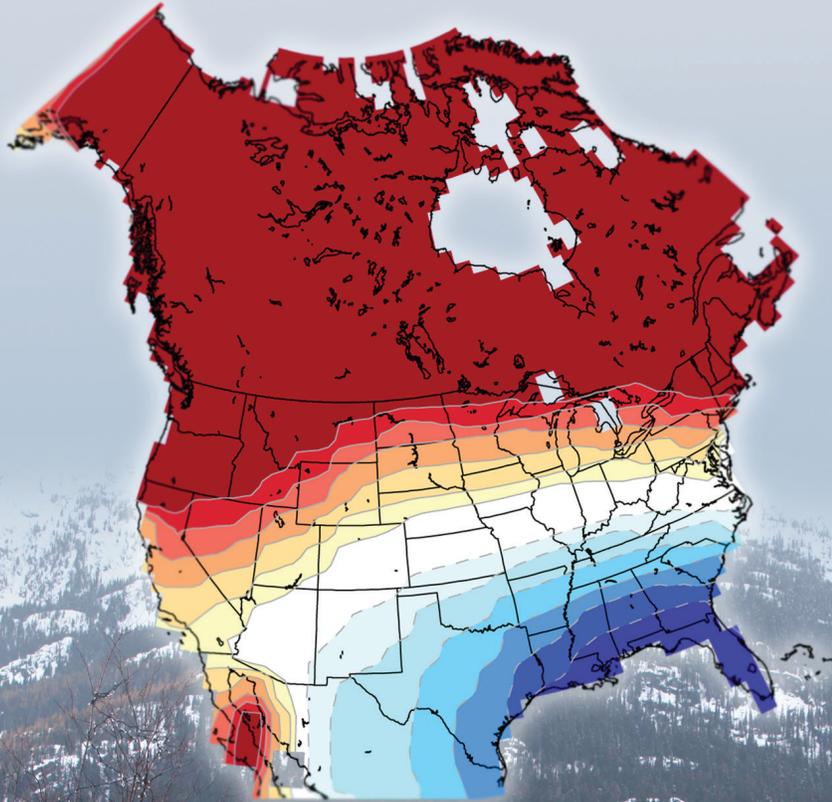


STATE OF THE CLIMATE IN 2010

J. Blunden, D. S. Arndt, and M. O. Baringer, Eds.

Associate Eds. K. M. Willett, A. J. Dolman, B. D. Hall, P. W. Thorne, J. M. Levy, H. J. Diamond,
J. Richter-Menge, M. Jeffries, R. L. Fogt, L. A. Vincent, and J. M. Renwick



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Three other TCs failed to make landfall: Neville (Category 1) in the Coral Sea in January, and Robyn and Sean (both Category 2) in the Indian Ocean in April. None had any impact on land areas.

e. *Tropical Cyclone Heat Potential*—G. J. Goni, J. A. Knaff, and I-I Lin

Variations in the Tropical Cyclone Heat Potential (TCHP) in each of the seven tropical cyclone basins are discussed in this section. The TCHP is defined as the ocean heat content contained between the sea surface and the depth of the 26°C isotherm. It has been shown that high TCHP values are more closely linked to intensity changes than SST (Shay et al. 2000; Goni and Trinanes 2003; Lin et al. 2008, 2009), provided that atmospheric conditions are also favorable.

Although SST data provide a measure of the surface ocean conditions, the data give no information about the subsurface (first tens of meters) ocean thermal structure. It is known that the ocean skin temperature erodes when the sea surface is affected by strong winds, creating a well-mixed layer that can reach depths of several tens of meters. As the TC progresses, it travels above waters with mixed layer temperatures similar to their skin temperatures. This provides the motivation to investigate and monitor the upper ocean thermal structure, which has become a key element in the study of tropical cyclone intensifications focused on predictions of sudden TC intensification. In addition, the inclusion of TCHP in statistical models has been shown to reduce intensity prediction errors for the most intense cyclones. Research has shown how the upper ocean thermal structure is a good indicator for predicting TC intensity (Mainelli et al. 2008).

Fields of TCHP show high spatial and temporal

variability associated with oceanic mesoscale features that can be detected globally using satellite altimetry (Lin et al. 2008; Goni et al. 2009). It has been shown that areas with high values of TCHP can be an important factor for TC intensification (e.g., Shay et al. 2000; Mainelli et al. 2008). To examine the interannual variability of TCHP with respect to tropical cyclones, TCHP anomalies are computed during the months of TC activity in each hemisphere: June–November in the Northern Hemisphere and November–April in the Southern Hemisphere. Anomalies are defined as departures from the mean TCHP calculated during the same months for the period 1993–2010. These anomalies show large variability within and among the tropical cyclone basins (Fig. 4.27).

The west Pacific basin generally exhibits the anomalies related to ENSO events, with 2010 being characterized by the onset of La Niña conditions, which have been in place in the equatorial Pacific Ocean since approximately June 2010. Similar to the conditions during 2008 and 2009, the South Pacific basin showed mostly positive anomalies. The north Indian basin exhibited positive values in the Bay of Bengal and in the Arabian Sea. The Gulf of Mexico (Fig. 4.27 insert, lower right) showed mostly negative values except for a region of positive values in the northern region. Similar to 2009, the tropical Atlantic exhibited mostly positive values, which is also observed in sea height and SST fields (<http://www.aoml.noaa.gov/phod/regsatprod/atln/index.php>). The most evident changes in TCHP between 2010 and 2009 are the decrease in values in the Gulf of Mexico and the southwestern Pacific Ocean and the increase in values in the western Pacific Ocean, Arabian Sea, and Bay of Bengal (Fig. 4.28).

During 2010, a number of major TCs were positively identified to have gained strength when traveling into regions of high values of TCHP, three TCs exhibited a weak link, and three did not show any link between ocean heat content and intensification. Some examples of these intensification events are shown in Fig. 4.29. The results presented here correspond to four major TCs, where the location of their intensification coincided with an increase of the values of TCHP along their tracks. These TCs were Igor (tropical Atlantic), Celia (Eastern North Pacific, ENP), Megi (Western North Pacific, WNP), and Phet (Arabian Sea). The cooling associated with the wake of intense TCs, which reached

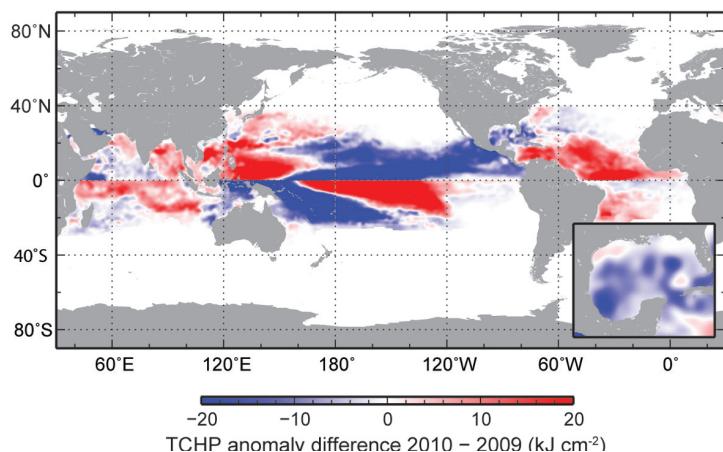


FIG. 4.28. Differences between the Tropical Cyclone Heat Potential (TCHP) fields in 2010 and 2009.

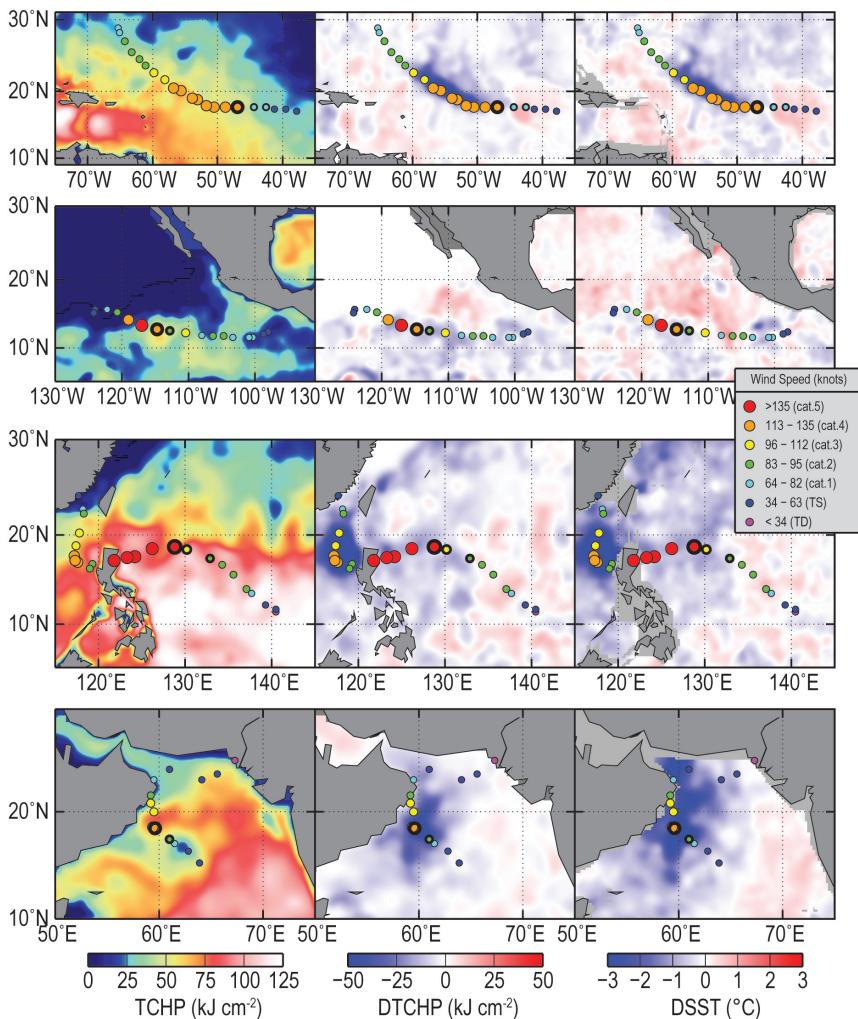


FIG. 4.29. (left) Tropical Cyclone Heat Potential (TCHP) and surface cooling given by the difference between post and pre storm values of (center) tropical cyclone heat potential and (right) sea surface temperature, for (from top to bottom) Hurricane Igor, Hurricane Celia, Typhoon Megi, and Cyclone Phet.

values of up to 50 kJ cm^{-2} in TCHP and above 3°C in SST, is important since these factors influence the upper ocean thermal structure on regional scales within weeks to months after the passage of the storms (Emanuel 2001; Hart et al. 2007).

In the Atlantic, preliminary best track estimates show Igor intensifying from 65 kts (33 m s^{-1}) to 130 kts (67 m s^{-1}) in 24 hours while the TC slowed down and the environmental vertical wind shear conditions improved. Values of TCHP under the track of this TC during this time also increased to values greater than 70 kJ cm^{-2} , well above the 50 kJ cm^{-2} usually found in cases of Atlantic rapid intensification (Mainelli et al. 2008). The post-storm surface cooling associated with the wake of this hurricane reached very high values, of approximately 5°C and 50 kJ cm^{-2} .

In the ENP, both Major Hurricanes Celia and Darby occurred in late June and showed peak intensity nearly coincident with positive TCHP anomalies. Celia formed on 18 June, southeast of Acapulco, Mexico, and on 24 June, with appropriately favorable atmospheric conditions given by the weakening of the shear, this cyclone rapidly intensified and gained its peak strength with winds of 140 kts (72 m s^{-1}). This intensification occurred when Celia traveled over a warm eddy containing waters with increased TCHP values which were close to 65 kJ cm^{-2} . The cooling under the track of this TC was weaker than Igor in the Atlantic Ocean, with observed SST values near 3°C and TCHP of 30 kJ cm^{-2} . This weaker oceanic response may be a response to the generally stronger vertical stratification found in the eastern Pacific that makes the ocean more difficult to mix. Despite the higher anomaly values of TCHP in the WNP, the season was a record-low

year of TC occurrence. Despite the small number of observed storms, the TCHP conditions in September and October 2010 were extraordinarily favorable in the WNP, especially to the west of 150°E and to the south of 20°N , with values ranging from 120 kJ cm^{-2} to 170 kJ cm^{-2} , which are values well above the TCHP values commonly observed for super typhoons in this region (Lin et al. 2008, 2009).

As compared to the conditions in 2009, 2010 TCHP values were significantly greater by approximately 20 kJ cm^{-2} to 50 kJ cm^{-2} (Fig. 4.28). These unusually high TCHP values provided very favorable ocean conditions for the intensification of Super Typhoon Megi, the most intense TC globally in 2010. Megi formed to the west of Guam on 12 October 2010, and strengthened to a Category 5 super typhoon by 17 October. According to the preliminary Joint Typhoon

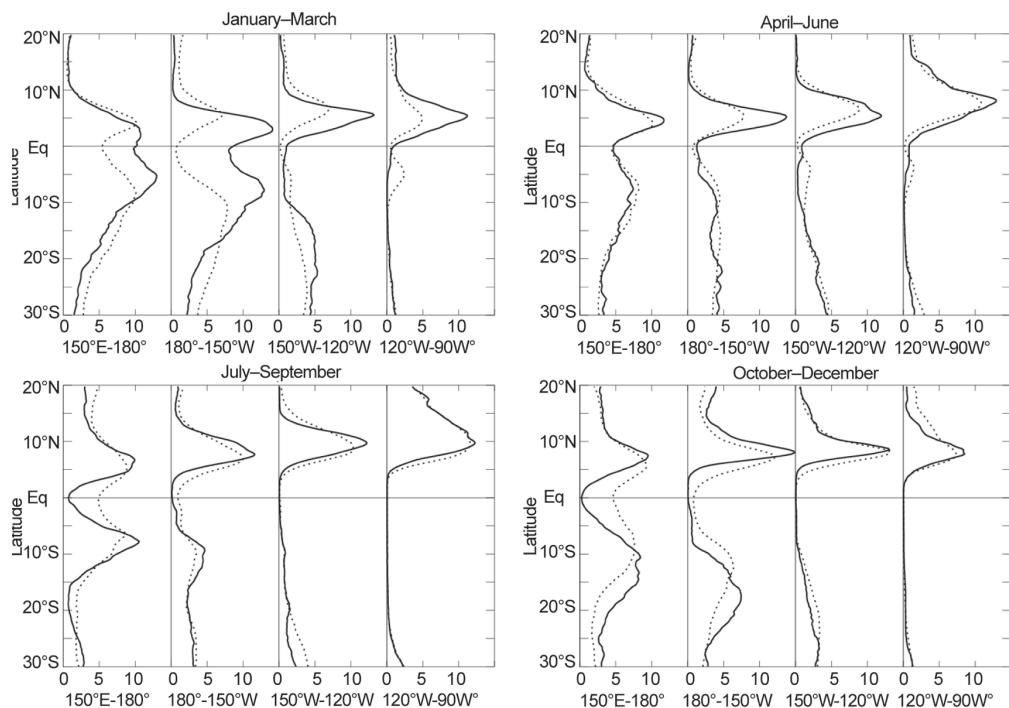


FIG. 4.30. Rainfall rate (mm day^{-1}) from TRMM 0.25° analysis for January–March, April–June, July–September, and October–December 2010. The separate panels for each three-month period show the 2010 rainfall cross-section between 20°N and 30°S (solid line) and the 1999–2008 climatology (dotted line), separately for four 30° sectors from 150°E – 180° to 120°W – 90°W .

Warning Center (JTWC) report, Megi's intensity reached 160 kts (82 m s^{-1}), and an aircraft estimated its central pressure at 885 hPa, which is among the lowest TC pressures ever observed. Megi developed in this very favorable warm pool (Fig. 4.29) of extremely high TCHP values (typically $\sim 100 \text{ kJ cm}^{-2}$ – 130 kJ cm^{-2}) throughout its genesis and intensification period. From 14 to 17 October, Megi intensified from a named storm to a Category 5 TC with maximum sustained winds of 160 kts (82 m s^{-1}). Megi subsequently made landfall in the Philippines.

Cyclone Phet was the most intense TC in the Arabian Sea in 2010 (Fig 4.29). The disturbance that eventually became Phet was identified early on 30 May and upgraded to a named storm on 31 May after a short genesis period. Early on 1 June, the moderate vertical wind shear relaxed and Phet intensified to a Category 1 cyclone with maximum sustained winds estimated at 65 kts (33 m s^{-1}) by JTWC. In the next 18 hours, it rapidly intensified from 65 kts (33 m s^{-1}) to 125 kts (64 m s^{-1}) to its peak at Category 4, an astonishing intensification rate well above the criteria for rapid intensification of 30 kts (15 m s^{-1}) in 24 hours (Kaplan and DeMaria 2003). The period of rapid intensification took place as Phet entered into a region

of high TCHP of $\sim 75 \text{ kJ cm}^{-2}$. After its departure from this high patch of TCHP, Phet weakened to approximately 105 kts (54 m s^{-1}) before making landfall in Oman, where it caused substantial damage estimated at $\sim \$780$ million (U.S. dollars) and accounted for 44 deaths. The storm later re-curved over the northern Arabian Sea making a second landfall near the India-Pakistan border.

f. Intertropical Convergence Zones

1) Pacific—A. B. Mullan

This discussion for the Pacific sector covers the two prominent convergence zones: the Intertropical Convergence Zone (ITCZ) in the Northern Hemisphere, which lies approximately parallel to the Equator with a slight poleward tilt on its eastern end, and varying in position from around 5°N – 7°N in February–May to 7°N – 10°N in August–November; and the South Pacific Convergence Zone (SPCZ), which extends diagonally from around the Solomon Islands (10°S , 160°E) to near 30°S , 140°W , and is most active during November–April.

The behavior of the Pacific convergence zones in 2010 is readily characterized in two parts, with the first half of the year dominated by El Niño and the second half by La Niña. Thus, in the first half of 2010, both the ITCZ and SPCZ tended to be further equatorward than usual, with well-above-normal rainfall east of the date line near the Equator. In the second half of 2010, both the ITCZ and SPCZ tended to be poleward of their normal positions, with a much enhanced dry zone along the Equator. Figure 4.30 shows quarterly rainfall in the Pacific along transects from 20°N to 30°S , as derived from the 0.25° -resolution