STATE OF THE CLIMATE IN 2011

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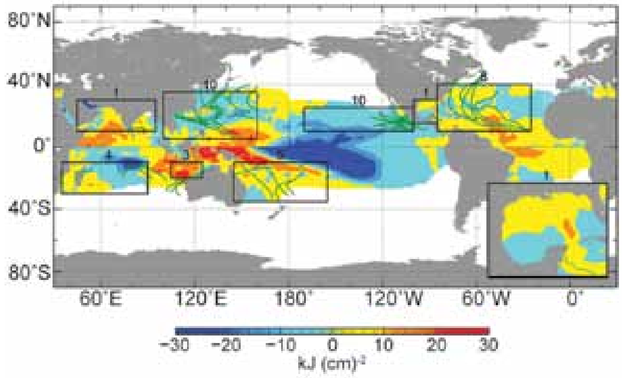

Fig. 4.27. Global anomalies of TCHP corresponding to 2011 computed as described in the text. The numbers above each box correspond to the number of Category 1 and above cyclones that traveled within each box. The Gulf of Mexico conditions during Jun–Nov 2011 are shown in the insert shown in the lower right corner.

from both, particularly Tasha, contributed to flooding farther inland. Errol, with a peak intensity of 65 kt (33 m s^{-1}), formed west of Darwin and moved to the northwest dissipating as it made landfall on the Indonesian island of Timor (not to be confused with the independent nation of East Timor) on 18 April.

e. *Tropical cyclone heat potential*—G. J. Goni, J. A. Knaff, and I-I Lin

This section summarizes the seven previously described TC basins from the standpoint of tropical cyclone heat potential (TCHP), by focusing on upper ocean temperature conditions during the season with respect to average values. TCHP, defined as the ocean heat content contained between the sea surface and the depth of the 26°C isotherm, has been shown to be more closely linked to intensity changes of tropical cyclones than sea surface temperature (SST) alone (Shay et al. 2000; Goni and Trinanes 2003; Lin et al. 2008, 2009a), provided that atmospheric conditions are also favorable. In general, fields of TCHP show high spatial and temporal variability associated with oceanic mesoscale features that can be globally detected with 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 the rapid intensification of tropical cyclones (TCs; e.g., Shay et al. 2000; Mainelli et al. 2008; Lin et al. 2009a).

To examine TCHP interannual variability, anomalies are computed during the months of TC activity in each hemisphere: June through November in the Northern Hemisphere and November through April in the Southern Hemisphere. Anomalies are defined as departures from the mean TCHP calculated during the same months for the period 1993–2011. These anomalies show large variability within and among the tropical cyclone basins. During the 2011 season, the basins exhibited the following TCHP anomalies:

- The Western North Pacific (WNP) basin exhibited both positive and negative TCHP anomaly values, while the Eastern North Pacific (ENP) had slightly negative values (Fig. 4.27).
- The Southwest Pacific basin had both positive and negative anomalies, although the cyclone basin continued exhibiting mostly high positive values.
- In the North Indian Ocean (NIO) basin, both the Bay of Bengal and Arabian Sea exhibited positive anomalies.
- In the Atlantic basin, the Gulf of Mexico (Fig. 4.27 insert, lower right) showed positive and negative anomalies associated with the variability of the Loop Current. In contrast to 2009 and 2010, the tropical Atlantic exhibited mostly negative values, which were largely observed in the sea height and sea surface temperature fields[7].
- In general, with respect to the 2010 anomalies, the WNP and NIO basins exhibited lower values of TCHP. On the other hand, the SIO and Southwest Pacific basins, as well as sections of the Gulf of Mexico, showed elevated TCHP values (Fig. 4.28).

[7] It should be noted that there were warm SST anomalies in the Atlantic in 2011, and SSTs do not necessarily equate to TCHP values.

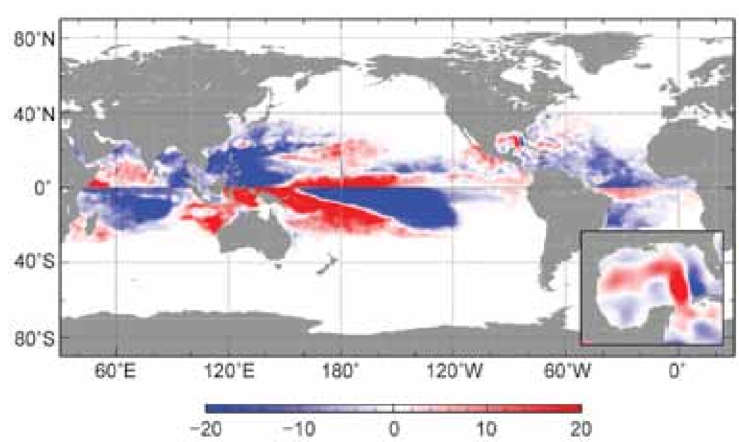

Fig. 4.28. Differences between the TCHP fields in 2011 and 2010

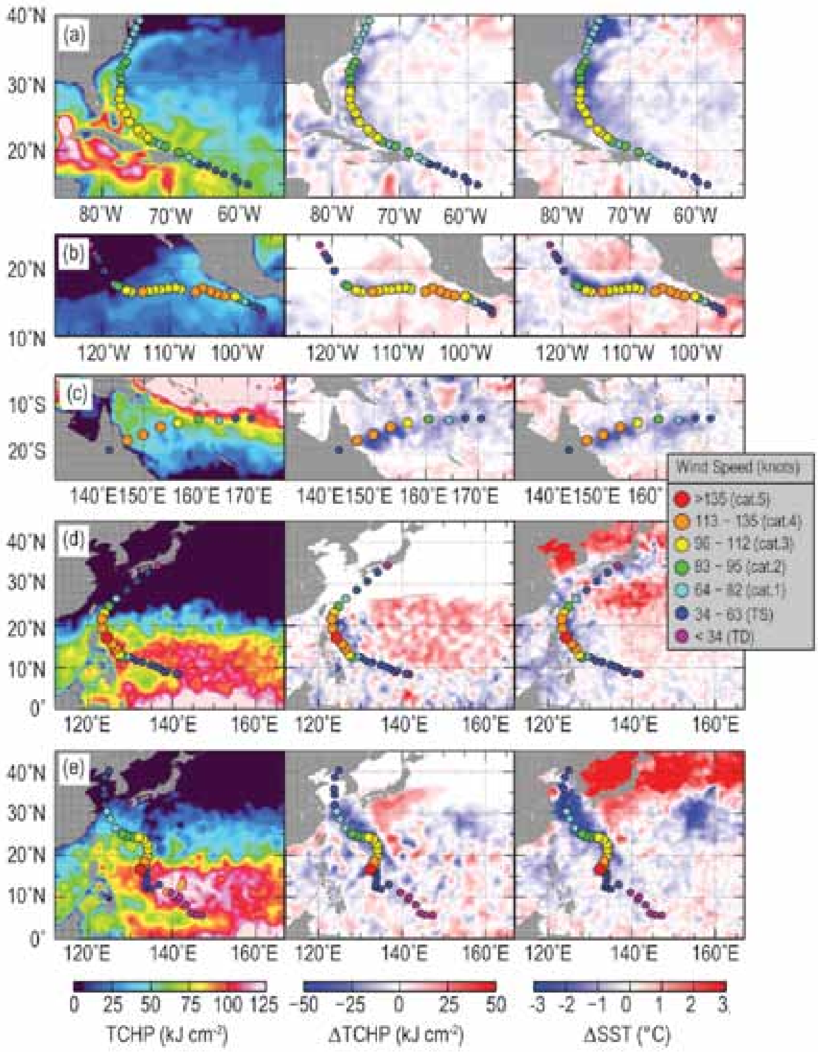

FIG. 4.29. (Left) Oceanic TCHP and surface cooling given by the difference between post- and pre-storm values of (center) TCHP and (right) SST for Hurricanes (a) Irene and (b) Hilary, (c) Tropical Cyclone Yasi, and Typhoons (d) Songda and (e) Muifa. The TCHP values correspond to two days before each TC reaches its maximum intensity value.

Five TCs, where the location of their intensification coincided with relatively high values of TCHP along their tracks, are highlighted in Fig. 4.29. These were Irene (Atlantic), Hilary (ENP), Yasi (Southwest Pacific), and Songda and Muifa (WNP). The cooling associated with the wake of major TCs reached values of up to 50 kJ cm^{-2} in TCHP and above 3°C in SST. This is important since large cooling could affect the intensification for subsequent TCs in the same region and may also influence the upper ocean thermal structure on regional scales within weeks to months after the passage of the cyclones (Emanuel 2001; Hart et al. 2007; Dare and McBride 2011).

Hurricane Irene, the first hurricane of the Atlantic season, developed during late August, and rapidly became a Category 3 major hurricane (Fig. 4.29a), when traveling over waters with TCHP values above 60 kJ cm^{-2}, and the cooling produced by this TC, even after weakening, reached values larger than 3°C in its track.

In the case of ENP Hurricane Hilary, while moving roughly parallel to the Mexican coast and within a very favorable atmospheric environment, Hilary quickly intensified up to 55 kts (28 m s^{-1}) on 22 September. While still moving west-northwest within a similarly favorable atmospheric environment, Hilary encountered higher values of TCHP and became a hurricane (Fig. 4.29b). The TCHP increased nearly three-fold from 15 kJ cm^{-2} to values exceeding 40 kJ cm^{-2} as the TC began its most rapid period of intensification. In this case, TCHP fields improved operational forecasts that were made by both the Statistical Hurricane Intensity Prediction Scheme (SHIPS; DeMaria et al. 2005) and Rapid Intensity Index (RII; Kaplan et al. 2010). During the next 24 hours, Hilary intensified very rapidly from 55 kts to 125 kts (28 m s^{-1} to 64 m s^{-1}). It is noteworthy that the atmospheric conditions remained nearly constant during this period, illustrating the positive effect that TCHP has on TC development and demonstrating how TCHP information can improve TC intensity forecast model output. With respect to Hurricane Hilary for example, TCHP values remained greater than 30 kJ cm^{-2} and this, coupled with favorable atmospheric conditions, persisted for the next 48 hours, allowing Hilary to sustain itself as a major hurricane for more than four days. Eventually, deteriorating ocean and atmospheric conditions caused Hilary to weaken as it continued to move west-northwestward towards the eastern portion of the basin.

The Southwest Pacific basin saw slightly reduced TC activity despite the anomalously elevated TCHP (Fig. 4.27). Nonetheless, three Category 4–5 TCs (Atu, Wilma, and Yasi) occurred in this region. Highlighted in Fig. 4.29c, Severe Tropical Cyclone Yasi, which was observed to rapidly intensify over high values of TCHP (> 50 kJ cm^{-2}) made landfall as a strong Category 4 TC in northern Queensland, Australia (see section 4d7*ii* above).

In the WNP, all of the Category 4 and 5 TCs were observed to intensify over high values of TCHP (typically > 75 kJ cm^{-2} in the western North Pacific) except for Typhoon Roke. Roke was observed intensifying over lower TCHP values (~40 kJ cm^{-2} – 50 kJ cm^{-2}). However, this was a relatively fast-moving typhoon, traveling at around 7.5 m s^{-1}, as it intensified to its peak at Category 4. As fast-moving TCs induce less storm-induced cooling, they tend to intensify over relatively lower TCHP regions (Lin et al. 2009b). During the WNP typhoon season, 10 typhoons reached Category 1 intensity and 60% of these reached either Category 4 or 5 status, which is the highest percentage of Category 4–5 typhoon occurrence since 2007[8]. Among these, Super Typhoon Songda was first identified on 20 May, and from 24–26 May was over an area of high TCHP (> 100 kJ cm^{-2}), and rapidly intensified to a Category 5 TC, at a rate of 37 kts day^{-1} (19 m s^{-1} day^{-1}; Fig. 4.29d). Between 2005 and 2011, this was the only Category 5 typhoon that occurred during the month of May over the WNP.

The high TCHP of values > 100 kJ cm^{-2} observed in May 2011 suggests that the ocean provided sufficient energy for intensification (Lin et al. 2009a,b), along with other possibly favorable atmospheric conditions. Finally, in the WNP basin, Super Typhoon Muifa (Fig. 4.29e) was first observed on 25 July at latitude 5.6°N. After 4.5 days of genesis time, Muifa rapidly intensified, from Category 2 (85 kts or 44 m s^{-1}) to Category 5 (140 kts or 72 m s^{-1}) in only 12 hours on 30 July. This extremely rapid intensification rate, equivalent to 55 kts (28 m s^{-1}) in 24 hours is almost double the 30 kts (15 m s^{-1}) per day criteria for rapid intensification (Kaplan et al. 2010). It is noteworthy that this rapid intensification took place over an area with high TCHP values that exceeded 120 kJ cm^{-2}.

f. Intertropical convergence zones

1) Pacific—A. B. Mullan

The intertropical convergence zone (ITCZ) lies approximately parallel to the equator, with a slight poleward tilt on its eastern end, and varies in position from around 5°N–7°N in February–May to 7°N–10°N in August–November. The other major convergence zone, the South Pacific convergence zone (SPCZ), extends diagonally from around the Solomon Islands (10°S, 160°E) to near 30°S, 140W°, and is most active in the November–April half-year.

The Pacific began 2011 in a moderate to strong La Niña, which weakened through the first two quarters of the year to neutral conditions. A weaker La Niña returned in August 2011. Thus, the year was dominated by stronger-than-normal surface easterlies near the date line, cooler sea surface temperatures from the date line eastwards, and the convergence zones being further poleward than usual in both hemispheres, with an enhanced dry zone along the equator. A double ITCZ was present in March and April, with a fairly prominent southern branch

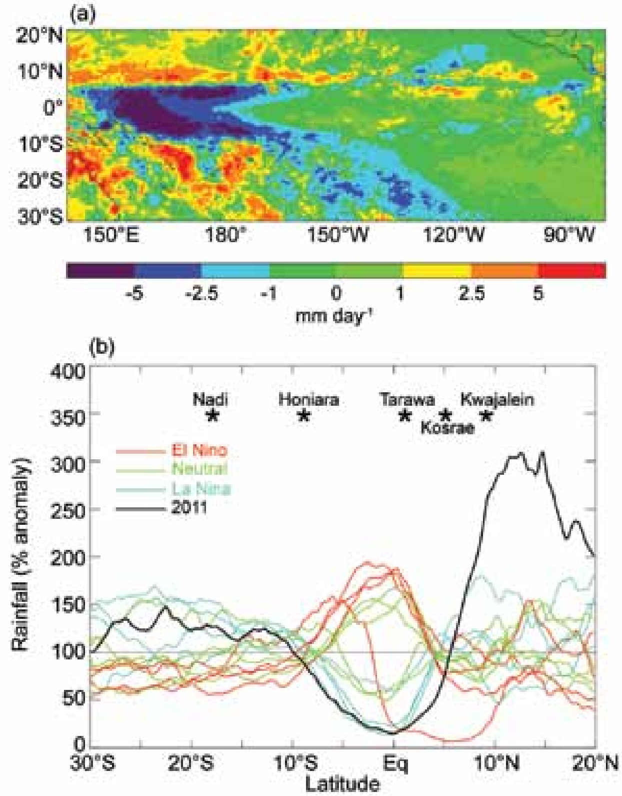

Fig. 4.30. (a) TRMM 3B43 rainfall anomaly for JFM 2011 (mm day^{-1}; relative to 1999–2008 mean); (b) Cross sections of JFM rainfall anomalies (% of 1999–2008 mean) for each year 1998 to 2011, averaged over sector 150°E–180°. Lines are colored according to ENSO status, except for 2011 (black). Stars mark latitude of selected island rainfall sites: Nadi (Fiji; 18°S, 175°E), Honiara (Solomon Islands; 9°S, 160°E), Tarawa (Kiribati; 1°N, 173°E), Kosrae (Micronesia; 5°N, 163°E), Kwajalein (Marshall Islands; 9°N, 167°E). The anomalous El Niño year is 1998.

[8]It should be noted that while both Songda and Muifa were briefly classified as Category 5 typhoons in the JTWC operational database, they were not officially classified as such by Japan Meteorological Agency, which is the official monitoring World Meteorological Organization center for the WNP.