NATIONAL HURRICANE CENTER TROPICAL CYCLONE REPORT

HURRICANE OTIS

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22–25 October 2023

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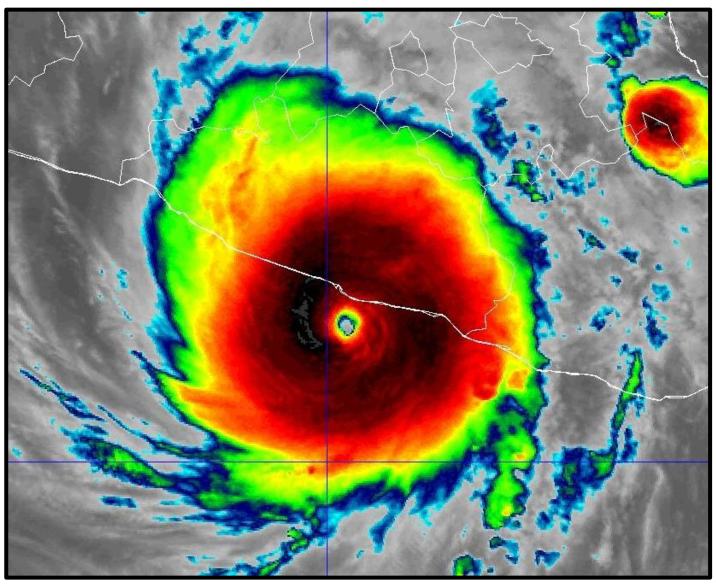

GOES-16 INFRARED SATELLITE IMAGERY OF CATEGORY 5 HURRICANE OTIS AT 0430 UTC 25 OCTOBER 2023, SHORTLY BEFORE IT MADE LANDFALL NEAR ACAPULCO, MEXICO. IMAGE COURTESY NOAA/NESDIS/STAR.

Otis produced catastrophic damage when it made landfall near Acapulco, Mexico, as a category 5 hurricane (on the Saffir-Simpson Hurricane Wind Scale). Otis is the strongest landfalling hurricane on record in the eastern Pacific basin since the NHC assumed operational responsibility for the basin in 1988. Otis caused at least 52 fatalities and an estimated $12–16 billion (USD) of total damage in Mexico, making it the costliest tropical cyclone on record for Mexico and one of the most expensive natural disasters in Mexico's history.

[1] Original Report date 7 March 2024. This version updates the observation table based on data provided by the National Meteorological Service of Mexico.

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SYNOPTIC HISTORY

The origins of Otis can be traced back to an area of disturbed weather that developed along the eastern North Pacific monsoon trough on 18 October. Satellite wind data that day indicated disorganized showers and thunderstorms along the monsoon trough were associated with a broad area of low pressure located several hundred miles south of the Gulf of Tehuantepec. The broad disturbance meandered during the next couple of days while continuing to produce disorganized convection, mainly over the western part of the circulation due to moderate to strong easterly shear. The disturbance began moving northwestward later on 20 October, and a well-defined area of low pressure became evident in satellite images by 0000 UTC 21 October, about 385 n mi south of Puerto Angel, Mexico. Shower and thunderstorm activity gradually increased in coverage that day, but the convection remained disorganized and displaced to the west and northwest of the center. Early on 22 October, showers and thunderstorms began to consolidate and show more persistent signs of organization. It is estimated that a tropical depression formed by 1200 UTC that day, when it was located about 465 n mi south-southeast of Acapulco, Mexico. Six hours later, the depression strengthened into Tropical Storm Otis. The "best track" chart of Otis' path is given in Fig. 1, with the wind and pressure histories shown in Figs. 2 and 3, respectively. The best track positions and intensities are listed in Table 1[2].

Otis moved slowly north-northwestward after formation within the flow between a mid-level trough to its northwest associated with Tropical Storm Norma and a weak ridge over the northwestern Caribbean Sea. Despite moving over 28–29°C sea-surface temperatures (SSTs) on 23 October, only modest strengthening occurred initially as convection pulsed to the west of the low-level center due to continued moderate easterly shear and the presence of some mid-level dry air. Later that day, Otis began moving slightly faster toward the northwest in response to a building ridge located to Otis' northeast over the Gulf of Mexico. The storm exhibited a well-defined low-level structure in microwave imagery late on 23 October, with a curved convective band over the western part of the circulation (Figs. 4a, b). Overnight, Otis moved into a slightly weaker shear environment while approaching anomalously warm SSTs (30–31°C; about 1–2°C above normal for October) offshore of southern Mexico. These conditions fueled a remarkable period of rapid intensification (RI) that began early on 24 October. As deep convection wrapped around the center of Otis that morning, an inner core solidified and an eye feature became evident in 89–GHz microwave imagery (Figs. 4c, d). It is estimated that Otis strengthened into a 65-kt hurricane by 1200 UTC 24 October, while centered about 165 n mi south-southeast of Acapulco.

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[2] A digital record of the complete best track, including wind radii, can be found on line at ftp://ftp.nhc.noaa.gov/atcf. Data for the current year's storms are located in the *btk* directory, while previous years' data are located in the *archive* directory.

The Air Force Reserve Hurricane Hunters arrived in Otis several hours later and provided crucial data in the midst of the extreme RI period. The flight-level and SFMR winds from the aircraft indicate that Otis likely reached major hurricane intensity by 1800 UTC on 24 October, when it was centered about 115 n mi south-southeast of Acapulco. The Hurricane Hunters reported Otis had a closed, circular eye with a diameter of around 10 n mi, and temperature data revealed the eye of the compact hurricane was quickly warming. Dropsonde data showed the minimum pressure of Otis dropped by about 10 mb during the 85 minutes between the two center fixes.

After the plane departed, satellite data revealed that Otis continued to rapidly strengthen as it approached the coast of Mexico (Figs. 4e, f). The symmetric eye continued to warm and became surrounded by a thick ring of very cold cloud tops with infrared brightness temperatures between -75 and -80°C. Satellite estimates indicate Otis reached an estimated peak intensity of 145 kt at 0300 UTC 25 October, when it was centered just 50 n mi south-southeast of Acapulco. Shortly before landfall, some cooling and filling of the eye became evident in infrared satellite images of the hurricane. It is estimated that Otis made landfall in Acapulco around 0645 UTC as a 140-kt category 5 hurricane. Once inland, rapid weakening occurred as Otis encountered the rugged terrain of southern Mexico. The cyclone weakened to a tropical storm by 1800 UTC 25 October and dissipated soon thereafter.

METEOROLOGICAL STATISTICS

Observations in Otis (Figs. 2 and 3) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and the Satellite Analysis Branch (SAB), objective Advanced Dvorak Technique (ADT) estimates and Satellite Consensus (SATCON) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. Observations also include flight-level, stepped frequency microwave radiometer (SFMR), and dropwindsonde observations from one flight of the 53rd Weather Reconnaissance Squadron of the U.S. Air Force Reserve Command that provided two center fixes on 24 October (Fig. 5). Data and imagery from NOAA polar-orbiting satellites including the Advanced Microwave Sounding Unit (AMSU), the NASA Global Precipitation Mission (GPM), the European Space Agency's Advanced Scatterometer (ASCAT), and Defense Meteorological Satellite Program (DMSP) satellites, among others, were also useful in constructing the best track of Otis.

There were no ship reports of winds of tropical storm force associated with Otis. Surface observations from land stations in Mexico are given in Table 2.

Winds and Pressure

Otis' estimated peak intensity of 145 kt from 0300–0600 UTC 25 October is based on raw ADT data-T numbers and special, non-routine Dvorak classifications performed by NHC forecasters early on 25 October. The raw ADT data-T numbers (depicted as hourly analysis estimates in Fig. 2) reached T7.0/140 kt at 2320 UTC 24 October and remained above T7.0

through 0510 UTC 25 October, peaking at T7.6/158 kt from 0210–0240 UTC that day. These numbers were consistent with the special subjective Dvorak classifications that yielded data-T numbers of T7.0/140 kt or higher in real time. The peak intensity of Otis at 0300 UTC 25 October marked the end of an historic period of RI in which Otis strengthened by an estimated 90 kt in just 21 h. This rate of strengthening is only bested in the eastern Pacific basin records by Hurricane Patricia[3], which strengthened by 105 kt in a 24-h period.

No reconnaissance data was available at the estimated time of Otis' peak intensity. However, aircraft data earlier that day indicated that the conventional objective and subjective satellite estimates late on 24 October significantly underestimated the true intensity of Otis due to the constraints of the Dvorak technique. The flight-level and SFMR wind data from the aircraft indicate that Otis likely reached major hurricane intensity (100 kt) by 1800 UTC 24 October. Meanwhile, the corresponding objective and subjective intensity estimates at that time ranged between 60 kt and 90 kt. Other datasets support the assessment that Otis was consistently stronger than indicated by conventional satellite estimates. An analysis of ASCAT Ultra High Resolution (UHR) data from 1603 UTC 24 October (not shown) by the NOAA/NESDIS Center for Satellite Applications and Research (STAR) yielded a peak wind estimate of 113–132 kt. Also, Synthetic Aperture Radar (SAR) data (Fig. 6) from 0052 UTC 25 October showed a peak wind of 128 kt. While the UHR ASCAT and SAR datasets are still being evaluated for their utility in estimating the peak winds of a tropical cyclone, both retrievals are significantly higher than the constrained Dvorak intensity estimates at those times. These datasets reinforce the notion that the conventional satellite estimates were lagging the strengthening winds of Otis during the extreme RI period. The estimated minimum central pressure of 922 mb is based on the Knaff-Zehr-Courtney (KZC) pressure-wind relationship.

The small size of Otis, the large satellite zenith viewing angle from both GOES-East and GOES-West around the time of landfall (Fig. 7), and limited surface observations in the landfall area complicate analyzing the precise landfall location and estimating the landfall intensity. There were no passive microwave imager overpasses leading up to landfall and no radar data available to better assess any structural changes to the hurricane. Satellite images indicate some cooling and filling of Otis' eye occurred shortly before it made landfall in Acapulco. Based on these changes to the satellite presentation, it seems reasonable to assume that some slight weakening occurred prior to landfall. Therefore, the estimated landfall intensity is set at 140 kt. This intensity makes category 5 Otis the strongest landfalling hurricane on record in the eastern Pacific basin since the NHC assumed operational forecast responsibility for the basin in 1988. Note that the NHC best track intensities typically have an uncertainty of about ±10%[4]. The estimated landfall pressure of 929 mb is based on the KZC pressure-wind relationship.

Otis brought major hurricane-force winds to the Acapulco metropolitan area near where the center made landfall in the state of Guerrero. The strongest wind observation was recorded by a weather station operated by the Tidal Service of Mexico at the Acapulco Port Authority (Administración Portuaria Integral, API). This station, located on the northwestern side of

[3] https://www.nhc.noaa.gov/data/tcr/EP202015_Patricia.pdf

[4] Landsea, C. W., and J. L. Franklin, 2013: Atlantic Hurricane Database Uncertainty and Presentation of a New Database Format. Mon. Wea. Rev., **141**, 3576-3592.

Acapulco Bay, measured a sustained wind of 99 kt and a gust of 178 kt at 0640 UTC 25 October. This site also recorded a minimum pressure of 963.5 mb at 0650 UTC that day. An automated Mexican Navy weather station on Isla Roqueta (IRQG3) reported a peak sustained wind of 71 kt at 0645 UTC that day and a peak gust of 116 kt, along with a minimum sea level pressure of 957.4 mb. Elsewhere, an elevated (994 ft) inland observation site at El Veladero National Park reported a gust of 95 kt at 0720 UTC that day.

Storm Surge

Hurricane Otis produced a catastrophic storm surge along portions of the coastline of the Mexican state of Guerrero near and east of the landfall location. Aerial imagery shows devastating storm surge flooding in coastal communities around Acapulco, and extensive damage to marinas was noted in Acapulco Bay with boats piled along the shoreline (Fig. 8). The maximum height of storm surge inundation remains unknown, however. A nearby tide station in Acapulco Bay, operated by the Tidal Service of Mexico, recorded incomplete data. Thus, there are no known tide station measurements that captured the peak storm surge.

Rainfall and Flooding

Otis produced heavy rainfall across Guerrero. Much of the state received 2–4 inches (~50–100 mm) of rain, with locally higher amounts near and to the east of the landfall location (Fig. 9). A storm total maximum of 10.47 inches (266.0 mm) of rain was measured in Acapulco. Elsewhere, 9.82 inches (249.4 mm) fell at El Veladero, and 8.66 inches (220.0 mm) were reported at Tierra Colorada. This heavy rainfall resulted in flash and riverine flooding and landslides across Guerrero (Fig. 10), including in Acapulco and Coyuca de Benítez. Heavy rainfall also occurred in the far southwestern portion of the state of Oaxaca, with 5.75 inches (146.1 mm) reported at El Dique Pescaditos.

CASUALTY AND DAMAGE STATISTICS

There is large uncertainty regarding the complete death toll from Otis. According to the latest update from the government of Mexico[5], Otis was responsible for 52 deaths[6], with another 32 people still missing following the storm. The consistent reporting of fatalities in the aftermath of a major hurricane can be challenging. Based on the number of people reported missing, the final death toll (including direct and indirect deaths) attributable to Otis could be much greater but is still unknown at the time of this report. The vast majority of the confirmed fatalities were in

[5] https://mexiconewsdaily.com/news/officials-update-hurricane-otis-death-toll-to-52-with-32-people-missing/

[6] Deaths occurring as a direct result of the forces of the tropical cyclone are referred to as "direct" deaths. These would include those persons who drowned in storm surge, rough seas, rip currents, and freshwater floods. Direct deaths also include casualties resulting from lightning and wind-related events (e.g., collapsing structures). Deaths occurring from such factors as heart attacks, house fires, electrocutions from downed power lines, vehicle accidents on wet roads, etc., are considered "indirect" deaths.

Acapulco. Many deaths appear to have occurred in or near Acapulco Bay, where the Secretary of the Mexican Navy reported that hundreds of small vessels and boats were lost or sunk during the storm. Landslides due to heavy rainfall were also responsible for numerous fatalities. Mexican officials reported that one soldier died after the wall of a home collapsed on him. In the neighboring municipality of Coyuca de Benítez, the municipal president reported 12 fatalities.

Various estimates from disaster risk analysis and reinsurance firms[7] indicate that the extreme winds, storm surge, and flooding rains associated with Otis produced between $12–16 billion (USD) in total damage (including economic and insured losses) in Mexico. These estimates make Otis the costliest tropical cyclone on record for Mexico, surpassing the inflation-adjusted economic losses from Hurricane Wilma[8] (2005). Over 250,000 homes were affected in the state of Guerrero, with more than 51,000 homes destroyed and around 80,000 seriously damaged. According to the United Nations World Health Organization, over 600 emergency shelters in Guerrero took in more than 34,000 displaced households in the days following the storm. Many schools were damaged or destroyed, affecting over 87,000 students across the state. More than 20,000 vehicles were damaged or destroyed. Critical infrastructure was severely damaged across the region, including thousands of utility poles and dozens of transmission lines and electrical substations. More than 500,000 customers in Guerrero were left without power following the storm, and many people in the region experienced water and sanitation system failures and telecommunication network disruptions.

The government of Mexico declared disaster areas in the municipalities of Acapulco de Juarez and Coyuca de Benítez. The Acapulco metropolitan area was ravaged by the destructive winds in the core of Otis (Figs. 11–13). Over 98% of homes and around 80% of the hotels in Acapulco were damaged, and many high-rise buildings were gutted as windows were blown out by the ferocious winds. More than 5,800 commercial establishments were damaged, including stores, restaurants, pharmacies, and shopping centers. Over 4,000 of these businesses are considered a total loss. More than 100 health clinics and at least two hospitals were damaged. The Acapulco International Airport was forced to suspend regular operations for a couple of weeks due to damage to the airport and air traffic control tower. Aerial imagery and videos show evidence of devastating storm surge flooding in coastal communities in and around Acapulco. Extensive damage to marinas and yacht clubs was noted in Acapulco Bay, with boats piled along the shoreline. This damage highlights the power of the storm surge and large breaking waves that Otis produced as it made landfall. Hundreds of marine vessels including yachts, ferries, and fishing boats washed up on land or sank in locations including Acapulco Bay and Puerto Marqués Bay (Fig. 14).

Heavy rainfall from Otis caused significant flooding that forced road closures, triggered landslides, and washed out roads across the state of Guerrero (Fig. 10). Damage was reported to over 20 locations along the state's highway network, including several major highways. This includes the federal highway between Acapulco and Chilpancingo, which was blocked by floodwaters and debris from landslides that delayed emergency services from reaching the affected areas after the storm. River flooding was reported at several locations, including along the Coyuca and Papagayo Rivers. At higher elevations above Acapulco, excessive rainfall

[7] https://assets.aon.com/-/media/files/aon/reports/2024/climate-and-catastrophe-insights-report.pdf
[8] https://www.nhc.noaa.gov/data/tcr/AL252005_Wilma.pdf

triggered mudslides and debris flows that swept away homes and vehicles in the surrounding mountainside communities.

Strong winds and heavy rains brought damage to other locations in Guerrero, including Coyuca de Benitez, Atoyac de Álvarez, Técpan de Galeana, and Xaltianguis. In the Coyuca de Benitez municipality, there were reports of downed trees, damaged roofs, and flooded homes and vehicles. Otis also brought devastating impacts to the state's agricultural sector. Many corn, coconut, and mango crops were damaged or destroyed.

FORECAST AND WARNING CRITIQUE

Genesis

The genesis of Otis was very well forecast (Table 3), with plenty of lead time in both the 7-day and 2-day Tropical Weather Outlooks (TWO). The disturbance from which Otis developed was introduced in the TWO over one week (180 h) prior to genesis. The 7-day formation chances were raised to the medium (40–60%) and high (>60%) categories 162 h and 138 h before genesis, respectively. A low 2-day chance of formation was introduced into the TWO 126 h before Otis formed. The 2-day probabilities were raised to the medium and high categories 72 h and 24 h before genesis, respectively. A well-defined area of low pressure formed offshore of Mexico by 21 October, but it took an additional day or so for the system to consolidate and produce enough organized convection for genesis to occur. Figure 15 shows composites of 7-day Graphical TWO genesis areas for each category prior to the formation of Otis. While some very early genesis forecast locations were too far east, the vast majority of outlook areas in the medium (40–60%) and high (>60%) categories correctly captured the location of genesis.

Track

A verification of NHC official track forecasts for Otis is given in Table 4a. Official track forecast (OFCL) errors were much greater than the mean official errors for the previous 5-year period at all forecast lead times. The climatology-persistence (OCD5) errors for Otis' track were lower than the 5-year means, suggesting that the track of Otis should have been easier to forecast than a typical eastern Pacific tropical cyclone. A homogeneous comparison of the official track errors with selected guidance models is given in Table 4b and Fig. 16. Despite the well above-average NHC errors, OFCL outperformed many of the individual models as well as the simple and corrected consensus aids at most verifying times.

Early in Otis' life cycle, there was a very large spread in the track guidance that contributed to the above-average OFCL track errors. The GFS model forecast for Otis (Fig. 17a) showed a weak cyclone remaining embedded in the eastern Pacific monsoon trough and meandering offshore with no landfall in Mexico. As a result, the GFS and related regional hurricane models like HAFS-A and HAFS-B had some of the largest track errors for Otis. Meanwhile, early ECMWF model solutions were relatively stronger than the rest of the guidance (albeit still much too weak) and produced a more consistent signal for Otis to be steered northwestward and approach the coast of Mexico near Acapulco (Fig. 17b). In fact, the ECMWF (EMXI) was the best performing track model for Otis, with the lowest errors of any model at all verified forecast times.

Intensity

A verification of NHC official intensity forecasts for Otis is given in Table 5a and Fig. 18. Official intensity forecast (OFCL) errors were substantially larger than the mean official errors for the previous 5-year period at all forecast lead times. The climatology-persistence (OCD5) errors were also much larger than the 5-year means, suggesting that Otis' intensity forecast was more difficult than for a typical eastern Pacific tropical cyclone. Figure 19 shows a distribution of 48-h intensity errors in the eastern Pacific basin over the past 10 years (2014–2023). One of the Otis forecasts resulted in the largest 48-h NHC intensity error in the basin since Hurricane Patricia (2015). A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 5b. It is noteworthy that the dynamical and statistical-dynamical models, as well as the consensus aids, performed even worse than OFCL at almost all verifying forecast periods. In fact, Fig. 18 shows that almost every piece of intensity guidance available to forecasters for Otis was unskillful (large, negative skill relative to climatology-persistence).

The extreme RI of Otis was not anticipated by NHC forecasters or the intensity guidance suite (Fig. 20). Early dynamical model forecasts for Otis were much too weak, with some global models suggesting the cyclone could even dissipate due to an expected increase in vertical wind shear in a relatively dry mid-level environment. Although Otis did struggle to consolidate on 23 October due to moderate easterly shear, the actual shear environment that Otis experienced on its approach to Mexico was not as strong as initially forecast. Once Otis became vertically aligned and developed an inner core early on 24 October (Fig. 4), the small tropical cyclone took advantage of more favorable environmental and oceanic conditions and underwent RI. The statistical-dynamical aids also failed to provide much advance notice for Otis' RI. Less than 24 h before Otis reached its peak intensity as a category 5 hurricane, the various SHIPS RI aids (Fig. 21) did not indicate that RI was likely. Ultimately, every SHIPS RI threshold in Fig. 21 was satisfied in the ensuing 24-h period as compact Otis reached category 5 intensity. Undoubtedly, the struggles of both the dynamical and statistical model guidance to anticipate Otis' historic RI will be the topic of future research.

The lack of observational data over the eastern Pacific Ocean can make intensity forecasting challenging in extreme RI cases, especially for small tropical cyclones like Otis. While passive microwave data can help assess the structural changes of a tropical cyclone, these images only provide forecasters with sporadic and delayed snapshots of the storm. The in-situ datasets collected by the Air Force Reserve Hurricane Hunters were crucial for forecasters to recognize that none of the models had an accurate representation of Otis' intensity and structure. Unfortunately, the RI of Otis was well underway by the time these data were received, and the hurricane continued to strengthen at an historic rate until it made landfall less than 12 h later.

Coastal Wind Watches and Warnings

Coastal watches and warnings issued by the government of Mexico in association with Otis are given in Table 6. A Tropical Storm Warning and Hurricane Watch were issued for the coast of Mexico from Lagunas de Chacahua to Técpan de Galeana, including Acapulco, at 2100 UTC 23 October. At this time, forecasters recognized the increased potential for Otis to impact Mexico as a hurricane, although it was unclear that significant RI would soon commence. A Hurricane Warning was issued for the coast of Guerrero from Punta Maldonado to Zihuatanejo, including Acapulco, at 0900 UTC 24 October. The Hurricane Watch and Hurricane Warning were issued 33 h and 21 h, respectively, before tropical-storm-force winds began in the Acapulco area around 0600 UTC 25 October.

ACKNOWLEDGEMENTS

Some data and observations were provided by the National Meteorological Service and the National Tidal Service of Mexico. Laura Alaka and Cody Fritz from the NHC Storm Surge Unit contributed to the storm surge and damage sections. Lisa Bucci produced the aircraft reconnaissance graphic (Fig. 5). Philippe Papin created the Graphical TWO verification figure (Fig. 15) and the global model comparison graphic (Fig. 17). John Cangialosi produced the eastern Pacific intensity forecast error histogram (Fig. 19).

Table 1. Best track for Hurricane Otis, 22–25 October 2023.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
21 / 0000	9.3	95.8	1007	25	low
21 / 0600	9.6	96.1	1007	25	"
21 / 1200	9.7	96.6	1007	25	"
21 / 1800	9.5	96.9	1007	25	"
22 / 0000	9.5	96.7	1007	25	"
22 / 0600	9.6	96.6	1006	30	"
22 / 1200	9.8	96.7	1006	30	tropical depression
22 / 1800	10.2	96.9	1004	35	tropical storm
23 / 0000	10.8	97.1	1004	35	"
23 / 0600	11.4	97.2	1004	35	"
23 / 1200	11.9	97.3	1003	40	"
23 / 1800	12.6	97.6	1001	45	"
24 / 0000	13.3	98.0	998	50	"
24 / 0600	13.8	98.5	994	55	"
24 / 1200	14.2	98.9	990	65	hurricane
24 / 1800	14.9	99.4	971	100	"
25 / 0000	15.7	99.6	938	130	"
25 / 0300	16.1	99.7	922	145	"
25 / 0600	16.7	99.8	924	145	"
25 / 0645	16.8	99.9	929	140	"
25 / 1200	17.7	100.3	980	85	"
25 / 1800	18.6	100.7	1004	40	tropical storm
25 / 2100					dissipated
25 / 0300	16.1	99.7	922	145	minimum pressure and maximum wind
25 / 0645	16.8	99.9	929	140	landfall in Acapulco, Mexico

Table 2. Surface observations for Hurricane Otis, 22–25 October 2023.

Location	Minimum Sea Level Pressure		Maximum Surface Wind Speed			Storm surge (ft)	Storm tide (ft)	Estimated Inundation (ft)	Total rain (in)
	Date/ time (UTC)	Press. (mb)	Date/ time (UTC)[a]	Sustained (kt)	Gust (kt)				
Mexico									
Guerrero									
Acapulco Port Authority (API) (16.85N 99.90W)	25/0650	963.5	25/0640	99	178				
Isla Roqueta (IRQG3) (16.82N 99.91W)	25/0645	957.4	25/0645	71	117				
El Veladero *elev. 994 ft* (16.88N 99.91W)	25/0700	972.8	25/0720	55	95				9.82
Acapulco Intl. AP (MMAA) (16.77N 99.75W)	25/0630	984.1 [I]	25/0710	63 [I]					
Acapulco (16.85N 99.91W)									10.47
Tierra Colorada (17.17N 99.53W)									8.66
Oaxaca									
El Dique Pescaditos									5.75

[a] Date/time is for sustained wind when both sustained and gust are listed.
[I] Incomplete

Table 3. Number of hours in advance of formation of Otis associated with the first NHC Tropical Weather Outlook forecast in the indicated likelihood category. Note that the timings for the "Low" category do not include forecasts of a 0% chance of genesis.

	Hours Before Genesis	
	48-Hour Outlook	168-Hour Outlook
Low (<40%)	126	180
Medium (40%-60%)	72	162
High (>60%)	24	138

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Otis, 22–25 October 2023. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	30.2	60.2	95.3	135.5	196.3	297.7		
OCD5	30.9	49.4	64.2	86.9	124.8	208.5		
Forecasts	12	10	8	6	4	2		
OFCL (2018-22)	22.1	34.0	45.4	56.0	70.9	78.7	100.5	117.8
OCD5 (2018-22)	36.7	73.4	114.0	156.9	193.2	244.5	317.0	376.0

Table 4b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Otis, 22–25 October 2023. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 4a due to the homogeneity requirement.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	30.2	59.6	95.3	135.5	196.3	297.7		
OCD5	30.9	**46.9**	**64.2**	**86.9**	**124.8**	**208.5**		
GFSI	42.2	94.0	161.4	240.8	310.5	407.5		
HWFI	41.1	71.9	106.0	141.0	**189.3**	**295.6**		
HMNI	37.2	67.0	105.8	137.1	**186.2**	327.4		
HFAI	47.4	104.5	149.9	188.4	268.6	359.3		
HFBI	41.0	80.3	117.7	166.6	252.6	330.6		
EMXI	**18.8**	**27.9**	**49.8**	**63.2**	**94.8**	**181.1**		
CMCI	30.8	**40.6**	**59.5**	**95.9**	**143.8**	**210.2**		
CTCI	42.7	92.4	139.8	197.5	263.4	379.3		
TVCE	36.0	69.6	108.5	149.2	214.1	319.6		
TVCX	34.0	67.3	104.4	144.0	205.3	302.2		
GFEX	**28.8**	**59.2**	103.4	150.8	203.8	**293.3**		
TVDG	34.7	68.7	109.5	150.2	214.7	315.8		
HCCA	35.6	62.0	**91.0**	141.6	205.0	305.8		
AEMI	43.3	93.2	154.9	207.6	268.3	355.3		
TABS	43.8	86.6	152.7	226.6	313.8	438.3		
TABM	40.5	91.0	157.8	240.4	328.9	448.2		
TABD	36.1	70.4	116.6	181.5	247.6	351.3		
Forecasts	12	9	8	6	4	2		

Table 5a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Otis, 22–25 October 2023. Mean errors for the previous 5-yr period are shown for comparison. Official errors that are smaller than the 5-yr means are shown in boldface type.

	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	16.2	29.5	39.4	51.7	60.0	22.5		
OCD5	20.8	29.9	32.2	30.0	41.5	25.0		
Forecasts	12	10	8	6	4	2		
OFCL (2018-22)	5.4	8.9	11.0	12.8	14.3	15.8	17.0	17.6
OCD5 (2018-22)	6.9	12.1	15.9	18.6	18.7	21.0	22.3	22.1

Table 5b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Otis, 22–25 October 2023. Errors smaller than the NHC official forecast are shown in boldface type. The number of official forecasts shown here will generally be smaller than that shown in Table 5a due to the homogeneity requirement.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	16.2	27.2	39.4	51.7	60.0	22.5		
OCD5	20.8	27.2	**32.2**	**30.0**	**41.5**	25.0		
HWFI	23.9	38.4	42.9	56.7	63.5	26.0		
HMNI	22.9	35.8	40.6	53.2	72.0	39.5		
HFAI	24.3	42.3	48.2	65.2	70.8	34.5		
HFBI	17.7	34.9	45.8	58.7	66.8	26.5		
DSHP	23.1	34.3	40.8	**50.0**	**50.2**	**21.5**		
LGEM	23.7	32.8	41.1	53.0	**55.0**	25.0		
ICON	22.9	35.1	41.5	52.2	**59.2**	23.0		
IVCN	21.6	36.0	43.8	55.8	62.2	25.0		
IVDR	21.5	36.7	44.6	56.5	64.0	28.5		
CTCI	21.2	37.2	47.9	60.7	66.2	35.5		
GFSI	25.5	41.3	50.0	62.7	71.2	36.0		
EMXI	27.2	36.6	43.0	56.5	64.2	30.0		
HCCA	17.7	29.3	**35.2**	52.2	63.0	34.0		
Forecasts	12	9	8	6	4	2		

Table 6. Mexico watch and warning summary for Hurricane Otis, 22–25 October 2023.

Date/Time (UTC)	Action	Location
23 / 0900	Tropical Storm Watch issued	Lagunas de Chacahua to Técpan de Galeana
23 / 2100	Tropical Storm Watch upgraded to Tropical Storm Warning	Lagunas de Chacahua to Técpan de Galeana
23 / 2100	Hurricane Watch issued	Lagunas de Chacahua to Técpan de Galeana
24 / 0900	Hurricane Warning issued	Punta Maldonado to Zihuatanejo
25 / 0900	Tropical Storm Warning discontinued	Lagunas de Chacahua to Punta Maldonado
25 / 0900	Hurricane Watch discontinued	Lagunas de Chacahua to Punta Maldonado
25 / 1500	Hurricane Warning discontinued	West of Acapulco to Zihuatanejo
25 / 1500	Hurricane Warning changed to Tropical Storm Warning	Punta Maldonado to Acapulco
25 / 2100	Tropical Storm Warning discontinued	All

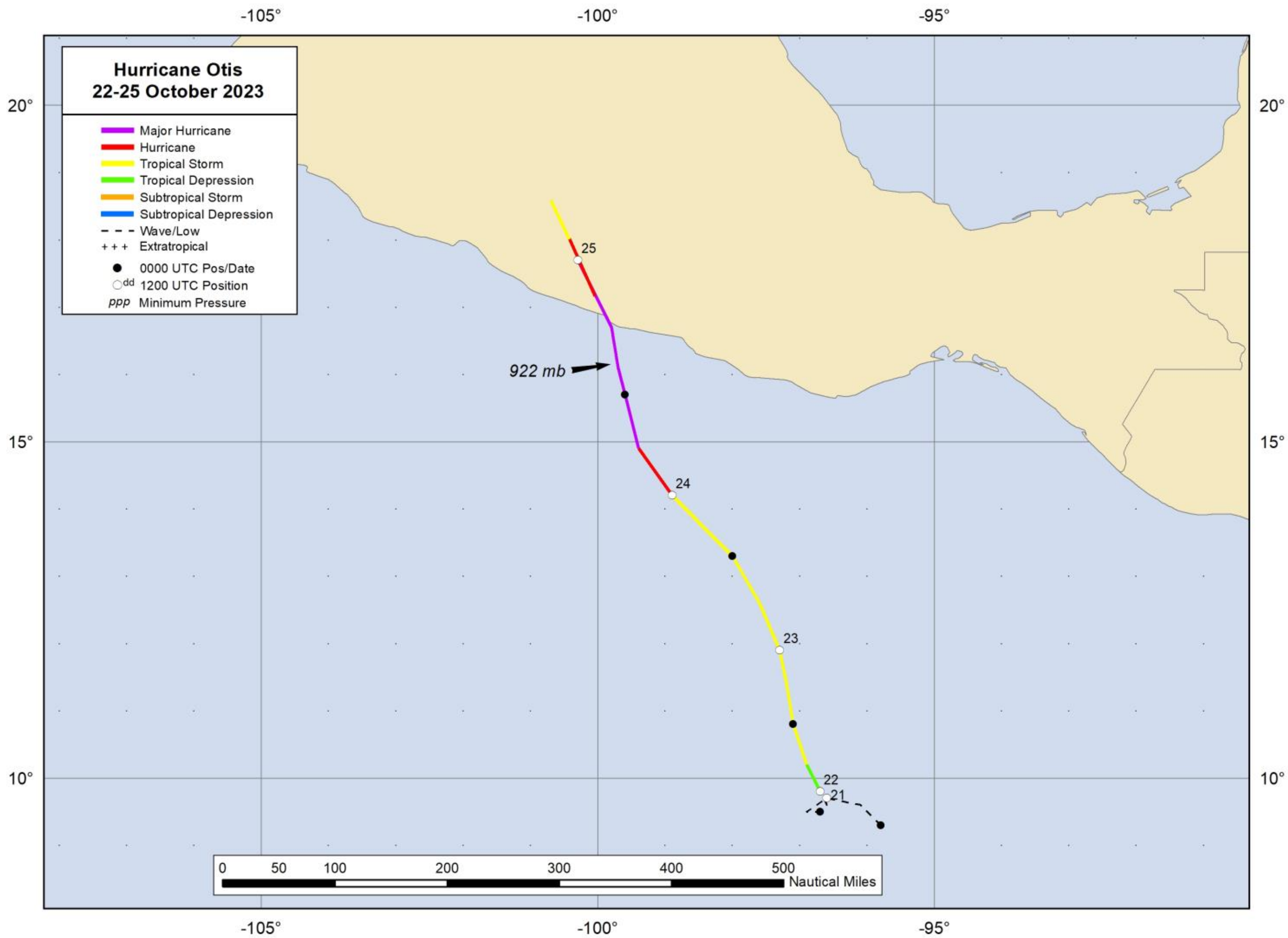

Figure 1. Best track positions for Hurricane Otis, 22–25 October 2023.

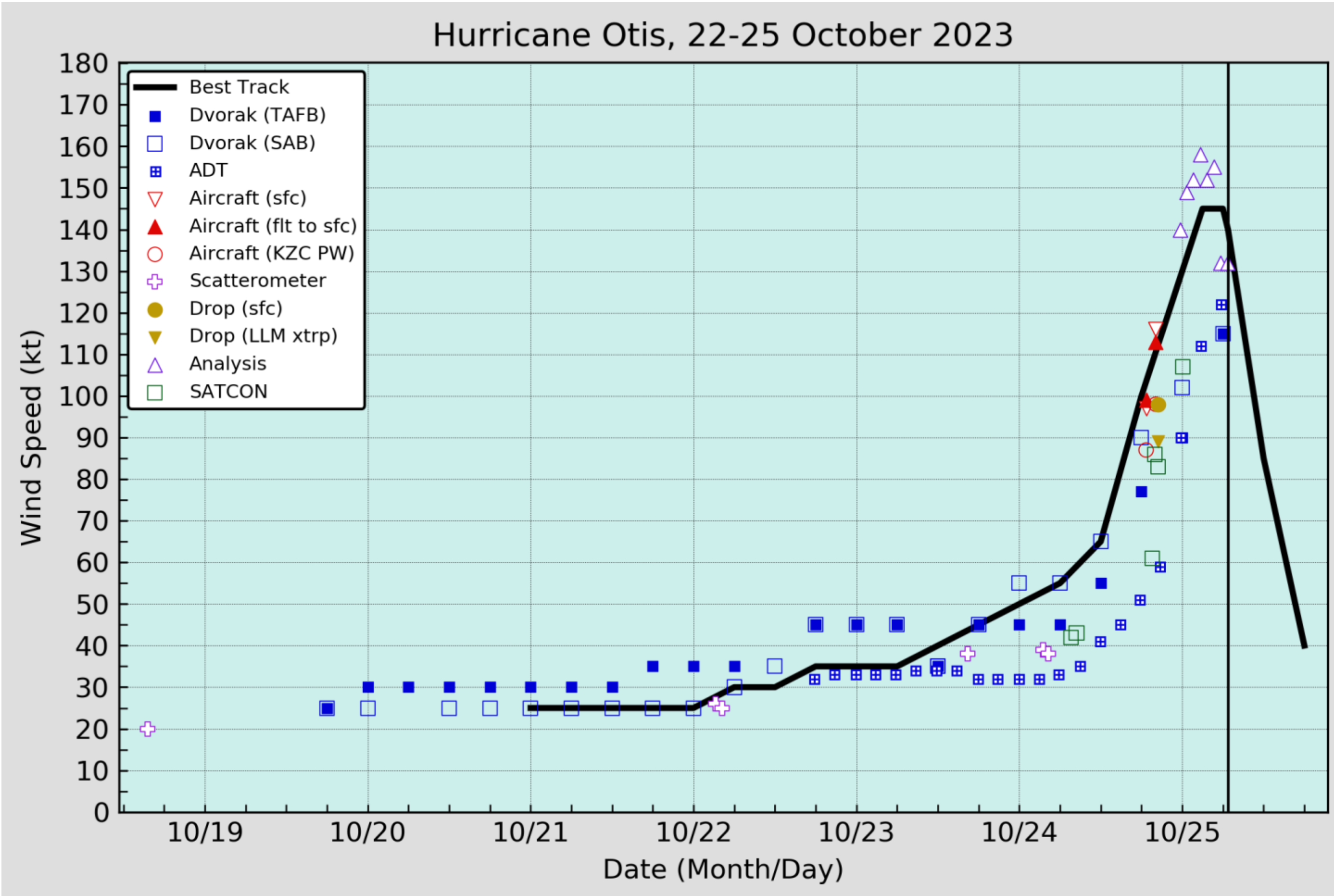

Figure 2. Selected wind observations and best track maximum sustained surface wind speed curve for Hurricane Otis, 22–25 October 2023. Aircraft observations have been adjusted for elevation using a 90% adjustment factor for observations from 700 mb. Dropwindsonde observations include actual 10 m winds (sfc), as well as surface estimates derived from the mean wind over the lowest 150 m of the wind sounding (LLM). Advanced Dvorak Technique (ADT) estimates represent the Current Intensity at the nominal observation time. The analysis symbols early on 25 October depict the raw ADT data-T numbers as described in the Winds and Pressure section of the report. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. Dashed vertical lines correspond to 0000 UTC, and the solid vertical line corresponds to landfall.

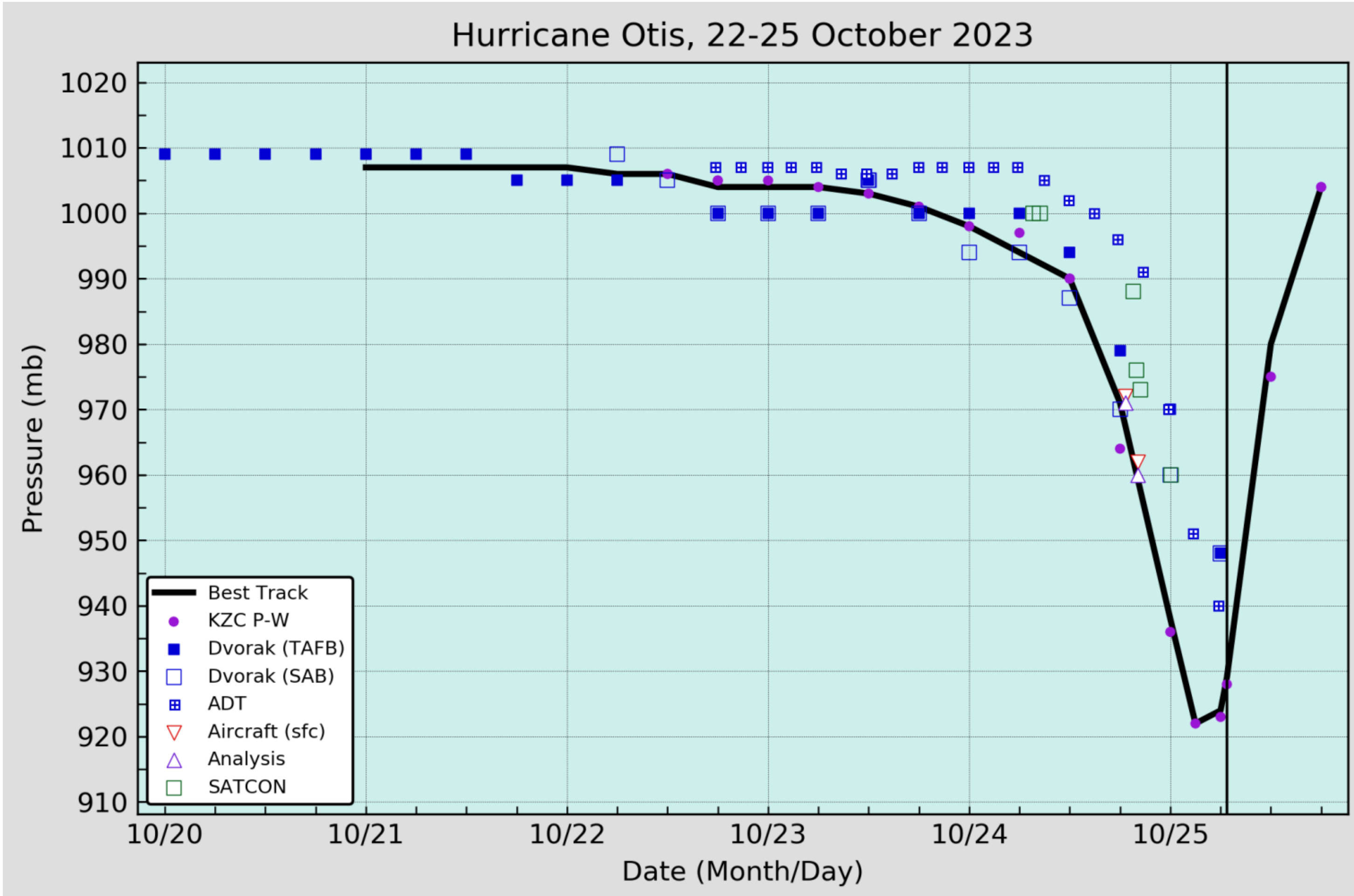

Figure 3. Selected pressure observations and best track minimum central pressure curve for Hurricane Otis, 22–25 October 2023. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney (KZC) pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC, and the solid vertical line corresponds to landfall.

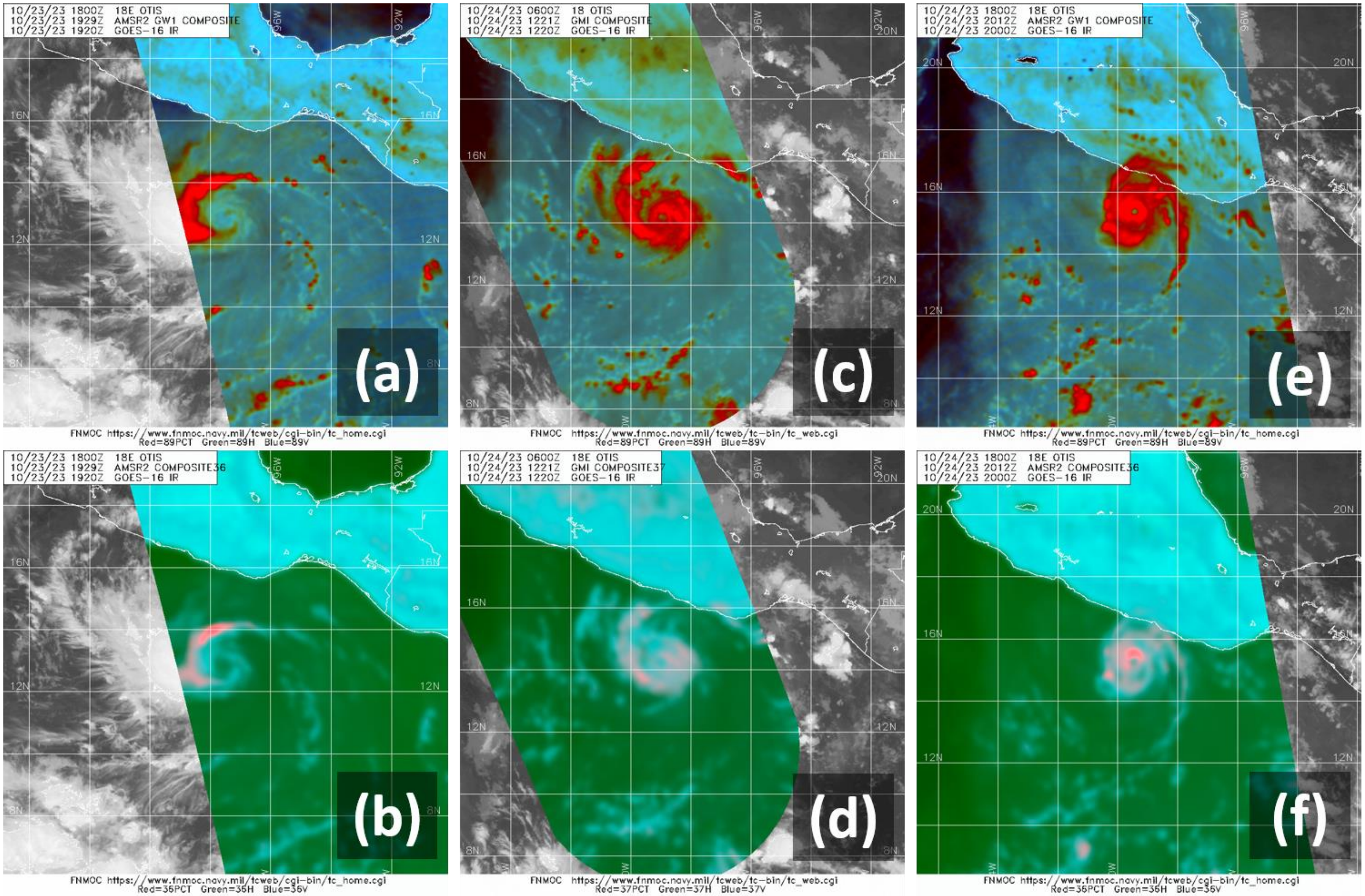

Figure 4. 89 GHz (top) and 37 GHz (bottom) color composite images during the rapid intensification of Otis. (a,b) AMSR-2 images from 1929 UTC 23 October showing a curved band over the western part of the exposed low-level circulation. (c,d) GMI images from 1221 UTC 24 October showing the appearance of a mid-level eye and an established inner core structure. (e,f) AMSR-2 images from 2012 UTC 24 October showing a symmetric eye surrounded by a well-defined central dense overcast.

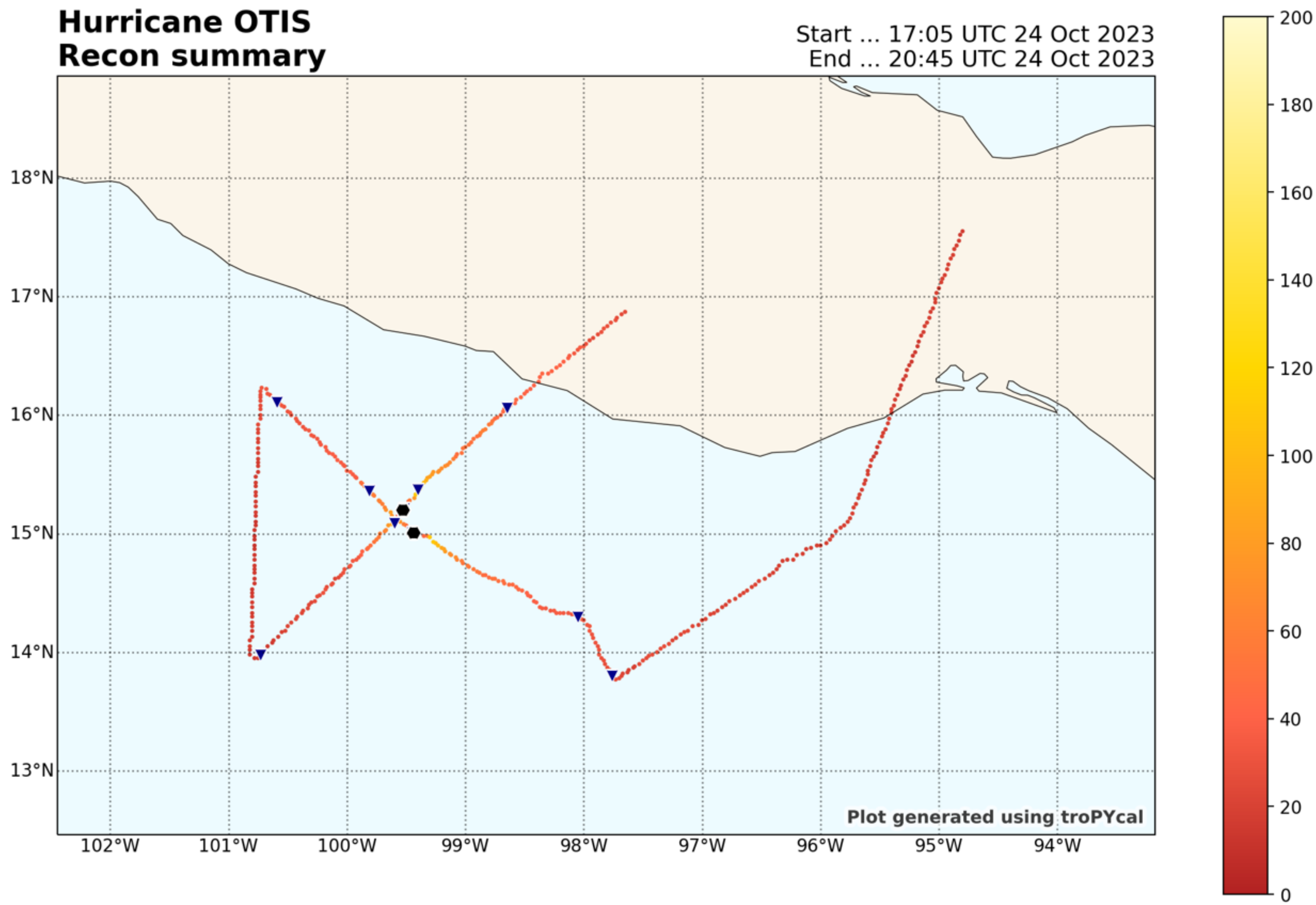

Figure 5. Air Force Reserve Hurricane Hunter aircraft flight tracks (colored lines) from a reconnaissance mission into Hurricane Otis on 24 October 2023. The black markers denote center fixes and the blue triangles indicate dropsonde locations. The color of the flight track represents the observed flight-level wind speed in knots at that location (see legend).

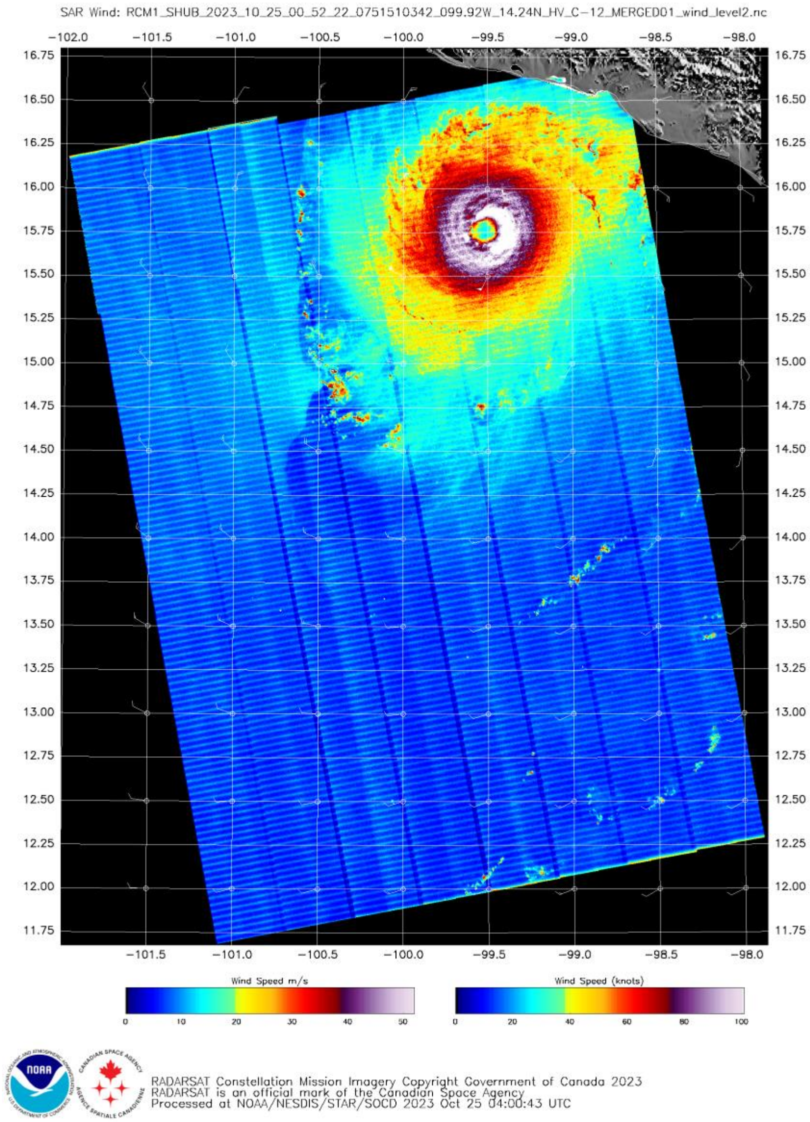

Figure 6. Synthetic Aperture Radar (SAR) pass over Hurricane Otis from the RCM-1 satellite at 0052 UTC 25 October. Image courtesy: NOAA/NESDIS/STAR.

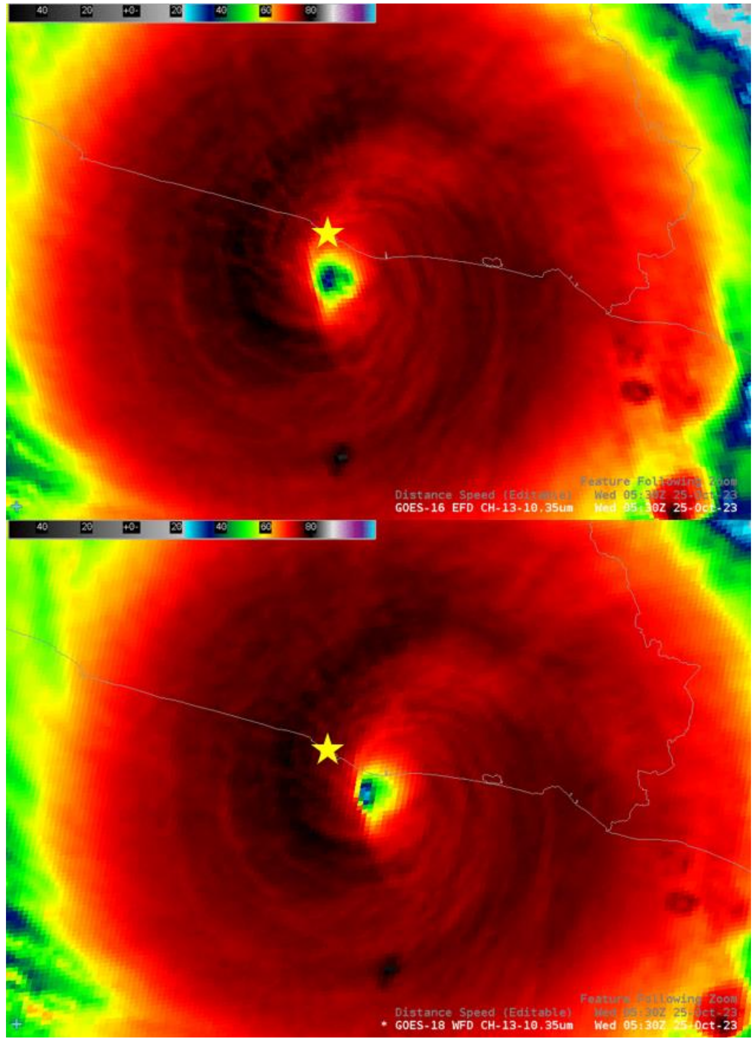

Figure 7. GOES-East (top) and GOES-West (bottom) images of Hurricane Otis at 0530 UTC 25 October 2023, shortly before landfall in Acapulco, Mexico. Note the displacement of the eye (parallax) due to the large viewing angles of the satellites. The gold star in each image denotes the location of Acapulco Bay. Image credit: Bill Line, NOAA/NESDIS/STAR. https://satelliteliaisonblog.com/2023/10/30/hurricane-otis-2023/

Figure 8. Damaged boats washed up along the shoreline in Acapulco, Mexico. Photo credit: David Guzman/EPA.

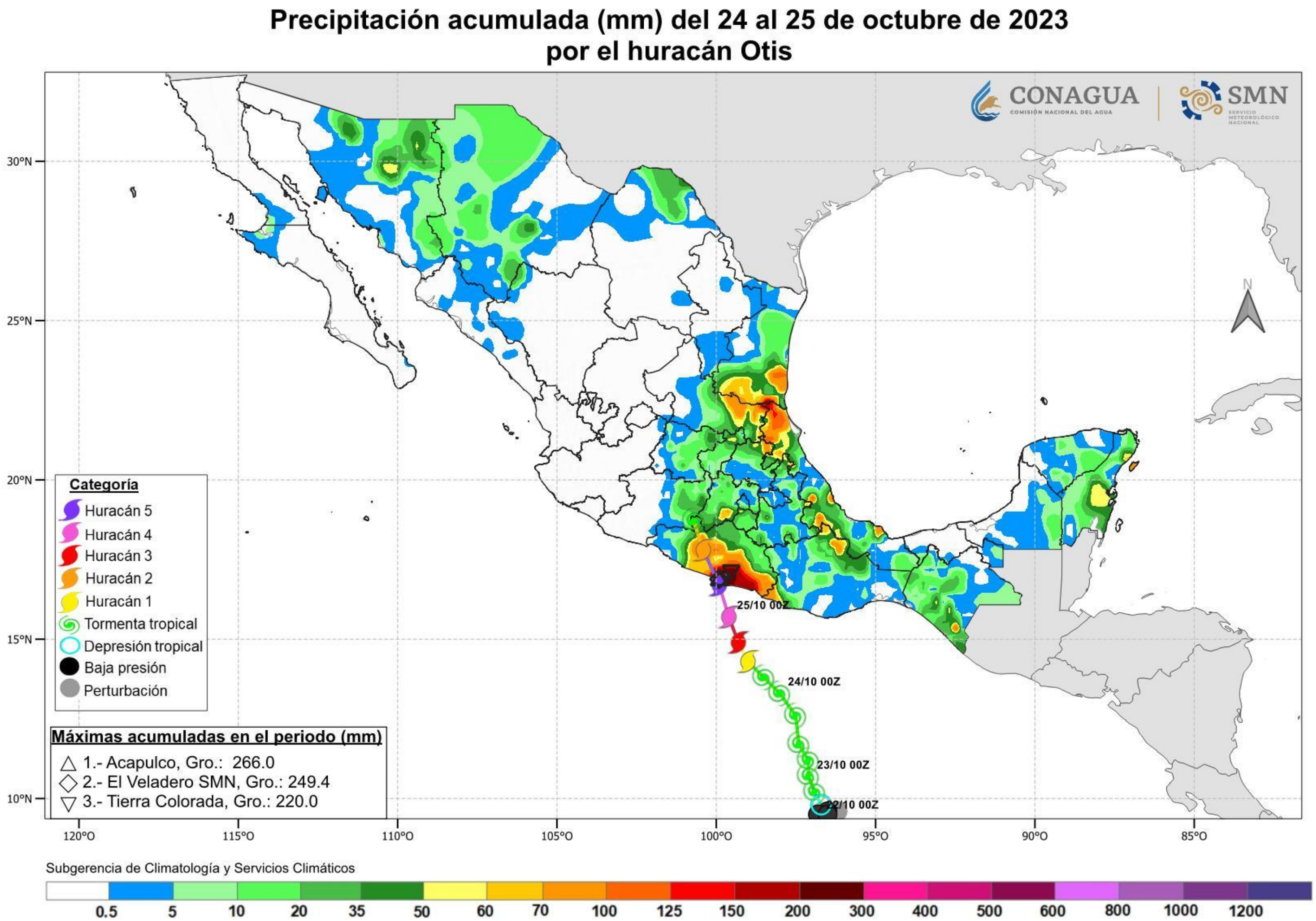

Figure 9. Rainfall accumulations (mm) in Mexico from 24–25 October 2023. Track and intensity are based on the operational NHC assessment. Not all of the rainfall depicted here is directly related to Otis. Image courtesy of CONAGUA and the National Meteorological Service of Mexico.

Figure 10. (Top left) Vehicles crossing a flooded road in Acapulco. Photo credit: Marco Ugarte/Associated Press. (Top right) Flooding in the municipality of Coyuca de Benitez. Photo credit: Marco Antonio Bravo Pineda. (Bottom left) Floodwaters from the Papagayo River cover the highway between Acapulco and Chilpancingo. Photo credit: Mexico Presidency via Reuters. (Bottom right) Damaged road from flooding in the Kilómetro 42 community between Acapulco and Xaltianguis. Photo credit: Rodrigo Oropeza/AFP/Getty Images.

Figure 11. Satellite images of Acapulco and the surrounding area before and after Hurricane Otis. (Left) Landsat 8 Operational Land Imager (OLI) image from 21 September 2023 prior to Otis. (Right) Landsat 9 OLI-2 image from 31 October 2023 after Otis' landfall. Note the brown landscape in the image on the right that indicates damage to trees and vegetation, and the discolored water in Laguna de Tres Palos from runoff of excess floodwaters. Image credit: Michala Garrison/NASA Earth Observatory, using Landsat data from the U.S. Geological Survey.

Figure 12. The extreme winds of Otis caused significant damage to high-rise buildings along the coast of Acapulco, Mexico. Photo credit: Rodrigo Oropeza, AFP/Getty Images.

Figure 13. (Top left) Strong winds downed trees, signs, and utility poles near the Acapulco International Airport. Photo credit: Felix Marquez/Associated Press. (Top right) An aerial view of hotel rooms in Acapulco destroyed by Otis. Photo credit: Luis Gutierrez/Norte Photo/Getty. (Bottom left) Damaged vehicles and debris in the Revolucion del Sur neighborhood near Acapulco. Photo credit: Victor Camacho/La Jornada. (Bottom right) Thick mud and debris cover a road in the Zapata neighborhood near Acapulco. Photo credit: James Fredrick.

Figure 14. Damaged and sunken boats near Manzanillo Beach in the western part of Acapulco Bay following the passage of Hurricane Otis. Photo credit: Quetzalli Nicte-Ha/Reuters.

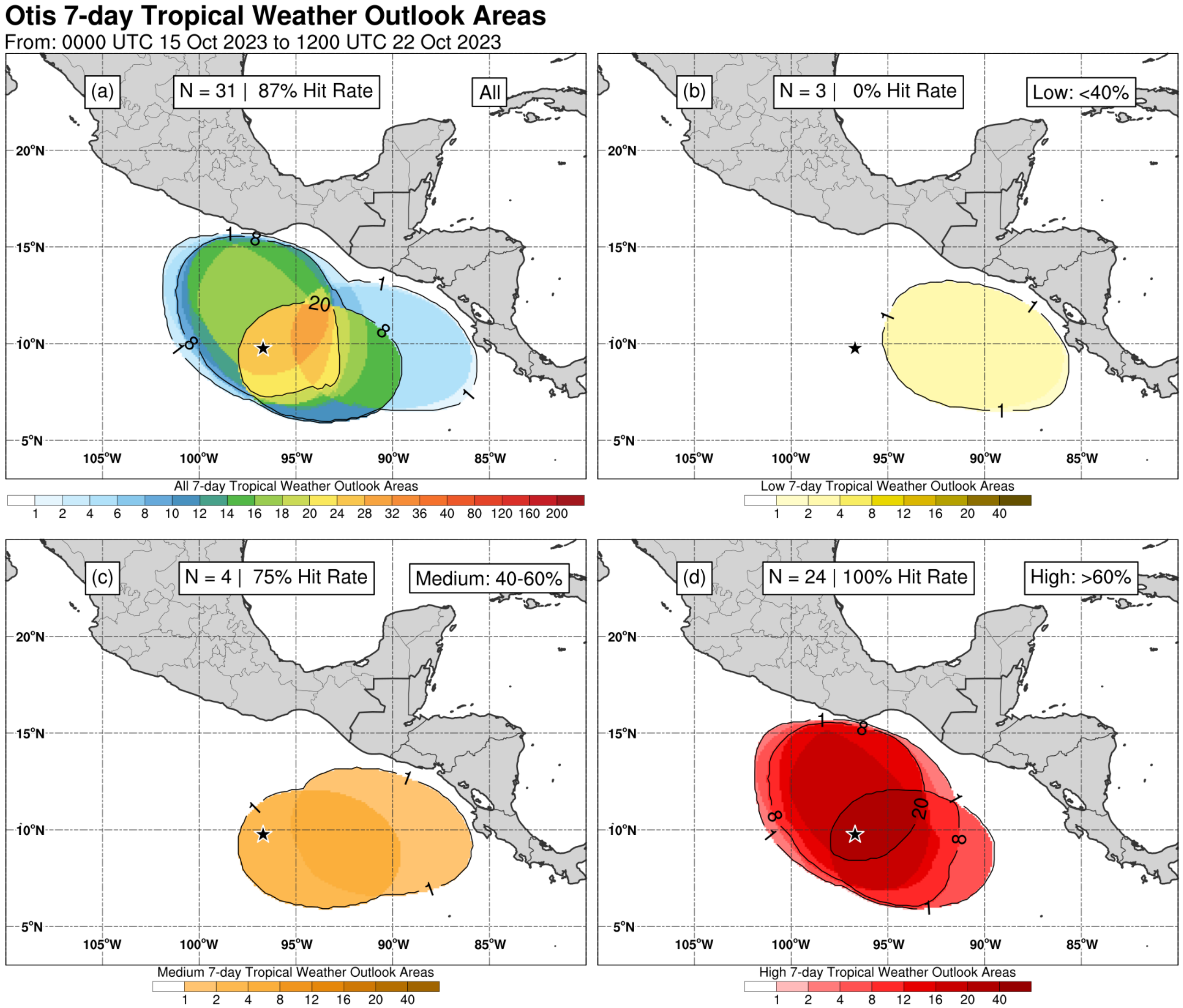

Figure 15. Composites of 7-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks prior to the formation of Otis for (a) all probabilistic genesis categories, (b) the low (<40%) category, (c) medium (40–60%) category, and (d) high (>60%) category. The location of genesis is indicated by the black star.

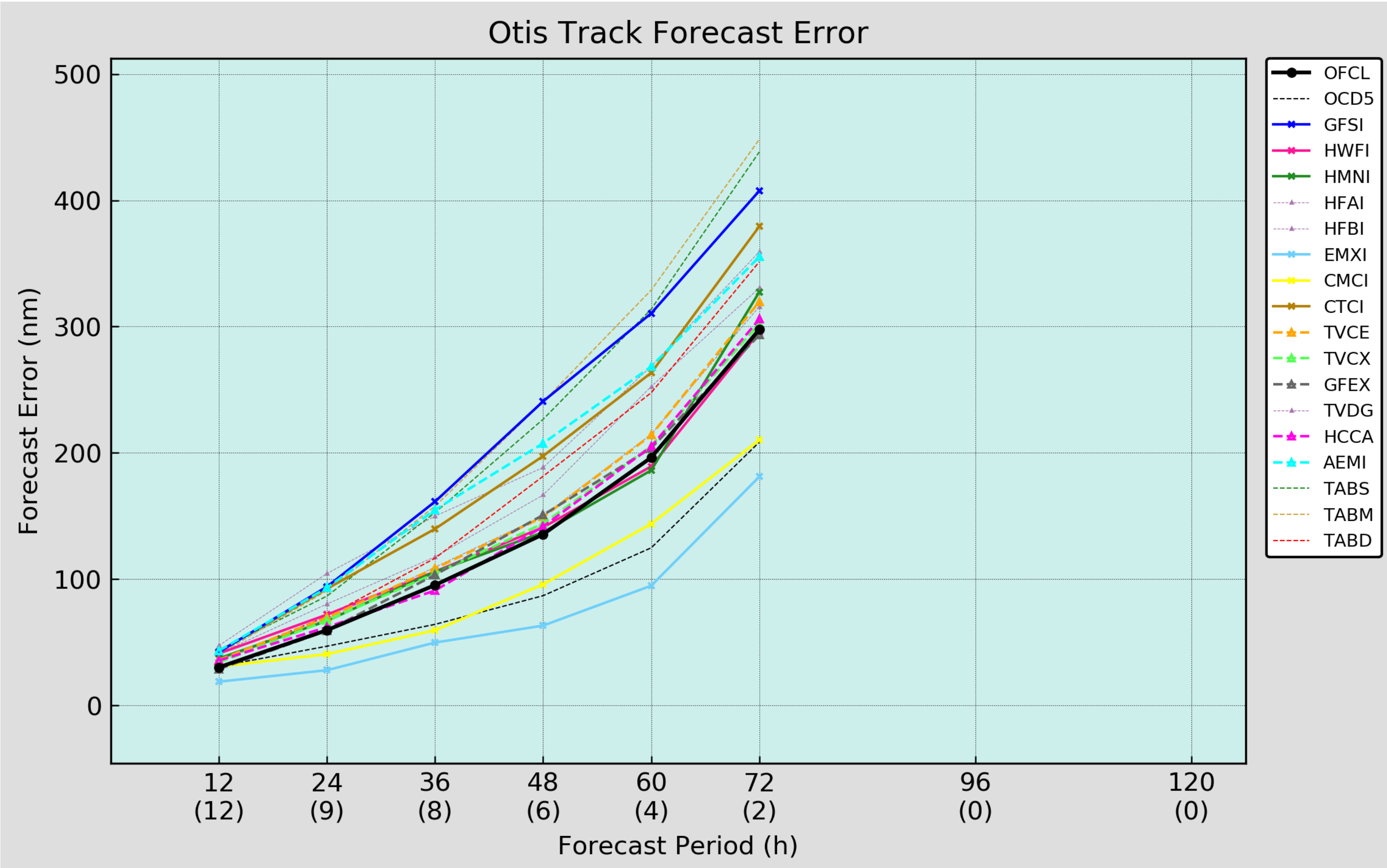

Figure 16. Homogenous comparison of NHC official track forecast errors (OFCL, black line) for Hurricane Otis to select models and consensus aids.

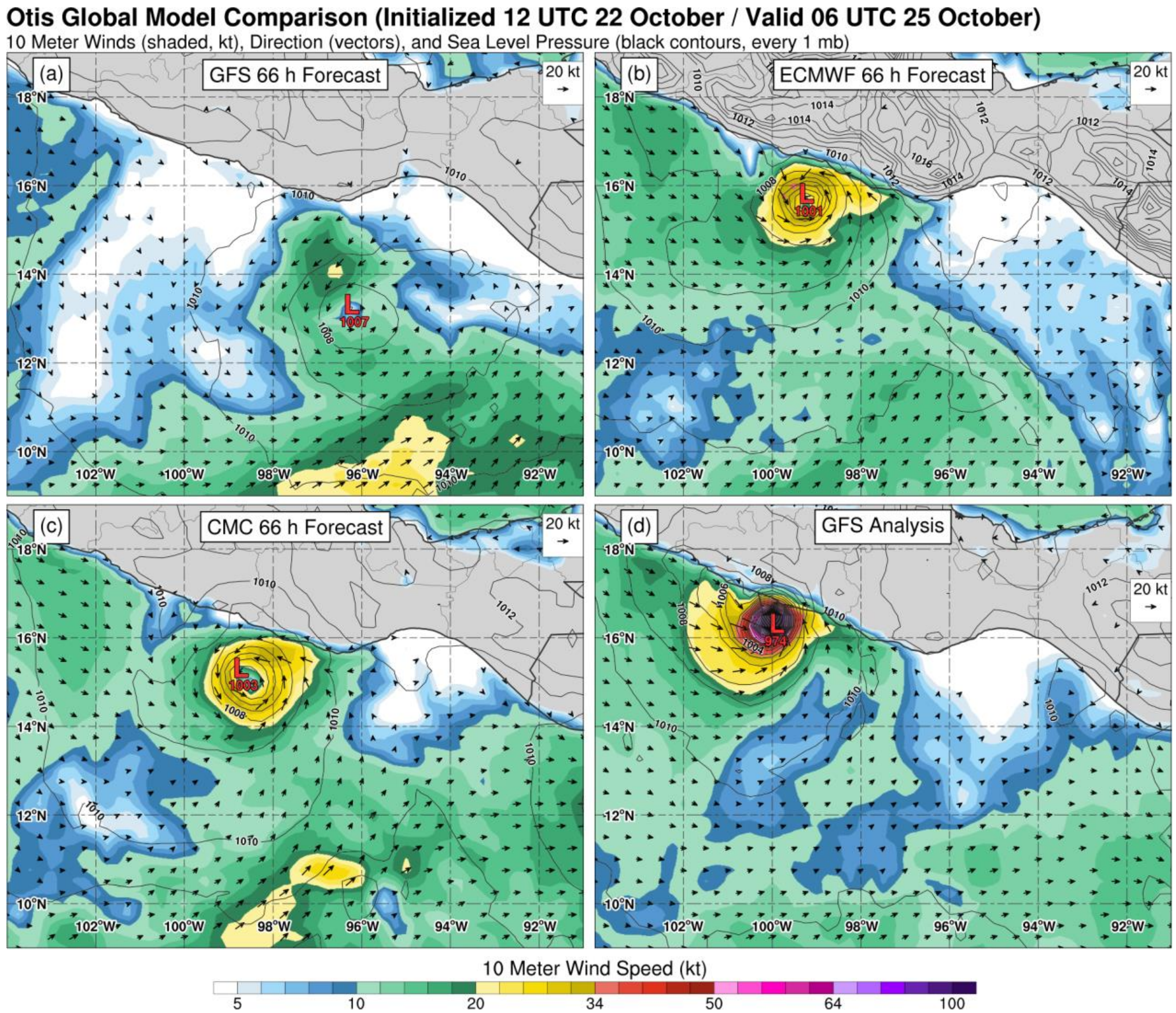

Figure 17. The 1200 UTC 22 October 2023 deterministic runs of the (a) GFS, (b) ECMWF, and (c) Canadian global models, all valid at forecast hour 66 (0600 UTC 25 October 2023), around the time that Otis made landfall in Acapulco. (d) GFS analysis valid at 0600 UTC 25 October 2023. The model fields depicted are mean sea level pressure (mb, black contours) and 10-m wind speed (kt, shaded) and direction (black vectors).

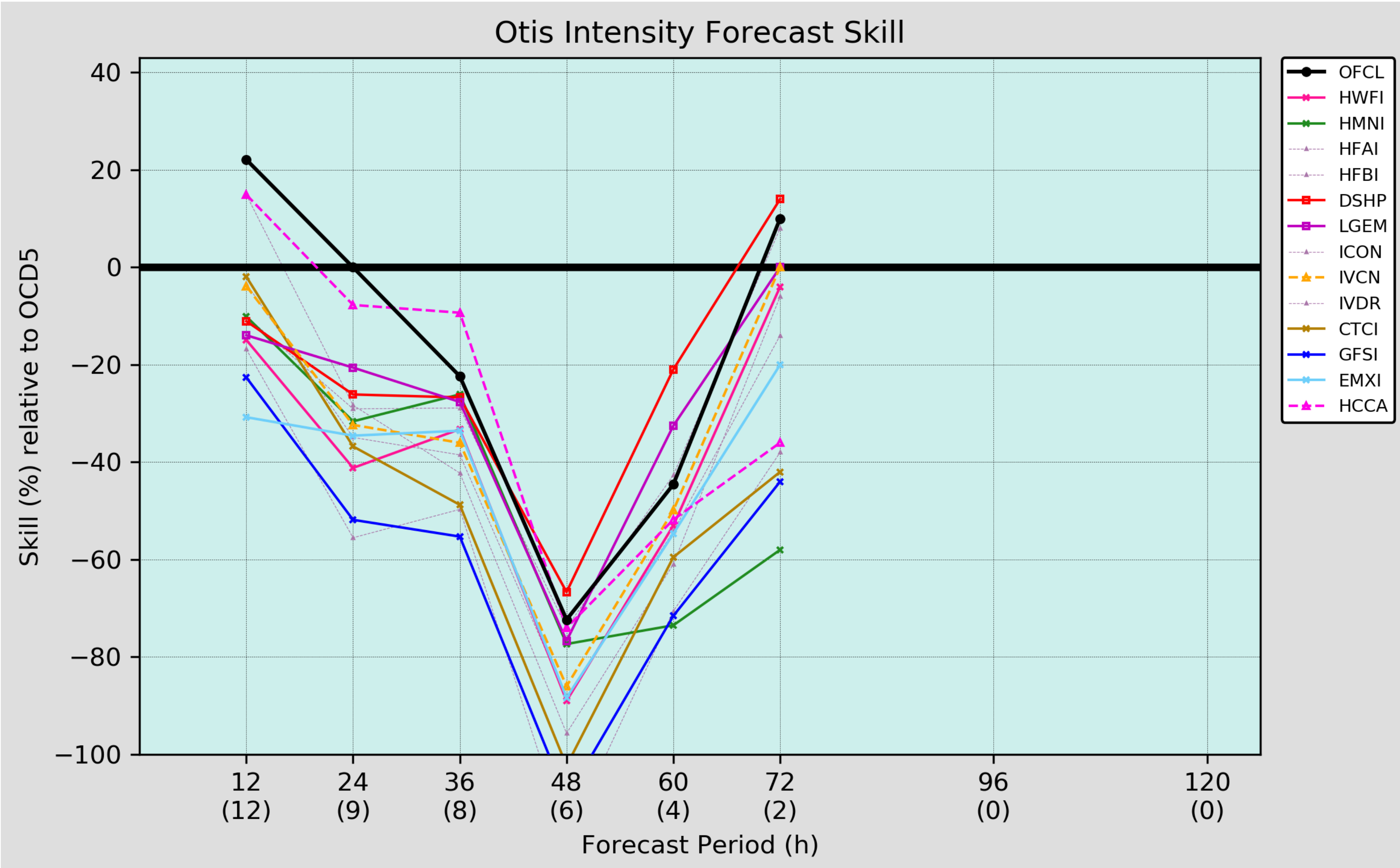

Figure 18. Homogenous comparison of NHC official intensity forecast skill (OFCL, black line) for Hurricane Otis to select models and consensus aids.

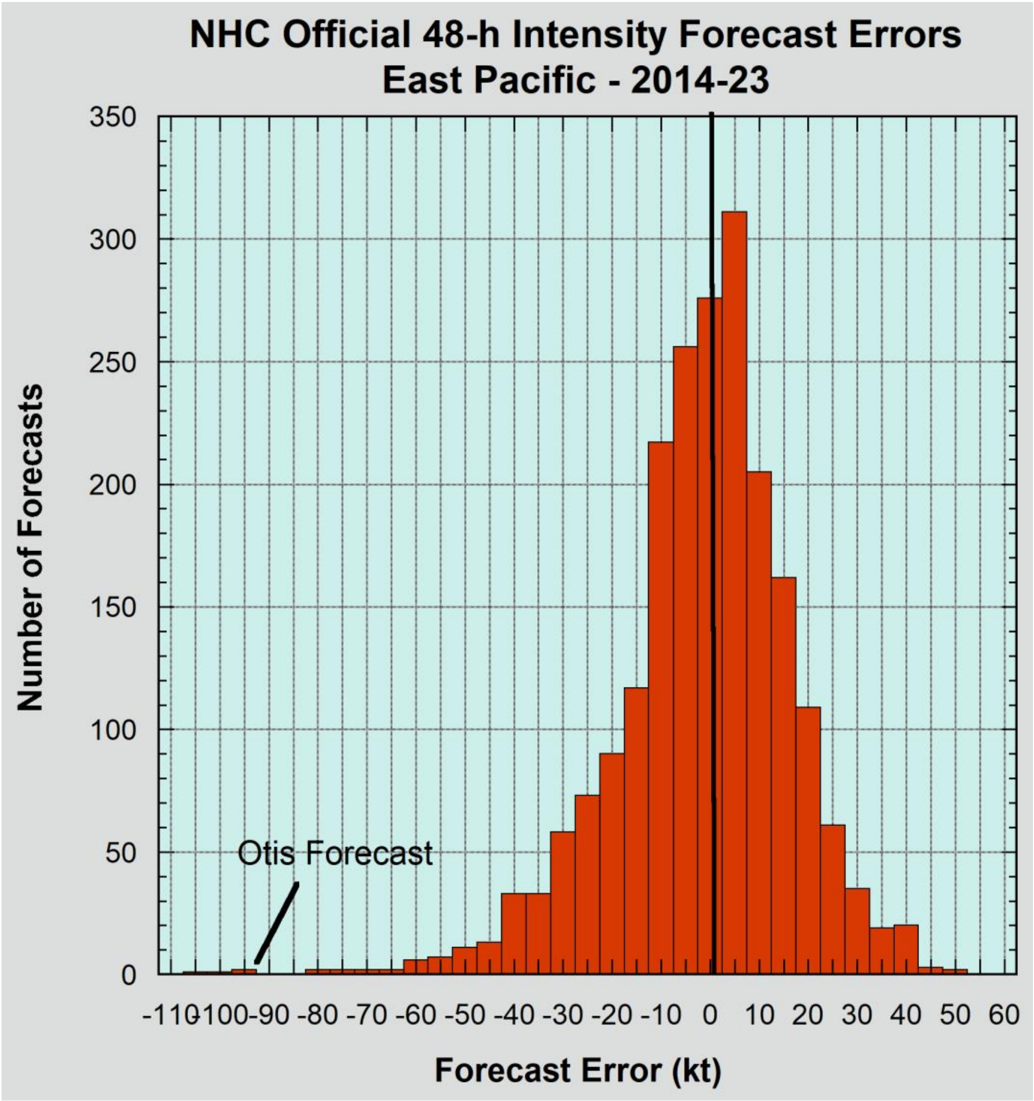

Figure 19. Distribution of NHC official 48-h intensity forecast errors in the eastern Pacific basin over the past 10 years (2014-2023).

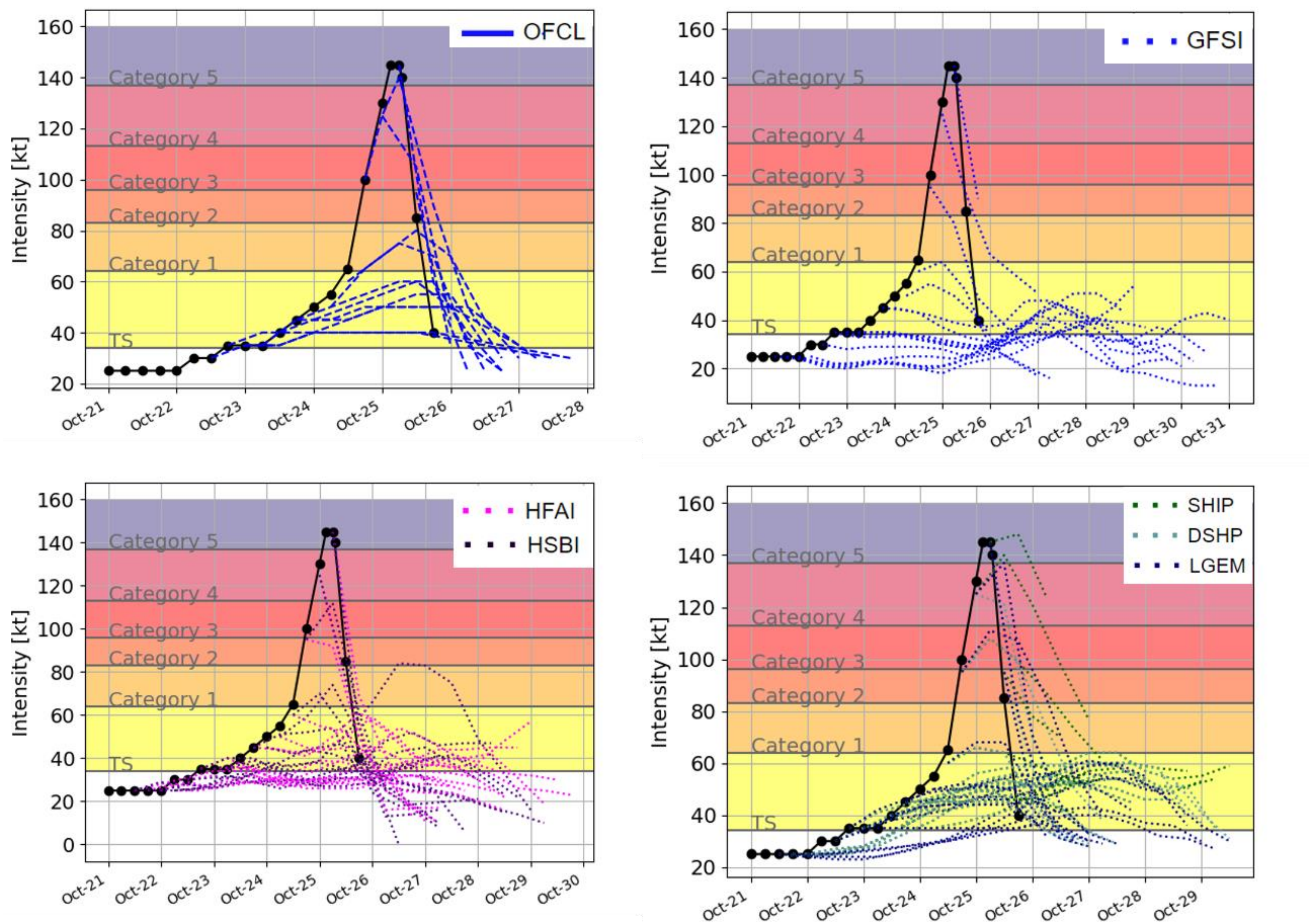

Figure 20. A comparison of NHC official intensity forecasts (top left) and various model forecasts to the final best track intensity of Otis, which is indicated by the solid black line and symbols at 6-h intervals.

SHIPS Matrix of RI probabilities

RI (kt / h)	20/12	25/24	30/24	35/24	40/24	45/36	55/48	65/72
SHIPS Consensus	5.6%	15.3%	10.3%	6.9%	5.0%	8.9%	6.9%	3.6%
SHIPS-RII	13.9%	33.9%	26.7%	18.8%	13.4%	25.7%	20.1%	10.3%
Logistic Regression	2.5%	8.8%	3.6%	1.9%	1.5%	0.8%	0.3%	0.4%
Bayesian	0.3%	3.1%	0.4%	0.1%	0.1%	0.3%	0.4%	0.0%
DTOPS	4.0%	4.0%	2.0%	4.0%	3.0%	1.0%	0.0%	0.0%

Figure 21. A matrix of SHIPS rapid intensification (RI) probabilities for Otis valid at 0600 UTC 24 October, just 24 h prior to its peak intensity as a category 5 hurricane. The color of each cell corresponds to the probability of a specific RI threshold being met, with warmer colors representing a higher probability of occurrence. Image courtesy: University of Wisconsin-Madison/CIMSS. https://tropic.ssec.wisc.edu/real-time/ai-ri/2023/ep182023_history.html