NATIONAL HURRICANE CENTER
TROPICAL CYCLONE REPORT

TROPICAL STORM MAX

(EP162023)

8 – 10 October 2023

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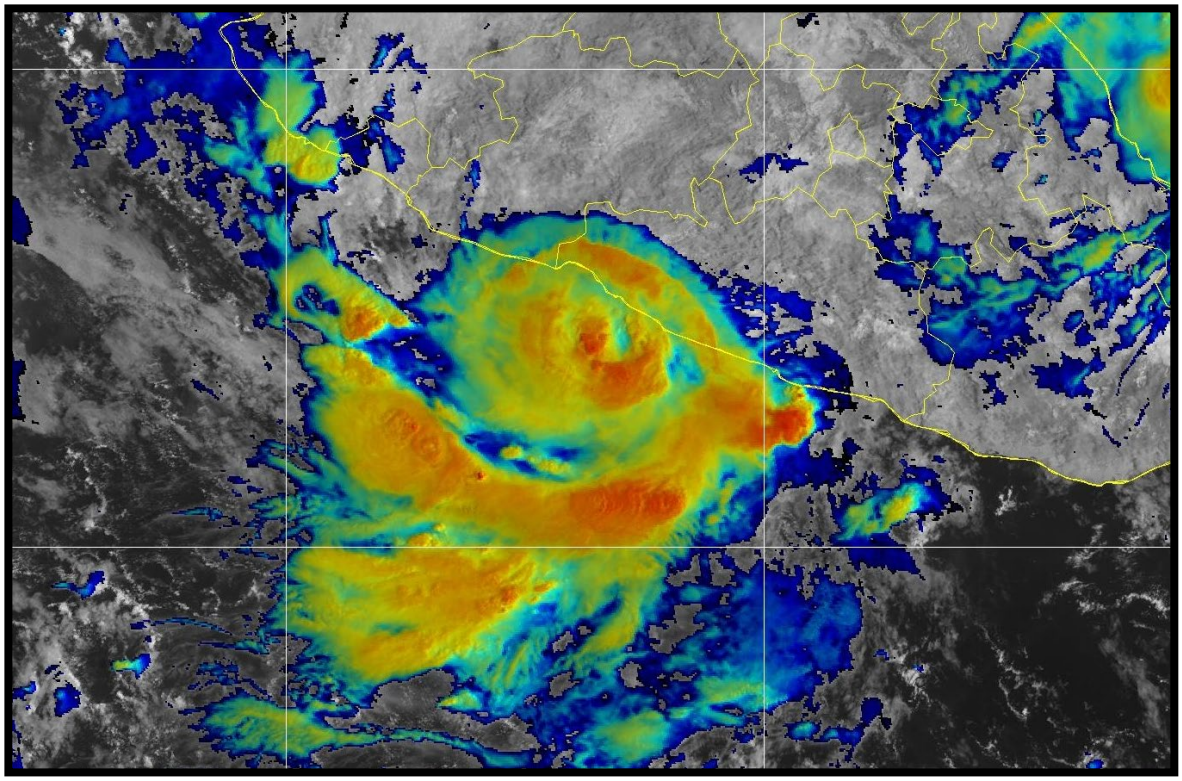

GOES-16 SANDWICH COMPOSITE IMAGE OF TROPICAL STORM MAX AT 1500 UTC 9 OCTOBER, ABOUT THREE HOURS BEFORE IT MADE LANDFALL ALONG THE COAST OF GUERRERO, MEXICO (IMAGE COURTESY OF NOAA/NESDIS/STAR)

Max was a small but strong tropical storm that made landfall near Puerto Vicente, Guerrero, Mexico. Max produced heavy rainfall and flooding across portions of southwestern Mexico, which was responsible for two fatalities.

Tropical Storm Max

8 – 10 OCTOBER 2023

SYNOPTIC HISTORY

Max's origin is not entirely clear, although it appears that a tropical wave which moved off the west coast of Africa on 19 and 20 September had some role. The wave moved westward over the central tropical Atlantic, with Tropical Storm Philippe forming along the northern portion of the wave on 23 September. A model analysis of mid-tropospheric vorticity and moisture suggests that the parent wave continued westward but became embedded within a drier air mass while moving across the Caribbean Sea (Fig. 1). The wave became diffuse on 1 and 2 October while moving across Central America, but vorticity increased beginning on 3 October over the far eastern Pacific basin. The disturbance continued slowly westward during the next few days, with a broad area of low pressure developing south of Mexico and deep convection gradually increasing in organization. A well-defined center of circulation developed on 8 October, and a tropical depression is estimated to have formed by 1800 UTC that day about 125 n mi south of Zihuatanejo, Mexico. The depression strengthened into a tropical storm 6 h later. The "best track" chart of Max's path is given in Fig. 2, with the wind and pressure histories shown in Figs. 3 and 4, respectively. The best track positions and intensities are listed in Table 1[1].

Max was initially located between a weak mid-tropospheric high centered over the Gulf of Mexico and Tropical Storm Lidia to its west. These steering features caused Max to move slowly northward toward the southwestern coast of Mexico. Max moved over warm sea surface temperatures around 30°C, and deep-layer easterly shear decreased from 20 kt to about 10 kt while the storm approached the coast. These conditions, along with Max's small size, allowed the storm to rapidly intensity from 30 kt to 60 kt over the 24-h period beginning at 1800 UTC 8 October, and both conventional (cover photo) and microwave (Fig. 5) satellite imagery suggested the development of a formative eye during the morning of 9 October. Max's strengthening was likely only halted by the center making landfall near Puerto Vicente, Guerrero, Mexico, around 1800 UTC that day. The storm weakened rapidly over the mountainous terrain of Mexico after landfall, and it is estimated to have dissipated by 0600 UTC 10 October.

METEOROLOGICAL STATISTICS

Observations in Max (Figs. 3 and 4) include subjective satellite-based Dvorak technique intensity estimates from the Tropical Analysis and Forecast Branch (TAFB) and Satellite Analysis Branch (SAB), and objective Advanced Dvorak Technique (ADT) estimates and Satellite

[1] 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.

Consensus (SATCON) estimates from the Cooperative Institute for Meteorological Satellite Studies/University of Wisconsin-Madison. 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 Max.

There were no ship reports of winds of tropical storm force associated with Max while it was a tropical cyclone. The bulk carrier *Bonny Island* (VRMC7) reported winds as high as 42 kt early on 8 October before Max became a tropical cyclone, but it is likely that the ship's anemometer is higher than the standard 10-m observing height above the sea surface.

Winds and Pressure

Max's estimated peak and landfall intensity of 60 kt at 1800 UTC 9 October is based primarily on subjective satellite intensity estimates, and supported by Ultra High Resolution (UHR) ASCAT and Synthetic Aperture Radar (SAR) data. SAB provided a Dvorak estimate of T3.5/55 kt at 1200 UTC 9 October before Max made landfall. TAFB operationally provided an estimate of T3.0/50 kt at 1800 UTC, although a second TAFB analyst conducting a post-evaluation of Dvorak classifications later provided an estimate of T3.5/55 kt. An analysis of UHR ASCAT data from 1612 UTC (Fig. 6a) by the NOAA/NESDIS Center for Satellite Applications and Research (STAR) yielded a peak wind estimate of 60-65 kt, and a partial SAR pass at 1235 UTC (Fig. 6b) also suggested maximum winds of 60-65 kt. Although UHR ASCAT and SAR are still being evaluated for their utility in estimating peak winds in a tropical cyclone (and thus are not depicted in Fig. 3), the general agreement of these two instruments in this case affords some degree of confidence in their validity. Based on a blend of these data, and considering the primitive eye that Max developed that day, the estimated peak intensity is 60 kt.

Max's estimated minimum and landfall pressure of 990 mb is based on the Knaff-Zehr-Courtney (KZC) pressure-wind relationship.

Max was a small tropical storm, with sustained tropical-storm-force winds only extending about 50 n mi away from the center and an estimated radius of maximum winds of 10 n mi at landfall. Therefore, only a small area in western Guerrero, Mexico, is estimated to have been affected by tropical-storm-force winds. The only report of strong winds was from an automated Mexican navy station at Puerto Vicente, which measured sustained winds of 35 kt with a gust to 63 kt around the time of Max's landfall. The lowest sea level pressure measured by the station was 997.0 mb at 1745 UTC.

Rainfall and Flooding

Over the two-day period from 8 to 9 October, Max produced at least 8 inches (200 mm) of rain over a localized portion of the central coast of the state of Guerrero, northwest of Acapulco (Fig. 7). The highest rainfall totals reported were 12.29 inches (312.2 mm) at San Jerónimo, 11.81 inches (300.0 mm) at Laguna de Coyuca, and 11.73 inches (298.0 mm) at Atoyac.

CASUALTY AND DAMAGE STATISTICS

Max caused two direct deaths[2] by drowning in the Mexican state of Guerrero. One death occurred in Nuxco when a man was swept away by a river while working on his farm. A second death occurred when a public transport van plunged into a sinkhole near the Cuajilote Bridge on the Acapulco-Zihuatanejo Highway, and a man inside the vehicle drowned. Two other people in the van were rescued alive. Two people were also rescued by helicopter after being trapped in a tree for about 10 hours due to flooding of the Técpan River.[3]

Media reports indicate that Max flooded over 90 homes and downed many trees in Guerrero, and the National Coordinator of Civil Protection issued an emergency declaration for the municipalities of Benito Juárez, Atoyac de Álvarez, Tecpan de Galeana, and Coyuca de Benítez. Many communities affected by Max were later devastated by Hurricane Otis later in October.[4] No total damage estimates are available as of this writing.

FORECAST AND WARNING CRITIQUE

The timing of Max's genesis was very well predicted. Table 2 provides the number of hours in advance of formation with the first NHC Tropical Weather Outlook (TWO) forecast in each likelihood category. A low (<40%) chance of genesis during the next 7 days was first indicated in the TWO exactly 7 days (168 h) before Max formed, and chances were raised to the medium (40–60%) category 156 h before formation and to the high (>60%) category 144 h before formation. For the 2-day forecast period, the precursor disturbance was given a low chance of genesis 108 h before formation, and the chances were raised to the medium and high categories 78 and 42 h, respectively, before genesis. NHC's forecast for the location of genesis was a little less accurate, however, and Max's formation location only fell within 77% of the genesis areas depicted in the Graphical TWO (Fig. 8). Figure 8 shows that the first several genesis areas depicted by NHC (particularly the low and medium 7-day forecasts) were too far east.

A verification of 12- and 24-h NHC official track forecasts for Max is given in Table 3a. Official track forecast errors were near or slightly above the mean official errors for the previous 5-year period. Climatology-persistence (OCD5) errors were higher than their respective 5-year means at all forecast times, suggesting that Max's track was a bit more atypical than for most eastern Pacific tropical cyclones.

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[2] 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.

[3] Tropical Storm Max leaves 2 dead, homes damaged in Guerrero. *Mexico News Daily*. 10 October 2023. https://mexiconewsdaily.com/news/tropical-storm-max-leaves-2-dead-homes-damaged-in-guerrero/

[4] Dorantes, Jesús. Comunidades de Guerrero golpeadas primero por Max y luego por Otis piden apoyo. Uno TV. 10 November 2023. https://www.unotv.com/estados/guerrero/afectados-por-max-y-otis-en-guerrero-piden-ayuda/

A homogeneous comparison of the official track errors with selected guidance models is given in Table 3b. A meaningful comparison of errors is not possible due to the small number of forecasts, and the UKMET (EGRI), NAVGEM (NVGI), and Florida State Superensemble (FSSE) were not included in the verification since they were not available for a sufficient number of forecast cycles. That said, the official track forecasts generally performed better than the global models but had higher errors than some of the consensus aids. The HFIP Corrected Consensus (HCCA) and the simple Trajectory and Beta Models (TABD, TABM, and TABS) had lower errors than the NHC forecasts at both 12 and 24 h.

A verification of 12- and 24-h NHC official intensity forecasts for Max is given in Table 4a. Official intensity errors were higher than the mean official errors for the previous 5-year period. OCD5 errors were higher than their respective 5-year means, indicating that Max's intensity was more difficult than usual to forecast. In particular, the short-duration rapid intensification event was not anticipated, and peak intensity forecasts were generally 10–15 kt too low.

A homogeneous comparison of the official intensity errors with selected guidance models is given in Table 4b. A comprehensive comparison of errors is not possible due to the small number of forecasts, and the FSSE was not included in the verification since it was not available for a sufficient number of forecast cycles. Despite not anticipating rapid intensification, the official intensity forecasts were quite skillful and had lower errors than every model and consensus aid at both 12 and 24 h. In fact, whereas the official forecasts indicated that Max would strengthen (Fig. 9a), many of the guidance aids showed nearly immediate weakening at every forecast cycle (Figs. 9b and 9c). HCCA was the best-performing intensity guidance and did indicate that Max had the potential to intensify (magenta lines, Fig. 9c).

Coastal watches and warnings issued by the government of Mexico in association with Max are given in Table 5. Max posed a risk of tropical-storm-force winds along the coast of Mexico before it became a tropical cyclone. Therefore, NHC initiated Potential Tropical Cyclone Advisories at 0300 UTC 8 October to issue a tropical storm watch, 15 h before the system became a tropical cyclone.

ACKNOWLEDGMENTS

Rainfall data in Fig. 7 were provided by CONAGUA, the national meteorological service of Mexico. Zorana Jelenak, Suebson Soisuvarn, Suleiman Alsweiss, and Paul Chang from the NOAA/NESDIS Center for Satellite Applications and Research (STAR) are thanked for their analysis of the Ultra High-Resolution (UHR) ASCAT data.

Table 1. Best track for Tropical Storm Max, 8–10 October 2023.

Date/Time (UTC)	Latitude (°N)	Longitude (°W)	Pressure (mb)	Wind Speed (kt)	Stage
08 / 0000	13.8	99.9	1007	25	disturbance
08 / 0600	14.3	100.6	1007	25	"
08 / 1200	14.9	101.2	1006	30	"
08 / 1800	15.5	101.5	1005	30	tropical depression
09 / 0000	16.1	101.6	1001	40	tropical storm
09 / 0600	16.5	101.5	997	50	"
09 / 1200	16.9	101.3	994	55	"
09 / 1800	17.3	101.1	990	60	"
10 / 0000	17.9	100.8	1000	35	"
10 / 0600					dissipated
09 / 1800	17.3	101.1	990	60	minimum pressure and maximum winds
09 / 1800	17.3	101.1	990	60	landfall near Puerto Vicente, Guerrero, Mexico

Table 2. Number of hours in advance of formation 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	**120-Hour Outlook**
Low (<40%)	108	168
Medium (40%-60%)	78	156
High (>60%)	42	144

Table 3a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) track forecast errors (n mi) for Tropical Storm Max, 8–10 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	23.0	49.0						
OCD5	42.4	110.1						
Forecasts	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 3b. Homogeneous comparison of selected track forecast guidance models (in n mi) for Tropical Storm Max, 8–10 October 2023. Errors smaller than the NHC official forecast are shown in boldface type.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	23.0	49.0						
OCD5	42.4	110.1						
GFSI	32.0	52.2						
EMXI	26.7	61.3						
CMCI	46.3	101.4						
HWFI	29.3	66.3						
HMNI	**21.3**	51.4						
HFAI	41.2	60.8						
HFBI	37.4	**48.4**						
CTCI	26.9	**36.2**						
HCCA	**18.2**	**37.7**						
AEMI	28.1	**33.4**						
GFEX	**22.7**	54.5						
TVCE	26.2	51.8						
TVCX	23.9	51.8						
TVDG	24.5	54.7						
TABD	**17.9**	**10.8**						
TABM	**17.4**	**34.8**						
TABS	**12.5**	**31.8**						
Forecasts	4	2						

Table 4a. NHC official (OFCL) and climatology-persistence skill baseline (OCD5) intensity forecast errors (kt) for Tropical Storm Max, 8–10 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	8.8	10.0						
OCD5	13.8	14.0						
Forecasts	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 4b. Homogeneous comparison of selected intensity forecast guidance models (in kt) for Tropical Storm Max, 8–10 October 2023. Errors smaller than the NHC official forecast are shown in boldface type.

Model ID	Forecast Period (h)							
	12	24	36	48	60	72	96	120
OFCL	8.8	10.0						
OCD5	13.8	14.0						
HWFI	18.5	23.5						
HMNI	16.5	22.5						
HFAI	19.0	26.5						
HFBI	19.0	27.0						
CTCI	19.5	27.0						
DSHP	15.0	16.5						
LGEM	13.2	15.0						
ICON	14.5	19.0						
IVCN	16.2	22.5						
IVDR	17.0	24.0						
HCCA	10.5	11.0						
GFSI	19.5	36.0						
EMXI	11.2	11.5						
Forecasts	4	2						

Table 5. Watch and warning summary along the Pacific coast of Mexico for Tropical Storm Max, 8–10 October 2023.

Date/Time (UTC)	Action	Location
8 / 0300	Tropical Storm Watch issued	Acapulco to Punta San Telmo
8 / 1500	Tropical Storm Warning issued	Acapulco to Punta San Telmo
9 / 2100	Tropical Storm Warning modified to	Acapulco to Lazaro Cardenas
10 / 0300	Tropical Storm Warning discontinued	All

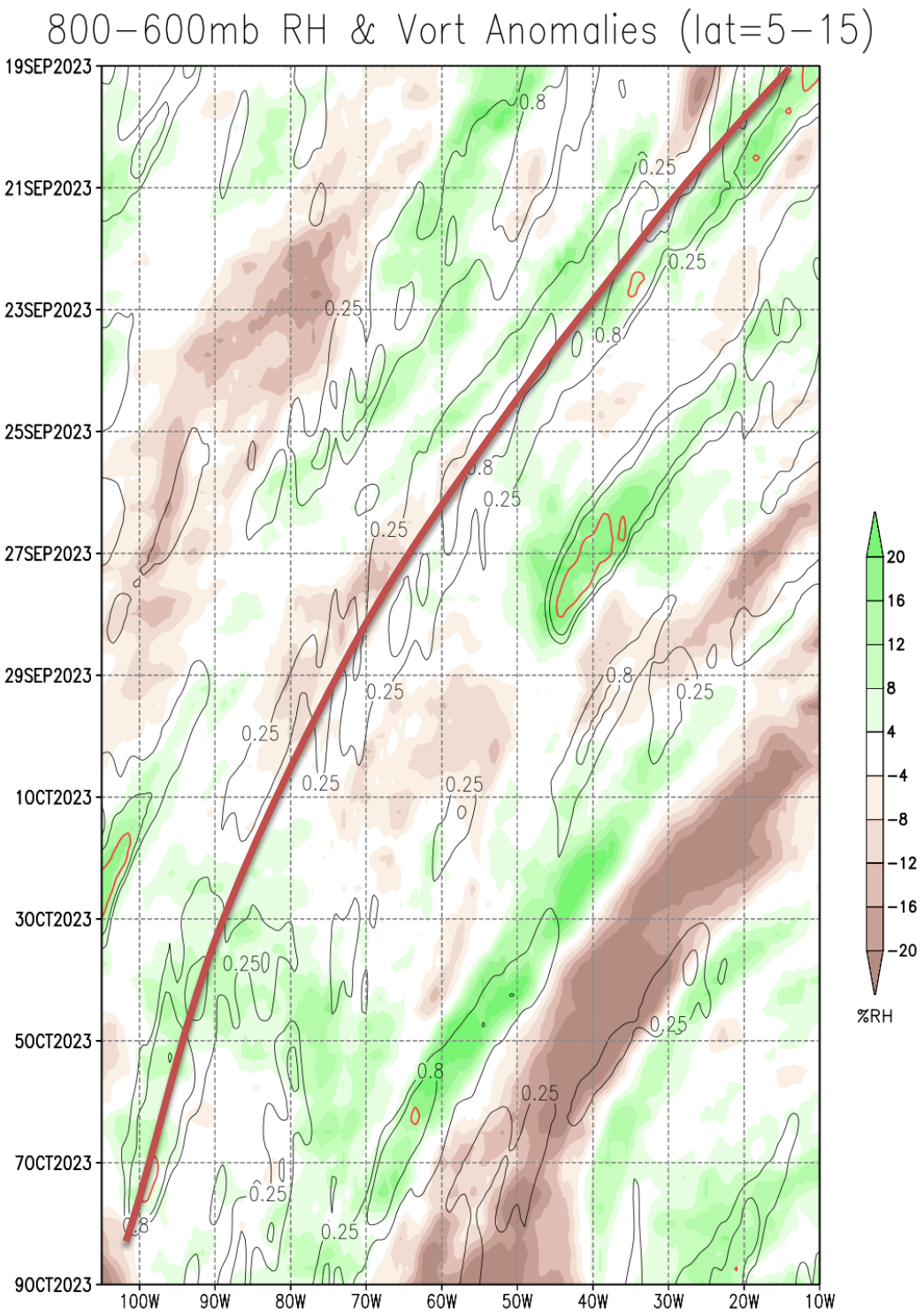

Figure 1. Hovmöller diagram of 800-600-mb relative humidity anomalies (percent, shaded) and relative vorticity anomalies (× 10^{-5} s^{-1}, contours) based on GFS analyses, averaged between 5°N and 15°N from 19 September through 9 October 2023. The solid red line denotes the tropical wave that contributed to the formation of Max.

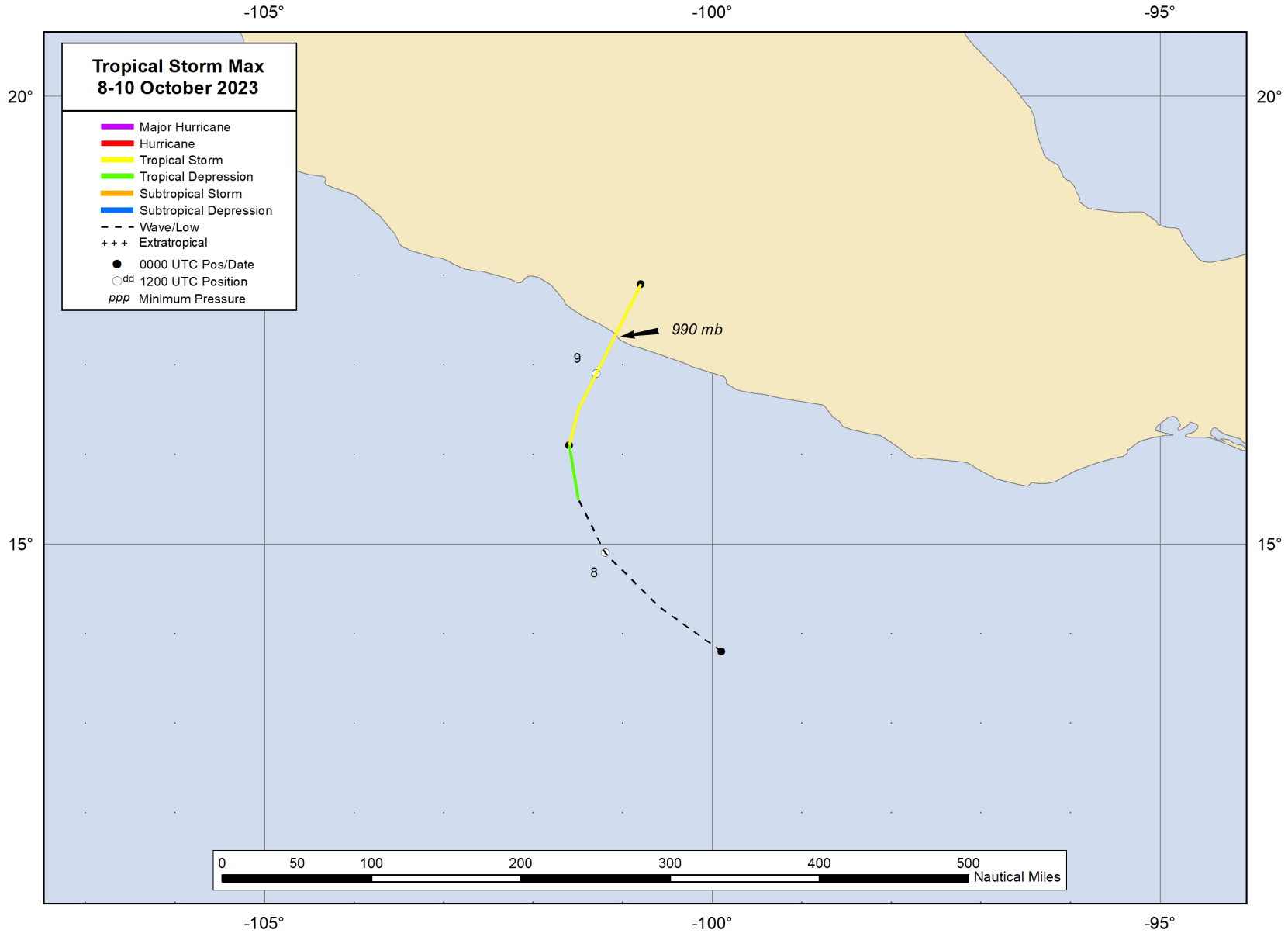

Figure 2. Best track positions for Tropical Storm Max, 8–10 October 2023.

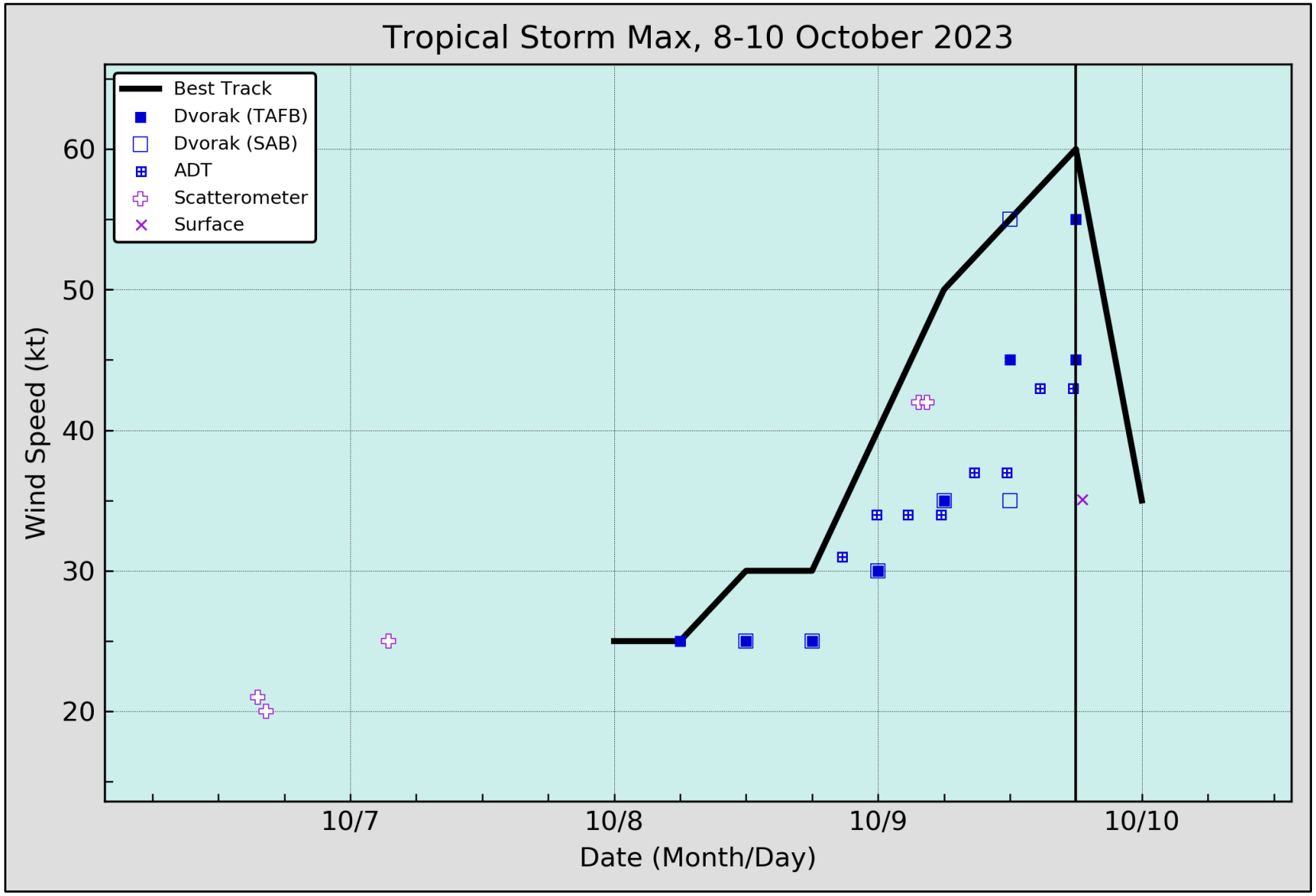

Figure 3. Selected wind observations and best track maximum sustained surface wind speed curve for Tropical Storm Max, 8–10 October 2023. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. Dashed vertical lines correspond to 0000 UTC, and the solid vertical line corresponds to landfall.

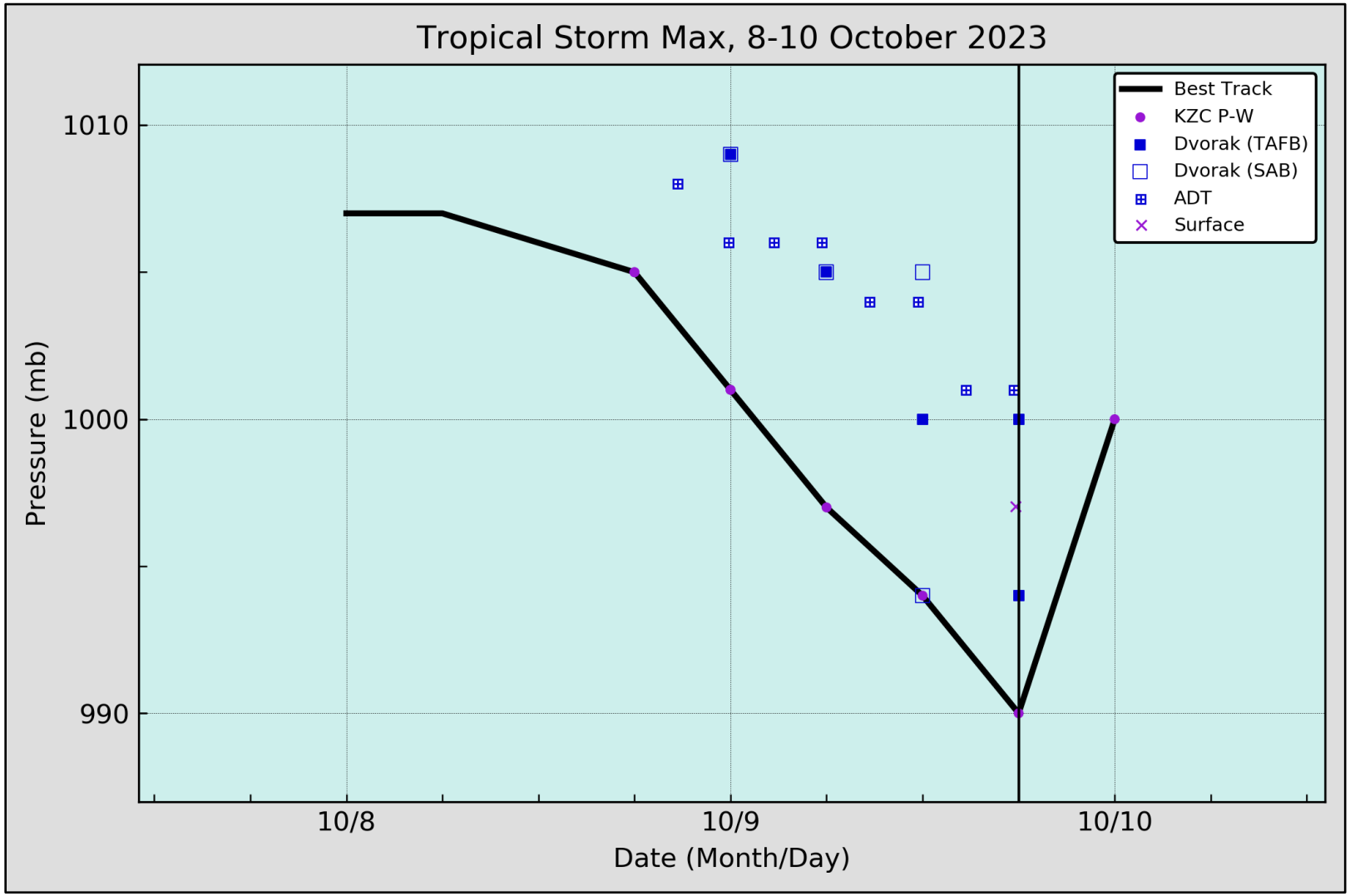

Figure 4. Selected pressure observations and best track minimum central pressure curve for Tropical Storm Max, 8–10 October 2023. Advanced Dvorak Technique estimates represent the Current Intensity at the nominal observation time. SATCON intensity estimates are from the Cooperative Institute for Meteorological Satellite Studies. KZC P-W refers to pressure estimates derived using the Knaff-Zehr-Courtney pressure-wind relationship. Dashed vertical lines correspond to 0000 UTC, and the solid vertical line corresponds to landfall.

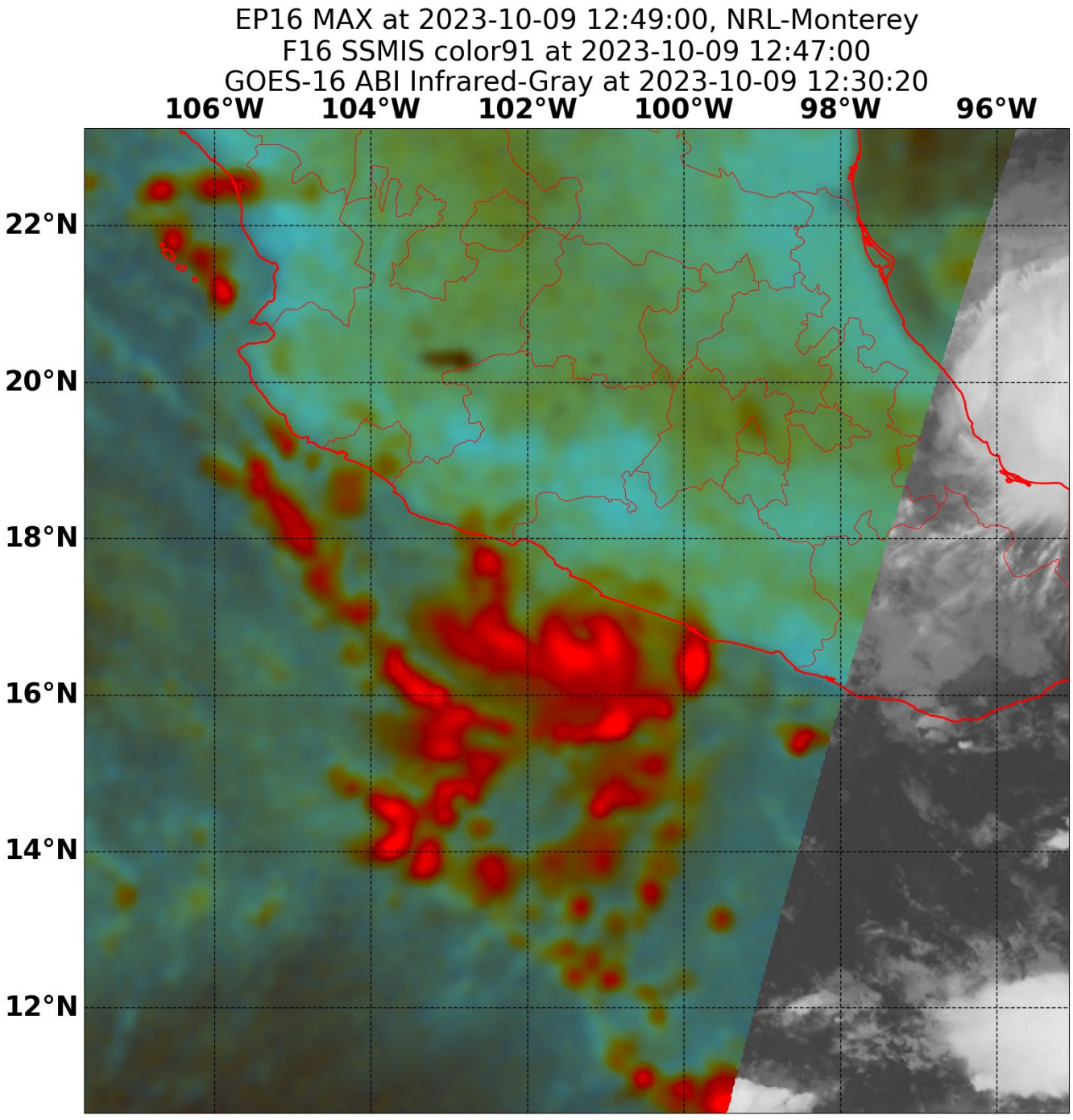

Figure 5. 91-GHz SSMIS microwave image of Tropical Storm Max at 1247 UTC 9 October, showing the development of a formative mid-level eye. Image courtesy of the Naval Research Laboratory.

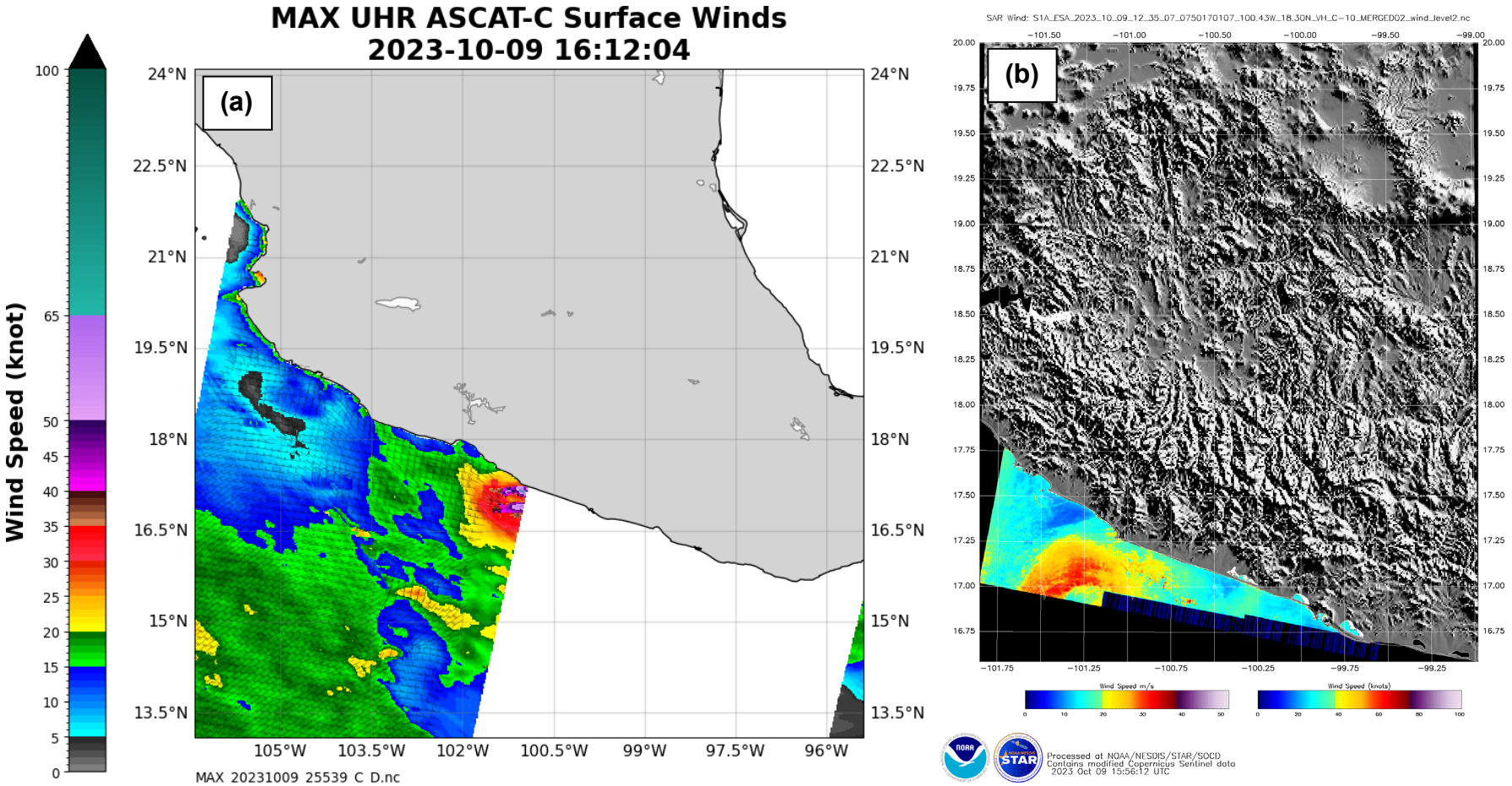

Figure 6. (a) Ultra High Resolution (UHR) ASCAT pass over Tropical Storm Max at 1612 UTC 9 October and (b) partial Synthetic Aperture Radar (SAR) pass at 1235 UTC 9 October. Images courtesy of the Naval Research Laboratory and NOAA/NESDIS/STAR.

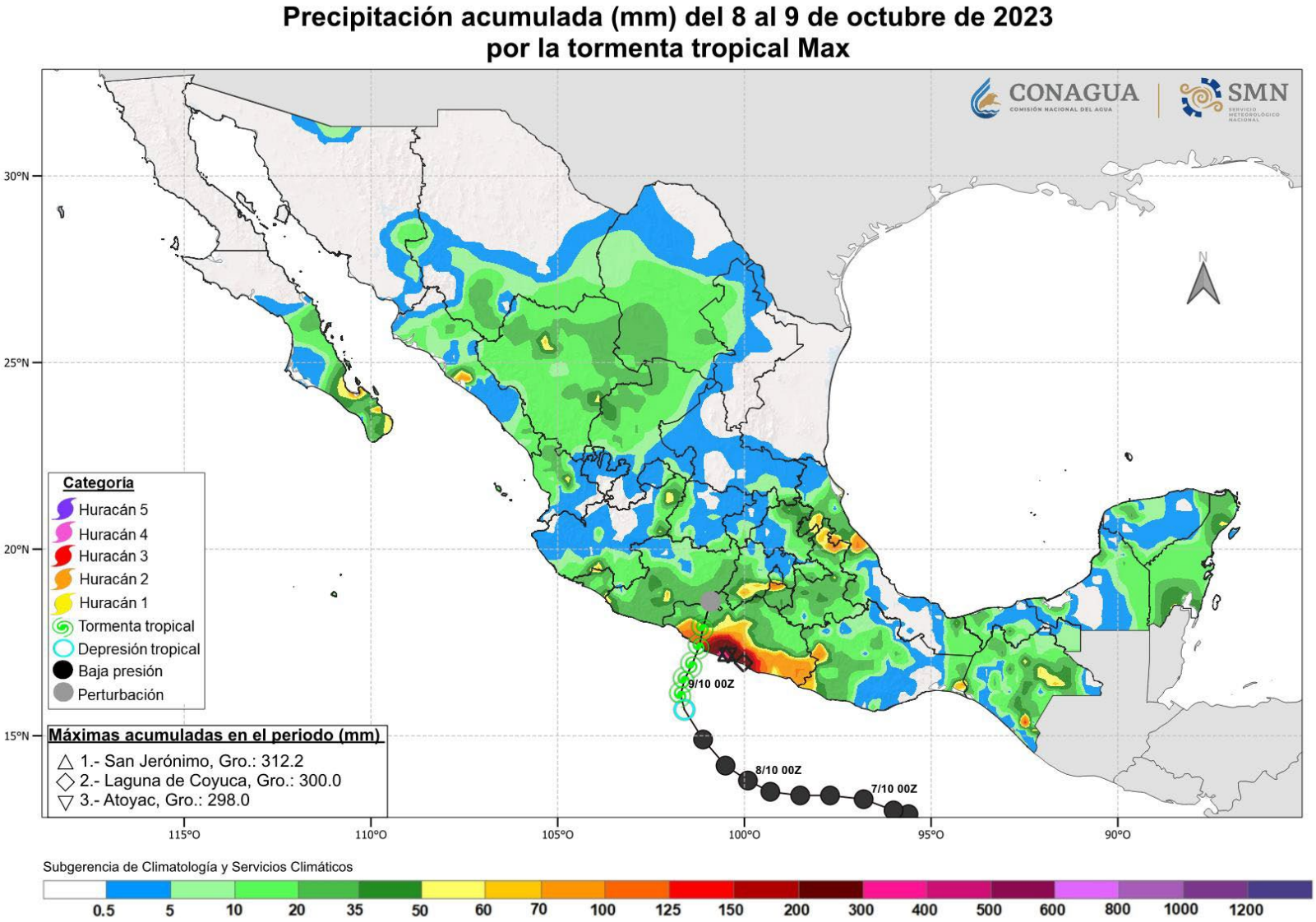

Figure 7. Rainfall accumulations (mm) in Mexico from 8 to 9 October 2023, including the effects of Tropical Storm Max. Max's track is based on operational location and intensity estimates. Image courtesy of CONAGUA, the National Meteorological Service of Mexico.

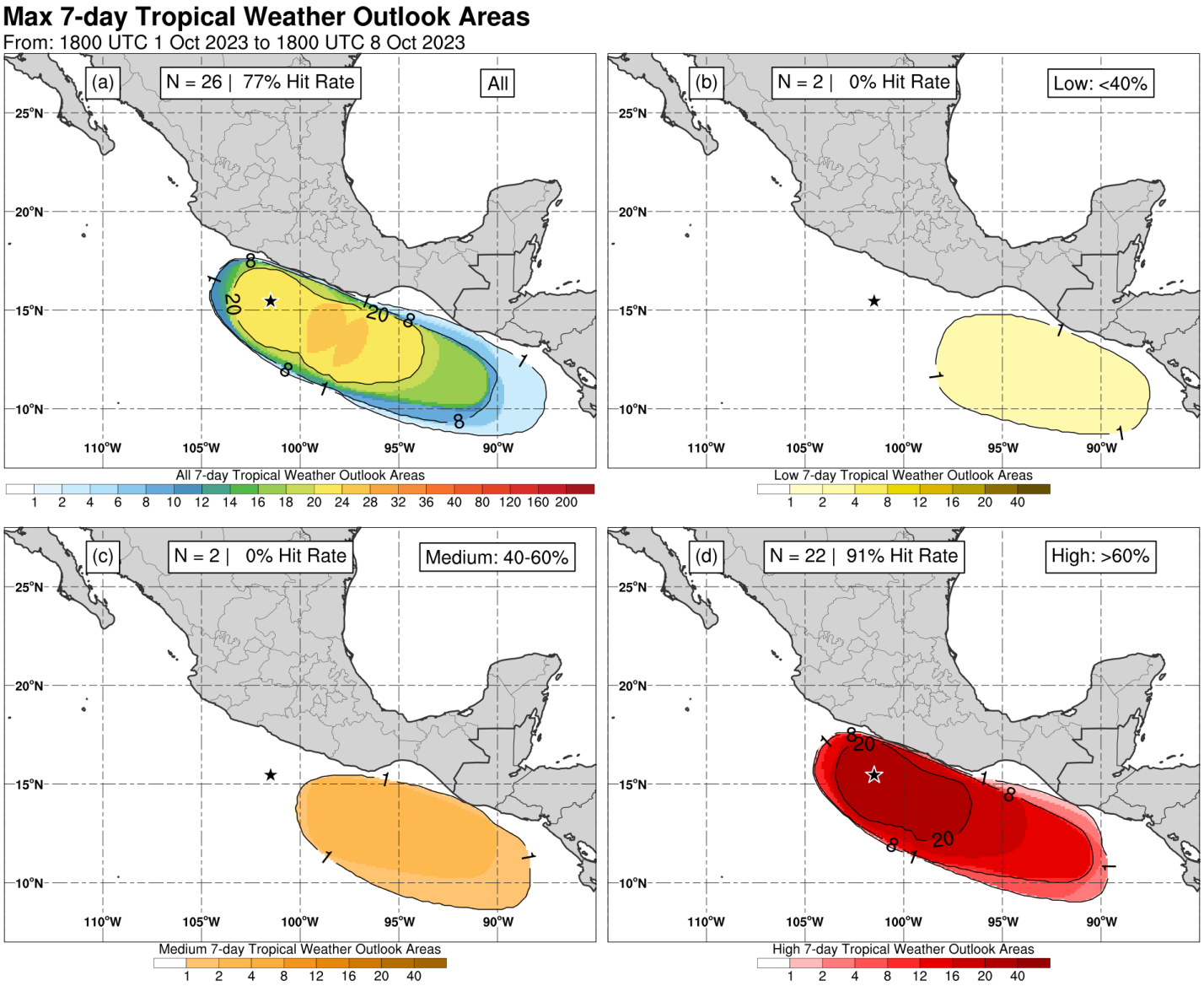

Figure 8. Composites of 5-day tropical cyclone genesis areas depicted in NHC's Tropical Weather Outlooks prior to the formation of Tropical Storm Max for (a) all probabilistic genesis categories, (b) the low (<40%) category, (c) medium (40–60%) category, and (d) high (>60%) category. Max's location of genesis is indicated by the black star.

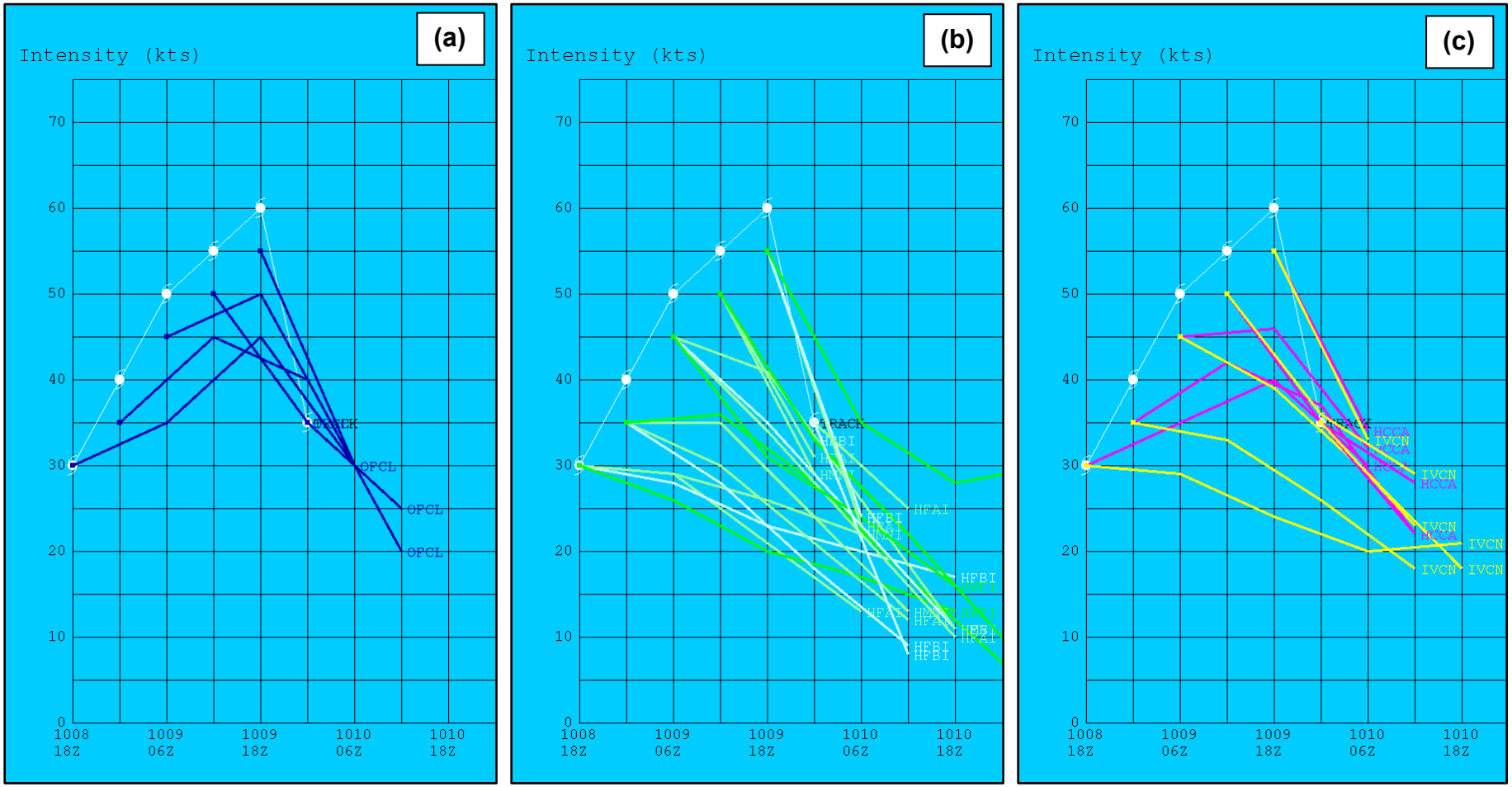

Figure 9. (a) NHC official intensity forecasts (OFCL), (b) dynamical hurricane model guidance (HWFI, HMNI, HFAI, and HFBI), and (c) consensus aids (IVCN and HCCA) for Tropical Storm Max for forecast cycles from 0000 UTC 8 October through 0000 UTC 10 October 2023. The NHC best track intensity is denoted by the white line and symbols.