P1.5 EVALUATION OF SATELLITE-BASED ESTIMATES OF PRECIPITATION IN THE YUCATAN REGION DURING HURRICANE WILMA

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1. INTRODUCTION

One of the most potent hurricanes in 2005, Hurricane Wilma was at a Category 4 stage when it made landfall on 21 October on the Mexican Yucatan Peninsula, crossing over Cozumel and stalling between 21-22 October, resulting in a sustained period of heavy rain and flooding. Preliminary reports of rainfall totals from the area exceeded 1-m, especially for Isla Mujeres offshore of Cancun in the state of Quintana Roo. Prompted by this extraordinary report, we analyze and compare several different multi-satellite based precipitation estimates during the passage of Hurricane Wilma. The different multi-satellite estimates represent a collection of methods to combine and blend rainfall datasets generated from intermittent, infrequent overpasses of passive microwave (PMW) imagers onboard low Earth orbiting satellites, with the rapid-refresh capabilities of geostationary visible/infrared (VIS/IR) imagers. Since the majority of the rainfall occurred over a brief 2-day period, this case represents an opportunity to examine the performance of these precipitation estimation schemes over short (e.g., 3-hour) time scales. Comparisons are made with hourly reports from available raingauge stations and Tropical Rainfall Measuring Mission (TRMM) Precipitation Radar (PR) estimates, to examine storm totals and individual 3-hour accumulations during the hurricane passage.

2. SATELLITE-BASED PRECIPITATION TECHNIQUES

In recent years, the requirements for climate modelling, data assimilation, nowcasting, and hydrological applications have created the need for daily and sub-daily precipitation analyses and their associated accuracy. The development of blended, high resolution precipitation products (HRPP) derived from satellite observations (typically blends of low Earth orbiting [LEO)]passive microwave radiometric [MW] and geostationary Earth orbiting [GEO] multispectral visible/infrared [VIS/IR] imagers) has rapidly advanced to the point where a typical “finest scale” product is a 3-hourly accumulated precipitation at a spatial resolution of 0.25° (approx. 25-km). These HRPP’s have the potential for providing quantitative precipitation estimation (QPE) when a developing or potential landfalling hurricane is offshore or in regions that lack functioning radars.

In this paper we compare quantitative results for five HRPP’s during the landfall of Hurricane Wilma during 21-22 October 2005. During this time the hurricane turned toward the northwest towards the Yucatan Peninsula of Mexico, where its maximum winds were near 130 kt (category 4). The center made landfall near the island of Cozumel around 2145 UTC on 21 October, and it was still category 4 intensity when it slowly crossed the coast of the Yucatan peninsula about 6 hours later, producing intense rainfall during a 42-hour period from 00 UTC on 21 October to 18 UTC on 22 October.

The five techniques that are examined are the CPC Morphing Technique (CMORPH, Joyce et.al., 2004), the Goddard Space Flight Center (GSFC) TRMM Multi-satellite Precipitation Analysis (TMPA, computed here as 3B42 Version-6, Huffman et. al, 2003), two variations of a technique developed at the University of Birmingham in the United Kingdom (Kidd et. al, 2003), and the NRL-Blend developed at the

Naval Research Laboratory (Turk et al., 2003). We will refer to the techniques of Kidd et. al. (2003) as UBIRM-1 and UBIRM-2, respectively. UBIRM-1 and UBIRM-2 both use the whole region for the spatial calibration, but UBIRM-1 uses a time averaging ± 6 hours either side of the 3-hour period (i.e. 15 hours in total), whilst UBORM-2 uses the whole time period (i.e. a single IR to rainrate curve based upon all available PMW/IR instances). The PMW data used for these calibrations was the TMI (1B11), SSM/I and AMSR-E, all calibrated against the TRMM PR.

While a full discussion of each of these techniques is beyond the scope of this paper, one key difference is that CMORPH is an "advection-type" algorithm (i.e., precipitation is advected in between PMW satellite overpasses via the use of motion vectors obtained from high-refresh GEO-IR), whereas the others are examples of "calibration-type" algorithm (i.e., PMW datasets near to the geostationary data in a space and time window are used to adjust subsequent geostationary images, and different techniques use different space/time windows to adjust). While regional-site validation efforts are currently addressing the accuracy and effectiveness of these and other HRPP's (Turk et. al. 2006), the validation of any of these HRPP's during hurricane conditions is often problematic owing to the performance degradation of conventional tipping-bucket raingauges during intense high winds. In Figure 1, the timeseries of the hourly accumulated precipitation between 21-23 October 2005 from the Isla Mujeres weather station is shown. The reported accumulated total during this time was 1746 mm (5.7 feet). Even if this is an overestimate due to site or instrumentation issues, it identifies this case as an extreme event worthy of study.

3. SATELLITE-DERIVED ACCUMULATIONS

The Tropical Rainfall Measuring Mission (TRMM) satellite made four passes over Wilma during 20-21 October, and the rain-derived imagery from a combined TRMM Microwave Imager (TMI) and Precipitation Radar (PR) products is shown in the four panels of Figure 2 (located at the end of this manuscript). The nearly stationary position of the eye is evident from the bottom two panels, which are about seven hours apart, although the eye is outside of the PR swath. TRMM made a direct overpass earlier near 0055 UTC on 21 October (upper right of Figure 2), where PR-derived rainrates are off-scale (i.e, in excess of 40 mm hr^{-1}).

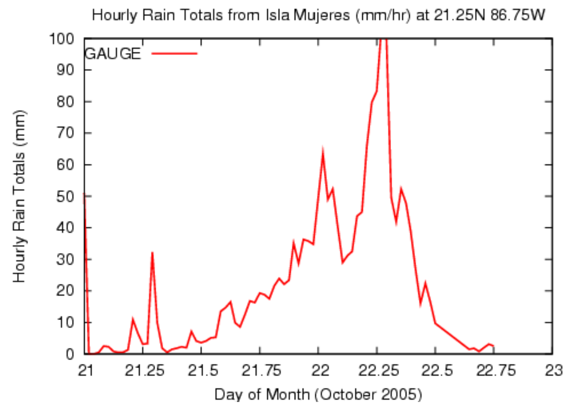

Figure 1. Time series of the hourly accumulated precipitation (mm) between 21-23 October 2005 from the Isla Mujeres weather station, just offshore of Cancun in Quintana Roo, Mexico. The reported accumulated total during this time was 1746 mm with a peak of 120 mm hr^{-1} (Data courtesy of Dr. Jorge Sanchez-Sesma, Mexican Institute of Water Technology).

In order to analyze the time evolution of the rainfall associated with the hurricane during this time, we present a sequence of 3-hourly rainfall accumulations. In Figure 3 (located at the end of this manuscript), an image sequence of 3-hourly accumulations from the CMORPH technique is shown (24 frames), beginning in the upper left and ending at lower right. The map region extends from 16°-26°N and 91°-81°W near the Yucatan Peninsula in the Mexican state of Quintana Roo. The image sequence begins at 00 UTC on 20 October 2005 (upper left) and ends at 21 UTC on 22 October 2005 (lower right). As evidenced in the TRMM imagery, CMORPH displays the nearly stationary eye position in the rainfall structure between 12 UTC on 21 October and 00 UTC on 22 October, after which the eyewall rainfall began to break apart. Peak values of the 3-hour accumulations (shown on the text box for each image) are in excess of 90 mm.

An identical image sequence is shown in Figures 4-7 (also located at the end of this manuscript) for the GSFC 3B42-Version 6, UBIRM-1, UBIRM-2, and the NRL-Blend, respectively. The 3B42-Version 6, UBIRM-1 and UBIRM-2 sequences all tend to show heavier rain accumulations than CMORPH on 20 October, prior to hurricane landfall. UBIRM-1 and UBIRM-2 display more of the symmetrical rain structure than 3B42 and NRL-Blend. This may be due to the manner whereby the latter two "fill in" geostationary-calibrated rainrates only in between successive PMW overpasses. UBIRM-1 and UBIRM-2 both pick up the rainfall maximum from the northern and southern parts of the eyewall as it moves to the northwest. This is better seen in Figure 8, which displays the overall total accumulations image for each of these five techniques for the 96-hour period beginning at 00 UTC on 20 October. In these images, the maximum value of any one pixel in the image is denoted in the image text, the largest being UBIRM-1 (792 mm) and the smallest being CMORPH (491 mm). However, the maximum value at any one point is a poor indicator of the maximum rainfall associated with a moving system such as a hurricane. The time evolution moves the heaviest rain from one point to another, and an estimate of the maximum rain should follow the storm movement (e.g., in these examples the rain associated with any given pixel advects to a different pixel 3 hours later).

We choose a simplified means to examine the overall maximum precipitation evolution associated with this storm. Since this case is limited to a rather small area extending approximately 3° of latitude on a side, these data are subsetted into over-ocean and over-land points within a box extending from 19°-22°N and 89°-86°W. For each three-hour accumulations dataset, we locate the maximum ocean and land pixel within this box.

Figures 9 and 10 highlights these results for the five techniques for over-ocean and over-land regions, displayed alongside the reported gauge accumulations from the data of Figure 1. Note that the satellite-based accumulations begin on 20 October, whereas the raingauge accumulations begin on 21 October. The time series plots (Figures 3-7) show that precipitation pushed north faster over ocean, i.e., to the right of the hurricane track) as one would expect, and that the accumulation there was higher than to the left of the track, which includes most of the land areas in our analysis box. When the data are analyzed in this fashion, the maximum value will be larger than the maximum (per-gridbox) accumulations in Figure 8, since the maximum value is separately determined each three hours.

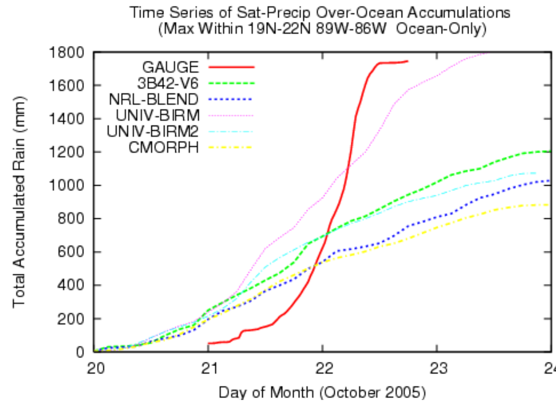

Figure 9. Time series of the maximum accumulated precipitation for over-ocean gridboxes <I reserve "pixel" for individual satellite footprints, sort of sysnonymous with "FOV"> between 20-24 October 2005 for the five satellite-precipitation techniques. The ordinate represents the maximum value found inside of a 3° box (19°-22°N and 89°-86°). The solid red line represents the raingauge accumulations from Figure 1.

Also, this analysis scheme causes the satellite accumulation to increment steadily, while the gauge shows the timeseries of the event passing its location. But even this storm-following approach generally fails to yield satellite estimates that approach the single, stationary gauge at Isla Mujeres.

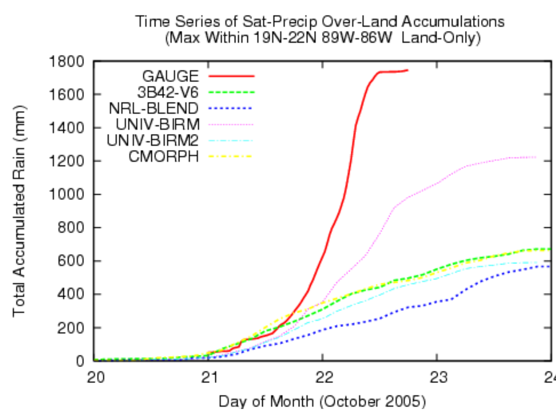

Figure 10. Same as Figure 9, but for over-land gridboxes only.

For both surface backgrounds, all techniques except UBIRM-1 track each other closely, ending within 100 mm of each other for over-land pixels and within 300 mm for over-ocean pixels.

4. CONCLUSIONS

This study has analyzed rainfall accumulations derived from five satellite-based precipitation techniques during the landfall of Hurricane Wilma upon the Yucatan Peninsula of Mexico. The time sequence of the 3-hourly accumulations was examined as well as the maximum rainfall evolution over ocean and land backgrounds within the track of Hurricane Wilma for the period 20-23 October 2005. The maximum accumulations noted for over-ocean were about twice that of the over-land. However, this could be a result of the limited capability of MW-based sensors to adequately assess over-land precipitation. We plan to study additional hurricane-related heavy rain events to examine the differences amongst the HRPP's in more detail.

Since the reported surface observations of precipitation totals were gathered from a single weather station, the study is an intercomparison rather than a validation. However, we note that there is an effort ongoing to perform regional site validation of these and other HRPP's through the Pilot Evaluation of High Resolution Precipitation Products (PEHRPP) of the International Precipitation Working Group (IPWG; Turk and Bauer, 2005). PEHRPP aims to characterize as clearly as possible the errors in various HRPPs across varying spatial and temporal scales, variable surfaces (cold surfaces, complex terrain), and climatic regimes (Ebert, 2005; Turk et. al, 2006).

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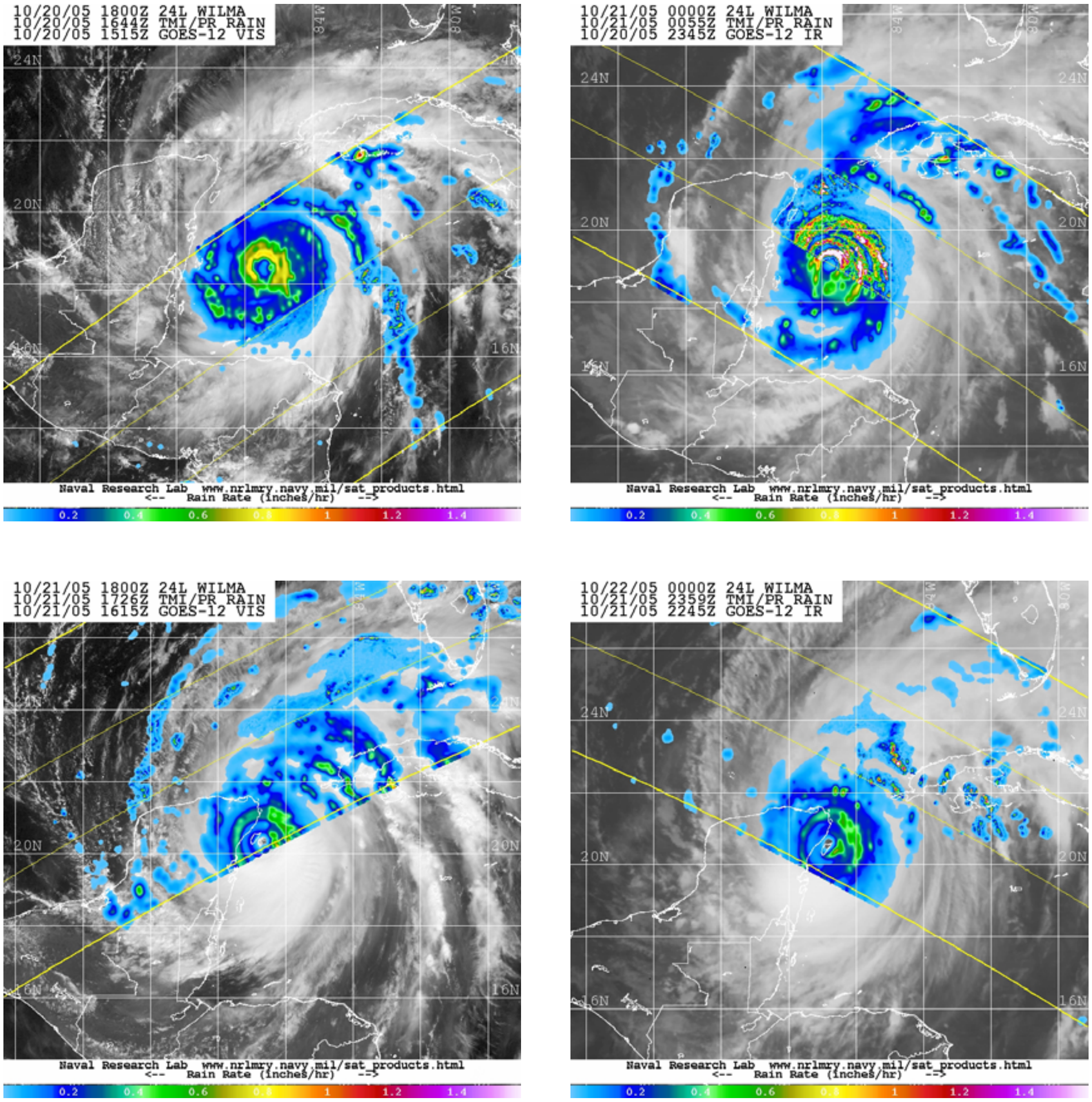

Figure 2. TRMM Microwave Imager (TMI) and Precipitation Radar (PR)-derived rainfall from four TRMM overpasses over Hurricane Wilma near the Mexican Yucatan Peninsula: 20 October 2005 at 1644 UTC (upper left), 21 October 2005 at 0055 UTC (upper right), 21 October 2005 at 1726 UTC (lower left), 21 October 2005 at 2359 UTC (lower right). The yellow lines indicate the swath edges of the PR (light yellow) and TMI (bold yellow) instruments. PR data is shown inside of its swath, and outside of the PR swath the TMI rainfall is shown. The grayscale background represents the GOES-12 channel-4 11-µm infrared imagery for nighttime overpasses (white=colder temperatures), and visible channel-1 imagery during daytime conditions (white=more reflective). The TMI and PR rainrates are from the 2A12 and 2A25 algorithms, respectively, and the color scale is in inches/hour.

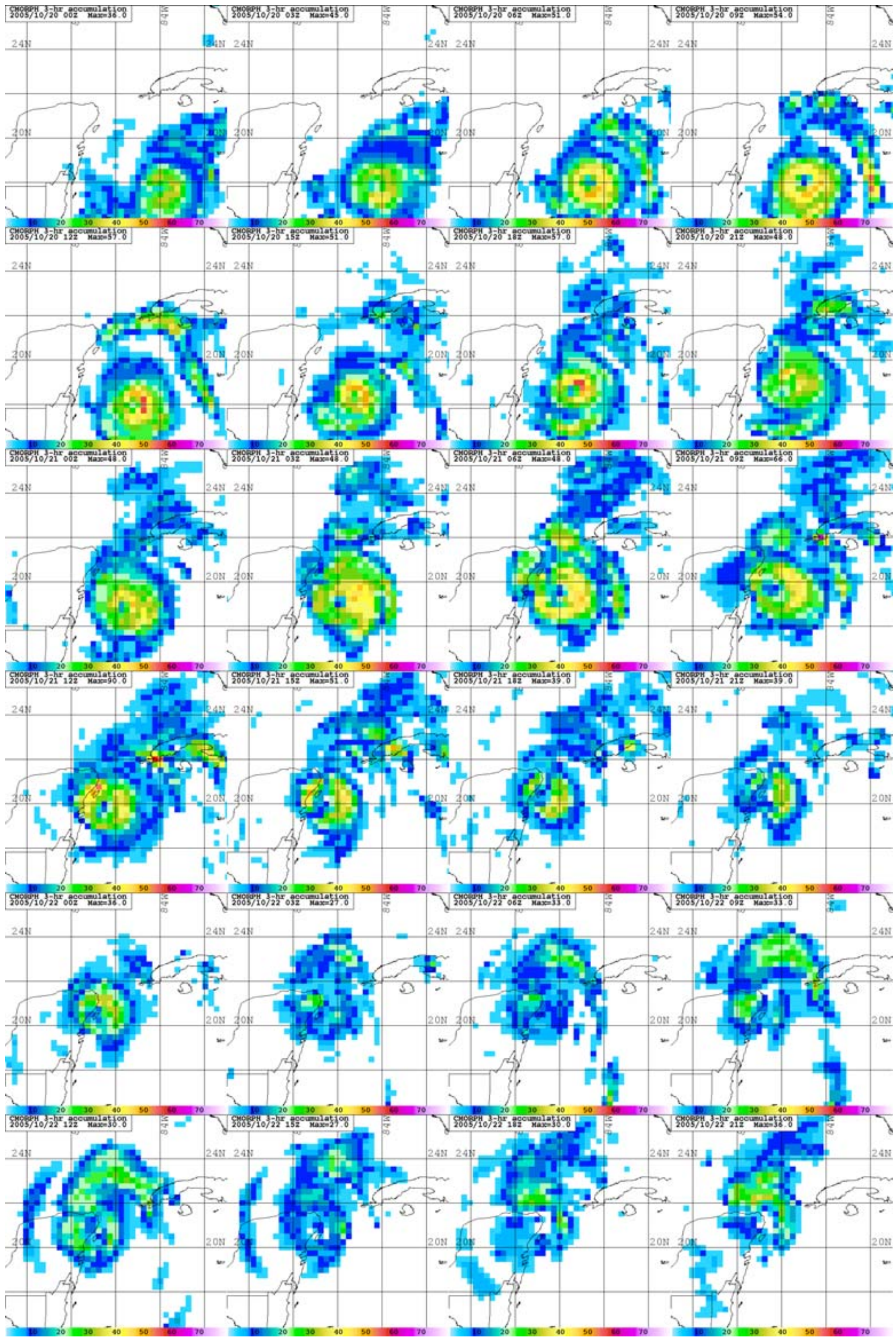

Figure 3. Time sequenced imagery every three hours, beginning in upper left and ending at lower right, representing the three-hour accumulated precipitation from the CMORPH satellite-precipitation technique. The region extends from 16°-26°N and 91°-81°W near the Yucatan Peninsula in the Mexican state of Quintana Roo, during the passage of Hurricane Wilma. The image sequence begins at 00 UTC on 20 October 2005 (upper left) and ends at 21 UTC on 22 October 2005 (lower right).

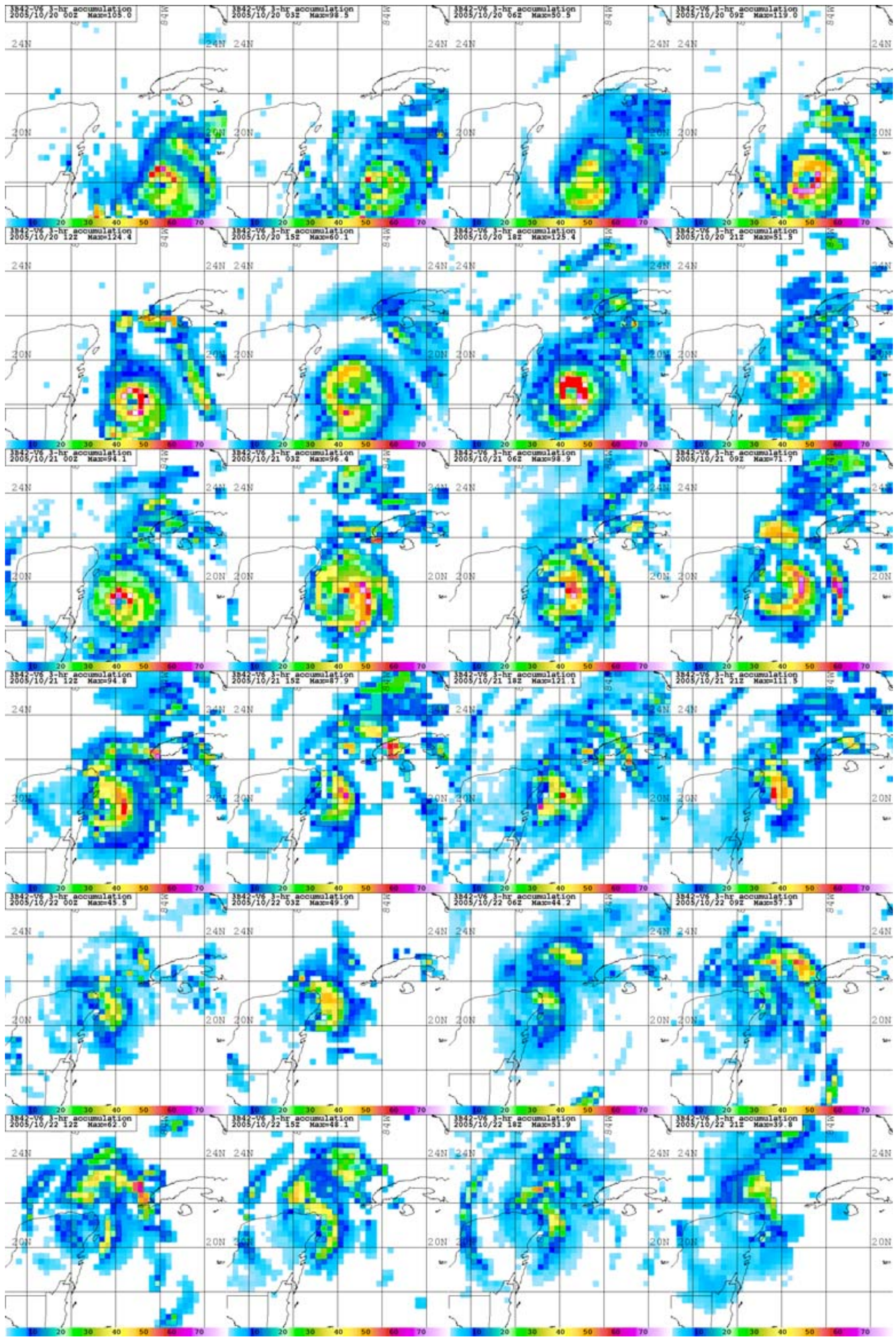

Figure 4. Same as Figure 1, but for the 3B42-V6 satellite-precipitation technique.

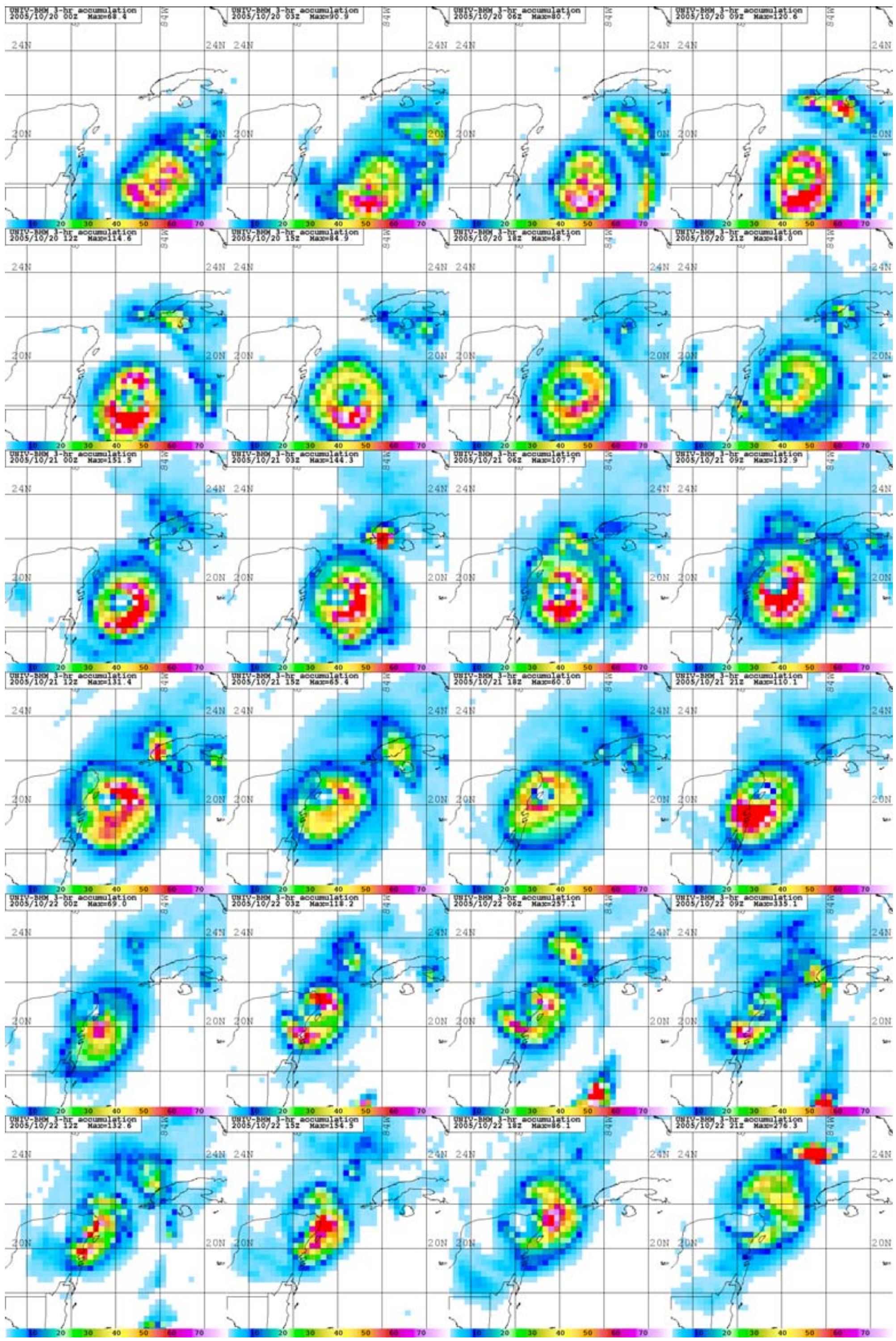

Figure 5. Same as Figure 1, but for the UBIRM-1 satellite-precipitation technique.

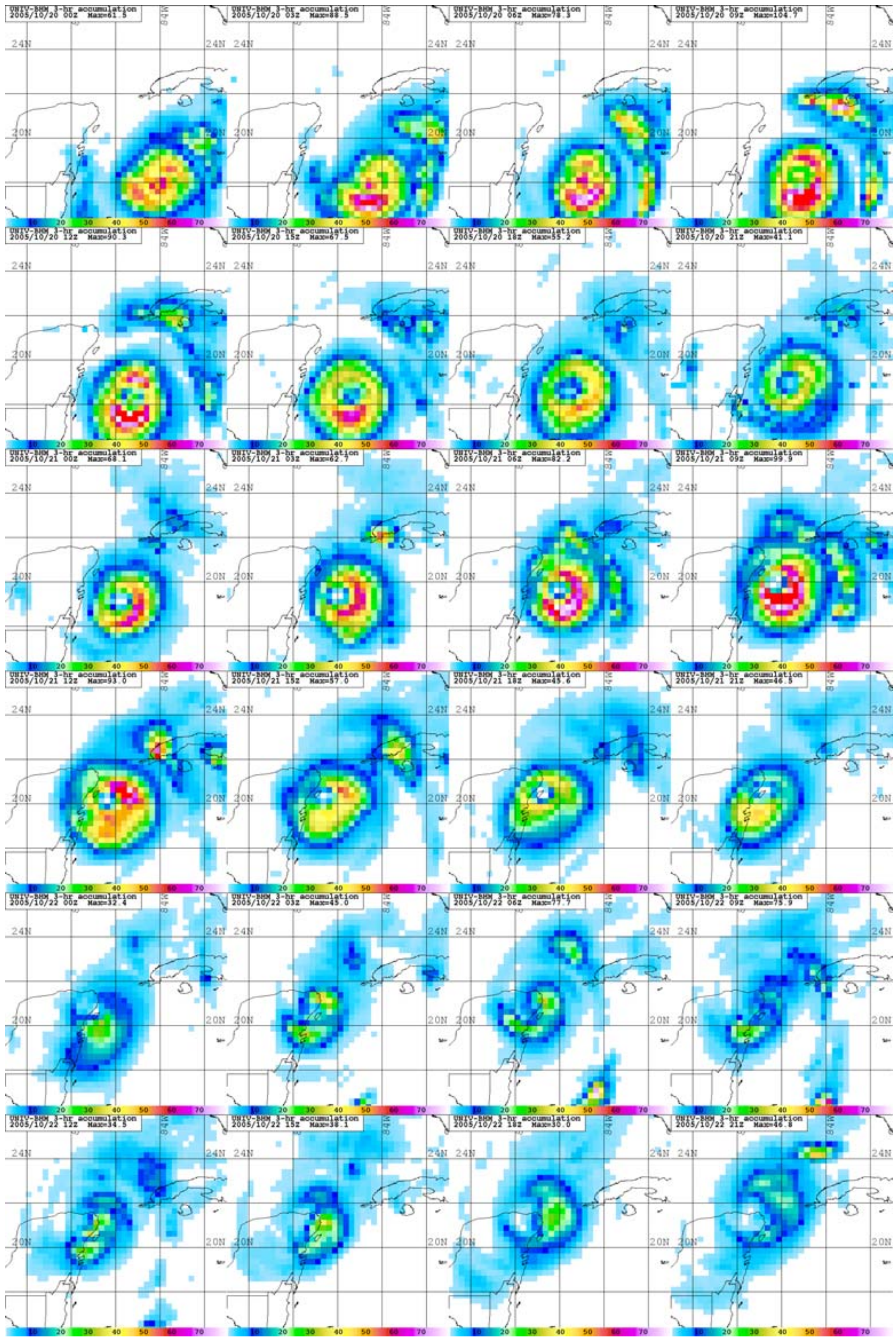

Figure 6. Same as Figure 1, but for the UBIRM-2 satellite-precipitation technique.

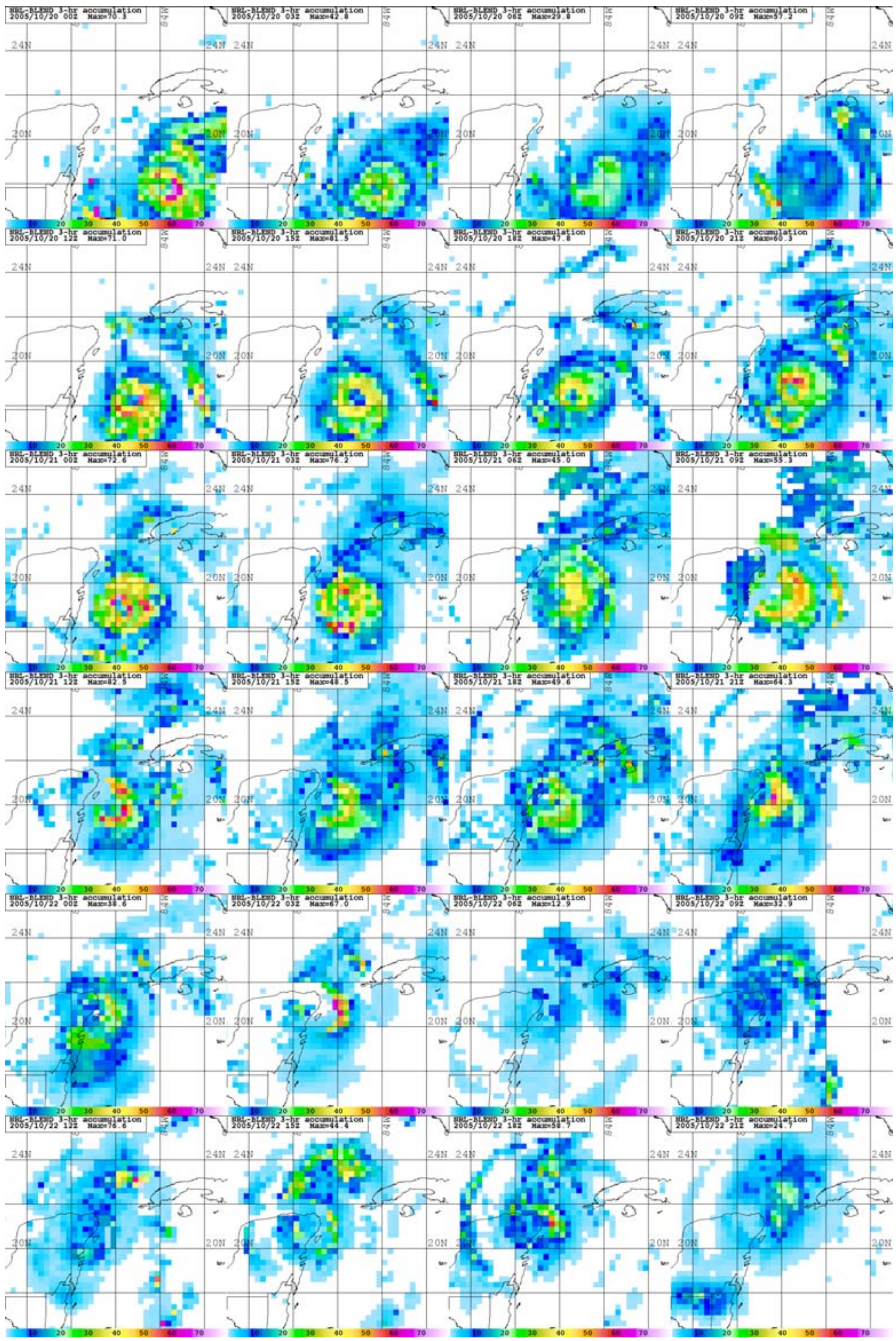

Figure 7. Same as Figure 1, but for the NRL-Blend satellite-precipitation technique.

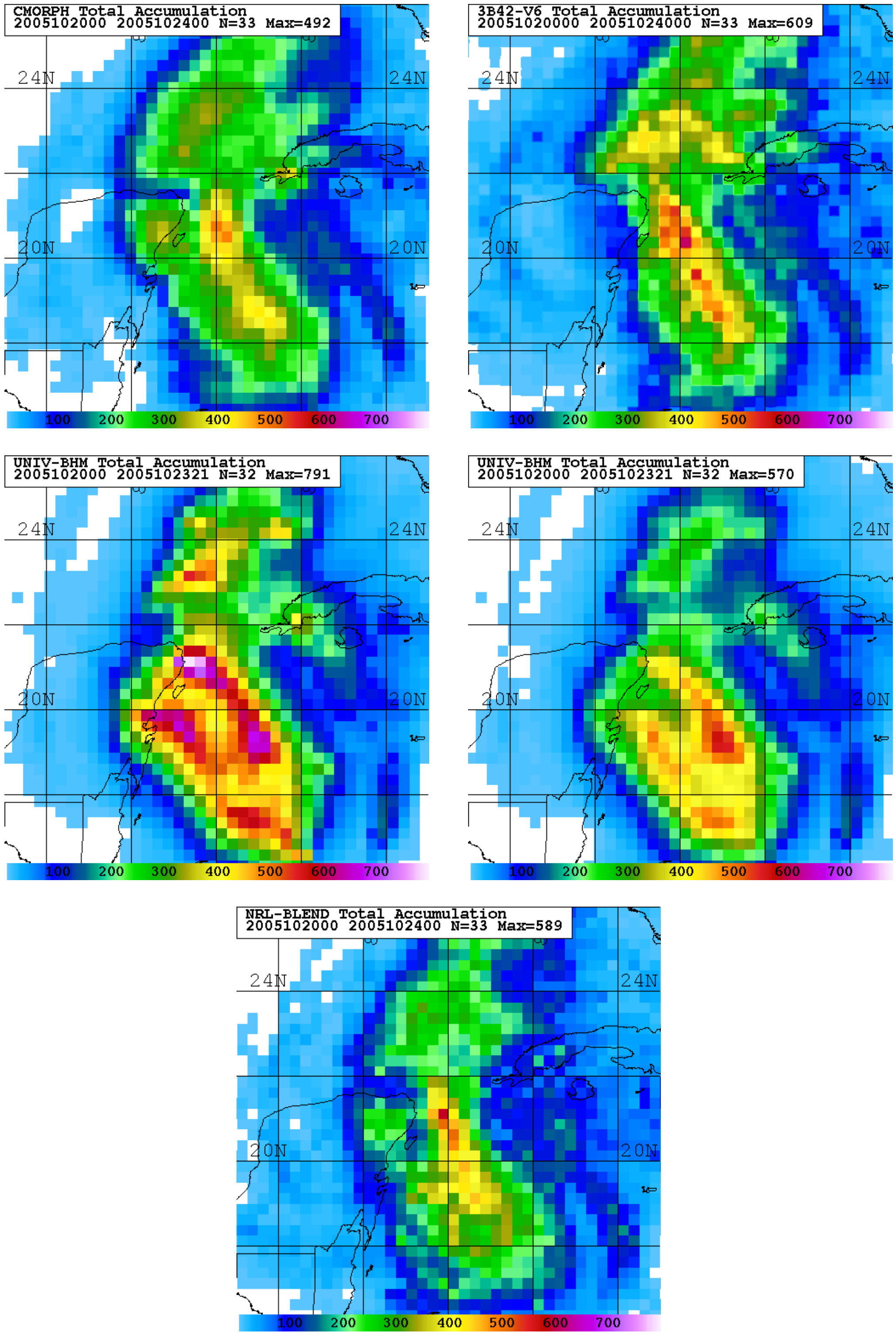

Figure 8. Total accumulations (mm) for the 96-hour period beginning on 00 UTC on 20 October for the five satellite-precipitation techniques examined. **Top row:** CMORPH and GSFC 3B42 Version 6. **Middle row:** UBIRM-1 and UBIRM-2. **Bottom**: NRL-Blend. The map projection is identical to the three-hour accumulations sequences in Figures 3-7. The maximum value is identified in the image text.