WORLD-RECORD RAINFALLS DURING TROPICAL CYCLONE GAMEDE

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A critical aspect of identifying climate change is the establishment and maintenance of verifiable weather data of weather and climate extremes. Since reported incidents of weather extremes are often used as indicators that the Earth's climate is changing and/or becoming more variable, confirmation of new weather extreme records should be recognized as a high priority in the meteorology community. Although several countries across the world have initiated weather and climate extremes committees (e.g., U.S. National Climate Extremes Committee, see online at www.ncdc.noaa.gov/oa/climate/monitoring/extremes/ncec.html) to identify, verify, and archive weather extremes within their own borders, until recently similar measures for documenting and archiving world weather extremes have not been established. In 2006, the World Meteorological Organization (WMO) Commission for Climatology (CCl) appointed a "rapporteur on climate extremes" to launch and maintain an official, unbiased list of weather and climate extremes for the world and, additionally, to establish procedures for the verification of future weather records.

Upon receipt of a new purported record, an ad hoc extremes committee is organized to provide an expert and unbiased recommendation on whether the extreme in question should be added to the list. The committee consists of the president of the Commission for Climatology, the chair of the CCl Open Programme Area Group (OPAG) on Monitoring and Analysis of Climate Variability and Change (the rapporteur is part of this OPAG), and a representative of the relevant member state's National Meteorological and Hydrologic Service, as well as experts in the appropriate meteorological phenomenon and observing instrumentation as required. The committee may also consult with a wide variety of additional experts as the need arises. Based on the available data from the event, the committee creates an evaluation and recommendation for the rapporteur on climate extremes, who then makes a judgment of the record's inclusion into the WMO CCl World Weather and Climate Extremes Archive.

A critical aspect of the committee's evaluation process is to ascertain potential errors arising in the recording of the purported weather extreme. For example, a 2006 report by Dhar and Nandargi indicated that on 10 June 2003, Cherrapunji, India, recorded a daily (24 h) rainfall total of 1,840 mm, which would have been a new world record. However, upon examination, an investigation conducted by Rupa Kumar Kolli at the request of the rapporteur proved that the published value was a misprint and that no 24-h rainfall record had been achieved at Cherrapunji for that date.

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TROPICAL CYCLONE GAMEDE. We detail in this paper the investigation of two possible new world-record rainfall events associated with the passage of a tropical cyclone (TC) in the South Indian Ocean. In February 2007, the major TC Gamede made two approaches to the island of La Réunion as it traversed a complex looping path in the Indian Ocean (Fig. 1). During the first passage, at a distance slightly more than 200 km northwest of the island on Saturday, 24 February 2007, winds first oriented from east-southeast veered progressively to east-northeast on Sunday, 25 February. They were particularly strong in the highlands and over the northern and southern coasts. Heavy

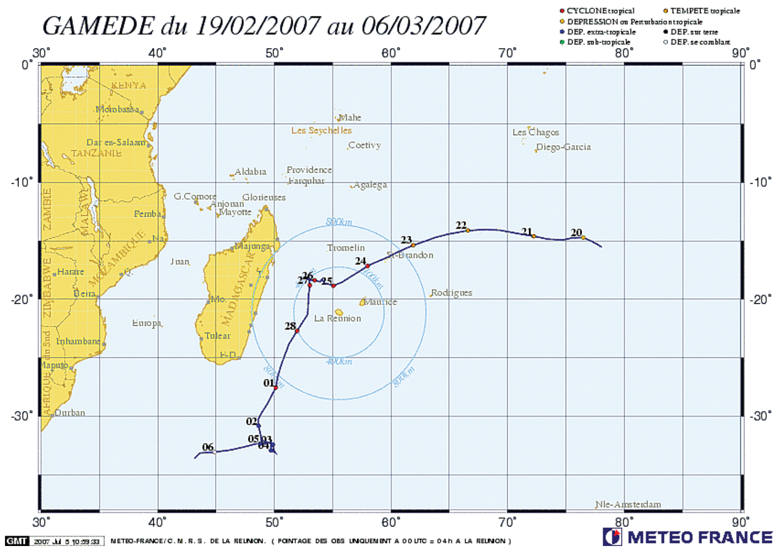

Fig. 1. Trajectory of TC Gamede from 19 Feb to 6 Mar 2007. Red dots correspond to conditions of established tropical cyclone (see online at www.meteo.fr/temps/domtom/La_Reunion).

rains started over the island's main volcano (Piton de la Fournaise) during the night from 23 to 24 February, extending then progressively to the whole highlands. Rainfall was more irregular at the coast, because of the succession of peripheral rainbands associated with the whole system. Following this first passage, TC Gamede moved away along a complicated trajectory involving two successive loops and a prolonged stop on the evening of Monday, 26 February. Despite the distance (400 km) to the TC's center, storm conditions over the island remained intense, with heavy rain continuing, especially in the highlands, and strong winds blowing from the east-northeast.

During a second close passage, to within 250 km west of the island on Tuesday (27 February) evening, while the cyclone was moving south, winds turned from northeast to north-northeast, and again strengthened over the highlands, so the western part of the island was hit in its turn. Rainfall intensity decreased close to the coast, but remained heavy in the highlands. It is only on the morning of 28 February that conditions improved across the entire island as the system moved away to the southwest.

TC GAMEDE PRECIPITATION OVER LA RÉUNION. The main feature of TC Gamede was a huge amount of rainfall inland, with several 3- and 4-day rainfall totals over 2 m across the island (Table 1). Rainfall was not associated with any extreme intensity peaks, but the cumulative totals over periods of 12 h and more reached remarkable—even exceptional—levels in the high-altitude sites of Salazie and Cilaos and over the volcano (Fig. 1).

It is important to note that the accumulated rainfalls mentioned in this chapter sometimes differ from the sums of daily totals appearing in Table 1, which correspond to fixed time intervals starting and ending at 0300 UTC (0700 local time). The accumulated rainfall amounts mentioned in the table are the maximum running totals beginning at 0100, 0200, to 2300 LT (all times presented are local time: UTC + 4) over periods of 24, 48, 72, and 96 h.

Specifically, the highest 24-h rainfall amount of 1,625 mm was recorded at Cratère Commerson from 1500 LT 24 to 1500 LT 25 February, which is somewhat less than the current world record of 1,825 mm measured at Foc-Foc during TC Denise in 1966, while additional impressive amounts of 1,489 mm (from 2100 LT 24 to 2100 LT 25 February) and 1,295 mm (from 2300 LT 24 to 2300 LT 25 February) were measured at Hell-Bourg and Bélouve, respectively. Even more impressive over 48 h, a rainfall total of 2,463 mm at Cratère Commerson was recorded from 0700 LT 24 to 0700 LT 26 February, very close to the world record of 2,467 mm at Aurère during an unnamed TC (8–10 April 1958). Other extreme precipitation values included 2,358 mm at Hell-Bourg over 48 h (from 2200 LT 24 to 2200 LT 26 February) and 2,185 mm at Bélouve (from 2300 LT 24 to 2300 LT 26 February) over the same time period.

Most importantly, an extreme rainfall of 3,929 mm over 72 h (from 1600 LT 24 to 1600 LT 27 February) was recorded at Cratère Commerson and a rate of 3,264 mm was recorded over the same time period at Hell-Bourg (from 1400 LT 24 to 1400 LT 27 February). Both of these values are well above previous world record of 3,240 mm over 72 h that had been measured at Grand-Ilet (see location in Fig. 2) during TC Hyacinthe in 1980. Somewhat smaller, but still impressive rainfall totals of 2,824 and 2,321 mm over 72 h were recorded at Bélouve and Cilaos, respectively.

New world records associated with this event have also been established for rainfall totals over a 4-day interval. The Cratère Commerson rain gauge registered a rainfall total of 4,869 mm over 4 days, while a rainfall amount of 3,633 mm was recorded at Hell-Bourg. These two values are well above the previous world record of 3,551 mm at Cratère Commerson during TC Hyacinthe in 1980. Other high rainfall values recorded on La Réunion during TC Gamede included 3,139 mm at Bélouve and 2,586 mm at Cilaos.

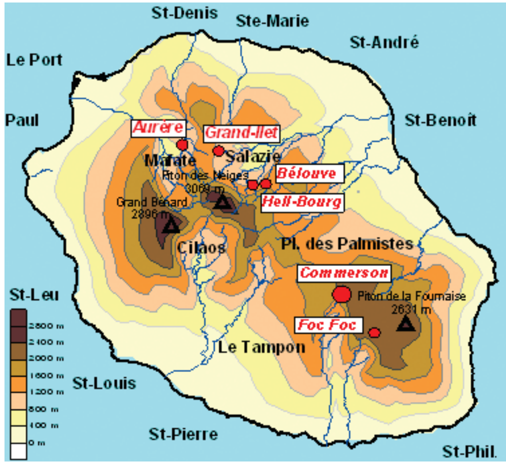

Fig. 2. Topographic map of La Réunion Island.

In addition, although these categories are not yet a part of the official WMO weather and climate archive, new world records were also established for rainfall totals over 5, 6, 7, 8, and 9 days with, respectively, 4,979; 5,075; 5,400; 5,510; and 5,512 mm at this same location (Cratèere Commerson).

The Commerson station is located north of the volcano at 21°12.48'S and 55°38.62'E, and is 2,310 m above sea level. It became operational on 1 January 1968. The local environment of the station is very open, which is relatively unusual at La Réunion due to the island's mountainous topography and vegetation. The instrumentation used to measure the rainfall at this location was a Précis-Mécanique tipping bucket rain gauge, type 3020 (20-g plastic buckets), with an aperture of 400 cm^2, installed at the site in May 2004.

Logs of maintenance and sensor calibration indicate that the rain gauge had been calibrated not long before the event (4 December 2006) and was rechecked on 9 January 2007. Following the passage of TC Gamede, the rain gauge was again examined on 10 April 2007. No problems with calibration were discovered.

One of the critical missions of the ad hoc investigation committee was to ascertain if there could be any anomalies in the manner in which data were collected. In this case, according to the person responsible for the climatological network in La Réunion, there is no objective reason to question measurements made at this site. The equipment was, and is, well protected inside an impervious aluminum cylinder and well fixed to the ground. Numerous studies have demonstrated that wind induces a loss of precipitation measured by the rain gauge. Indeed, a comparison by one of the committee members (Y. Boodhoo) of collocated wind shielded and nonshielded precipitation measurements taken during the passage of TC Gamede at nearby Mauritius (Station Vacoas) reveals that the shielded rain gauge received more rainfall (11 mm over the course of 6 days from 21 to 27 February) than its unshielded counterpart. Because the precipitation gauge is not shielded, it is considered likely that the record values observed at Cratère Commerson are conservative totals of the rainfall.

Tropical cyclones affect La Réunion Island from December to April, during the hot season, with a maximum probability in January and February. Statistically, a significant event affects the island every 5–10 yr, but it is not impossible to observe this type of phenomena during two consecutive years (e.g., TC Colina in 1993 and TC Hollanda in 1994). Over the 2–3 days when the cyclone generally affects La Réunion weather, typical rainfall ranges from 300 to 600 mm close to the coast and from 1,000 to 1,500 mm in the highlands (even much more in some cases). Tropical cyclone precipitation always starts in the highlands of La Réunion as a result of the extreme orography (70% of the island lies between altitudes from 400 to 3,069 m; see Fig. 2). At the end of a TC passage, again due to orographic uplift, precipitation tends to continue in the highlands even as the lowland rains have stopped. Consequently, it is not surprising that the highlands of the island recorded the greatest rainfall amounts (Fig. 3). It is normal during tropical cyclone passages for the Commerson site, which is at a high elevation, to receive the highest quantities of any observing site on the island (Table 1). In addition, because of its geographical position, the orographic effect at Commerson is at a maximum, no matter what the wind direction. This is not true for other stations in the highlands, where this orographic effect is dependent on the wind direction.

SUMMARY AND CONCLUSIONS. In summary, a fairly even distribution of rain was observed over the 4 days for more than half of the island sta-

Station name	Elev (m)	City	Max tot (mm) 1 day	2 days	3 days	4 days	TC Diwa	TC Hyacinthe
Les Avirons-Cirad	170	Les Avirons	45	88	102	130	117	340
Bras-Panon	480	Bras-Panon	172	280	391	471	774	
Ravine Citrons	487	Entre-Deux	225	427	610	714	458	
Pont-Mathurin	20	Etang-Sale	50	98	113	134	176	345
Piton-Bloc-Cirad	810	Petite-Ile	310	540	810	990	272	
Pl. Palmistes	1032	Pl. Palmistes	625	1122	1581	1932	1542	2151
Le Port	9	Le Port	93	174	220	246	171	639
Possession	9	La Possession	192	382	459	535	288	798
Dos D'Ane	915	La Possession	564	1116	1372	**1603**	980	1540
Aurère	940	La Possession	869	1569	2127	2680	1757	1759
Menciol	181	Saint-Andre	203	386	496	561	461	1002
Beauvallon	16	Saint-Benoit	102	178	270	321	422	891
St-Bonoit	43	Saint-Benoit	118	192	266	309	550	973
Providence	138	Saint-Denis	153	269	378	448	312	1005
Chaudron	38	Saint-Denis	140	241	359	421	321	708
Pl. Chicots	1834	Saint-Denis	658	1238	1734	2124		
Commerson	2310	Saint-Joseph	1397	**2463**	**3637**	**4869**	2879	3551
La Crete-Cirad	650	Saint-Joseph	590	**1071**	**1467**	**1830**	882	1040
Carreau-Alfred	1380	Saint-Leu	150	259	385	478	518	1429
Piton St-Leu-Cirad	572	Saint-Leu	88	160	189	270	176	509
Les Makes	980	Saint-Louis	348	627	793	892	441	825
Tapage-Cirad	850	Saint-Louis	350	600	750	849	434	645
St-Paul-Cirad	186	Saint-Paul	187	369	451	519	305	1049
Bdn-Saint-Paul-Cirad	580	Saint-Paul	242	455	593	695	415	752
Ravine Cabris-Cirad	373	Saint-Pierre	173	295	338	434	236	741
Ligne-Paradis-Cirad	150	Saint-Pierre	164	193	249	345	167	605
Le Baril	115	Saint-Philippe	325	641	799	855	869	
St. Philippe	30	Saint-Philippe	207	331	420	455	756	540
Gillot-Aero	10	Saint-Marie	133	221	333	388	324	657
Bellecombe	2245	Sainte-Rose	1131	1615	2082	2331	1798	2587
Bagatelle	262	Sainte-Suzanne	174	324	474	534	503	849
Grand-Ilet	1185	Salazie	725	1311	1743	2083	2958	3485
Hell-Bourg	975	Salazie	1111	**2172**	**3053**	**3633**	2579	1746
Bélouve	1500	Salazie	1097	2004	**2711**	**3139**	2372	1700
Pl. Des Cafres	1560	Le Tampon	500	938	1342	1745	959	1586
Le Tampon-Cirad	786	Le Tampon	392	734	**948**	**1220**	561	754
Cilaos	1197	Cilaos	840	1550	**2185**	**2586**	1632	1643

Table 1. The 1-, 2-, 3-, and 4-day maximum total rainfall accumulations (mm) for stations on La Réunion from 24 to 27 Feb 2007. As example, the 2-day total value is computed as the maximum of the totals for the 24–25, 25–26, and 26–27 Feb 2-day periods. Four-day totals during the recent TCs Diwa (2006) and Hyacinthe (1980) are given for comparison. Values in bold are record values for the given locations (stations having at least 30 years of data). A climatological day corresponds to a 24-h period from 0300 to 0300 UTC (0700 local time) the day after.

tions and, on 24 February, the two highest sites, Commerson and Bellecombe, received the greatest rainfall total with comparable values. On 25 and 26 February, comparable daily rainfall rates were again observed at Commerson, Hell-Bourg, and Bélouve. On 27 February, rainfall rates were decreasing at stations in the northern half of the island, while keeping the same order of magnitude in the southern half.

Even if one can question the behavior of rain gauges in such extreme conditions (a general concern for verification of rainfall extremes), it appears that the observed record rainfalls are indeed credible. Under strong winds, errors in tipping bucket rain gauge measurements tend to be underestimates rather than overestimates because of aerodynamic effects around the instrument. However, it should be noted that the previous official world-record rainfall values at La Réunion (at Commerson for most of them) were recorded with the same type of rain gauges.

Consequently, it was the recommendation of the committee and subsequent approval of the rapporteur that two new world rainfall records have been established at La Réunion associated with the passage of the intense TC Gamede. First, an extreme rainfall rate of 3,929 mm over 72 h as recorded at Cratère Commerson is now the new 72-h world-record rainfall total. Second, a new world-record rainfall is established for the Cratère Commerson rain gauge when it registered a rainfall total of 4,869 mm over a 4-day period. (These records are now a part of the WMO World Weather and Climate Archive currently housed online at http://wmo.asu.edu.)

As the perception or the actual occurrence of more frequent extreme-weather events grows, the goal of the WMO World Weather and Climate Extremes database is to archive and verify extreme record events, such as the highest/lowest recorded temperatures and pressures on the Earth, the strongest winds, and the greatest precipitation (over different time intervals), as well as records involving the world's most destructive storms, hurricanes, and tornadoes. In the past, without the existence of such an official designate to determine and maintain regional or world records of extreme-weather events, the critical supportive documentation needed to assess the validity of a weather record event was often hard to find or simply did not exist. The WMO CCl Extreme Weather and Climate Archive, together with the procedures for evaluating potential new records, now provides the essential documentation and certification for weather extremes around the world.

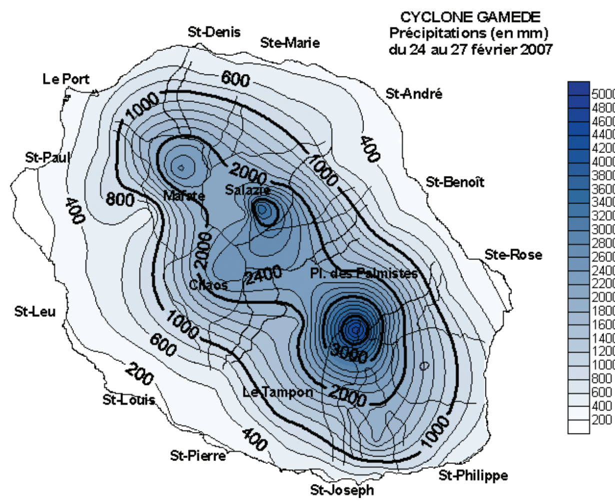

FIG. 3. Isohyet map of the 4-day precipitation accumulations (mm) for stations on La Réunion, 24–27 Feb 2007.

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FOR FURTHER READING

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