JRC TECHNICAL REPORTS

Tropical Cyclone GIOVANNA
Madagascar, February 2012

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CONTENTS

1.   EXECUTIVE SUMMARY

Tropical Cyclone Giovanna hit Madagascar on February 13, 2012, killing 35 people and causing extensive damage. It formed in the South Indian Ocean on February 09 and moved W-SW toward the East coast of Madagascar, increasing its strength and reaching Hurricane Category 4 on February 13. Giovanna made landfall between Brickaville (also known as Vohibinany) and Vatomandry (around 100 km South of Toamasina, the capital of the Province) on February 13 at about 22 UTC. Strong winds and heavy rainfall, as well as some degree of storm surge, affected the landfall area. After the landfall it moved inland in a W-SW direction, uprooting trees, damaging infrastructure, causing landslides and flooding. Over the land it rapidly weakened into a Tropical Storm. On February 14 evening, it moved into Mozambique Channel and then turned southwards, moving around the southern part of Madagascar. On February 16, Giovanna turned eastwards, along the bottom of Madagascar, then moved away from the coast, where it strengthened into a Hurricane of Category 2. On February 20, it turned North, losing significantly strength and quickly dissipating (see Figure 1).
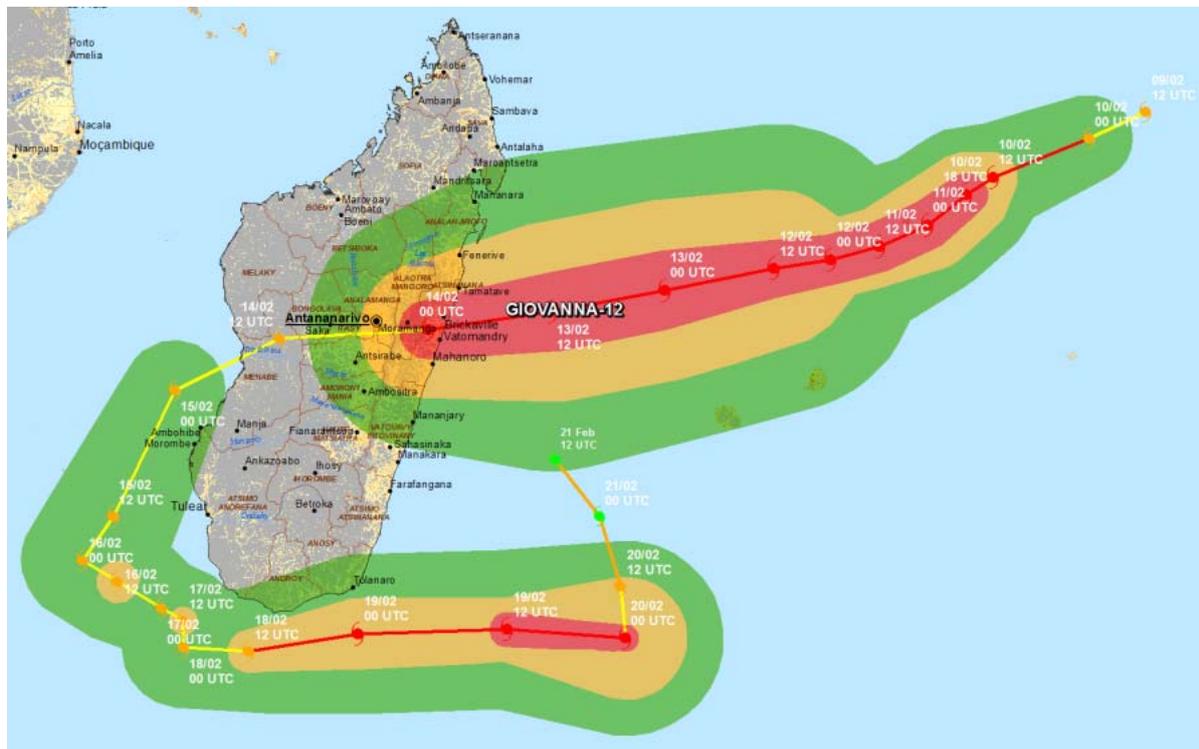

Figure 1 - Trajectory of tropical cyclone Giovanna

The Joint Research Centre (JRC) of the European Commission has developed the Global Disaster Alert and Coordination System (GDACS[1]), a global monitoring system created to alert the humanitarian community about potential disasters needing international intervention. The system automatically invokes numerical models in order to analyse the level of the hazard of natural disasters like earthquakes, tsunamis, cyclones, floods, volcanoes. Tropical cyclones (TCs) are some of the most damaging events; they affect the coastal population with three dangerous effects: strong wind, heavy rain and storm surge. In order to estimate the area and the population affected by a cyclone, all the three types of physical impacts must be taken into account. GDACS includes the analysis of the first and the second effects, and recently also the third effect – storm surge phenomena – was implemented in the HyFlux2 code (Probst and Franchello, 2012), routinely used in GDACS to model inundation due to tsunami run-up.

For the cyclone Giovanna, GDACS issued the following alerts:

- **Red Alert** for wind impact in Madagascar
- **Orange Alert** for rain impact in Madagascar
- **Orange Alert** for storm surge in Madagascar

This report analyses and discusses the automatic impact assessments of GDACS for all three components.

Advisory	Alert color	Date (UTC)	Category	Wind speed	Wind gusts	Population affected by cyclone winds (>120km/h)	Location (lon, lat)
1		2/9/2012 12:00:00 PM	Tropical storm	64 km/h (40 mph)	84 km/h (52 mph)	no people	65.1, -14.1
2		2/10/2012	Tropical storm	93 km/h (58 mph)	121 km/h (75 mph)	no people	63.8, -14.7
3		2/10/2012 12:00:00 PM	Category 1	121 km/h (75 mph)	148 km/h (92 mph)	no people	61.6, -15.6
4		2/10/2012 6:00:00 PM	Category 3	204 km/h (127 mph)	249 km/h (155 mph)	no people	61, -16
5		2/11/2012	Category 4	222 km/h (138 mph)	269 km/h (166 mph)	no people	60.1, -16.7
6		2/11/2012 12:00:00 PM	Category 3	195 km/h (121 mph)	241 km/h (150 mph)	no people	59, -17.2
7		2/12/2012	Category 3	185 km/h (115 mph)	232 km/h (144 mph)	no people	57.9, -17.5
8		2/12/2012 12:00:00 PM	Category 3	185 km/h (115 mph)	232 km/h (144 mph)	no people	56.6, -17.7
9		2/13/2012	Category 4	232 km/h (144 mph)	278 km/h (172 mph)	no people	54.1, -18.2
10		2/13/2012 12:00:00 PM	Category 4	232 km/h (144 mph)	278 km/h (172 mph)	1.2 million people	51.5, -18.7
11		2/14/2012	Category 2	175 km/h (109 mph)	212 km/h (132 mph)	6.5 million people	48.7, -19.1
12		2/14/2012 12:00:00 PM	Tropical storm	64 km/h (40 mph)	84 km/h (52 mph)	450000 people	45.3, -19.3
13		2/15/2012	Tropical storm	74 km/h (46 mph)	93 km/h (58 mph)	<1000 people	42.9, -20.5
14		2/15/2012 12:00:00 PM	Tropical storm	84 km/h (52 mph)	101 km/h (63 mph)	no people	41.5, -23.4
15		2/16/2012	Tropical storm	93 km/h (58 mph)	121 km/h (75 mph)	no people	40.8, -24.4
16		2/16/2012 12:00:00 PM	Tropical storm	101 km/h (63 mph)	130 km/h (81 mph)	no people	41.6, -24.9
17		2/17/2012	Tropical storm	93 km/h (58 mph)	121 km/h (75 mph)	no people	42.6, -25.5
18		2/17/2012 12:00:00 PM	Tropical storm	101 km/h (63 mph)	130 km/h (81 mph)	no people	43.1, -25.8
19		2/18/2012	Tropical storm	84 km/h (52 mph)	101 km/h (63 mph)	no people	43.1, -26.4
20		2/18/2012 12:00:00 PM	Tropical storm	111 km/h (69 mph)	138 km/h (86 mph)	32000 people	44.6, -26.5
21		2/19/2012	Category 1	121 km/h (75 mph)	148 km/h (92 mph)	no people	47.1, -26.1
22		2/19/2012 12:00:00 PM	Category 2	158 km/h (98 mph)	195 km/h (121 mph)	no people	50.5, -26
23		2/20/2012	Category 1	121 km/h (75 mph)	148 km/h (92 mph)	no people	53.2, -26.2
24		2/20/2012 12:00:00 PM	Tropical storm	84 km/h (52 mph)	101 km/h (63 mph)	no people	53.1, -25
25		2/21/2012	Tropical depression	56 km/h (35 mph)	74 km/h (46 mph)	no people	52.6, -23.4
25		2/21/2012 12:00:00 PM	Tropical depression	47 km/h (29 mph)	64 km/h (40 mph)	no people	51.6, -22.1

Figure 2 - Event Time Line (GDACS) – The alert level colour is related to population affected by high winds.

2. IMPACT ASSESSMENT

2.1 HIGH WIND

2.1.1 Model assessment

Tropical cyclones around the globe are monitored as a result of international cooperation, coordinated at the global and regional levels by World Meteorological Organization. The Regional Specialized Meteorological Centres (RSMCs) and the Tropical Cyclone Warning Centres (TCWCs), have the regional responsibility to forecast and monitor cyclones. The data in the cyclone bulletins are not available in a single standard format, making it difficult to use in an automatic system like GDACS. To overcome this problem, Pacific Disaster Center (PDC, www.pdc.org), set up an automatic routine which includes cyclone bulletins from the Joint Typhoon Warning Centre, which covers all basins, into a geospatial database[2]. This source of information enabled JRC to implement more advanced impact models which provide improved information for humanitarian emergency managers. The areas affected by high winds (wind buffers at 35, 50 and 64knots) are calculated using the wind radii or, in case they are not provided, through a regression analysis based on historical data. More information in Annex 1 and in Vernaccini et al. (2007).

The reconstructed wind field for cyclone Giovanna is shown in Figure 3. The red area represents the area where the winds could reach 64 knots, orange area 50 knots, green area 35 knots. On February 13 (around 22 UTC) Giovanna made landfall between Brickaville (also known as Ampasimanolotra) and Vatomandry, affecting the area with very strong winds. At 12UTC, before landfall, it was a hurricane of Category 4, with a V_{max} of 232 km/h.
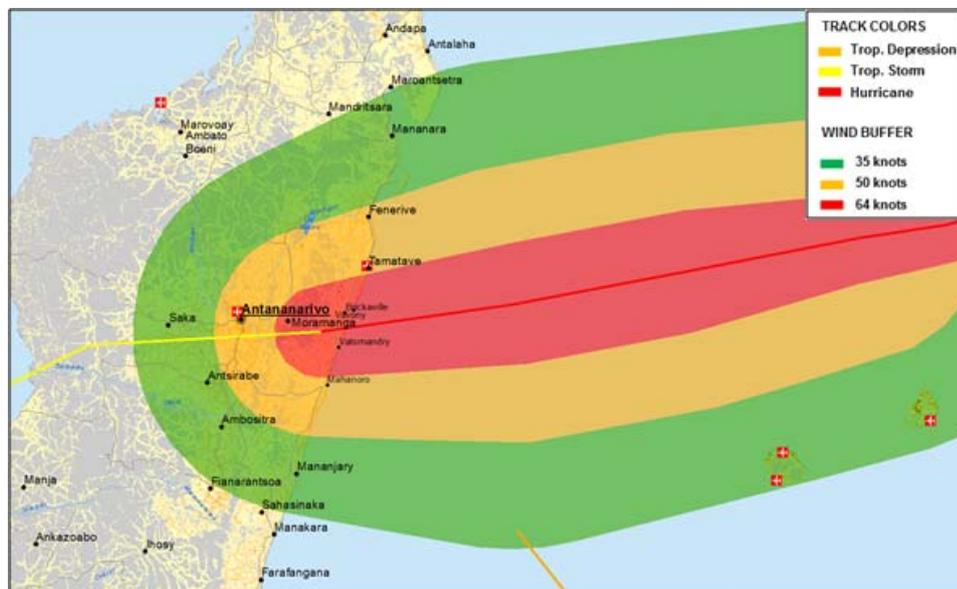
Figure 3 - GDACS - Wind buffers for tropical cyclone Giovanna

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[2] TC GIOVANNA developed in the South Indian Ocean, in this basin the TC bulletins, provided by PDC, include Joint Typhoon Warning Center (JTWC) data, which are routinely updated every 12 hours. Each TC bulletin includes the position of TC center, the maximum sustained wind based on 1-min average (V_{max}) and the wind radii. The wind radii represent the maximum radial extent – in nautical miles - of winds reaching 34, 50, and 64 knots in each quadrant (NE, SE, SW, and NW).

Comparison with NOAA-NESDIS MTCSWA product

The NOAA Multiplatform Tropical Cyclone Surface Wind Analysis (MTCSWA) product provides six-hourly estimate of cyclone wind fields based on a variety of satellite based winds and wind proxies. Several data, text and graphical products are available[3] (Annex 1). In our analysis we have used the *surface wind analysis (inner core scale)* graphical product.

The NOAA NESDIS surface wind fields of Giovanna, during the landfall, is shown in Figure 4. The red area shows the winds higher than 65 knots. Vatomandry is located inside the red area, Mahanoro in the Orange area (winds between 65 and 50 knots), and Brickaville in the border of orange-yellow area (winds are around 50 knots).

The NOAA-NESDIS area of maximum winds is about 50 km south when compared with the GDACS maximum winds (Figure 3). Therefore the area affected by strong winds (i.e. wind speed higher than 64 knots, or red area in both figures) in GDACS is reaching from Toamasina to Mahanoro, while in the NOAA satellite product it reaches from Brickaville to Mahanoro.
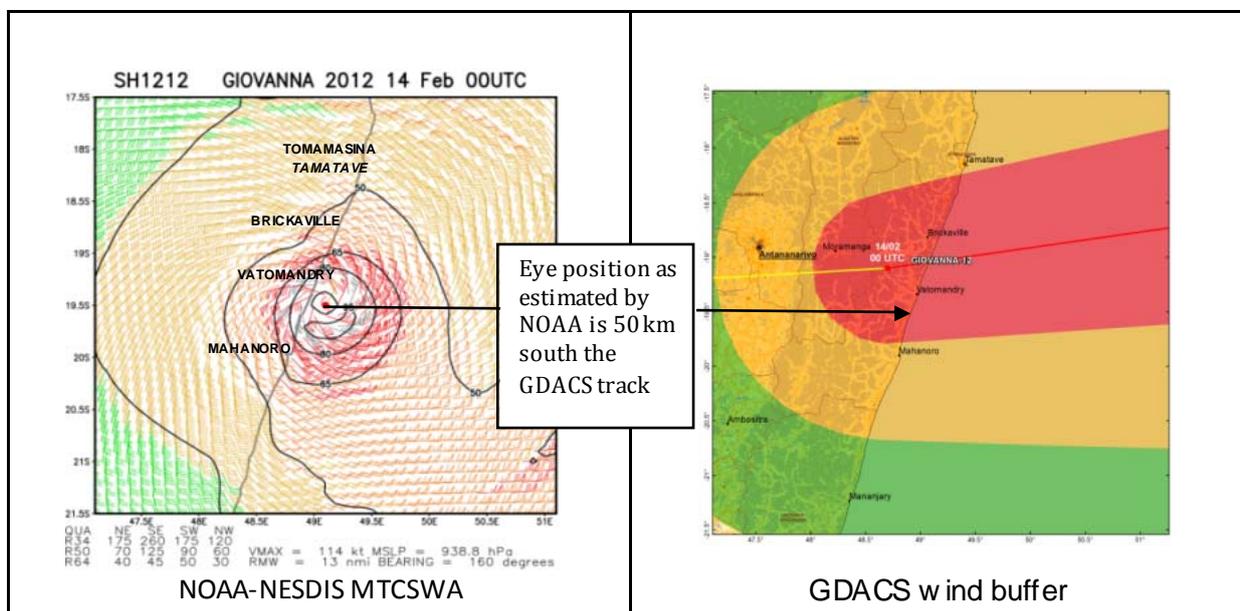
Figure 4 - NOAA-NESDIS MTCSWA - Surface wind field of GIOVANNA (as of 14 February 00UTC) – Inner core scale on the left (Source: ftp://satepsanone.nesdis.noaa.gov/MTCSWA/SH122012/) and GDACS - Wind buffers on the right.

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[3] http://www.ssd.noaa.gov/PS/TROP/mtcswa.html

2.1.2. Wind impact

Most of the damage by tropical cyclone Giovanna, was caused by strong winds. The total number of unroofed houses is 27656 (*Bureau National pour la Gestion des Risques et Catastrophes*[4] -BNGRC- report of 06 Apr 2012). Antisanana is the region most affected. The total number of houses unroofed is shown in Table 1:

ANTISANANA REGION			
District	*Houses unroofed (source BNGRC)*	*Population (Houses estimated using an occupancy rate of 4.6[5])*	*Ratio Houses unroofed/tot*100 (%)*
Toamasina I	201	179,045 (38,923)	0.5%
Brickaville (Vohibinany)	10,303	159,301 (34,631)	29.8%
Vatomandry	12,902	129,146 (28,075)	46.0%
Antanambao Manampotsy	270	46,174 (10,038)	2.7%
Mahanoro	217	212,118 (46,113)	0.5%

Table 1 - Number of houses unroofed in Antisanana region.

The real impact of the Cyclone Giovanna due to high wind should be evaluated with the information of unroofed (direct correlation) and/or destroyed buildings. The number of unroofed and destroyed buildings by district is reported in the table of the BNGRC Report (Table 6). The affected districts are shown in the maps below (Figure 5).

Most damage was reported in the areas affected by high wind (red areas), specifically on the landfall point, and along the cyclone track. The exception is the district of Mampikov in the north of the island, which is outside of the areas of strong winds.

The damage statistics indicate a higher amount of unroofed buildings in the Brickaville (Vohibinany) and lower in Mahanoro, supporting the track provided by JTWC and used by GDACS. The more southern track, and associated wind field, of NOAA/NESDIS would suggest more wind damage in Mahanoro.

With an average occupancy rate of 4.6 people/house (as estimated by the national statistics bureau INSTAT, 2005), damage rates are as high as 46% in Vatomandry, where the storm made landfall (see Table 1).

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[4] http://www.bngrc.mg

[5] INSTAT, 2005, Population : LandScan
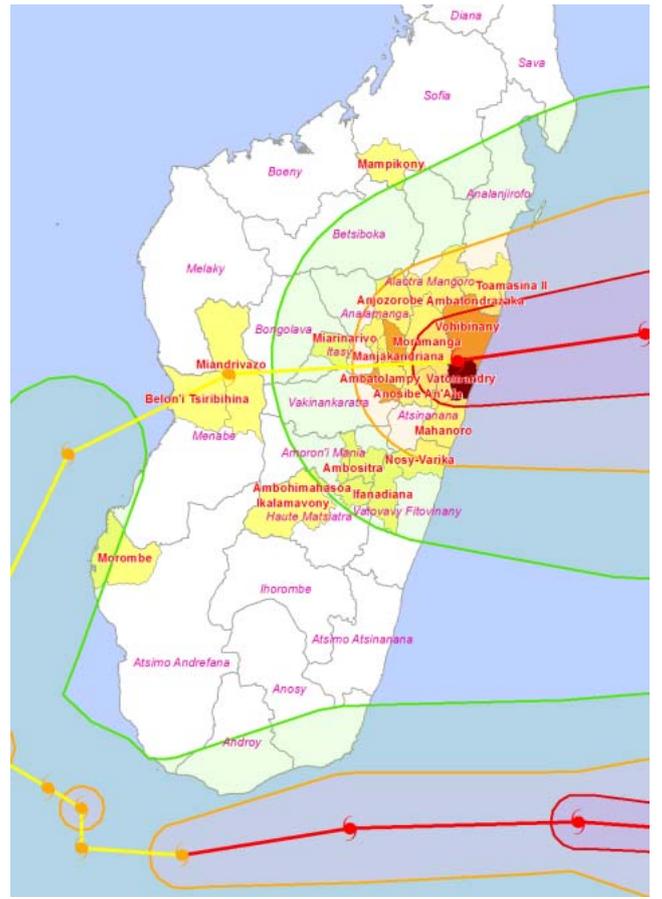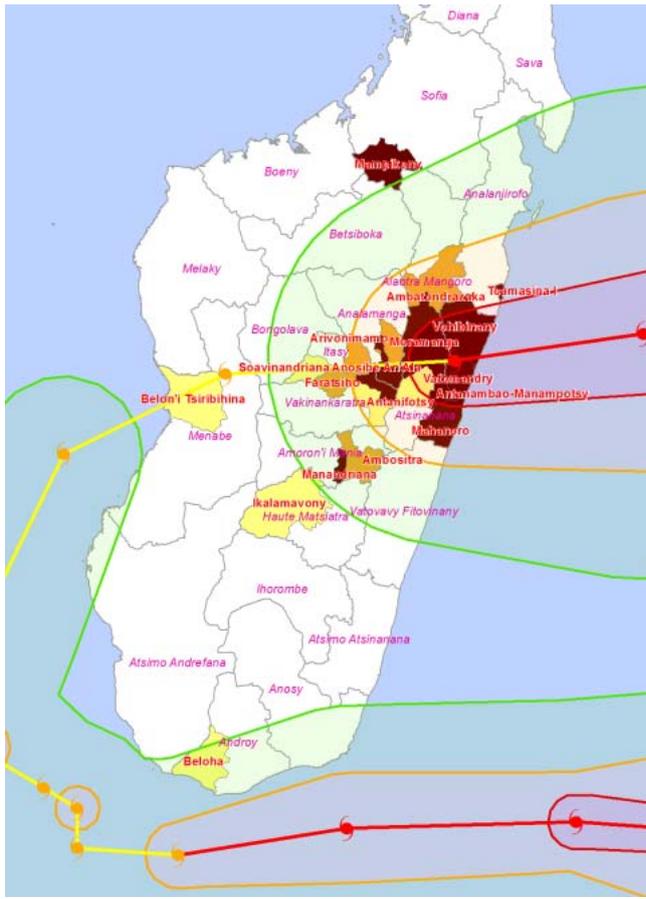
Figure 5 – Affected districts by high wind in red scale. On the left the unroofed buildings, on the right the destroyed buildings. The red area represents the area where the winds could reach 64 knots, orange area 50 knots, green area 35 knots.

2.1.3. GDACS Alert Model for Wind Speed

The GDACS alert levels are based on the risk formula factors, cyclone's wind speed (hazard), population affected, and vulnerability (of the affected country). The alert level is assigned according to the following criteria:

Wind speed	Population	Vulnerability	Alert Level
38 – 73 mph (TS)	< 10M	Low – Medium - High	Green
38 – 73 mph (TS)	> 10M	High	Orange
74 – 110 mph (Cat 1-2)	> 100K or > 10%	Medium – High	Orange
74 – 110 mph (Cat 1-2)	> 1M	High	Red
> 111 mph (Cat 3)	> 100K or > 10%	Medium – High	Red
> 111 mph (Cat 3)	> 1M	Low	Orange
> 131 mph (Cat 4)	> 1M	Low	Red

GDACS uses a disaster-specific vulnerability ranking for countries. The following table shows the Medium and High vulnerable countries. This ranking is based on historical data of population affected by cyclones (Vernaccini et al., 2007).

Vulnerability	COUNTRY
Medium	American Samoa, Anguilla, Aruba, Belize, British Virgin Islands, Cape Verde, China, Cook Islands, Costa Rica, Dominican Republic, Fiji, Guam, Honduras, Jamaica, Lao People's Democratic Republic, Malaysia, Mauritius, Mexico, New Caledonia, Nicaragua, Northern Mariana Islands, Pakistan, Palau, Philippines, Puerto Rico, Réunion, Saint Vincent and the Grenadines, Samoa, Swaziland, Thailand, Tonga, Trinidad and Tobago, Turks and Caicos Islands, Vanuatu
High	Bangladesh, Cambodia, Comoros, Democratic People's Republic of Korea, El Salvador, French Polynesia, Guatemala, Haiti, India, Madagascar, Marshall Islands, Montserrat, Mozambique, Myanmar, Niue, Papua New Guinea, Solomon Islands, Viet Nam

For the Tropical Cyclone Giovanna, the GDACS alert level was Red in Madagascar, mainly because of the high wind speed and the high vulnerability of the country.

2.2. HEAVY RAINFALL

2.2.1. Model assessment

In order to assess the rainfall caused by Giovanna we compared two rainfall products. These are daily composites of the "Tropical Rainfall Measuring Mission" (TRMM) and 6h forecasts of "Ensemble Tropical Rainfall Potential" (eTRaP) data.

It is important to point out that both products do not measure the real rain fall but are either estimates from multiple satellites (for TRMM) or in the case of eTRaP ensemble data from single orbit "Tropical Rainfall Potentials" (TRaP) forecasts.

The TRMM-based 3B42 [6] product provides a TRMM-adjusted merged-infrared (IR) precipitation estimation. The algorithm adjusts (using TRMM infrared and passive microwave data) multi-sensor infrared precipitation data (GMS, GOES-E, GOES-W, Meteosat-7, Meteosat-5, and NOAA-12).

eTRaP (Ebert *et al.*, 2009), on the other hand, uses data from three space-borne passive microwave sensors AMSU, TRMM and SSMI (previously also AMSRE). It is an ensemble approach with TRaP forecasts, which are 24-hour precipitation forecasts based on along-track extrapolation of satellite-estimated rain rates (with steps of 15 minutes). The resolution of eTRaP is 0.036 degrees (~4km) compared to 0.25 (~30km) for TRMM. However eTRaP are produced only for tropical cyclones over an area of 30 x 30 degrees and do not have a global coverage (between 50N and 50S) like TRMM.

To enable a comparison we summed up the eTRaP 6h interval to daily raster composites and then cut each of the global TRMM raster data to the same geographical extent as the daily eTRaP raster. After that each daily raster set was summed up over the duration of the cyclone to produce total rainfall maps for each of the products (i.e. the cumulated rainfall for the period from 10 to 21 February 2012). Finally we evaluated the difference by subtracting the total TRMM raster from the total eTRaP raster.
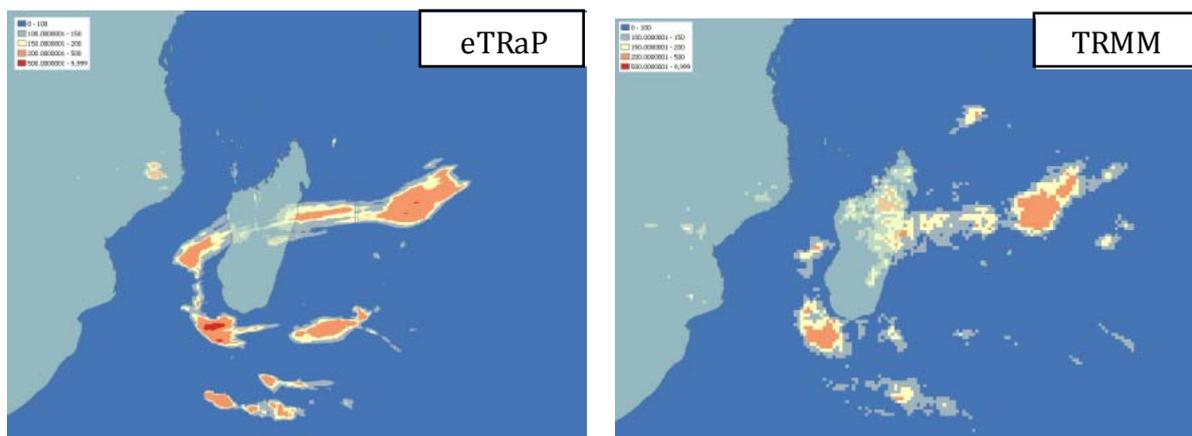
Figure 6 - eTRaP and TRMM total rainfall from 10.02.2012 to 21.02.2012. Colour scale (rainfall in mm) of both images is identical

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[6] See
http://disc.sci.gsfc.nasa.gov/precipitation/documentation/TRMM_README/TRMM_3B42_readme.shtml/

Comparing the two data sets (see Figure 6) reveals several things:

- As mentioned above the resolution of eTRaP is much higher. But it also shows higher totals and appears to be less fuzzy. A look at the subtracted map below (Figure 7) highlights these and more subtle differences.
- Peak rainfall values in eTRaP are higher than TRMM values and more spatially pronounced. This is expected with a higher resolution model.
- The TRMM rain fall track considerably widens at land fall, whereas eTRaP indicates only a thin rainfall track that does not change after land fall.
- The dissipation of the cyclone south of Madagascar is not well resolved in TRMM data. eTRaP on the other hand shows a number of well-defined rainfall tracks during this stage.

These observations are explained by the methodological differences. Both products use satellite data as a source, but eTRAP uses a high-resolution grid to forecast data, while TRMM uses a calibration method based on spatio-temporal interpolation. Extremes in rainfall are better described with higher resolution systems, since they affect small areas[7].
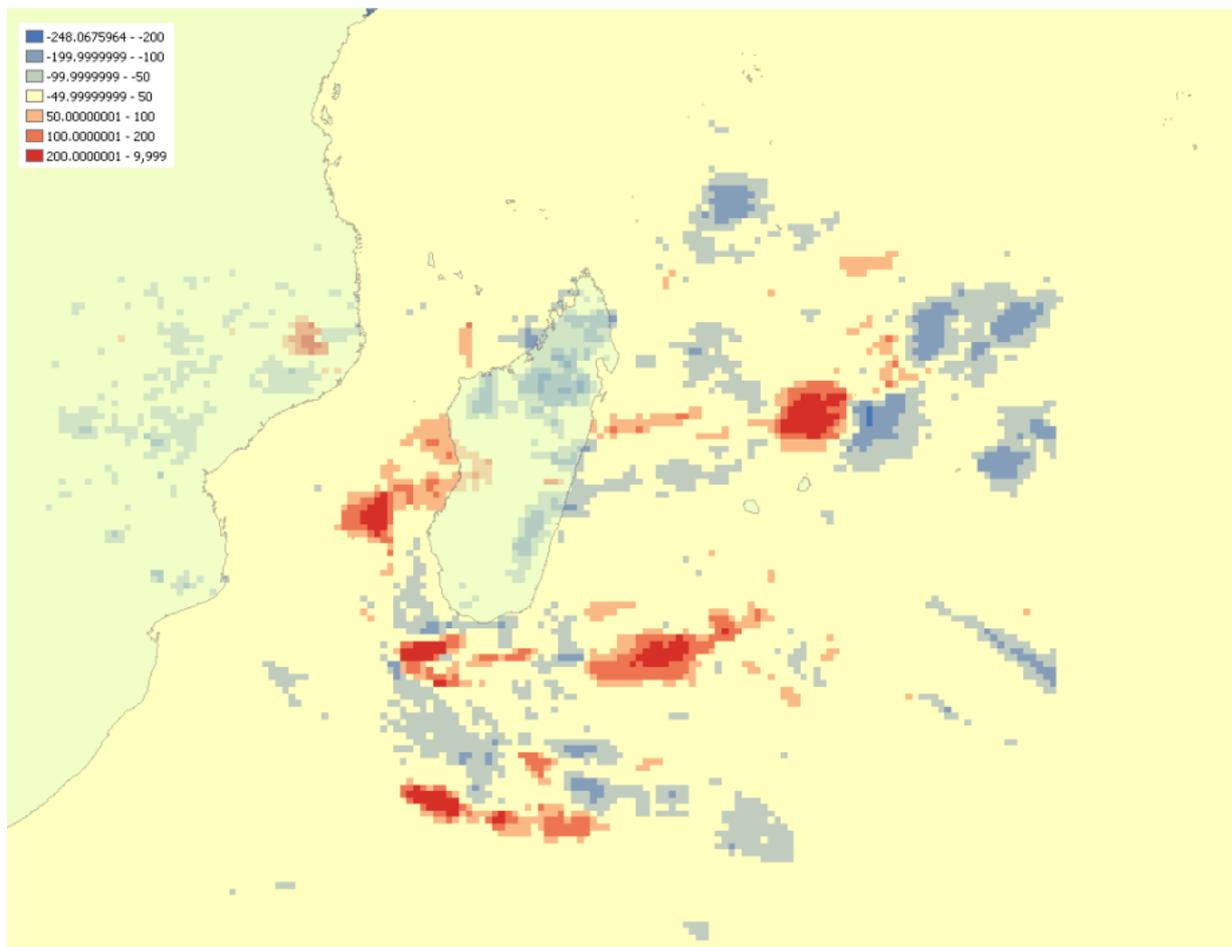
Figure 7 - Subtracted rainfall totals from TRMM and eTRaP. Red colours represent the areas where the values of eTRaP are higher than those of TRMM. Blue colours the areas where the values of eTRaP are lower than those of TRMM. Yellow colours are areas with differences less 50 mm

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[7] See for example Scientific Basis for Working Group I of the International Panel on Climate Change: Report http://www.ipcc.ch/ipccreports/tar/wg1/334.htm

2.2.2. Rainfall impact

In order to validate the performance as well as the consistency of the rainfall products, the ground measurement of the rain from the METAR stations available in Madagascar has been analysed (Figure 8). METAR data, redistributed by NOAA's Aviation Weather Center[8], was used in the absence of access to data from synoptic weather stations or rain gauges.

According to the METAR data, it appears that both TRMM and eTRaP overestimate the amount of rain to 2-3 times. This is not consistent with validation studies (Ebert *et al.*, 2009), which indicate a general underestimation of extreme rainfall. This comparison is not conclusive, since the quality of the METAR data is unknown.
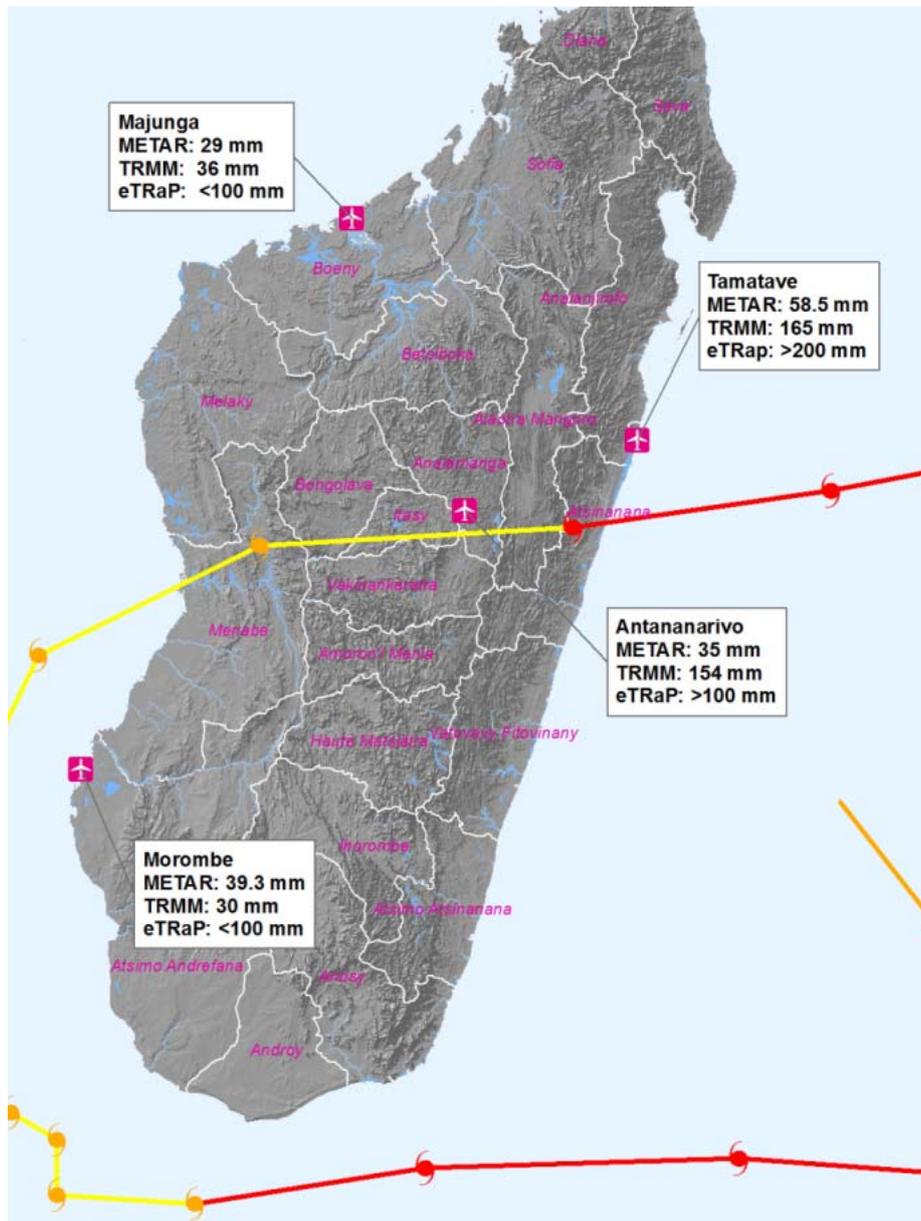
Figure 8 – METAR station vs TRMM and eTRaP estimations.

The real impact of the Cyclone Giovanna due to high rain should be evaluated with the information of floods and/or landslides. In the table of the BNGRC Report (Table 6 in Annex II) the number of flooded building are reported by district. The affected districts are shown in the maps below (Figure 9), together with the eTRaP and TRMM rainfall. In addition to the BNGRS Report, there are also reports on floods in area of Antananarivo[9].

The number of flooded houses, according to the BNGRC report (Table 6 in Annex II), are shown Table 2.
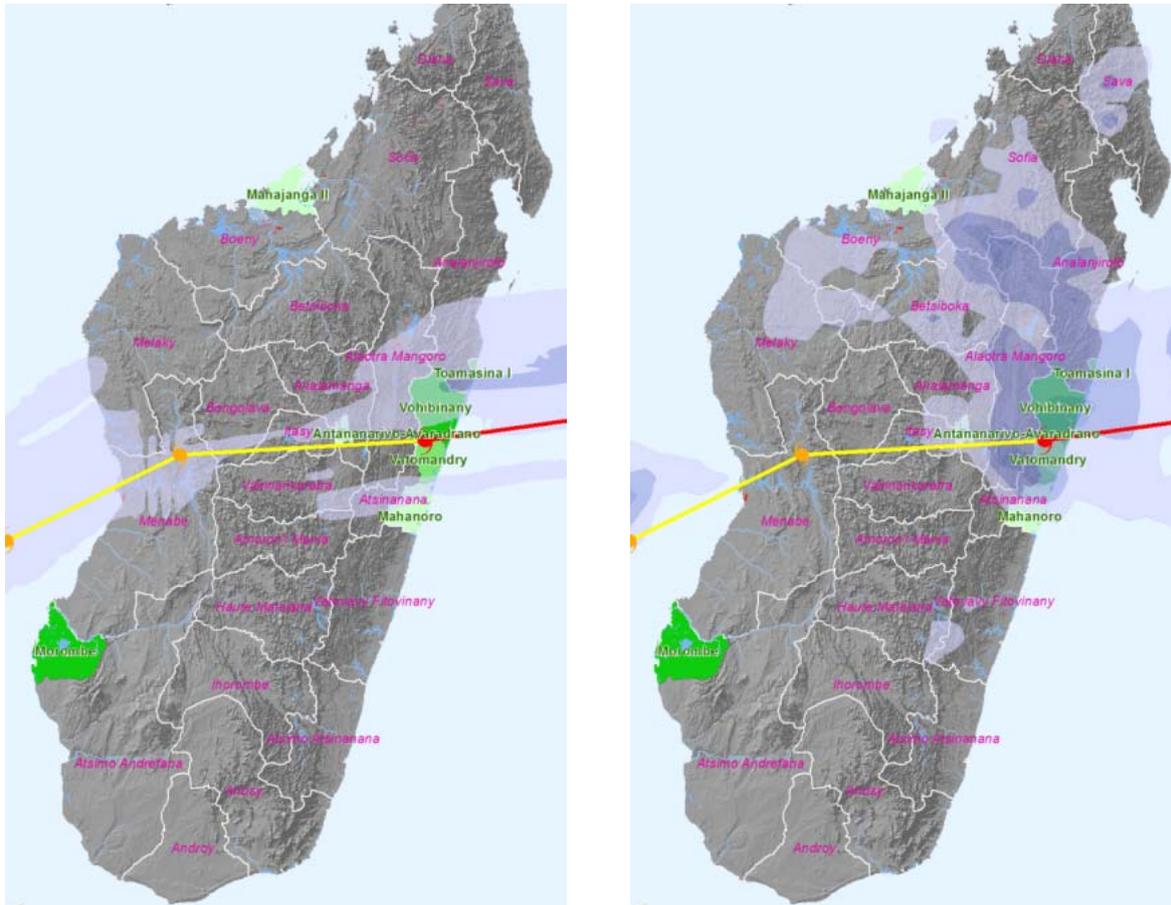
Figure 9 – Affected districts by flood in green scale. On the left eTRaP total rainfall above 100mm, on the right TRMM total rainfall above 100mm. Colour scale (rainfall in mm) of both images is identical: isochromes are set at 100mm.

We can notice that only TRMM shows rainfall in the north of the island, which can explain the floods in the district of Mahajangall. The reported floods in the Morombe district in the south-west of Madagascar do not have evidence in either of the rainfall models.

Nevertheless, the eTRaP and TRMM rainfall data are useful to identify areas at risk for flooding.

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[9] http://reliefweb.int/sites/reliefweb.int/files/resources/map_1686.pdf "In the capital, Antananarivo, flooding and the overflowing of the Imamba River was observed."

2.2.3. GDACS Alert Model for Rain

Currently, GDACS uses eTRaP accumulation data for its alert model. The GDACS model for the rain impact is simple, and sets alert levels based on total accumulation on land:

- **Green** when the total rain is below 200mm;
- **Orange** when is between 200mm and 500mm;
- **Red** when the total rain is above 500mm.

Usually, rainfall thresholds for alerting must consider the local climatology to identify anomalies. However, the accumulation during cyclones is so extreme that also absolute values can be used to set alert levels. The GDACS thresholds are high in order to avoid "false" alerts for minor events. Only extreme events that have a high likelihood of causing floods are flagged.

For the Cyclone Giovanna, the GDACS alert level was Orange in Madagascar and in Mozambique.

The rainfall in Mozambique might not be directly correlated with the cyclone system, but it was observed and included in the model space of eTRaP, and was therefore included in the analysis.

In Madagascar, minor-medium floods have been reported in the areas in Madagascar where eTRaP estimated more than 200mm (Figure 10, Toamasina, Vohibinany in the north and Mahanoro and Marolambo in the south). Heavier flood damage figures in the districts Brickaville (Vohibinany), Vatomadry and Antananarivo are not corresponding with eTRaP rainfall data. TRMM data, on the other hand, provides high accumulation values also in these regions.

ANTISANANA REGION			
District	*Houses flooded (source BNGRC)*	*Population (Houses, estimated using an occupancy rate of 4.6)*	*Ratio (%)*
Toamasina I	103	179,045 (38,923)	0.3%
Brickaville (Vohibinany)	384	159,301 (34,631)	1.1%
Vatomandry	122	129,146 (28,075)	0.4%
Mahanoro	10	212,118 (46,113)	0.02%

Table 2 - Number of houses flooded in Antisanana region, according to BNGRC report.

The rainfall data currently used in GDACS is sufficient to set an alert level (i.e. flag dangerous amounts of rainfall) and to identify the location at province level. More detailed information at district level is not reliable.
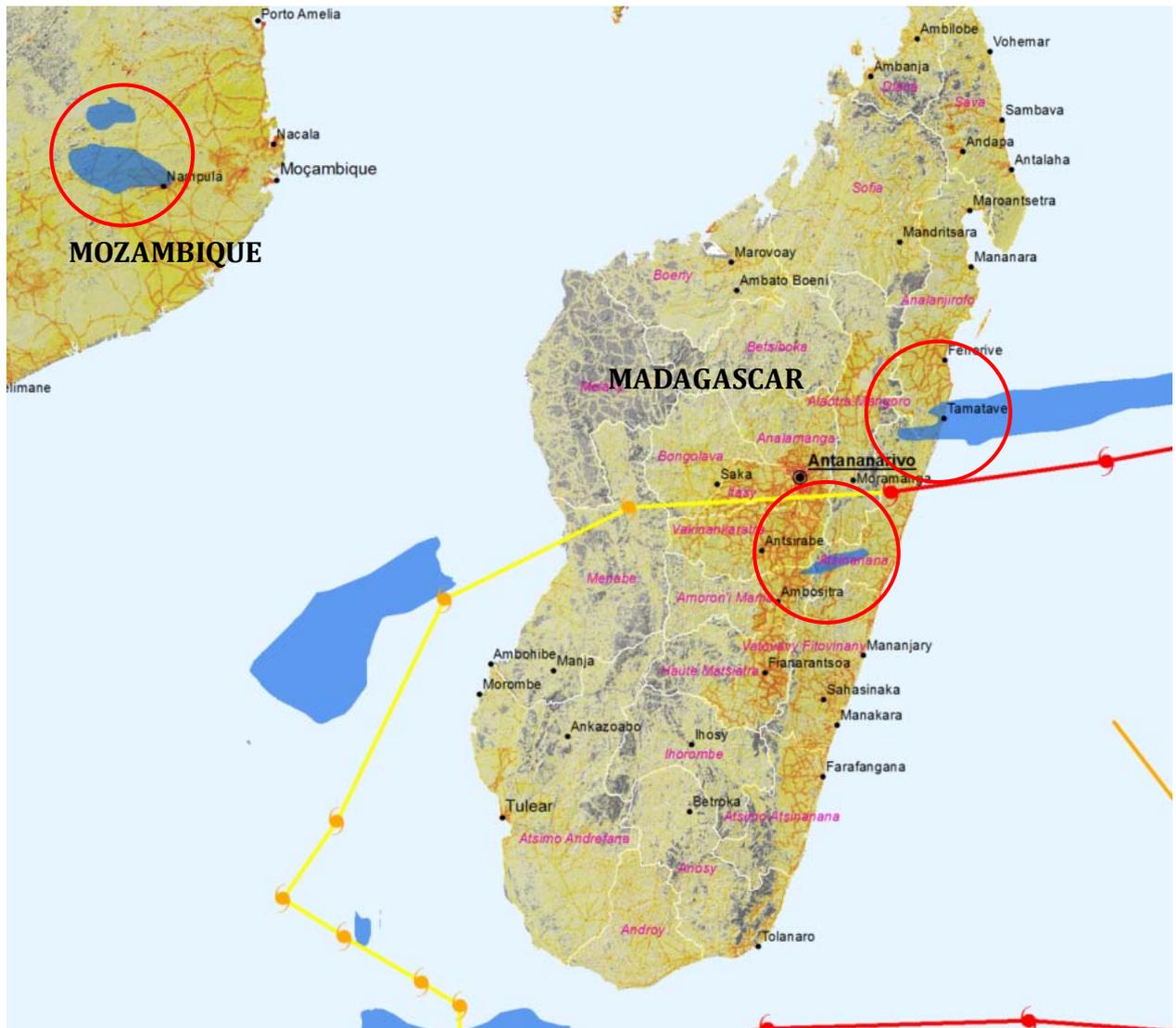
Figure 10 - Affected areas by medium rainfall accumulation in blue (200mm-500mm, GDACS Orange alert). The population density is shown in yellow-red scale.

2.3. STORM SURGE

Storm surge is an abnormal rise of water above the predicted astronomical tides, generated by strong winds and by a drop in the atmospheric pressure. In particular in areas with shallow coastlines, storm surges with category 5 cyclones can create surges of 5 meters and higher, causing inundation of coastal cities and land.

Saffir-Simpson Category	Maximum sustained wind speed			Storm surge	
	mi/h	m/s	kt	ft	m
1	74-95	33-42	64-82	3-5	1.0-1.7
2	96-110	43-49	83-95	6-8	1.8-2.6
3	111-130	50-58	96-113	9-12	2.7-3.8
4	131-155	59-69	114-135	13-18	3.9-5.6
5	156+	70+	136+	19+	5.7+

Table 3. Average storm surges per Saffir Simpson Category. In 2010, NOAA revised the scale and does not longer include the storm surge estimates, since they are generally not valid. http://www.aoml.noaa.gov/hrd/tcfaq/tcfaqHED.html.

The JRC has developed a hydrodynamic model for calculating the storm surge caused by cyclones in near real-time, therefore the above table is not used to estimate the storm surge.

2.3.1. Model Assessment

Model Description

The wind friction and pressure gradient of a cyclone generate long waves that can be modelled by the shallow water equations. Since 2004, the JRC has developed experience in tsunami early warning system (Annunziato, 2007) and inundation modelling using HyFlux2 code, which solves the shallow water equations by a finite volume method (Franchello, 2008; Franchello, 2010). Therefore the JRC has introduced the atmospheric forcing in the shallow water equations, solved by the HyFlux2 code, to simulate the storm surge phenomena.
The Holland parametric model (Holland, 1980; Holland et al. 2010) is used to infer such forcing into the source terms of the shallow water equations. This model develops an idealized representation of the TC, based on a few key parameters (Holland parameters): track, maximum wind speed (V_{max}) or minimum central pressure (P_c), and the radius of maximum wind (R_{max}). The method solves simplified equations and therefore is very efficient and widely used in storm surge modelling. The Holland's parameters are not globally available; therefore the JRC has developed a Monte Carlo method to obtain the required parameters using the data available[10] in the cyclones bulletins provided by the Joint Typhoon Warning Centre, through the Pacific Disaster Centre (PDC). These bulletins are described in Annex 1.

Calculation

The calculation has been performed using PDC bulletins[11], which include the analysis (time 0) and the forecasts. When a new bulletin is available an automatic procedure submits a simulation . The initial conditions of the simulation are taken from the results at time 0 of the

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[10] Maximum velocity (*Vmax*) and wind radii at 39, 58 and 74mph in the four quadrants.

[11] Tropical Cyclone developed in the South Indian Ocean. In this basin, the bulletins, provided by PDC, are based on Joint Typhoon Warning Centre (JTWC) data. Hereafter, these bulletins will be named **PDC/JTWC bulletins**.

previous bulletin[12]. A forecast of 72 hour is performed. The published results are related from past to current bulletins.

The map of the maximum storm surge, from bulletin 1 to bulletin 24, simulated by HyFlux2 is shown in Figure 11. A maximum storm surge more than 1m has been calculated in the landfall area in the East coast of Madagascar. The calculations obtained using as input the bulletins provided before and after the landfall in this area are shown in the Table 4 and

Table 5.

Figure 11 - Maximum sea level above normal tide simulated by HyFlux2

a) _FORECAST – Simulation 1 day before landfall_

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[12] In case of bulletin delivered every 6 hours the simulation starts at time -6 hours in respect to the actual forecast

One day before the landfall, using as input the forecast data **of Bulletin 9 (13February 00UTC)**, we estimated a possible storm surge of more than 1 m (from 20 to 00UTC) in the area of Vavony (with an uncertainty of 50 km north/south), with a maximum storm surge of 1.6 m in Vavony forecast for 13 February at 22 UTC (see Table 4).

Date	Name	Country	Storm surge height (m)
13 Feb 2012 22:00:00	Vavony		1.6m
13 Feb 2012 22:00:00	Ampanotoamaizina	Madagascar	1.3m
13 Feb 2012 22:00:00	Ambila-Lemaitso	Madagascar	1.2m
13 Feb 2012 22:00:00	Kalomalala		1.0m
14 Feb 2012 00:00:00	Vohitramposina	Madagascar	1.0m
13 Feb 2012 22:00:00	Amboditafara	Madagascar	0.9m
13 Feb 2012 21:00:00	Tampina	Madagascar	0.8m
13 Feb 2012 23:00:00	Ampitabe	Madagascar	0.8m
14 Feb 2012 20:00:00	Antohgo		0.7m
14 Feb 2012 21:00:00	Kivalo Est		0.7m
14 Feb 2012 21:00:00	Morondava	Madagascar	0.7m
13 Feb 2012 23:00:00	Manakambahiny	Madagascar	0.6m
13 Feb 2012 20:00:00	Tamatave	Madagascar	0.5m
13 Feb 2012 20:00:00	Mahatsara	Madagascar	0.5m

Table 4 - Locations affected by storm surge. (Calculations based on advisory number 9)

b) *Simulation after landfall*

Using the first bulletin available after the landfall (**bulletin 11 of 14 February 00UTC**), we estimated a maximum storm surge of 1.7m in Vohitramposina at 23UTC (

Table 5).

Date	Name	Country	Storm surge height (m)
13 Feb 2012 23:00:00	Vohitramposina	Madagascar	1.7m
13 Feb 2012 22:00:00	Ampitabe	Madagascar	1.4m
13 Feb 2012 23:00:00	Manakambahiny	Madagascar	1.4m
13 Feb 2012 22:00:00	Kalomalala		1.3m
13 Feb 2012 22:00:00	Amboditafara	Madagascar	1.3m
13 Feb 2012 22:00:00	Ambila-Lemaitso	Madagascar	1.0m
13 Feb 2012 19:00:00	Ampanotoamaizina	Madagascar	0.9m
13 Feb 2012 23:00:00	Vatomandry	Madagascar	0.9m
14 Feb 2012 00:00:00	Ambohidara	Madagascar	0.8m
13 Feb 2012 23:00:00	Maintinandry	Madagascar	0.7m
13 Feb 2012 23:00:00	Seranandavitra	Madagascar	0.7m
14 Feb 2012 00:00:00	Marosiky	Madagascar	0.7m
13 Feb 2012 19:00:00	Ankarefo	Madagascar	0.5m
13 Feb 2012 19:00:00	Tampina	Madagascar	0.5m

Table 5 -Locations affected by Storm surge (Calculation based on bulletin 11)
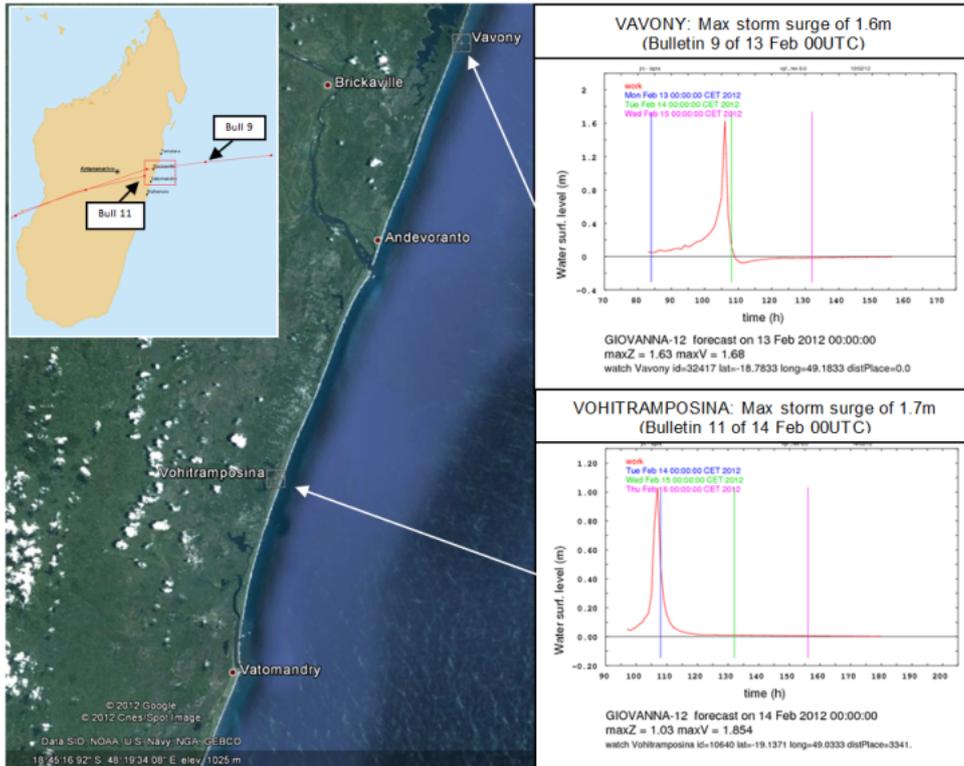
Figure 12 - Locations affected by the max of storm surge, using as input the bulletin provided before the landfall (in Vavony) and after landfall (in Vatomandry) and plot of the event time.

The height of maximum storm surge calculated using the data provided before and after the landfall is very similar, but there is a difference in the location of max height: before the landfall the maximum height was estimated in Vavony (1.6m), after the landfall in Vohitramposina (1.7m). Vohitramposina is around 45 km South of Vavony. This difference is due to the fact that the forecast track of bulletin 9 was further to the North than the track of bulletin 11.

Measurements

In order to evaluate JRC storm surge model, we try to compare our calculations with the measurements of the tide gauge located in Toamasina, around 90 km N of the "landfall cyclone eye" (Figure 14).

The tide gauge in Toamasina is the *"VEGA VEGAPULS62 CONTACT FREE RADAR SENSOR",* deployed by SHOM, a pulsed-wave contact-free radar that transmits in the K band (around 26 GHz). The operating principle is based on the measurement of the transmission time of the microwave pulse-transmitted by the radar and reflected by the interface to be measured. Half of this time is equivalent to the distance between the sensor's reference point and the surface of the water[13]. The location and the image of this tide gauge are shown in Figure 13.

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[13] source: *SHOM (*http://refmar.shom.fr/instrumentations-maregraphiques*)*
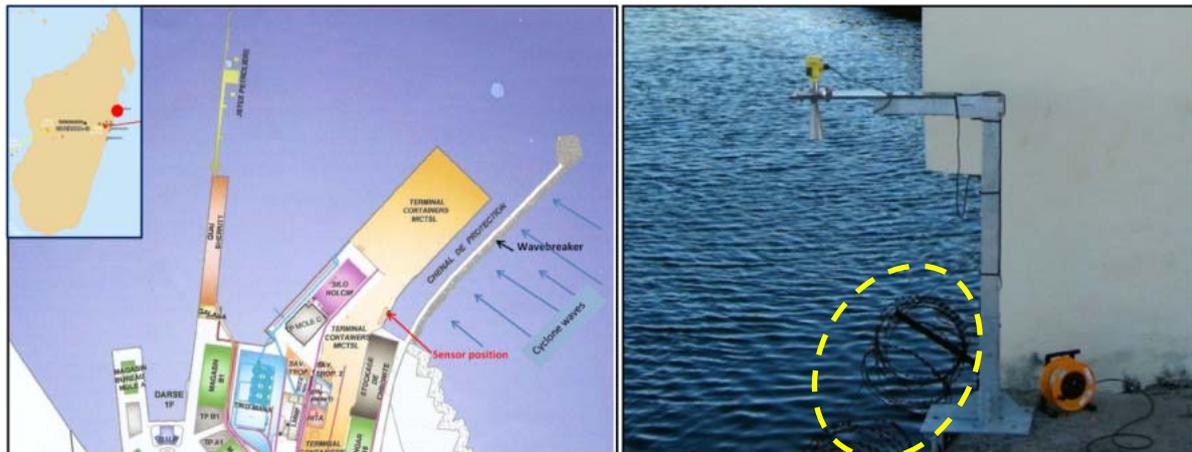
Figure 13 - Vega Vegapuls62 radar sensor in the open air - Toamasina (Madagascar) tide gauge observatory (Source: SHOM http://refmar.shom.fr/image/image_gallery?uuid=b4a9dc3f-de85-4b72-91e8-5ad1a864ca78&groupId=10227&t=1312547547320)

The tide gauge measurements in Toamasina showed, for the period between 13 February 10UTC and 14 February 06UTC, an increase of sea level above 2 m (the instrument went off scale), with strong oscillations probably due to the cyclone winds (Figure 14, bottom). HyFlux2 code estimated in that location a storm surge lower than 20 cm (Figure 14, top). According to local port authority (Personal Communication, 02/2012), a sea level increase of 2 m didn't occur: they noted an increase not more than 50 cm. Under the device there is a barbed wire (see yellow circle in Figure 13). When this wire is wet, the signal of the sensor reflected over it before reaching the sea, consequently a wrong sea level is recorded (Personal Communication, 09/2012). Therefore the recorded value of 2 m is due to this barbed wire. Moreover in front of the device there is a wave breaker (Figure 13), where the cyclone waves break and the remaining seawater and sea sprays fly over this device, affecting the observations correctness. Other tide gauges, suitable to evaluate our calculations, are not available in the area, making validation of the storm surge calculation with in-situ data impossible. It should be noted that those measurements have been installed to measure tsunami surge and not tropical cyclones storm surge.
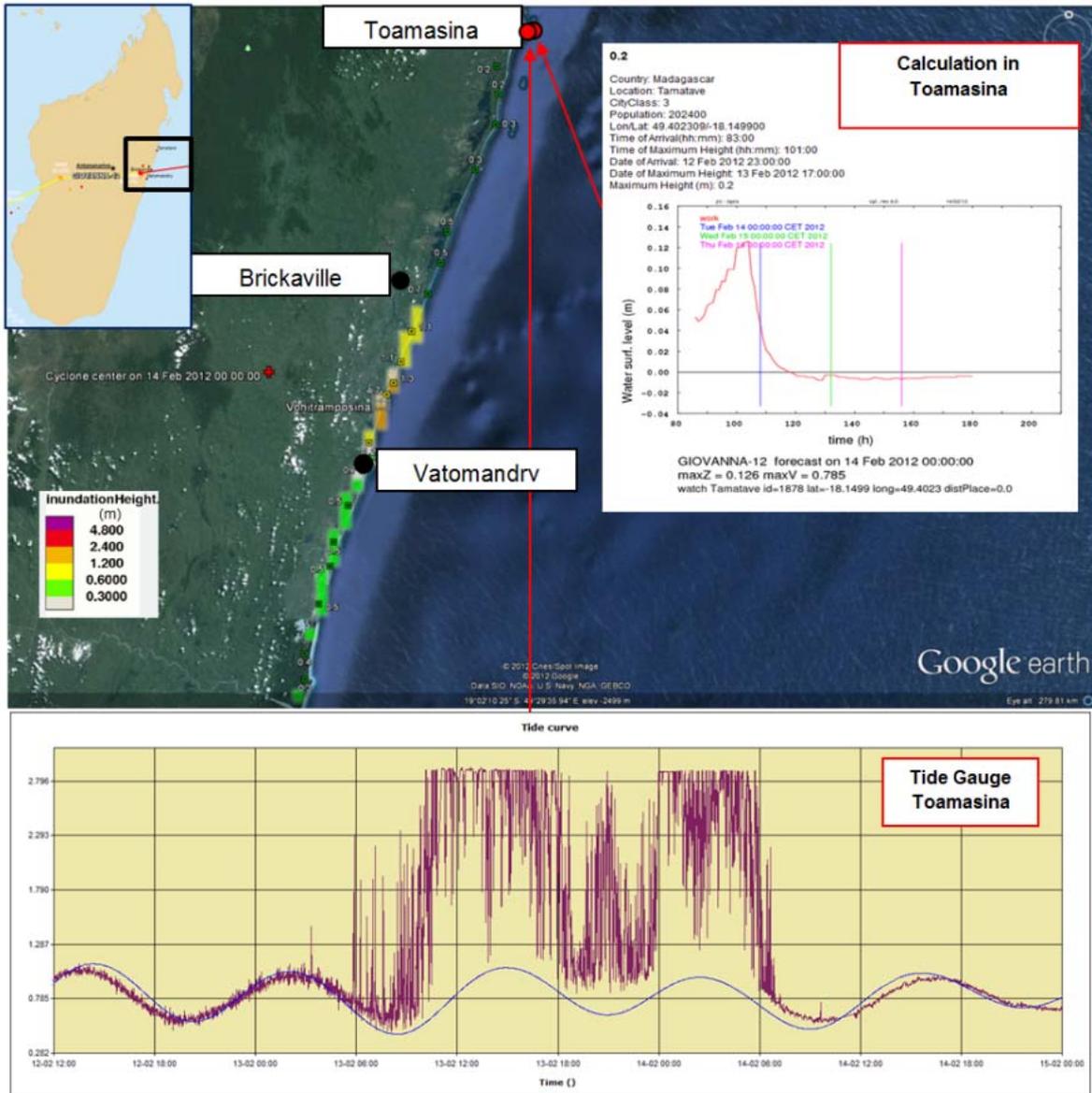
Figure 14 - Inundation height calculated and mean sea level observed at the Toamasina tide gauge

Calculations using different input data

In order to assess the simulation uncertainty, additional calculations have been performed using wind field parameters published by Météo-France Regional Specialized Meteorological Centre (RSMC) La Réunion and a NOAA-NESDIS satellite product[14] described in Annex I.

The maximum sea level above normal tide simulated by HyFlux2, using as input the PDC/JTWC and RSMC La Reunion bulletins (called hereafter TC bulletins) and the NOAA-NESDIS data, is shown in Figure 15.

The results of these calculations show that:

- The area affected by storm surge (when the TC was located North of La Reunion and Mauritius Islands) calculated using RSMC La Reunion data was wider than that using PDC/JTWC data.
- Giovanna's wind speed predictions were more intense in PDC/JTWC bulletins than in those of RSMC La Reunion. As a consequence, the maximum storm surge calculated using these data is higher than that using RSMC La Reunion data.
- The place of maximum storm surge (Vohintramposina) calculated using the PDC/JTWC bulletins was the same of that obtained using RSMC La Reunion data, but the value using PDC/JTWC data (1.7m) was higher than that using RSMC La Reunion data (1.1m).
- The TC bulletins and the NOAA NESDIS had a different track: the track of satellite observations was further to the South, than that of the TC bulletins. As a consequence, the maximum storm surge calculated based on NESDIS data was 60km more south (1.3m in Ambohidara).

In Toamasina the calculations using as inputs RSMC La Reunion bulletins and NOAA satellite data showed a storm surge lower than 20cm (Figure 15), a result consistent with PDC/JTWC bulletins. We can conclude that this tide gauge is not well equipped to measure storm surge in cyclone conditions.

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[14] In our calculations we have used the NOAA product for storm surge modeling, which provides track, V_{max}, wind radii, R_{max}, Pc and Environmental Pressure every 6 hours.
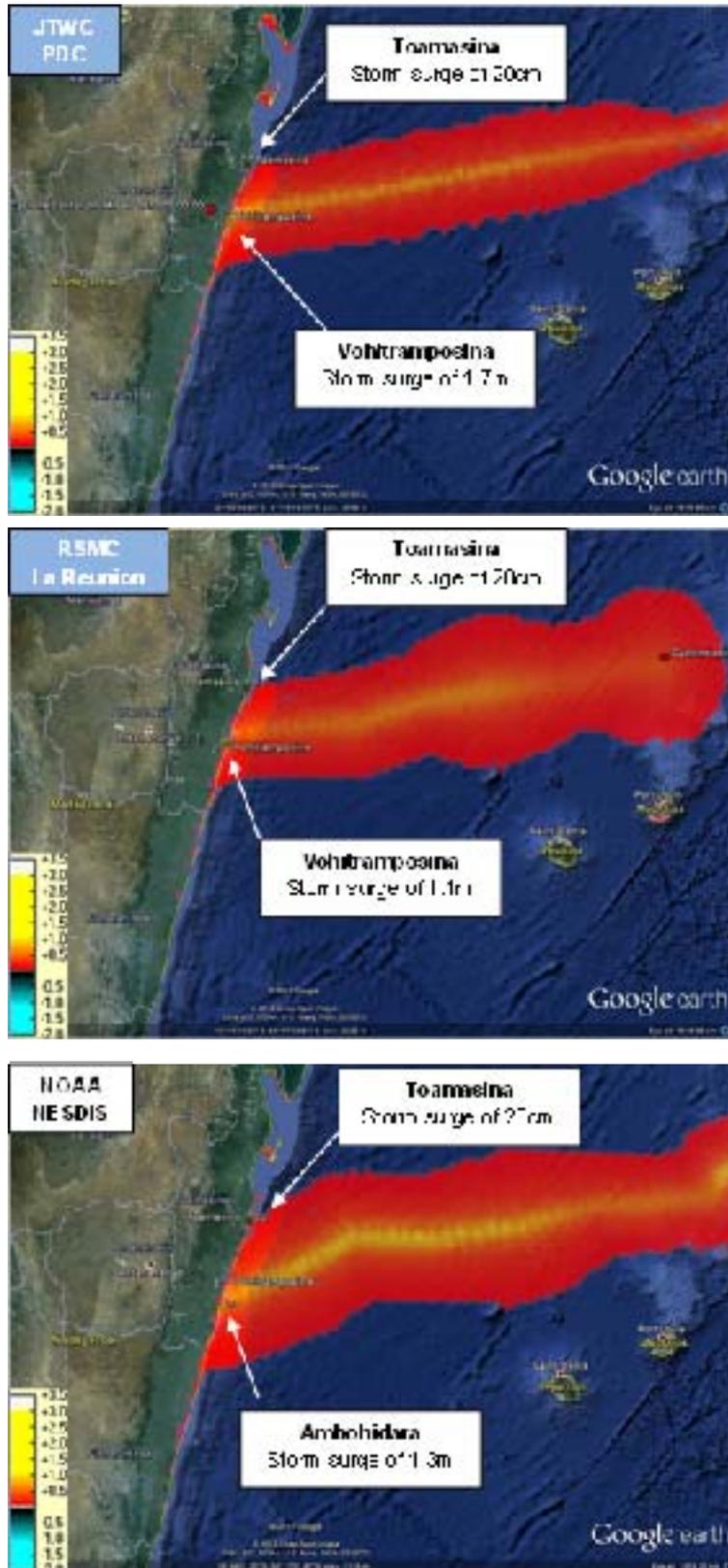
Figure 15 - Maximum sea level above normal tide simulated by HyFlux2, using as input the PDC/JTWC bulletins (top), RSMC-La Reunion bulletins (middle) and NOAA-NESDIS data (bottom).

2.3.2. Storm surge impact

The governmental BNGRC reports do not mention specifically on storm surge impact. However, UNOSAT/UNITAR, a United Nations entity producing rapid satellite-based maps in the aftermath of disasters, produced two damaged assessment maps including storm surge damage: one for the City of Vatomandry (Figure 16) and one for Brickaville (Figure 17). These maps give a clear indication of the extensive damage to buildings as a result of strong winds and storm surge within the coastal city of Vatomandry and in the area of Brickaville, along the Rianila River. Below a "selection" of these maps is presented, the full maps can be found at http://www.unitar.org .
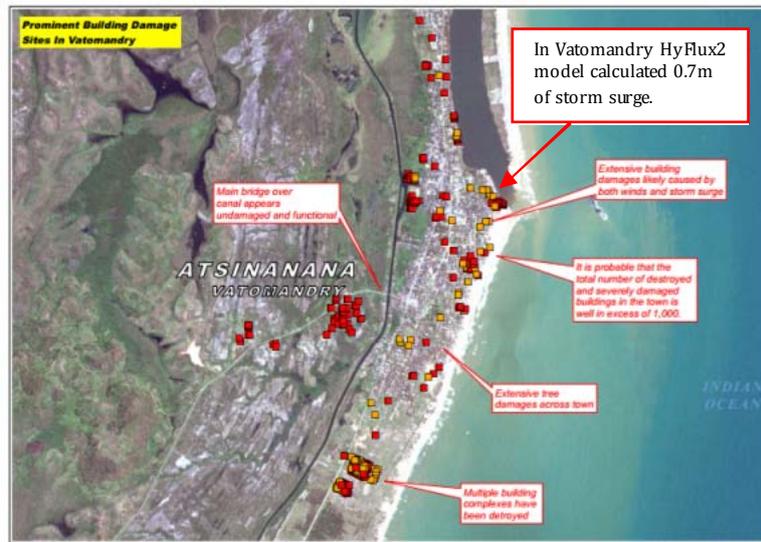
Figure 16 – Selection of *UNITAR/UNOSAT Building Damage Sites in Vatomandry* Map (Source: http://unosat-maps.web.cern.ch/unosat-maps/MD/TC20120218MDG/UNOSAT_MDG_TC2012-VatomandryDamages_v2.pdf)

Figure 17 – Selection of *UNITAR/UNOSAT Building Damage Sites in Brickaville* Map (Source: http://unosat-maps.web.cern.ch/unosat-maps/MD/TC20120218MDG/UNOSAT_MDG_TC2011-BrickavilleDamages_v1.pdf)
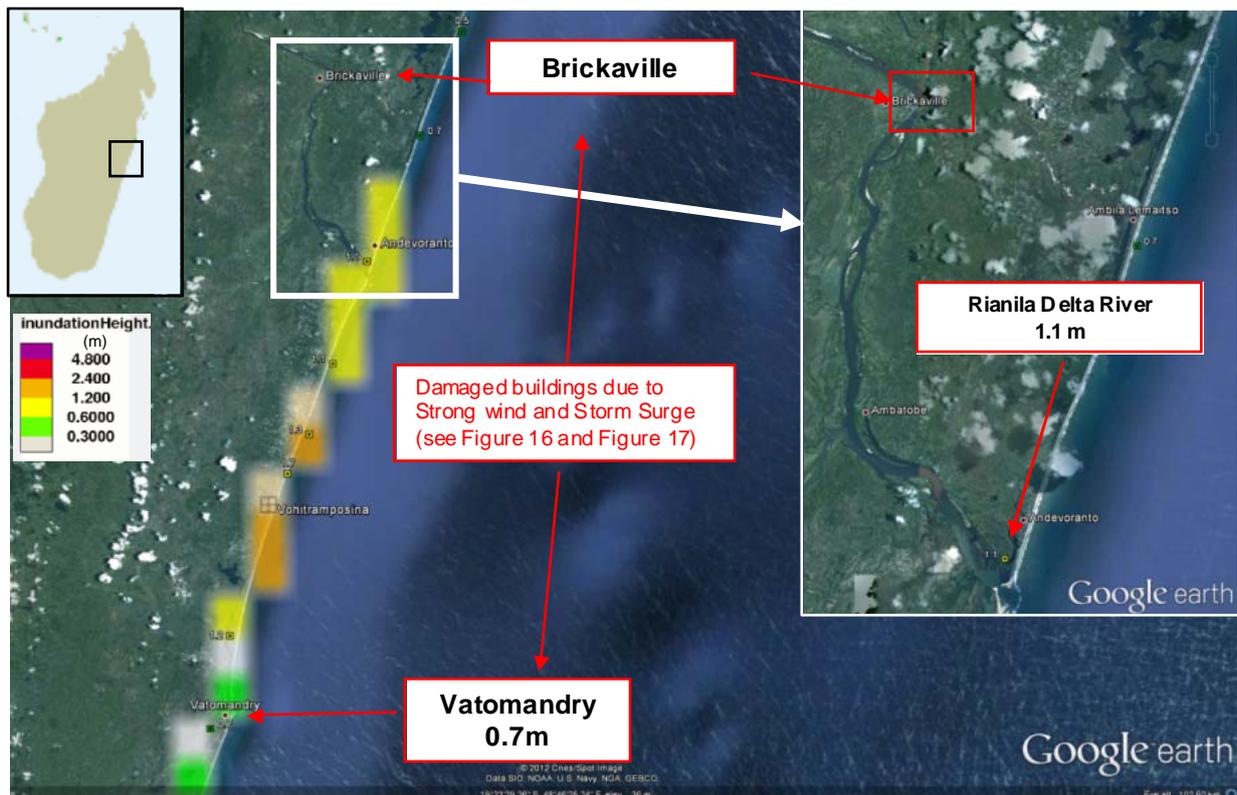
Figure 18 - Storm Surge calculated in Brickaville and Vatomandry using as input PDC/JTWC Bulletins

The storm surge calculated by HyFlux 2, using as input PDC/JTWC Bulletin 11, in the area of Vatomandry and Brickaville is shown in Figure 18. In Vatomandry a 0.7 m storm surge has been calculated by the JRC model. The storm surge in Brickaville can be due to wind effects on the Rianila River, in a point which is 20km far from the Sea; this effect is not yet included in HyFlux2 storm surge model : however, in the delta of the river a storm surge of 1.1m has been calculated.

2.3.3. GDACS Alert model for Storm Surge

The GDACS alert levels are based on the maximum storm surge height:
- **Green** when the storm surge is below 1.5m;
- **Orange** when the storm surge is between 1.5m and 3m;
- **Red** when the storm surge is above 3m.

For tropical cyclone Giovanna, the GDACS alert level was Orange in Madagascar.

3. CONCLUSION

JRC has developed GDACS, an early warning system created to alert the humanitarian community about potential disasters which are under development. Tropical cyclones are some of the most damaging events, affecting the coastal population with three dangerous effects: strong wind, heavy rain and storm surge. GDACS includes the analysis of the first and the second effects, and recently also the third effect (storm surge) has been implemented.

The overall GDACS alert level for tropical cyclone Giovanna in Madagascar was Red. The overall alert level is the maximum of the three components: red for wind impact, orange for rain and orange storm surge impact. An impact assessment for all the three alerts has been presented in this report.

The wind impact assessment by BNGRC has shown that most of the damage due to Giovanna was caused by strong winds. The region most affected has been Antisanana. GDACS alert level was Red, due to the high wind and the high vulnerability of the country in the same area.

The rain impact alert level in GDACS is based on the estimation of the total accumulation of rainfall on land using NOAA eTRaP data; for Giovanna the alert level was Orange (total accumulation between 200-500mm) in Madagascar and in Mozambique. The analysis showed that eTRaP rainfall data is consistent with other data, but has spatial and temporal differences. In the absence of rain gauge data, the absolute accuracy could not be established. We compared the data with officially reported flood damage. The applicability of the data was considered fine for alert levels at regional level, but not at local level due to spatial uncertainty.

The storm surge GDACS alert level is based on the HyFlux2 calculations; for Giovanna in Madagascar the alert level was Orange (max height between 1.5-3m). In the absence of accurate tide gauge data, the absolute accuracy could not be established. We compared our results with two UNOSAT/UNITAR impact assessment maps of two damaged cities (Brickaville and Vatomadry). These maps gave a clear indication of building damages, as a result of strong winds and storm surge. JRC calculations showed a storm surge of 0.7m in Vatomandry and 1.1 m in the delta of Rinanila River which is 20 km downstream of Brickaville where the storm surge was detected.

Overall, the GDACS models performed well. Alert levels for all hazard components were consistent with the observed impact. The location and timing of the information could accurately identify the affected provinces. GDACS information is appropriate for near real-time strategic decision making.

4. ANNEXES

ANNEX I: Tropical Cyclone Data

PDC/JTWC Tropical Cyclone Data

TCs around the globe are monitored as a result of international cooperation, coordinated at the global and regional levels by World Meteorological Organization (WMO). The Regional Specialized Meteorological Centres (RSMCs) and the Tropical Cyclone Warning Centres (TCWCs), have the regional responsibility to forecast and monitor the TCs (http://www.wmo.int/pages/prog/www/tcp/Advisories-RSMCs.html).   Also   other organizations, such as the Joint Typhoon Warning Center (JTWC), provide information about tropical cyclones to the public. The data in the TC bulletins are not available in a single standard format, making it difficult to use in an automatic system like GDACS. To overcome this problem, Pacific Disaster Center (PDC, www.pdc.org), set up an automatic routine which includes TC bulletins from all RSMCs and TCWCs into a single database covering all TC basins. The NOAA bulletins are included for the Atlantic, Eastern Pacific and Central Pacific basins, while the JTWC bulletins are included for the rest of the world. TC GIOVANNA developed in the South Indian Ocean, therefore in this basin the TC bulletins provided by PDC include JTWC data. JTWC is the U.S. Department of Defence agency responsible for issuing tropical cyclone warnings for the Pacific and Indian Oceans. JTWC products in the North Pacific and North Indian Ocean tropical cyclone warnings are routinely updated every six hours, while in South Indian and South Pacific Ocean are routinely updated every twelve hours. The bulletins include position of TC center, the maximum sustained wind based on 1-min average (V_{max}) and the wind radii. The wind radii represent the maximum radial extent – in nautical miles - of winds reaching 34, 50, and 64 knots in each quadrant (NE, SE, SW, and NW). More information can be found at www.usno.navy.mil/JTWC/

RSMC La Réunion Tropical Cyclone Bulletins

RSMC La Réunion Bulletin: These bulletins provide forecasts of track and intensity (Vmax) through 120h. Wind Radii are given by quadrant for 28 knots, 34, 48, 64 knots plus the Radius of Maximum winds (R_{max}). Number of wind radii and R_{max} forecast are provided. More information at http://www.meteo.fr/temps/domtom/La_Reunion/meteoreunion2/ .

NOAA - NESDIS MTCSWA product

National Oceanic and Atmospheric Administration (NOAA) - National Environmental Satellite, Data, and Information Service (NESDIS) MTCSWA product: it is a Multiplatform Tropical Cyclone Surface Wind Analysis (MTCSWA) product, which provides six-hourly estimates of Tropical Cyclone wind fields based on a variety of satellite based winds and wind   proxies.   Several   data,   text   and   graphical   products   are   available   at http://www.ssd.noaa.gov/PS/TROP/mtcswa.html. In our analysis we have used the graphical product - surface wind analysis (inner core scale) - and the storm surge text product, which provides track, V_{max}, wind radii, R_{max}, P_c and Environmental Pressure every 6 hours. More information in Knaff and De Maria (2010).

ANNEX II: AFFECTED AREA AND POPULATION

As of April 06, 15:00 UTC, the damage toll of the passage of Tropical Cyclone GIOVANNA-12 across Madagascar was 35 dead, 284 injured, 246,869 affected, 44,159 houses completely destroyed (see Table 6).

Most of the damage was caused by strong wind.

- Total houses unroofed: 27 656
- Total houses flooded: 1 135

CLUSTER HABITAT

REGIONS / DISTRICTS	Nbr total de communes	Nbr de communes ayant fournies les données	Décédés	Blessés	Disparus	Sinistrés	Cas des communes chefs lieu	Cas des communes en dehors des chefs lieux	Totalement Détruites	Endommagées (décoiffées)	Inondées	Totalement Détruites	Endommagées (décoiffées)	Inondées	Sites d'hébergements actuels
AMORON'I MANIA															0
AMBOSITRA	18	2	0	2	0	0	0	145	26	15	0	0	0	0	0
MANANDRIANA	5	5	0	0	0	0	0	0	4	112	0	0	2		0
VATOVAVY FITOVINANY															0
NOSY VARIKA	22	2	0	20	0	1820	0	0	394	0	0	0	0		0
IFANADIANA	12	1	0	2	0	0	0	0	2	0	0	0	4		0
ALAOTRA MANGORO															0
AMBATONDRAZAKA	20	20	3	5	0	705	0	0	117	15	0	0	0		0
ANOSIBE AN'ALA	9	5	0	0	0	108	0	0	30	3	0	0	0		0
MORAMANGA	10	10	12	3	0	6304	0	0	361	1354	0	0	25		0
ATSINANANA															0
BRICKAVILLE	17	17	11	188	0	101747	925	8221	6627	10303	384	0	0	0	0
TOAMASINA I	1	1	0	3	0	0	0	0	33	201	103	0	0		0
ANTANAMBAO MANAMPOTSY	5	0	0	0	0	500	0	0	730	270	0	1	1		0
VATOMANDRY	19	19	2	25	0	108602	1167	21061	30496	12902	122	0	0		0
TOAMASINA II	17	7	0	0	0	1068	614	0	979	0	0	0	0		0
MAHANORO	11	5	0	5	0	10748	0	742	525	217	10	0	0		EPP, District, Asos, espace privé / 0
MAROLAMBO	17	1	1	0	0	0	0	0	0	0	0	0	0		0
HAUTE MATSIATRA															0
AMBOHIMAHASOA	14	1	0	0	0	0	0	0	4	0	0	0	9		0
IKALAMAVONY	8	1	0	0	0	0	0	0	1	2	0	0	0		0
ATSIMO ANDREFANA															0
MOROMBE	8	1	0	0	0	0	0	0	40	0	407	0	1		0
BOENY															0
MAHAJANGAII	10	1	0	0	0	0	0	0	0	0	1	0	0	1	0
SOFIA															0
MAMPIKONY	8	2	3	0	0	7270	1225	0	72	834	0	0	0		0
MENABE															0
MIANDRIVAZO	4	1	0	0	0	150	0	0	0	20	0	0	0		0
BELO-SUR-TSIRIBIHINA	12	1				119			15	2					0
ANALAMANGA															0
ANTANANARIVO-ATSIMONDRANO	13	12	0	0	0	522	0	0	8	272	4	0			0
ANTANANARIVO-AVARADRANO	14	14	1		0	2336		0	781		1				0
AMBOHIDRATRIMO	25	25	0		0	31	0	0	11	0	0	0	13		0
ANDRAMASINA	12	12	0		0	540	0	0	45	220	0	0	0		0
ANKAZOBE	13	2	0		0	16	0	0	0	0	0	0			0
ANJOZOROBE		1	0		0	0	0	0		99	0	0	8		0
MANJAKANDRIANA	25	20	0		0	1557	0	0	1260	24	0	0	0		0
ANTANANARIVO-RENIVOHITRA	6	6	1	23	0	1581	82	0	43	60	103	0			FJKM Mandroseza, Grande salle FIP / 0
ITASY															0
MIARINARIVO		8	0		0	384	0	0	42	0	0	0	4		0
SOAVINANDRIANA	15	7	0		0	48	0	0	5	0	0	0	0		0
ARIVONIMAMO	22	13	0		0	163	0	0	25	0	0	0	4		0
MELAKY															0
MAINTIRANO	16	1	1		0	0	0	0	0	0	0	0	0		0
VAKINANKARATRA															0
AMBATOLAMPY		15	0		0	0	0	0	1513	651	0	0	0		0
ANTANIFOTSY		1	0		0	0	0	0		5	0	0	0		0
ANTSIRABE I		1	0	8	0	0	0	0	0	0	0	0	0		0
FARATSIHO		1	0		0	550	0	0		35	0	0	0		0
MANDOTO		1	0		0	0	0	0		5	0	0	0		0
ANDROY															0
BELOHA		1								5			1		0
TOTAL	697	250	35	284	0	246 869	4 013	30 169	44 159	27 656	1 135	1	72	1	0

Table 6 - BNGRC Report (as of 06 April 2012) – CLUSTER HABITAT (Source: BNGRC Report)

BILAN DES DEGATS HUMAIN ET MATERIEL SUITE AU PASSAGE DU CYCLONE TROPICAL TRES INTENSE GIOVANNA

MAMPIKONY
-> 03 décédés
-> 7 270 sinistrés
-> 1 225 déplacés
-> 72 cases détruites
-> 834 cases endommagées

AMBATONDRAZAKA
-> 03 décédés
-> 05 blessés
-> 705 sinistrés
-> 117 cases détruites
-> 15 cases endommagées

TAMATAVE II
-> 1 058 sinistrés
-> 614 déplacés
-> 979 cases détruites

MORAMANGA
-> 12 décédés
-> 03 blessés
-> 6 304 sinistrés
-> 361 cases détruites
-> 1 354 cases endommagées
-> 25 logements administratifs

BRICKAVILLE
-> 11 décédés
-> 188 blessés
-> 101 747 sinistrés
-> 9 146 déplacés
-> 6 527 cases détruites
-> 10 303 cases endommagées
-> 384 cases inondées

MANJAKANDRIANA
-> 1 557 sinistrés
-> 1 260 cases détruites
-> 24 cases endommagées

VATOMANDRY
-> 02 décédés
-> 25 blessés
-> 108 602 sinistrés
-> 22 228 déplacés
-> 30 496 cases détruites
-> 12 902 cases endommagées
-> 122 cases inondées

ANTANANARIVO AVARADRANO
-> 01 décédé
-> 2 336 sinistrés
-> 781 cases détruites
-> 01 case inondée

MAINTIRANO
-> 01 décédé

ANTANAMBAO MANAMPOTSY
-> 500 sinistrés
-> 730 cases détruites
-> 270 cases endommagées
-> 01 logement administratif détruit
-> 01 logement administratif

ANTANANRIVO RENIVOHITRA
-> 01 décédé
-> 23 blessés
-> 1 581 sinistrés
-> 82 déplacés
-> 43 cases détruites
-> 60 cases endommagées
-> 103 cases inondées

MAHANORO
-> 05 blessés
-> 10 748 sinistrés
-> 742 déplacés
-> 525 cases détruites
-> 217 cases endommagées
-> 10 cases inondées

BELO / TSIRIBIHINA
-> 119 sinistrés
-> 15 cases détruites
-> 02 cases endommagées

MIANDRIVAZO
-> 150 sinistrés
-> 20 cases endommagées

MAROLAMBO
-> 01 décédé

SOAVINANDRIANA
-> 48 sinistrés
-> 05 cases détruites

NOSY VARIKA
-> 20 blessés
-> 1 820 sinistrés
-> 394 cases détruites

MIARINARIVO
-> 384 sinistrés
-> 42 cases détruites
-> 04 logements administratifs endommagés

AMBOSITRA
-> 02 blessés
-> 145 sinistrés
-> 145 déplacés
-> 26 cases détruites

ARIVONIMAMO
-> 163 sinistrés
-> 25 cases endommagées
-> 04 logements administratifs endommagés

TOTAL BILAN HUMAIN
-> Décédés: 35
-> Blessés: 284
-> Disparu: 00
-> Sinistrés: 246 869
-> Déplacés: 34 182
-> Cases détruites: 44 159
-> Cases endommagées: 27 656
-> Cases inondées: 1 135

MOROMBE
-> 40 cases détruites
-> 407 cases inondées

IFANADIANA
-> 02 blessés
-> 02 cases détruites
-> 04 logements administratifs endommagés

Bureau National de Gestion des Risques et des Catastrophes

Cyclone tropical très intense GIOVANNA (Février 2012)
Situation du 28 Mars 2012

Sources de données:
BNGRC/CERVO, FTM et METEO MALAGASY

Légende
Nombre de sinistrés
· 0 - 384
● 385 - 1068
◉ 1069 - 2336
◎ 2337 - 10748
◉ 10749 - 108602

Nombre de décès
0
1
2
3
11
12
— Trajectoire du Giovanna

Créé : 28 Mars 2012
Document : Carte_bilan_Giovanna.mxd
Projection / datum: UTM 38 / WGS 84 zone 38 S
Numéro GLIDE : TC-2012-000020-CCC

Produit du BNGRC / CERVO
http://www.bngrc.mg

0   40   80   160
Kilomètres

BNGRC / CERVO 08

Figure 19 - TC GIOVANNA-Victims and Damage. BNGRC Report (Source: BNGRC Report of 06 Apr).

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Abstract

JRC has developed GDACS, an early warning system created to alert the humanitarian community about potential disasters which are under development. Tropical cyclones are some of the most damaging events, affecting the coastal population with three dangerous effects: strong wind, heavy rain and storm surge. GDACS includes the analysis of the first and the second effects, and recently also the third effect (storm surge) has been implemented.
An impact assessment for all the three alerts are presented in the report.
Wind alert level estimated by GDACS was Red, due to the high wind and the high vulnerability of the affected country. The wind impact assessment by BNGRC has confirmed that most of the damage due to Giovanna was caused by strong winds. The region most affected has been Antisanana.
The rain impact alert level in GDACS is based on the estimation of the total accumulation of rainfall on land using NOAA eTRaP data. The applicability of the data was considered fine for alert levels at regional level, but not at local level due to spatial uncertainty.
The storm surge GDACS alert level is based on the calculations of the JRC code *HyFlux2*. The accuracy of the estimated storm surge height could not be established because the available tide gauge was malfunctioning. We compared our results with two UNOSAT/UNITAR impact assessment maps of two damaged cities (Brickaville and Vatomadry). These maps gave a clear indication of building damages, as a result of strong winds and storm surge while the JRC calculations showed a storm surge in the order of 1 m.
Overall, the GDACS models performed well. Alert levels for all hazard components were consistent with the observed impact. The location and timing of the information could accurately identify the affected provinces. GDACS information is appropriate for near real-time strategic decision making.

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Key policy areas include: environment and climate change; energy and transport; agriculture and food security; health and consumer protection; information society and digital agenda; safety and security including nuclear; all supported through a cross-cutting and multi-disciplinary approach.