JRC Scientific and Technical Reports

Humanitarian Impact of Tropical Cyclones

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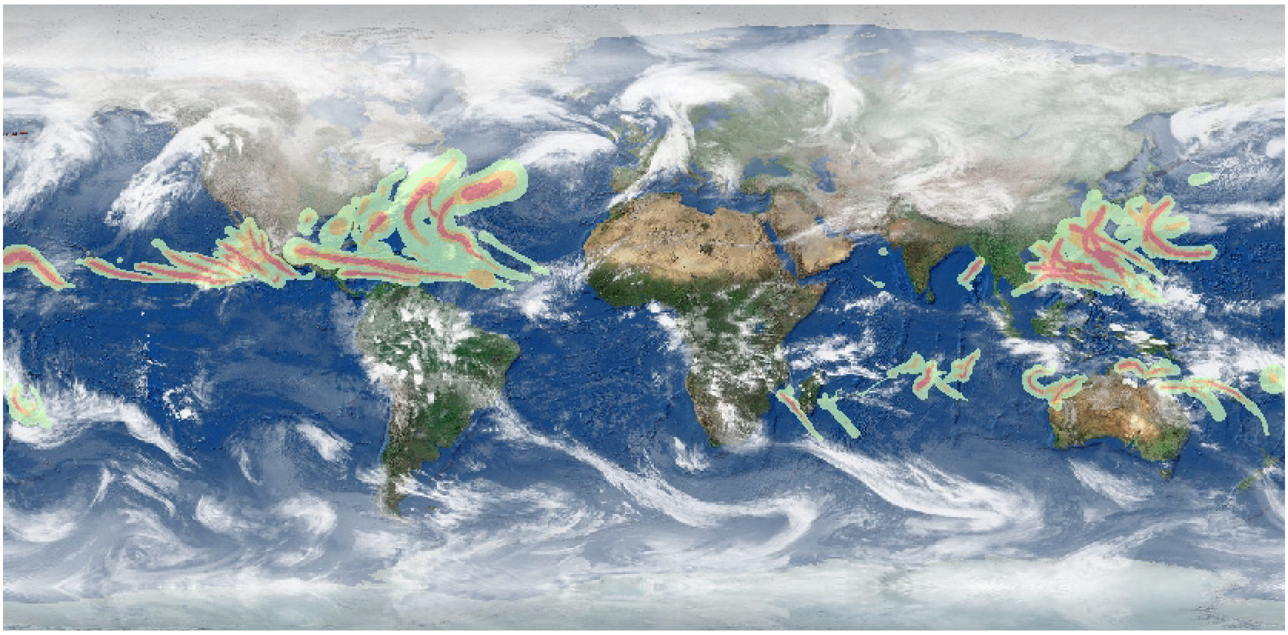

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Content

1 Abstract

JRC's research on tropical cyclones of 2007 builds the foundations for an innovative cyclone alert model. In contrast with the work of 2006 (focusing on wind speed modelling), 2007 focused on integrating data provided by other organisations into a single consequence analysis model.

A collaboration with the Pacific Disaster Center allowed JRC to access structured data on tropical cyclone track information. This new source of information, available since August 2007, enables us to implement more advanced impact models which provide improved information for humanitarian emergency managers. As a result, since October 2007 GDACS maps feature tropical cyclone wind buffers overlaid on global real-time cloud images. While a lot of modelling work has been completed and geoprocessing systems were put in place to exploit this new source of data, the resulting products have not been integrated fully in GDACS.

A more informal collaboration with NOAA TRaP allowed JRC to start addressing the rainfall component of tropical cyclones. Currently, TRaP images are published in GDACS reports, but the data is not exploited yet.

With regards to storm surge modelling, a global dataset of population in low lying coastal areas was created successfully. This dataset is a prerequisite to calculate the impact of storm surges associated with tropical cyclones.

In the first quarter of 2008, all these products will be integrated seamlessly in GDACS. They will allow an alert score based on the three hazards of a tropical cyclone: wind, rain and surge. No other system is currently providing such information.

2 Introduction

Part of the role of the Global Disaster Alert and Coordination System is the generation of alerts for natural disasters. These alerts are targeting the international humanitarian aid community who have to react quickly to provide sufficient aid in the first critical 72h after the disaster struck.

Disaster alerts are different from hazard alerts. Not every natural hazard is a humanitarian disaster for obvious reasons: either no population is affected or the scale of the event is too low for disrupting society.

Tropical cyclones (including hurricanes and typhoons) are some of the most damaging events. They occur in yearly cycles and affect the coastal population through high wind speeds (destroying dwellings and infrastructure), storm surges and associated floods (destroying crops) and heavy rainfall sometimes causing riverine floods and landslides.

In recent years, several organisations have set up services with near-real time information on tropical cyclones. The Regional Specialized Meteorological Centres coordinated by the World Meteorological Organisations (WMO) have the mandate to monitor cyclones and provide track forecasts. These Centres also provide bulletins with Storm Watch and Storm Warning alerts for selected cities. In particular the National Hurricane Centre (NHC) of the United States National Oceanic and Atmospheric Administration (NOAA) provides products and services targeted towards the disaster management community (although they are restricted to Atlantic and East Pacific hurricanes). NOAA has also experimental rainfall monitoring and forecasting products. The UK Tropical Storm Risk (TSR) venture – comprised of experts on insurance, risk management and seasonal climate forecasting – forecasts the risk for tropical storms worldwide. They also provide alerts on ongoing storms, identifying cities at risk.

Most available products are related to cyclone wind speed. However, most of the impact of cyclones is caused by floods resulting from extreme rainfall and storm surge. In 2007, NOAA started providing experimental rainfall monitoring and forecasting products (e.g. Tropical Rainfall Potential or TRaP). Also TSR followed track and provides rainfall probabilities based on UK Met Office models. NOAA has also experimental products for storm surges.

However, few organisations provide comprehensive impact analysis reports. JRC has been evaluating cyclone impact since 2005 (mostly based on wind speed and population). In 2006, JRC attempted to improve the reports by including a horizontal wind speed distribution model which did not provide expected results because of lack of physical measurements (in particular pressure related measures) in a real-time environment.

In 2007, JRC's strategy shifted towards integrating information from various partners and thereby creating a value-added product. JRC established partnerships with other organisations. A Memorandum of Understanding was signed with the Pacific Disaster Centre on exchanging cyclone track data. An informal collaboration with NOAA TRaP was set up in August 2007. Further, initial contacts were established with Tropical Storm Risk on exchanging wind field information.

Information from all these partners is now integrated in a new tropical cyclone section in the GDACS website (www.gdacs.org).

3 Estimating the size of the disaster

3.1 Tropical cyclone impact modelling

The major hazards produced by a tropical cyclone are (1) high winds, (2) heavy rainfall around the cyclone eye and (3) storm surge (the rising of the sea level due to the low pressure, high winds, and high waves associated with a storm as it makes landfall). High winds can be destructive as such (in particular for Category 2 storms or higher), but simple preparedness measures such as storm shutters can avoid a lot of damage (FEMA, 2004). Since cyclone tracks can be forecasted up to 72h, preparedness and evacuation of people is the norm rather than the exception. On the other hand, extreme rainfall and storm surge result in floods, which cause most of the damage and deaths.

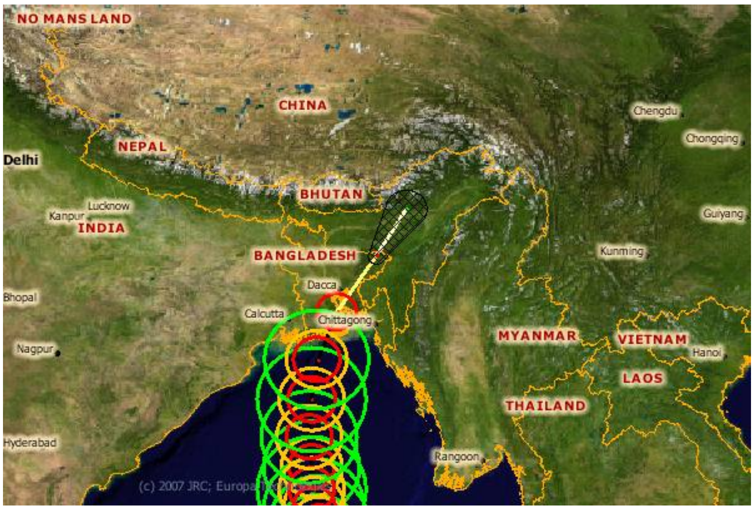


Figure 1. Real-time map of Cyclone Sidr, 2007.

The overall humanitarian impact of a tropical storm is the combination of all the three aforementioned hazards. While all three contribute to the damage and impact, only the cyclone wind speed can be modelled with accuracy based on meteorological measurements and models. Rainfall predictions, also based on meteorological models, are much less reliable (although new products became available in 2007).

Storm surge prediction models are least developed. Typically, hurricane advisories only contain average storm surge values based on historical data correlated with wind speed (see Annex). Furthermore, the impact of storm surge does not only depend on sea level rise, but also on the coastal elevation. To model storm surge would require a geographical database consisting of sea bathymetry (with resolution of 1km or better) and inland topography surrounding the cyclone landfall point (with a vertical accuracy of 1m or better).

Ultimately, though, the impact of a tropical cyclone is largely determined by its maximum wind speed, a quantity that is accurately forecast up to 72h in advance. While more detailed information about wind speed profiles, rainfall and storm surge will undoubtedly improve impact assessments, it is more important to focus on the other aspects of risk. Based on the classical risk formula (Thywissen, 2006), risk to population is determined by the hazard, the presence or amount of population in the affected area and the vulnerability and resilience of that population. By the end of 2007, GDACS is still the only system that considers both these elements in its impact assessment.

The challenge in calculating the population at risk is to determine the area that is affected by the cyclone. The population in that area can then be easily calculated using geoprocessing techniques. Given the fact that only wind speed is modelled accurately at this point, one can assume – in a first approximation – that rainfall and storm surge occur in the same area of extreme winds (Matyas, 2006). In realty, as wind radii can vary widely across all four quadrants, it is reasonable to assume that the spatial extent of the rain shield should also differ among the quadrants.

However, real-time rainfall estimate products are becoming increasingly available and JRC is planning to integrate this information in the impact assessment in 2008 (see section 3).

This section will describe a new method to determine the affected area that has been implemented in GDACS in 2007. Before August 2007, GDACS used a fixed area of 100km around the eye of the cyclone as the affected area, independent of the wind speed. Now, GDACS uses continuous buffers based on wind fields measured and forecasted by meteorological models.

3.2 Tropical cyclone winds

3.2.1 Data source

The authoritative source for tropical cyclone data lies with the Regional Specialized Meteorological Centres (RSMC) coordinated by the World Meteorological Organisations (WMO). Each 6 hours, RSMCs publish a cyclone advisory, including information on wind speed, pressure, and track locations. However, this data is not available in a single place and a single (standard) format, making it difficult to use in an automatic system like GDACS.

The University of Hawaii SOLAR lab[1] has been collecting and publishing information from all basins. Up to 2007, SOLAR was the only source available (although it does not republish all information) and GDACS relied on it with reasonable results. However, this service is not meant to be used for emergency management and is therefore not as robust, accurate and reliable as required by GDACS, and not all the information are published (i.e. wind radii).

To overcome this, JRC and the Pacific Disaster Centre (PDC) set up an automatic scraping and parsing routine which ingests tropical cyclone advisories from all RSMCs into a single database covering all ocean basins. The data is then published as a Web Feature Service (WFS), which is a standard for publishing geospatial data. This allows other applications to query records using standards-based protocols. PDC implemented the WFS service with ESRI's ArcIMS WFS connector.

3.2.2 Description of the data

The data republished by PDC[2] contains most of the elements reported in the official advisory bulletins. However, the data is structured in different layers, each with geographical elements (as points, lines or polygons) and attributes.

Current Storm Positions, Forecast Storm Positions, and Previous Storm Positions
These three layers represent active tropical cyclones in all ocean basins. The Current Storm Positions layer shows the current location of any tropical cyclone. The Previous Storm Positions layer shows the cyclone storm track up to the current location. The Forecast Storm Positions layer shows predicted storm locations. This information is based on message traffic received from the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS), and the Naval Pacific Meteorology and Oceanography Center's Joint Typhoon Warning Center (JTWC). Layer attributes information:

Attribute Name	Description
Name	Name of the tropical cyclone
Advisory Time	Time of current cyclone position (UTC)
Advisory Date	Advisory date for the cyclone position dd-mmm-yyyy
Day/Hr	Time of forecast position ddhh (UTC)
Latitude	Latitude of position (dd)

[1] http://www.solar.ifa.hawaii.edu/Tropical/tropical.html

[2] http://www.pdc.org/atlas/html/atlas-info.pdf

Longitude	Longitude of position (dd)
Wind Speed	Wind speeds of the cyclone (mph)
Wind Gusts	Gust speeds of the cyclone (mph)
Pressure	Central Pressure (mb)
Track Heading	Directional heading
Track Speed	Speed of cyclone movement (mph)
Storm Status	Strength/category of cyclone: Tropical depression: 0 – 38 mph Tropical storm: 39 – 73 mph Hurricane/typhoon: 74 – 150 mph Super typhoon: > 150 mph
Wind radii in four quadrants, expressed in nautical miles (nm). Wind radii represent the maximum distance from the cyclone's eye at which a given wind speed can be exceeded.	
Wind Radii 34kt NE, SE, SW, NW	Wind radii for Tropical storm at 34kt
Wind Radii 50kt NE, SE, SW, NW	Wind radii for Tropical storm at 50kt
Wind Radii 64kt NE, SE, SW, NW	Wind radii for Hurricane at 64kt

Potential Track Area (3 and 5 day)
The cone of uncertainty is a polygonal shape around the forecast points for a storm advisory that represents the average error in the forecasted locations over the last 10 years. It is a visual aid used in hurricane forecasting of the track that balloons outward from a storm's current position, three to five days into the future.

Attribute Name	Description
Name	Name of the tropical cyclone
Advisory Number	Corresponding forecast advisory number

Active Wind Radii, and Forecast Wind Radii
The Active Storm Winds layers represent current tropical cyclones. This information is based on message traffic received from the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service/Tropical Prediction Center/National Hurricane Center (NWS/NCEP/TPC), and the Naval Pacific Meteorology and Oceanography Center/Joint Typhoon Warning Center (JTWC). Past, current and predicted storm winds are reported at each position.

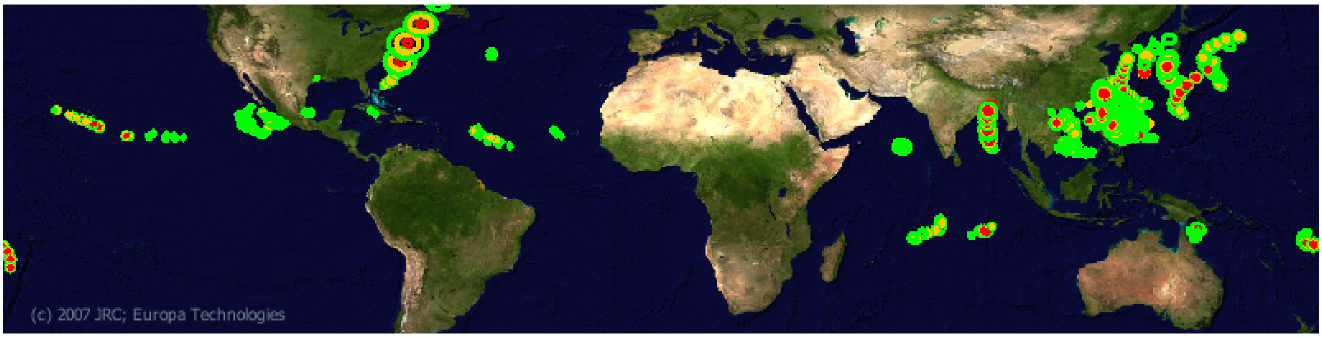
Attribute Name	Description
Name	Name of Storm
Advisory Number	Storm Advisory Number
Wind Status	Wind speed within radii
Wind Distance	Distance winds extend from center

3.2.3 Data handling and storing

The data from PDC is downloaded regularly by JRC as part of the GDACS geoprocessing tool called AsgardLite. AsgardLite calls the WFS service and processes the resulting XML. The data is processed and then stored in a spatial database (in this case ArcSDE, the ESRI Spatial Database Engine, upon a Microsoft SQL Server database). This allows the creation of interactive maps through the JRC Web Mapping Service (WMS), needed to include maps in the cyclone reports.

At JRC, the information from PDC is stored in different layers, more adapted to the mapping needs for GDACS. In particular five layers have been defined in ArcSDE and are continually updated:

- track_cones: stores the cones as polygons, with attributes type (3 or 5 days), active, name, advisory_number
- track_point: stores the track points, with attributes type (current, forecast and previous), active, name, advisory_number, advisory_date, advisory_time, day_hr, latitude, longitude, wind speed, wind gusts, pressure, track heading, track speed, storm status
- track_line: a line feature, connecting the track points (for display purposes)
- wind_radii: stores circles within which the wind speed exceeds a given value, with attributes type (threshold wind speed), active, name, advisory_number, advisory_date, advisory_time, wind_status, wind_distance
- wind_buffers: stores wind buffers (constructed by connecting wind radii) with attributes type (threshold wind speed), active, name, advisory_number, wind status.



3.2.4 Determination of affected area

Before the PDC data became available, GDACS assumed the affected area to be a circle of 100km around a cyclone's eye. However, it is clear that this area should vary with the maximum wind speed. Furthermore, what is needed to calculate the affected population is the integrated area affected by a given wind speed and not the area affected at a given time. With only one track point every six hours, large portions of the affected population can be overlooked (see Figure 2).

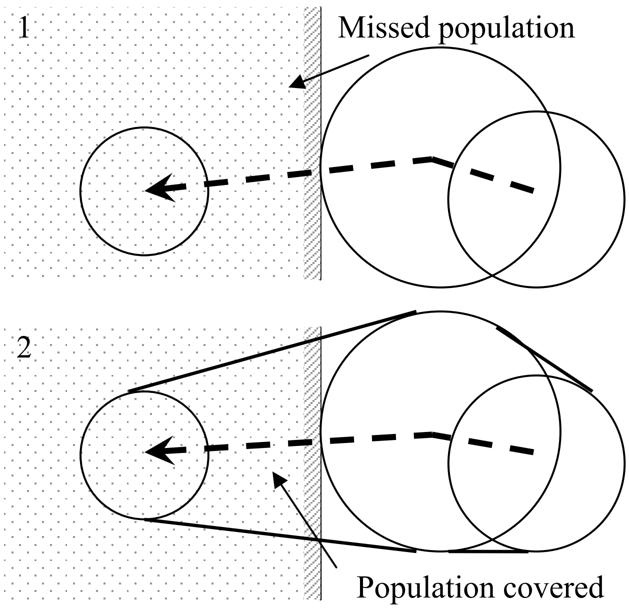


Figure 2. (1) Previous circle based method in GDACS and (2) current buffer based method. Circles indicate area with winds over tropical cyclone speed (74mph). The new method covers all affected population and takes wind speed into account.

The wind radii published by PDC allow reconstructing wind buffers. This is realized by first determining a radius for each track point. Because there are 4 radii forecasted for each track point (one in each quadrant), there are several options to determine this radius (see Figure 3). The forecasted radius is defined as the maximum distance from the eye of the storm within which winds up to a given speed (39mph, 58mph or 74mph) can occur. Some organisations (TSR and NHC) use all four forecasted radii to draw irregular shapes (asymmetric winds buffer). PDC takes the minimum radius to draw a circle around the track point. However, at JRC we take the maximum radius to draw a circle around the track. So, if they are 25, 45, 10, and 30, then the radius for PDC will be 30, while for JRC will be 45 (see Figure 3). If the radii are 35, 25, 0, and 35, then the radius for PDC will be 0, and the circle will not be created. The reason is that there are often 0 values in the radii, which indicate no data. This underestimates the affected area. To be conservative on the number of people affected, JRC takes the maximum value.

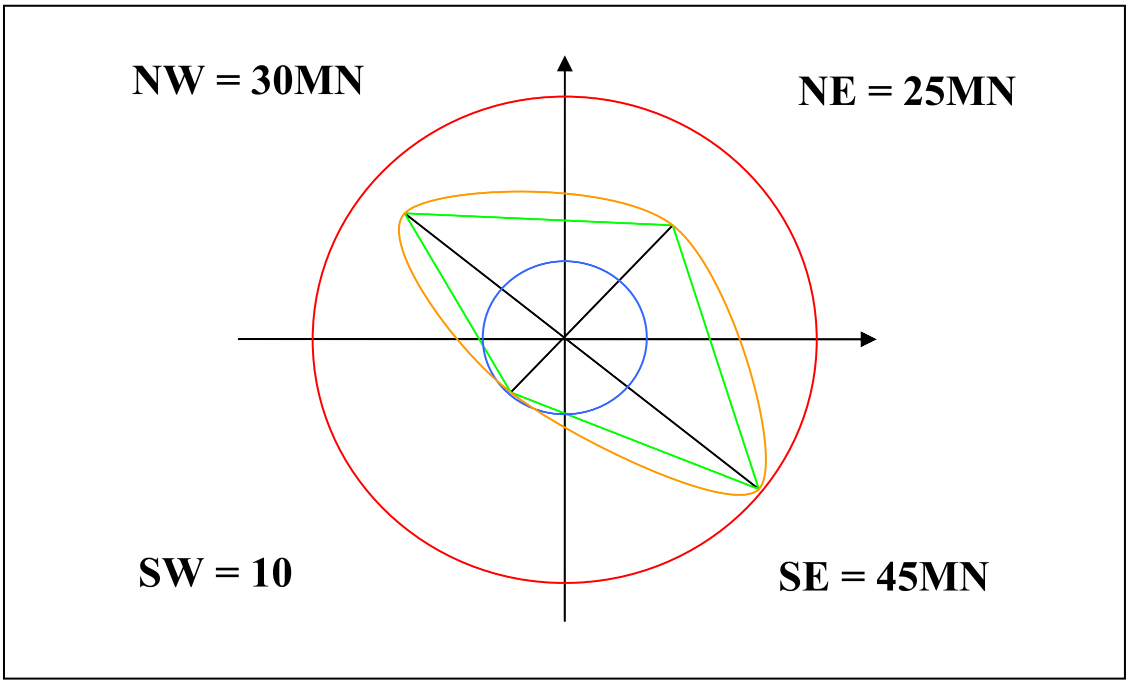


Figure 3: Different graphical representation of wind radii (Blue = PDC; Green = TSR; Orange = NHC; Red = GDACS)

Next, the wind speeds in the area between forecasted points must be estimated. This is typically done by creating the envelope of all wind circles at a given speed. At JRC, the wind circles are spatially interpolated and merged into buffers. This method ensures geometric coherence. Special cases (such as the geographic horizon at 180 decimal degrees longitude and at 90 degrees latitude) must be taken into account.

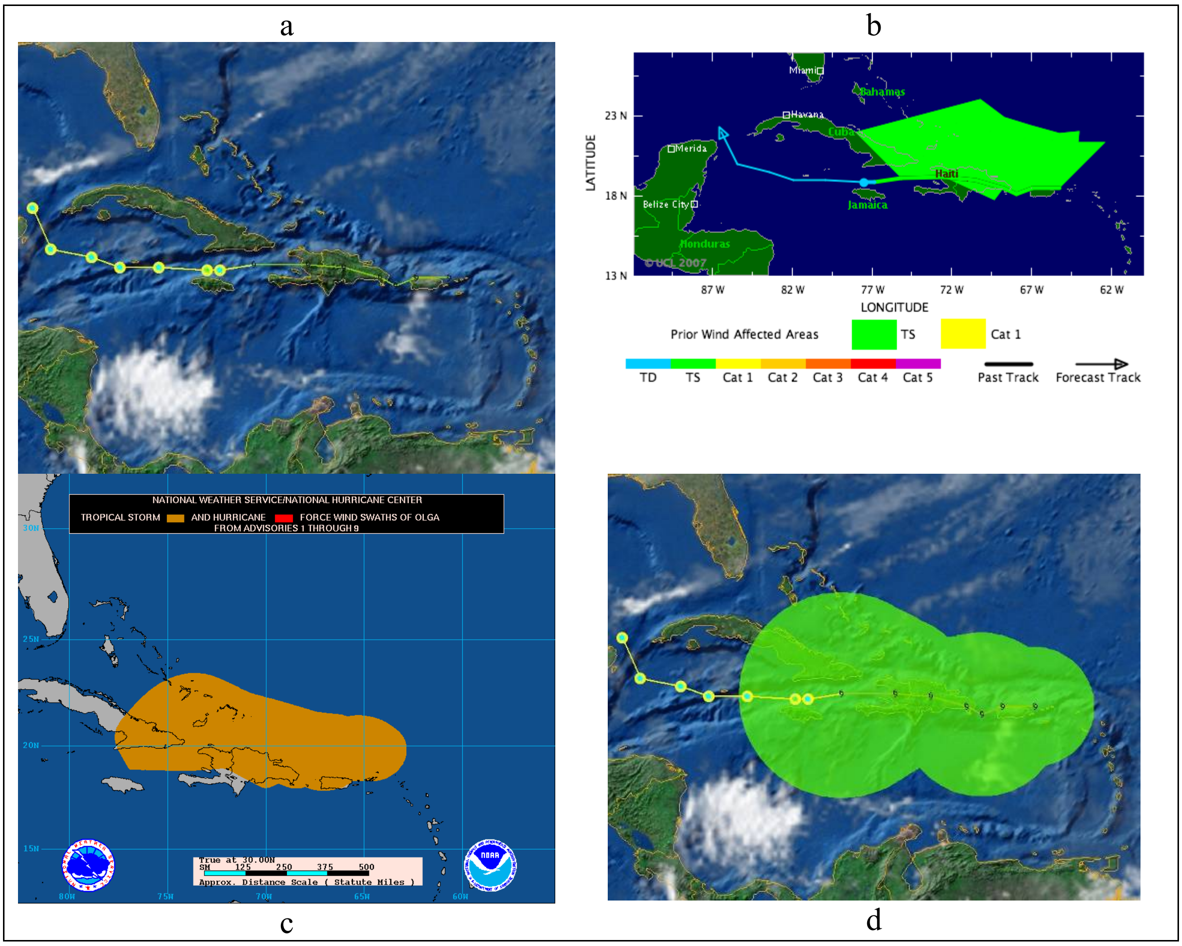


Figure 4: Tropical Storm Olga (December 2007) wind buffers for (a) PDC, (b) TSR, (c) NHC, (d) JRC.

The resulting buffers represent the area of a tropical cyclone affected by a given wind speed. Since tropical storm forecasts only provide wind speed radii for three wind speeds (39mph and 58mph for tropical storms and 74mph for cyclones) only three affected areas can be calculated with this method. Depending on the method to create wind areas for points and buffers, the result looks different. Figure 4 shows an example of the wind buffers created by four organizations. TSR and NHC use very similar methods and take asymmetry into account. However, 0 values of wind radii in some of the quadrant can create unrealistic results (i.e. completely asymmetric buffer, see Figure 4). On the other hand, PDC and JRC use symmetric buffers, whereby PDC uses the minimum radius and JRC the maximum radius. Also for PDC, 0 values create unrealistic results (no buffers), while for JRC the affected area is overestimated.

In some cases, wind radii are not given in the advisory bulletins. In this case, JRC estimates wind radii based on the maximum sustained wind speed (which is always given) and an expected wind radius based on a regression analysis of data from previous storms (Figure 5).

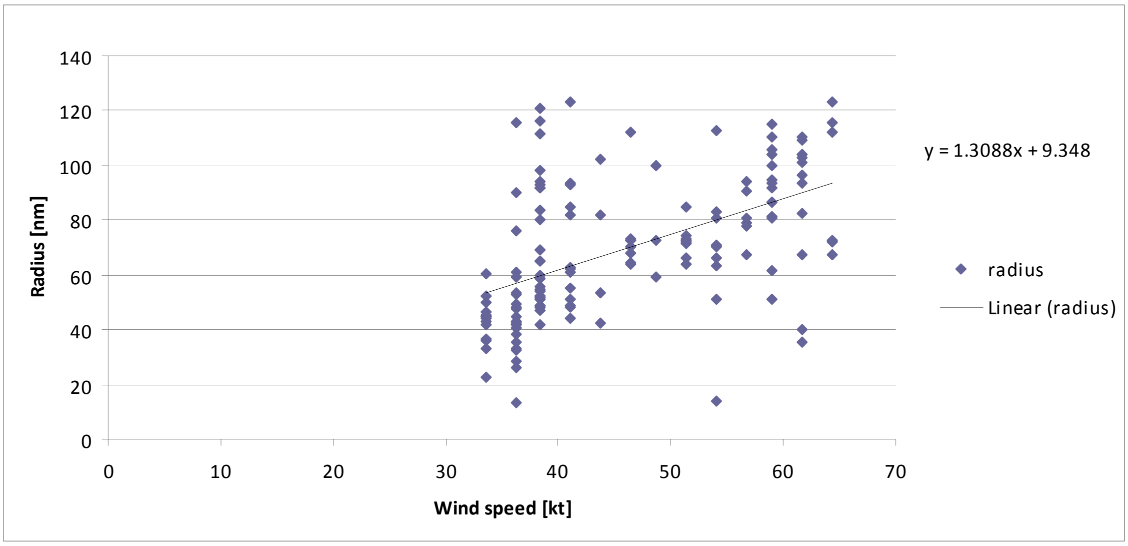


Figure 5: Expected wind radius based on a regression analysis of data from previous storms.

3.2.5 Analysis of affected area

Once the affected area has been determined, it can be analyzed. The population in the area is calculated, the affected cities are listed and the countries and provinces are determined. This information is obtained through a geoprocessing web service (SDERunner) at JRC (Gadenz S., 2007). For each storm, SDERunner is called several times by AsgardLite to provide necessary data to calculate the cyclone impact.

Several models have been developed in SDERunner to cover the complexity of a climatic event such as a tropical cyclone.

- HU1: Neighbourhood model for comprehensive hurricane impact. It requires a wind buffer (or other polygon) as input, and returns a list of features from predefined geographic layers (countries, provinces, cities, nuclear plants, dams, ports, airports, etc.).
- HU2: Neighbourhood model for hurricane impact on major cities. Similar to HU1, but with less output. Better for large polygons.
- HU3: Neighbourhood model for hurricane impact with variable output. Similar to HU1 and HU2, but with an additional input parameter to determine the level of detail required in the output (e.g. city class level).
- BU1: Buffer model. Given a set of track points with associated information such as wind radii and interpolation steps, it returns an interpolated buffer.
- BU2: Combination of BU1 and HU1. Given a set of track points (and associated information), it provides a buffer and returns a list of features into that buffer. Moreover, the model calculates for each feature when the cyclone reaches it and when it leaves.
- GEOSTAT1: Calculates statistics on an attribute of a set of feature falling into a polygon. This will be used to calculate rainfall averages in a cyclone buffer, based on TRaP data (see further).

3.2.6 Alert score calculation

The result of an impact analysis must be an alert score, which can be used to determine if a cyclone will likely be a humanitarian disaster. To calculate this score, AsgardLite implemented impact models as follows.

Until July 2007, the evaluation of the potential humanitarian impact of tropical cyclone considered the hurricane magnitude (in the Saffir-Simpson (S-S) hurricane scale) and the population within 100km of cyclone's eye (MODEL1). The alert level was established according to the following criteria:

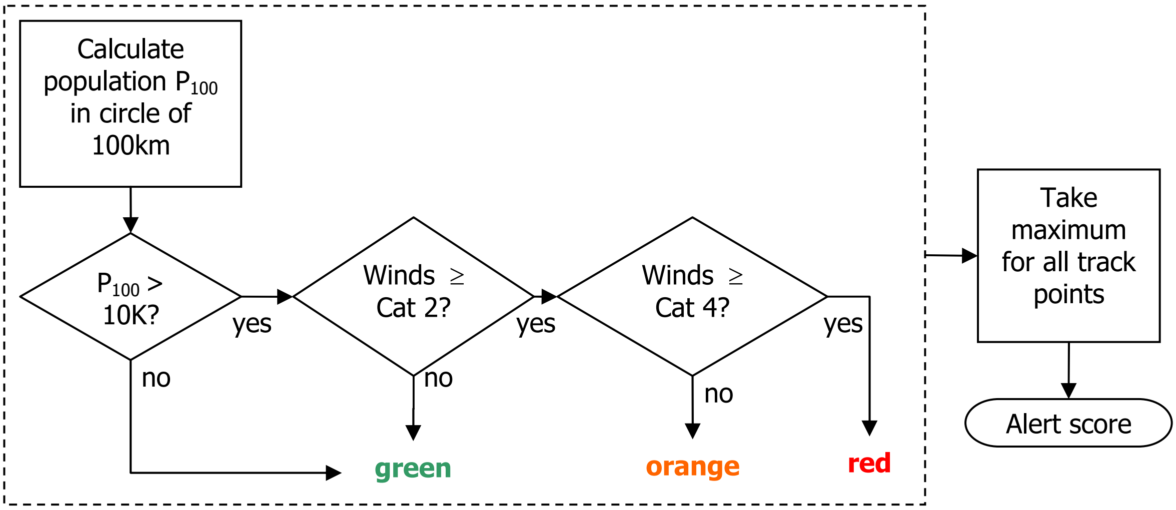


Figure 6. Alert score calculation since July 2007 (MODEL1).

Since July 2007, the alert score was calculated based on the population in Category 1 wind speed circles (MODEL2). As explained in section 2.2.4, this method underestimates the population at risk and has not always had correct results. Nevertheless, the results were satisfactory and no big disasters were missed.

The alert score for a tropical cyclone is the maximum value of alert scores for individual track points. In each point, the alert score is set to Orange if there is population within the area affected by cyclone strength (Category 1) winds, based on the wind radii. However, if the maximum sustained wind speed is of Category 3 or higher (i.e. more than 111 mph), the alert score is set to Red.

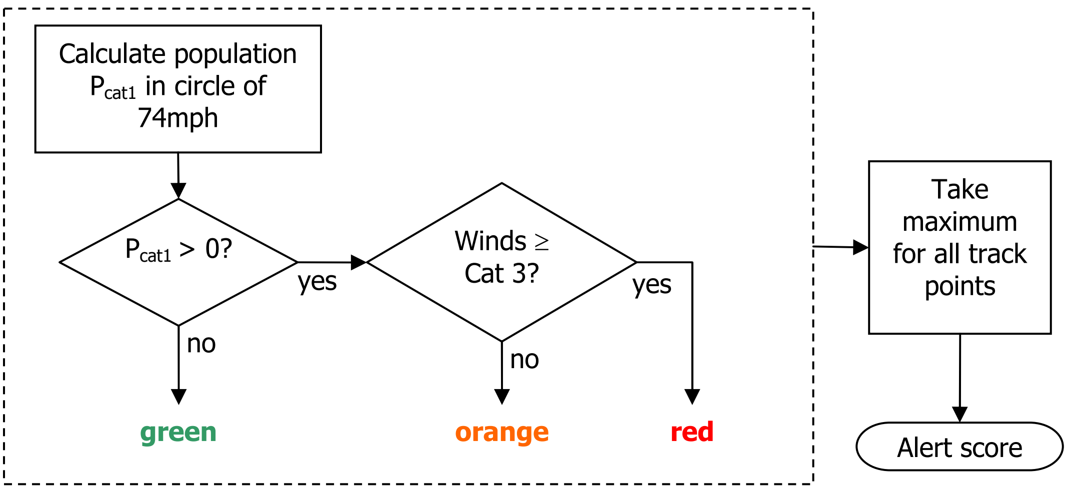


Figure 7. Alert score calculation from July 2007 (MODEL2).

From 2008, a new model will be operational (MODEL3). If the population affected by cyclone wind speed is below a chosen threshold (P_0) the alert level is Green. In some cases tropical storms have been humanitarian disasters, but this was mainly due to excessive rainfall. This will be discussed in section 3. If population is affected by winds of 74mph or higher, the alert level is at least Orange.

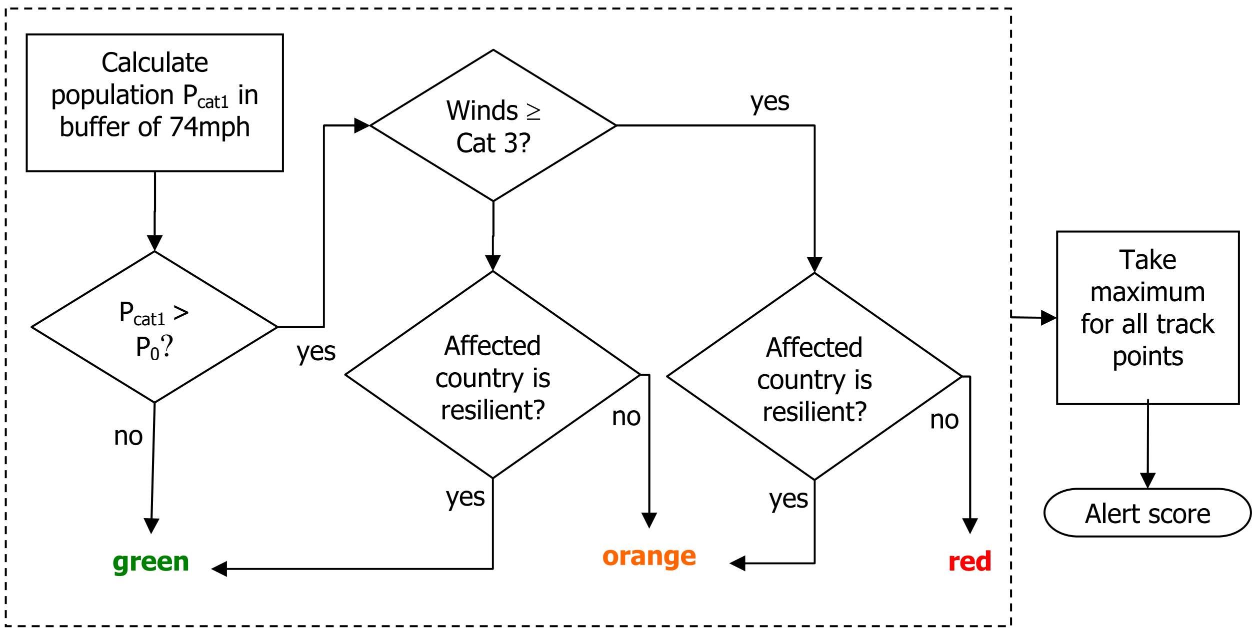


Figure 8. Flow chart of alert level calculation for MODEL3. Wind buffers are used to calculate population affected by a given wind speed, depending on the resilience of a country.

For the impact of cyclones, we consider the resilience of affected countries. For vulnerable countries, a Category 3 storm (winds over 112mph) will trigger a Red alert, while for resilient countries this must be Category 4 (winds over 132mph). A country's resilience is determined by its Human Development Index (HDI)[3]. Countries with a HDI of 0.9 or more can be considered resilience and able to cope with a Category 3 tropical cyclone. These countries include the United States of America, Japan and Australia.

At landfall, a tropical storm rapidly loses energy. Wind speeds drop quickly below Category 1 winds. In this case, there would be no buffer between the last point in the ocean and the first point on land. As a result, the calculation would estimate no population affected. In order to avoid this, we calculate Category 1 buffers point by point. For points with Category 1 wind speeds a buffer is created with the next point, keeping wind speed constant. This overestimates the affected area, but saves the landfall scenario.

[3] http://hdr.undp.org/

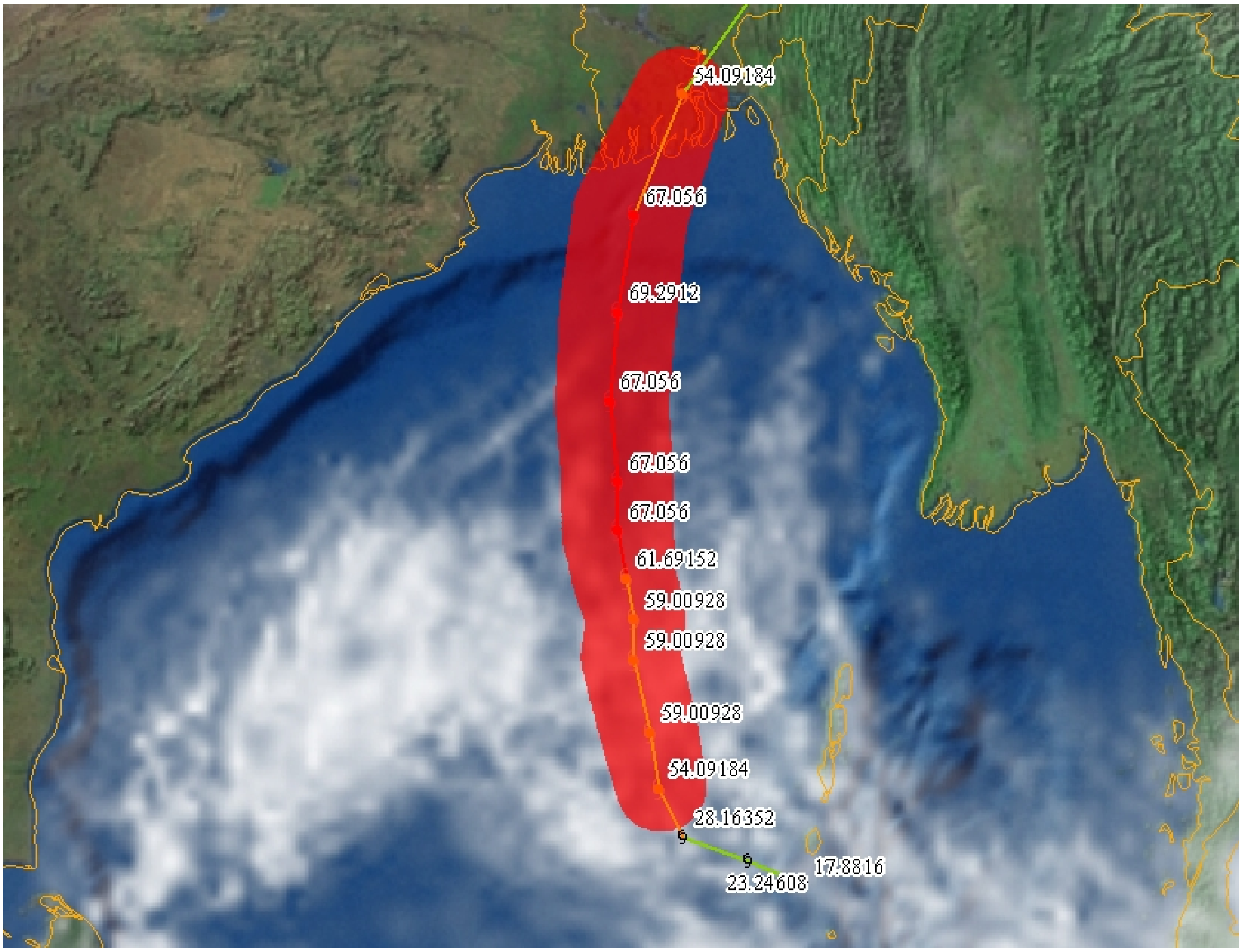


Figure 9: Category 1 (64kt) wind buffer for Typhoon Sidr in 2007. The wind speed of the last point (inland) is below the Category 1 strength but it has been kept constant for landfall scenario.

3.3 Accuracy evaluation

The accuracy of the tropical cyclone models depends on several factors. First, accuracy of cyclone track parameters is determined by the source of this data. Forecasted track parameters have some level of error, which is necessarily reflected in GDACS reports. Second, GDACS impact models show lists of affected cities and infrastructure, time of arrival of the storm in different cities and features and impact maps. The accuracy of these depends on the underlying databases. JRC relies on its Digital Map Archive, for which data is updated continuously with open content and commercial datasets. Third, and most important, the accuracy of the alert score or alert level (as percentage of over- or underestimated alerts) must be considered. This is the final classification of a tropical storm in terms of humanitarian aid. It must be directly linked to the likelihood of a need of humanitarian intervention.

The alert score of GDACS models has been compared with databases on international humanitarian intervention: the OCHA Financial Tracking System (FTS) and ECHO's HOPE database, the most comprehensive databases on the topic.

The following list indicates the tropical cyclones, hurricanes and typhoons flagged as Red in GDACS and some Orange and Green alerts that received funding.

	Storm name, Country	Date	GDACS Alert Level	Reported aid contribution (FTS)	Glide Number and comments	Evaluation
MODEL2	Sidr, Bangladesh	Nov 2007	**Red**	**US$ 181 million**	**TC-2007-000208-BGD**	**Correct**
	Guba, Papua Guinea	Nov 2007	**Green**	**US$ 1.15 million**	Most impact from floods caused by heavy rain and storm surge.	**Missed**
	Noel, Caribbean	Oct 2007	**Orange** **Green** in Caribbean	**US$ 17.3 million**	**TC-2007-000198-DOM** Orange alert for Canada. Most damage and casualties caused by storm surge and heavy rain.	**Missed**
	Kajiki, Japan	Oct 2007	**Red**		GDACS detected 584 people affected by Category 3 wind speeds. A minimum population threshold should be implemented	**False**
	Krosa, China	Oct 2007	**Red**		**TC-2007-000179-CHN** Affected Taiwan.	**False**
	Wipha, China	Sep 2007	**Red**		**TC-2007-000162-CHN** Damage was estimated at over US$ 700 million.	**Correct**
	Felix, El Salvador, Honduras, Nicaragua	Sep 2007	**Red**	**US$ 21 million**	**TC-2007-000150-NIC**	**Correct**
	Sepat, Taiwan, China	Aug 2007	**Red**		**TC-2007-000137-TWN** Damage was estimated at over US$ 880 million.	**Correct**
	Dean, Caribbean	Aug 2007	**Red**	**US$ 8.1 million**		**Correct**
MODEL1	03B, Pakistan	Jun 2007	**Green**	**US$ 31.5 million**	**TC-2007-000084-PAK**	**Missed**
	Gonu, Oman	Jun 2007	**Orange**	US$ 730,000		**Correct**
	Akash, Bangladesh	May 2007	**Green**	US$ 480,000		**Missed**
	Indlala, Madagascar	Mar 2007	**Orange**	**US$ 21.2 million**	**TC-2007-000034-MDG** Include funds for seasonal flood events.	**Correct**
	Bondo, Madagascar	Dec 2006	**Red**		**TC-2006-000193-MDG** No reports were found on direct damage by Bondo, but it might have aggravated seasonal floods (see funds for Indlala)	**False**
	Durian, Philippines	Dec 2006	**Red**	**US$ 16.5 million**	**TC-2006-000175-VNM**	**Correct**
	Chebi, Philippines	Nov 2006	**Red**			**False**
	Cimaron, Philippines	Nov 2006	**Red**		Swedish International Development Cooperation Agency contributed US$ 350,000 to aid efforts.	**Correct**
	Xangsane, Philippines/Vietnam	Oct 2006	**Red**	US$ 430,000	**TC-2006-000144-PHL**	**Correct**
	Shanshan, Taiwan/Japan/South Korea	Sep 2006	**Red**		Only minor impact to Japanese Islands and South Korea	**False**
	Saomai, China	Aug 2006	**Red**		**TC-2006-000114-CHN** IFRC appealed for US$ 4.8 million, China allocated US$ 15.2 million for Saomai and earlier storms	**Correct**
	Gamma, Honduras	Nov 2005	**Green**	US$ 547,000	Tropical Storm that affected Islas de la Bahia. This was officially not a hurricane.	**Missed**
	Wilma, Caribbean	Oct 2005	**Red**	**US$ 1 million**	**TC-2005-000178-BHS**	**Correct**
	Stan, Mexico and Guatemala	Oct 2005	**Green**	**US$ 1.5 million**	Cyclone Category 1. Most damage and casualties caused by landslides and heavy rain.	**Missed**
	Beta, Nicaragua	Oct 2005	**Orange**	US$ 450,000		**Correct**
	Longwang	Oct 2005	**Red**	US$ 86,000	**TC-2005-000172-CHN**	**Correct**
	Nabi, Japan	Sep 2005	**Red**		**TC-2005-000154-JPN**	**False**
	Damrey, Vietnam	Sep 2005	**Orange**	US$ 837,000	**TC-2005-000164-VNM**	**Correct**

	Katrina, USA	Aug 2005	**Red**	–	**TC-2005-000144-USA** Estimated damage for US$ 81.2 billion; 1,836 people killed.	**Correct**
	Emily, Caribbean	Jul 2005	**Red**	**US$ 1.5 million**	**TC-2005-000115-TTO/GRD/VCT**	**Correct**
	Dennis, Jamaica	Jul 2005	**Red**	**US$ 1.2 million**	**TC-2005-000112-JAM**	**Correct**
	Percy, Cook Islands/Tokelau	Mar 2005	**Green**	US$ 446,000	The funds have been attributed to Percy, but they cover most likely combined damage by Meena and Percy	**Missed**
	Meena, Cook Islands/Tokelau	Feb 2005	**Red**		**TC-2005-000012----**	**Correct**

The results of the performance of the GDACS alerts are summarized in the **Error! Reference source not found.**.

Table 1. GDACS alerts compared to humanitarian response. Financial data is from OCHA's Financial Tracking System (FTS) and ECHO's HOPE database.

<table>
<tr><td>Period of observation: January 2005 to December 2007</td><td>Number of events</td><td>Correctly not alerted</td><td>Correctly alerted</td><td>False alert</td><td>Missed alert</td></tr>
<tr><td rowspan="2">Tropical Cyclones</td><td>487</td><td>455</td><td>19</td><td>6</td><td>7</td></tr>
<tr><td colspan="5">Total funds: 314 million US$
Total funds for correctly alerts: 261.5 million US$ (~83%)
Total funds for missed alerts: 52.5 million US$ (~17%)</td></tr>
</table>

The new buffer-based method MODEL3 has started to be evaluated using the Best Track (BTK) data from NOAA (May 2006 to November 2007) and JTWC (2006).

Because it compensates for known drawbacks of the circle-based method (i.e. false alert for typhoon Kajiki in Japan, Krosa in Taiwan, Shanshan in Taiwan, Japan and South Korea) as well as the lack of resilience (i.e. missed alert for hurricane Dean in Jamaica), its performance is expected to be better.

In early 2008, it is foreseen to re-analyze all tropical cyclones using the buffer method and MODEL3 alert score method for optimal results.

4 Additional components

4.1 Tropical Rainfall

Weather satellites have been used since the sixties to map clouds, sea surface temperatures, and vertical temperature and moisture distributions. These data are supplemented by crucial ground observations, and are subsequently input to numerical models which try to predict the short-term evolution of the weather. The results are then made available to the public, most directly in the form of composite weather maps. The rain shown on these maps comes mostly from ground weather radars.

Unfortunately, the crucial ground observations are often simply not available over the tropics because these regions are typically inaccessible. In addition, the large-scale numerical models are still inaccurate over the tropics, mainly because there is not yet a solid understanding of the often severe dynamics which govern the circulation in the warm moist tropical atmosphere, and which have a determining effect on the weather far away from the tropics. The unprecedented precision of the measurements of satellite based system as TRMM is replacing the missing ground measurements over the tropics, and it allows modelling of tropical rainfall processes to better predictions of rainfall.

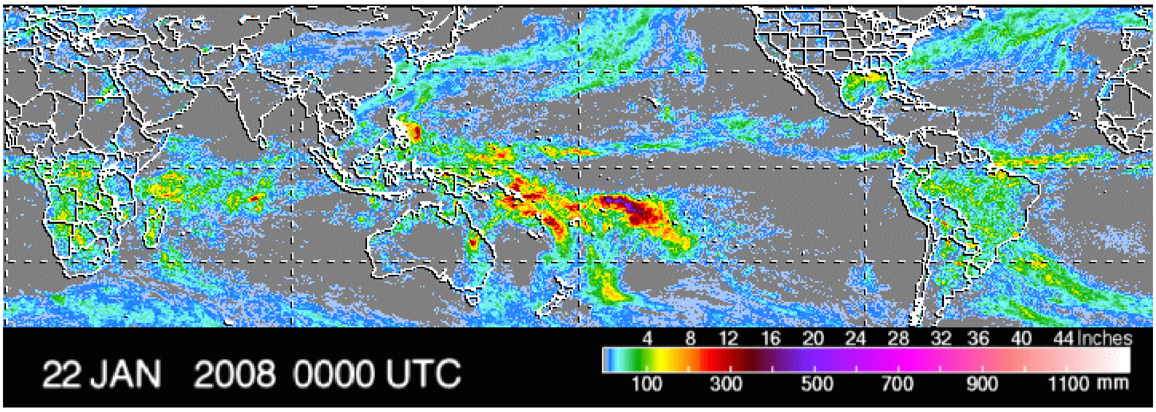
4.1.1 Accumulation: Tropical Rainfall Measuring Mission (TRMM) – NASA/JAXA

The Tropical Rainfall Measuring Mission (TRMM) is a joint project between NASA and the Japanese space agency, JAXA. The TRMM satellite was launched in November of 1997 and rainfall products from the Precipitation Radar (PR) and TRMM Microwave Imager (TMI) have been available since December 1997.

A series of quasi-global, near-real-time, TRMM-based precipitation estimates is available to the research community via anonymous ftp[4]. One of the products (3B-42) is being provided by merging high quality (HQ) microwave and infrared (IR) precipitation estimates. These gridded estimates are on a 3-hour temporal resolution and a 0.25-degree by 0.25-degree spatial resolution in a global belt extending from 50 degrees South to 50 degrees North latitude.

The 3B-42 estimates are produced in four stages; (1) the microwave estimates precipitation are calibrated and combined, (2) infrared precipitation estimates are created using the calibrated microwave precipitation, (3) the microwave and IR estimates are combined, and (4) rescaling to monthly data is applied. Each precipitation field is best interpreted as the precipitation rate effective at the nominal observation time.

[4] ftp://trmmopen.gsfc.nasa.gov/pub/merged



NOAA National Environmental Satellite Data and Information Service NESDIS uses TRMM data as part of its Tropical Rainfall Potential (TRaP) program to estimate flood potential in hurricanes.

4.1.2 Potential Rainfall for the next 24 hr (NOAA - Operational Satellite Derived Tropical Rainfall Potential)

Inland flooding caused by heavy rainfall from landfalling tropical cyclones is a significant threat to life and property. The tropical rainfall potential (TRaP) technique, which couples satellite estimates of rain rate in tropical cyclones with track forecasts to produce a forecast of 24-h rainfall from a storm, was developed to better estimate the magnitude of this threat (Kidder *et al.*, 2004). TRaPs is generated using forecast bulletins from the Regional Specialized Meteorological Centers (RSMC) at Miami, Honolulu, Tokyo, La Reunion, Perth, Darwin, Brisbane and Nadi and/or from the U.S. Joint Typhoon Warning Center (JTWC). TRaPs is updated whenever a new forecast or new rain rate data becomes available with the restriction that the rain rate data must be within 3 hours of the synoptic time associated with the forecast (i.e., 00Z, 06Z, 12Z and 18Z) and the rain rate data covers most, if not all, of the storm.

The microwave sensor will be AMSU, SSM/I, AMSRE or TRMM. The rainfall totals are available in four 6-hour increments and a 24 hour cumulative total. The rainfall totals will be 00 (for 0-6 hour totals), 06 (for 6-12 hour totals), 12 (for 12-18 hour totals), 18 (for 18-24 hour totals) and 24 (for the 24 hour cumulative total).

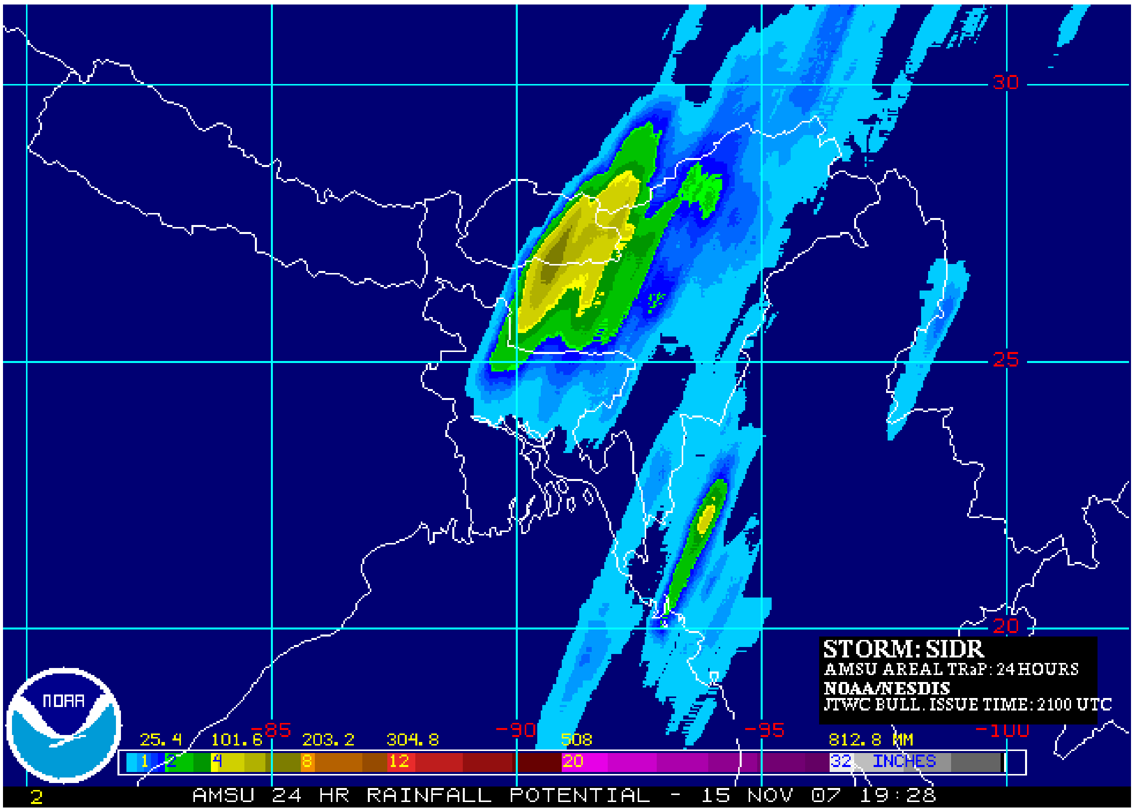


Figure 10: An image supported by SSM/I sensor data shows a representation of rainfall from Typhoon Sidr prior to its impact on the coast. The data helps to provide additional clues on cyclone's strengthening.

4.1.3 Rainfall model component

Currently, the latest image from TRaP model is published in the Tropical Cyclone GDACS report (in partnership with NOAA TRaP). In early 2008, TRaP data will be integrated in GDACS and provide additional information for the tropical cyclone alert score.

Derived from data ending with real-time TRMM based 3B42 products, a list of locations with at least 35mm of accumulation of rainfall in the last 24h is provided on Internet[5]. We use the data to populate a SDE layer that has been integrate in the tropical cyclone model (BU2). Recent studies (Mytas, 2006) show that hurricane rain shields are mostly contained within the gale-force winds (34kt). Therefore, the Tropical Depression buffer has been use as affected area in the BU2 model.

4.2 Storm surge

4.2.1 Vulnerable coastal population dataset

In order to assess the feasibility and to highlight the problems connected with the evaluation of the coasts vulnerability to a storm surge as well as a potential Tsunami, an evaluation of the population in the coastal areas living within a defined height interval has been performed.

In particular the number of inhabitants in the coastal zone in the geographical areas where the height is 5m above the normal sea level has been determined. The same methodology will be applied to produce similar datasets for different elevation thresholds (2m, 10m).

[5] http://trmm.gsfc.nasa.gov/trmm_rain/Events/flood_one_day.html

The data we have used are the following: a digital elevation model (DEM) of 3” (approximately 90mt on the equator) of spatial resolution (SRTM, USGS) and a population density model (PDM) of 30” (LandScan, approximately 1km on the equator) both on global scale.

Starting from the DEM, the procedure consisted in the creation of a global dataset representing the number of inhabitants in the first 30 km of coastal areas where the height is below 5 m above the normal sea level (a).

Due to the different resolution between the DEM and the PDM an error would be introduced because the distribution of the population inside the single pixel is unknown. To avoid that, the DEM has been downscaled to the PDM resolution and then a zonal statistic technique has been applied in order to assign to each pixel the percentage of the area below 5m (b).

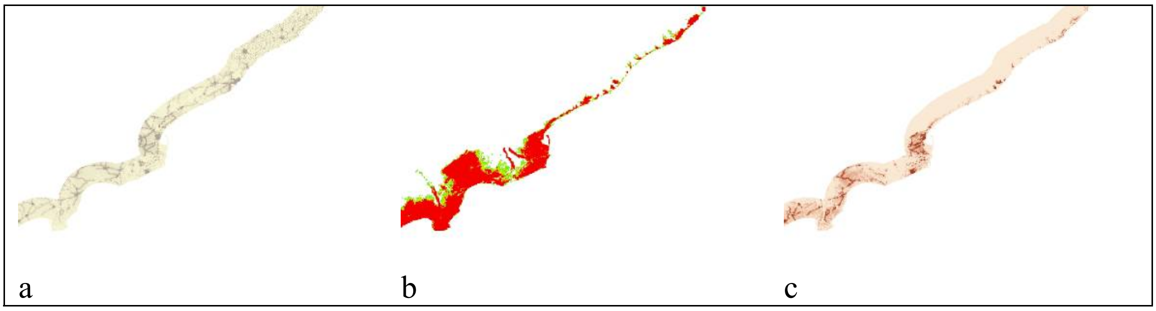


Figure 11. Calculation of coastal population.

The final step consisted to overlay the population dataset to the obtained coastal DEM below 5m in order to create a final dataset representing the estimation of the population of the world that leave on the coastal area below 5m (c).

4.2.2 Storm surge model component

Storm surge are abnormal rise in the water level caused by the wind and pressure forces of a tropical cyclone. Storm surge produces most of the flood damage and drowning associated with either the storms that make landfall or the ones that closely approach the coastline.

The assumption of our model is that the depression area that generates the surge could be estimated with the wind speed buffer. Based on the Saffir-Simpson classification of cyclones according to wind speed the extent of the flooded area could be estimated (Annex).

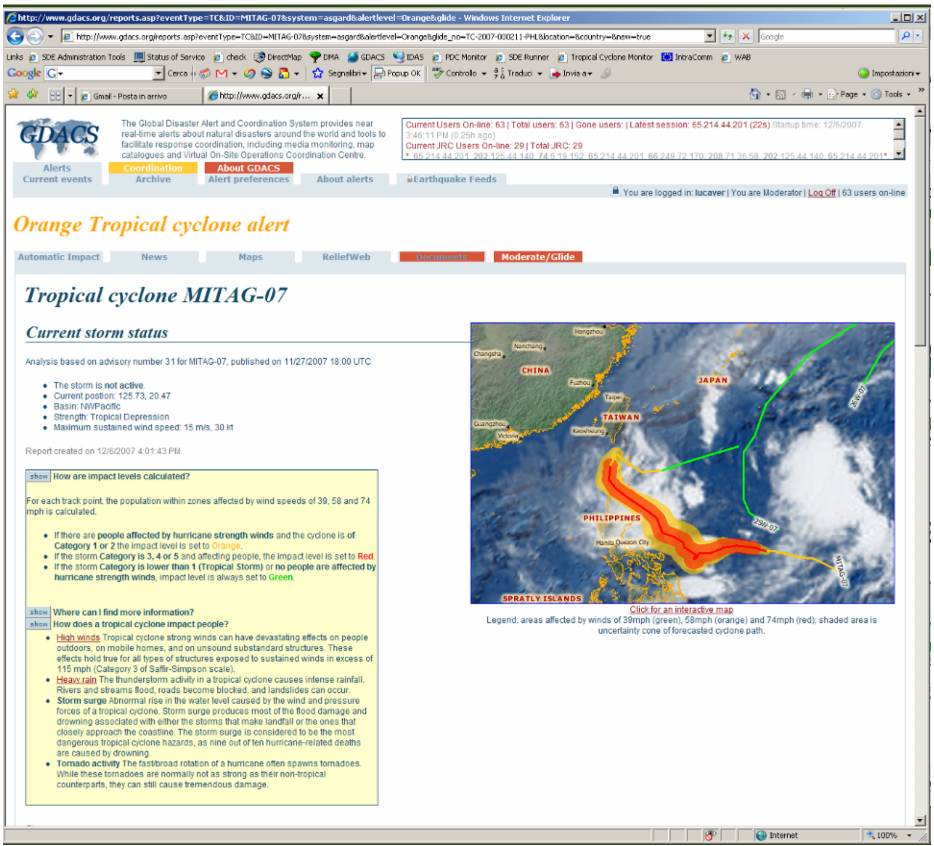
The storm surge component will be completed in 2008.

5 GDACS Tropical Cyclone Report

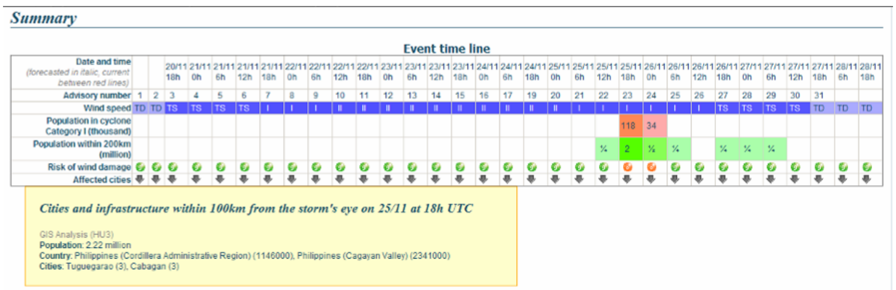
All information scraped, downloaded, calculated and inferred must be conveyed in a user-friendly manner to disaster managers. This is the purpose of the tropical cyclone report.

Currently, the following elements are part of the report:

- Storm data: position, strength and category of the storm, taken from the source
- Storm overview map: a map with (1) storm track, (2) wind buffers, (3) geographic features (cities and countries) on background of (3) real-time clouds



- Storm time line: a summary of information each six hours, including alert score, wind speed, storm category, population affected by Category 1 winds or higher, population within 100km, and affected cities.



Summary

Event time line

Date and time (forecasted in italic, current between red lines)			20/11 18h	21/11 0h	21/11 6h	21/11 12h	21/11 18h	22/11 0h	22/11 6h	22/11 12h	22/11 18h	23/11 0h	23/11 6h	23/11 12h	23/11 18h	24/11 0h	24/11 6h	24/11 18h	25/11 0h	25/11 6h	25/11 12h	25/11 18h	26/11 0h	26/11 6h	26/11 12h	26/11 18h	27/11 0h	27/11 6h	27/11 12h	27/11 18h	28/11 6h	28/11 18h
Advisory number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	19	20	21	22	23	24	25	26	27	28	29	30	31		
Wind speed	TD	TD	TS	TS	TS	TS	I	I	I	II	II	II	II	II	II	II	II	II	II	I	I	I	I	I	I	TS	TS	TS	TS	TD	TD	TD
Population in cyclone Category I (thousand)																						118	34									
Population within 200km (million)																					¼	2	½	¼		¼	¼	¼				
Risk of wind damage																																
Affected cities																																

Cities and infrastructure within 100km from the storm's eye on 25/11 at 18h UTC

GIS Analysis (HU3)
Population: 2.22 million
Country: Philippines (Cordillera Administrative Region) (1146000), Philippines (Cagayan Valley) (2341000)
Cities: Tuguegarao (3), Cabagan (3)

- Affected cities and critical infrastructure: for each storm track point, a report with lists and maps shows what is affected

Affected cities and critical infrastructure (advisory number: 31)

For each track point of the cyclone, a list of cities and critical infrastructure hit by high winds with speed bigger than hurricane strength is shown below. Click on the button show to see the data.

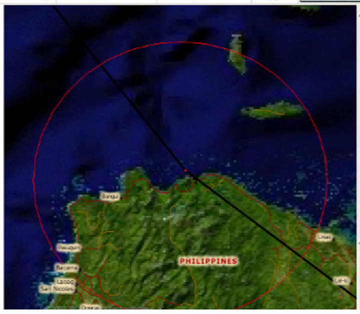
Track

alertcolor	date time	advisory number	coords	wind speed	wind gusts	storm status	Population within 100km	Population in hurricane	country	impact
		1	11.6,137.4	15 m/s (30 kt, 34 mph)	20 m/s (39 kt, 45 mph)	Tropical Depression	0	0		Not near land
		2	12.6,137.1	15 m/s (30 kt, 34 mph)	20 m/s (39 kt, 45 mph)	Tropical Depression	0	0		Not near land
	11/20/2007 18:00 UTC	3	13.6,135.1	17 m/s (34 kt, 39 mph)	23 m/s (45 kt, 51 mph)	Tropical Storm	0	0		Not near land
	11/21/2007 00:00 UTC	4	13.8,133.8	20 m/s (39 kt, 45 mph)	25 m/s (50 kt, 57 mph)	Tropical Storm	0	0		Not near land
	11/21/2007 06:00 UTC	5	14.2,132.3	23 m/s (45 kt, 51 mph)	28 m/s (54 kt, 62 mph)	Tropical Storm	0	0		Not near land
	11/21/2007 12:00 UTC	6	14.2,131.7	28 m/s (54 kt, 62 mph)	36 m/s (70 kt, 80 mph)	Tropical Storm	0	0		Not near land
	11/21/2007 18:00 UTC	7	14.4,130.8	33 m/s (65 kt, 74 mph)	41 m/s (79 kt, 91 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/22/2007 00:00 UTC	8	14.6,129.5	36 m/s (70 kt, 80 mph)	43 m/s (85 kt, 97 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/22/2007 06:00 UTC	9	14.5,128.6	41 m/s (79 kt, 91 mph)	51 m/s (99 kt, 114 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/22/2007 12:00 UTC	10	14.1,127.7	43 m/s (85 kt, 97 mph)	54 m/s (105 kt, 120 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/22/2007 18:00 UTC	11	14,126.9	46 m/s (90 kt, 103 mph)	56 m/s (110 kt, 126 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/23/2007 00:00 UTC	12	13.6,126.7	46 m/s (90 kt, 103 mph)	56 m/s (110 kt, 126 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/23/2007 06:00 UTC	13	13.6,126.5	48 m/s (94 kt, 108 mph)	59 m/s (114 kt, 131 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/23/2007 12:00 UTC	14	13.9,126.6	48 m/s (94 kt, 108 mph)	59 m/s (114 kt, 131 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/23/2007 18:00 UTC	15	14.2,126.3	48 m/s (94 kt, 108 mph)	59 m/s (114 kt, 131 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/24/2007 00:00 UTC	16	14.4,125.9	48 m/s (94 kt, 108 mph)	59 m/s (114 kt, 131 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/24/2007 06:00 UTC	17	14.9,125.8	43 m/s (85 kt, 97 mph)	54 m/s (105 kt, 120 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/24/2007 18:00 UTC	19	15.2,125.1	43 m/s (85 kt, 97 mph)	54 m/s (105 kt, 120 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/25/2007 00:00 UTC	20	15.5,124.3	43 m/s (85 kt, 97 mph)	54 m/s (105 kt, 120 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/25/2007 06:00 UTC	21	16.5,123.9	41 m/s (79 kt, 91 mph)	51 m/s (99 kt, 114 mph)	Hurricane/Typhoon > 74 mph	0	0		Not near land
	11/25/2007 12:00 UTC	22	17.1,123.3	38 m/s (74 kt, 85 mph)	46 m/s (90 kt, 103 mph)	Hurricane/Typhoon > 74 mph	9580	0	Philippines	impact report
	11/25/2007 18:00 UTC	23	17.9,122.1	38 m/s (74 kt, 85 mph)	46 m/s (90 kt, 103 mph)	Hurricane/Typhoon > 74 mph	2.22 million	0.11 million	Philippines	impact report
	11/26/2007 00:00 UTC	24	18.6,121	38 m/s (74 kt, 85 mph)	46 m/s (90 kt, 103 mph)	Hurricane/Typhoon > 74 mph	0.95 million	0.03 million	Philippines	impact report

Affected Population in hurricane: 0.03 million

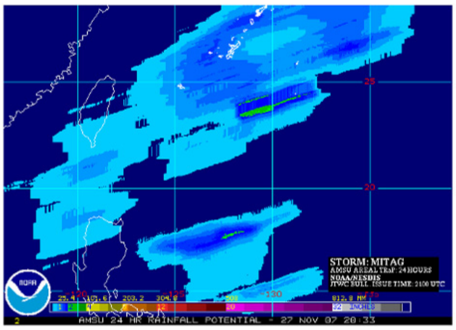
Affected Cities

Name	Provinces	Country	City Class (1 to 6)	Distance (km)
Namuac	Cagayan Valley	Philippines	5	17
Claveria	Cagayan Valley	Philippines	5	8
Santiago	Cagayan Valley	Philippines	5	12
Batitgao	Cagayan Valley	Philippines	5	14
Aggao	Ilocos	Philippines	5	13
Portugal	Cagayan Valley	Philippines	5	2
Kilkiling	Cagayan Valley	Philippines	5	6
Tangatong	Ilocos Norte	Philippines	5	22
Macatel	Cagayan Valley	Philippines	5	6
Filomeno	Cagayan Valley	Philippines	5	10
Maragnat	Cagayan Valley	Philippines	5	11
Bunot	Cagayan Valley	Philippines	5	14
Adam	Ilocos	Philippines	5	17
Tanglagan	Cordillera Administrative Region	Philippines	5	25
Masi	Cordillera Administrative Region	Philippines	6	26
Bangui	Ilocos	Philippines	4	25



- Potential rainfall for the next 24h: TRaP image (in collaboration with NOAA TRaP).

Potential Rainfall for the next 24 hr (NOAA - Operational Satellite Derived Tropical Rainfall Potential)



See more details for MITAG-07 on the NOAA website.

Based on the advances in tropical cyclones impact modelling, the report will feature new items in 2008:

- Alert score for rainfall, and associated information. Statistics by city and by time.
- Alert score for storm surge, and associated information. Maps with likely storm surge affected areas. Statistics on affected population.
- Impact reports by city and critical infrastructure: for feature of interest the arrival time of the cyclone, the duration, wind speed and end time will be displayed.

6 Conclusion

JRC's research on tropical cyclones of 2007 builds the foundations for an innovative cyclone alert model. In contrast with the work of 2006 (focusing on wind speed modelling), 2007 focused on integrating data provided by other organisations into a single consequence analysis model.

A collaboration with the Pacific Disaster Center allowed JRC to access structured data on tropical cyclone track information. This new source of information, available since August 2007, enables us to implement more advanced impact models which provide improved information for humanitarian emergency managers. As a result, since October 2007 GDACS maps feature tropical cyclone wind buffers overlaid on global real-time cloud images. While a lot of modelling work has been completed and geoprocessing systems were put in place to exploit this new source of data, the resulting products have not been integrated fully in GDACS.

A more informal collaboration with NOAA TRaP allowed JRC to start addressing the rainfall component of tropical cyclones. Currently, TRaP images are published in GDACS reports, but the data is not exploited yet.

With regards to storm surge modelling, a global dataset of population in low lying coastal areas was created successfully. This dataset is a prerequisite to calculate the impact of storm surges associated with tropical cyclones.

In the first quarter of 2008, all these products will be integrated seamlessly in GDACS. They will allow an alert score based on the three hazards of a tropical cyclone: wind, rain and surge. No other system is currently providing such information.

7 References

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8 Annex

Saffir-Simpson Scale (source: http://www.aoml.noaa.gov/hrd/tcfaq/D1.html**)**

Saffir-Simpson Category	Maximum sustained wind speed				Minimum central pressure	Storm surge	
	mph	**m/s**	**kts**	**km/h**	**mb**	**ft**	**m**
TD	38	17	33	62			
TS	39-73	17.5-32.5	34-63	63-117		0-3	0-0.9
1	74-95	33-42	64-82	119-153	> 980	3-5	1.0-1.7
2	96-110	43-49	83-95	154-177	979-965	6-8	1.8-2.6
3	111-130	50-58	96-113	178-209	964-945	9-12	2.7-3.8
4	131-155	59-69	114-135	210-249	944-920	13-18	3.9-5.6
5	156+	70+	136+	250+	< 920	19+	5.7+

Wind speed (m/s)	**Saffir-Simpson Category**	**Damage description**	**Flooded area**
< 17.5	TROPICAL STORM	Extensive damage with rainfall-produced flooding	
33 -42	CAT 1	Low-lying coastal roads inundated, minor pier damage	
43 -49	CAT 2	Coast roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane centre. Considerable damage to piers. Marinas flooded. Evacuation of some shoreline residences and low-lying areas required.	population affected (coastal areas)
50 – 58	CAT 3	Serious flooding at coast and many smaller structures near coast destroyed; larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane centre arrives. Flat terrain 5 feet or less above sea level flooded inland 8 miles or more. Evacuation of low-lying residences within several blocks of shoreline possibly required	population affected (coastal areas: 5 feet above sea level X 8 miles - flooded) Evacuation pop: several blocks from shore
59 – 69	CAT 4	Flat terrain 10 feet or less above sea level flooded inland as far as 6 miles. Major damage to lower floors of structures near shore due to flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane centre arrives. Major erosion of beaches. Massive evacuation of all residences within 500 yards of shore possibly required, and of single-story residences within 2 miles of shore.	population affected (coastal areas: 10 feet above sea level X 6 miles – flooded) Evacuation pop: 2 miles from shore
> 70	CAT 5	Major damage to lower floors of all structures less than 15 feet above sea level within 500 yards of shore. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane centre arrives. Massive evacuation of residential areas on low ground within 5 to 10 miles of shore possibly required.	population affected (coastal areas: 15 feet above sea level X 500 yards – flooded) Evacuation pop: 5 to 10 miles from shore

European Commission

EUR 23083 EN – Joint Research Centre – Institute for the Protection and Security of the Citizen
Title: Humanitarian Impact of Tropical Cyclones
Author(s): Luca Vernaccini, Tom De Groeve, Simone Gadenz
Luxembourg: Office for Official Publications of the European Communities
2007 – 29 pp. – 21 x 30 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593

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