JRC TECHNICAL REPORTS

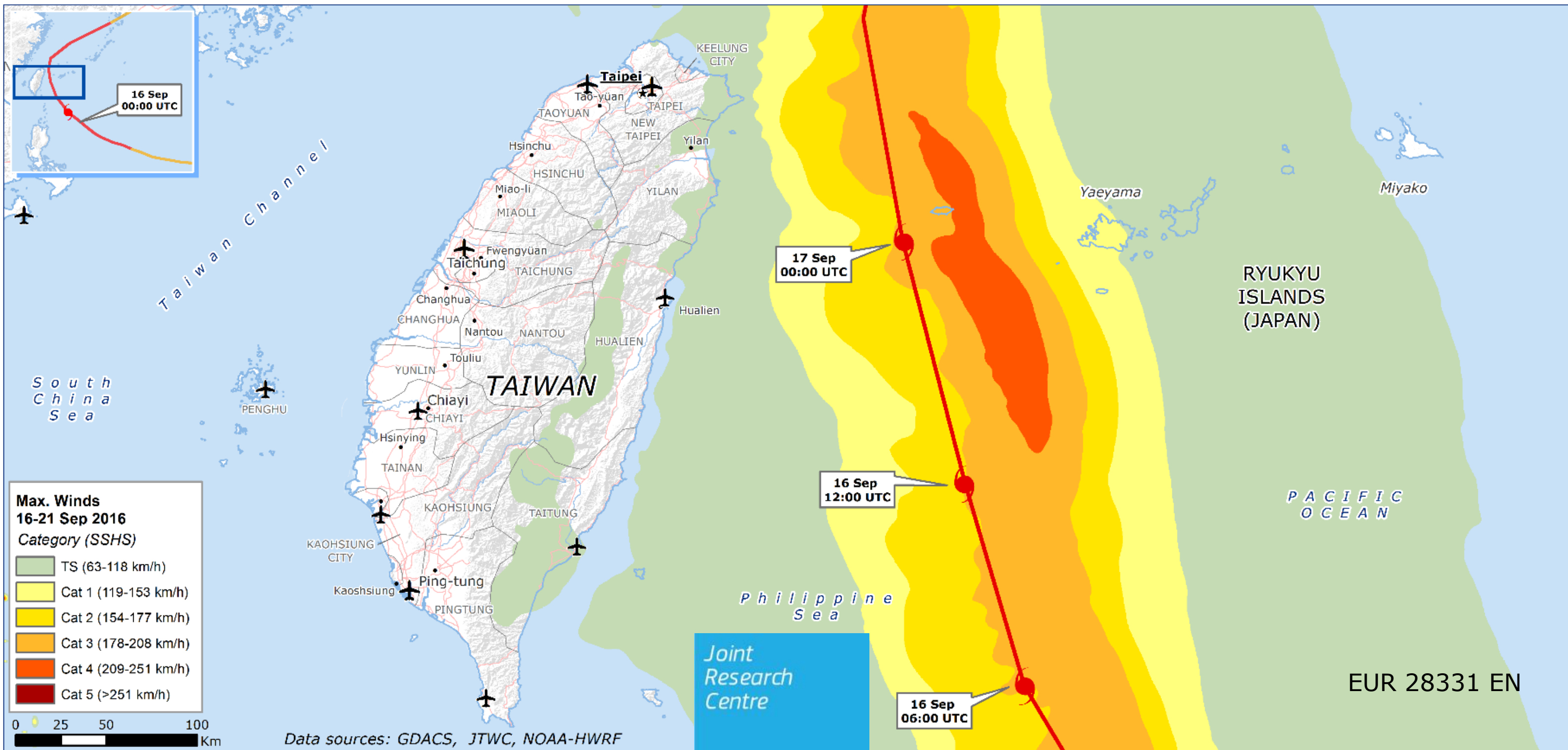
TROPICAL CYCLONES in GDACS Data sources

Past, current and future Tropical Cyclones data sources used in GDACS

Pamela Probst

Alessandro Annunziato

2016



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Contents

Abstract

The Global Disaster Alert and Coordination System (GDACS) provides alerts and preliminary impact estimations of the natural disasters around the world, like earthquakes, tsunami, tropical cyclones and floods. The Tropical Cyclones (TCs) are among the most damaging events. They affect the population with three dangerous effects: strong wind, heavy rain and storm surge.

GDACS has developed a system that includes the analysis of all these effects for every TC occurring worldwide, using several different data sources. This report describes these data sources and the tools developed by the JRC to include the TC information in GDACS, as well as the new products that could be used to improve the current system.

1 Introduction

The Global Disaster Alert and Coordination System (GDACS, www.gdacs.org) has been created by the Joint Research Centre of European Commission in collaboration with the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) to provide alerts and preliminary impact estimations of the natural disasters around the world (e.g. earthquakes, tsunamis, tropical cyclones and floods). Tropical Cyclones (TCs) are among the most damaging events. They affect the coastal population every year with three dangerous effects: strong wind, heavy rain and storm surge. In order to estimate the area and the population affected all the three types of physical impacts must be taken into account. GDACS includes all these dangerous effects, using several data sources.

The TCs around the globe are monitored as a result of an international cooperation, coordinated at the global and regional levels by the 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 each TC basins (see Annex 1). These centers provide information on TC position, intensity and other parameters for all TCs everywhere in the world, but this information is not available in a single standard format, so it is difficult to use these data in an automatic system like GDACS. In addition to the RSMC and TCWC also other organizations, such as the Joint Typhoon Warning Center (JTWC), provide the TC information.

In 2007, the Pacific Disaster Centre (PDC) set up an automatic routine which includes TC bulletins from JTWC and NOAA into a single database, covering all TC basins, and in the same year the JRC started using this source of information in order to include the TCs in GDACS. At the beginning these data were used only for the wind impact (see Vernaccini et al. 2007), then in 2011 also as input in the method that infer the wind and pressure fields in the JRC storm surge model (see Probst and Franchello, 2012). In 2014, JRC set up a new automatic routine, without using the systems of PDC anymore. This routine includes the data of JTWC and NOAA into a single database, covering all the TCs basins. JRC started using this new method at the beginning of October 2014.

In addition to these TC products, there are also a number of TC models (e.g. NOAA Fluid Dynamics Laboratory / GFDL - Hurricane Model[1], and NOAA Hurricane Weather Research and Forecast System / HWRF[2]) able to represent the wind and pressure fields of a TC, which can be used for the wind impact and also as input in the JRC storm surge model. The output of these models was not available globally in real time, when the JRC developed the storm surge model and the GDACS wind impact methodology, but now the TC data of HWRF are available for all the TC basins. Therefore this new source could be used in GDACS and in the JRC storm surge model. The JRC is implementing several new tools to use this product in GDACS, as described in Probst et al. (2016).

Also the global weather forecasting models (e.g. European Centre for Medium Weather Forecast-ECMWF-High resolution model) provide wind and pressure fields. In the past years the global models, due to their coarse grid size, had several problems to resolve the extreme pressure gradients associated with TCs (Van Der Grijin, 2002), but recently their resolution had notably improved, therefore the global model should be able to reproduce the extreme pressure gradient inside a TC and could be used for the wind, rain and storm surge impacts in GDACS.

A brief description of the TC bulletins available is presented in Section 2, while the historical, current and future data sources used in GDACS are in Section 3. Concluding remark are in Section 4.

[1] GFDL Hurricane Model: http://www.gfdl.noaa.gov/operational-hurricane-forecasting
[2] HWRF model: http://hwrf.aoml.noaa.gov/

GLOBAL DISASTER ALERT AND COORDINATION SYSTEM INCLUDES THE ANALYSIS OF THE THREE EFFECTS

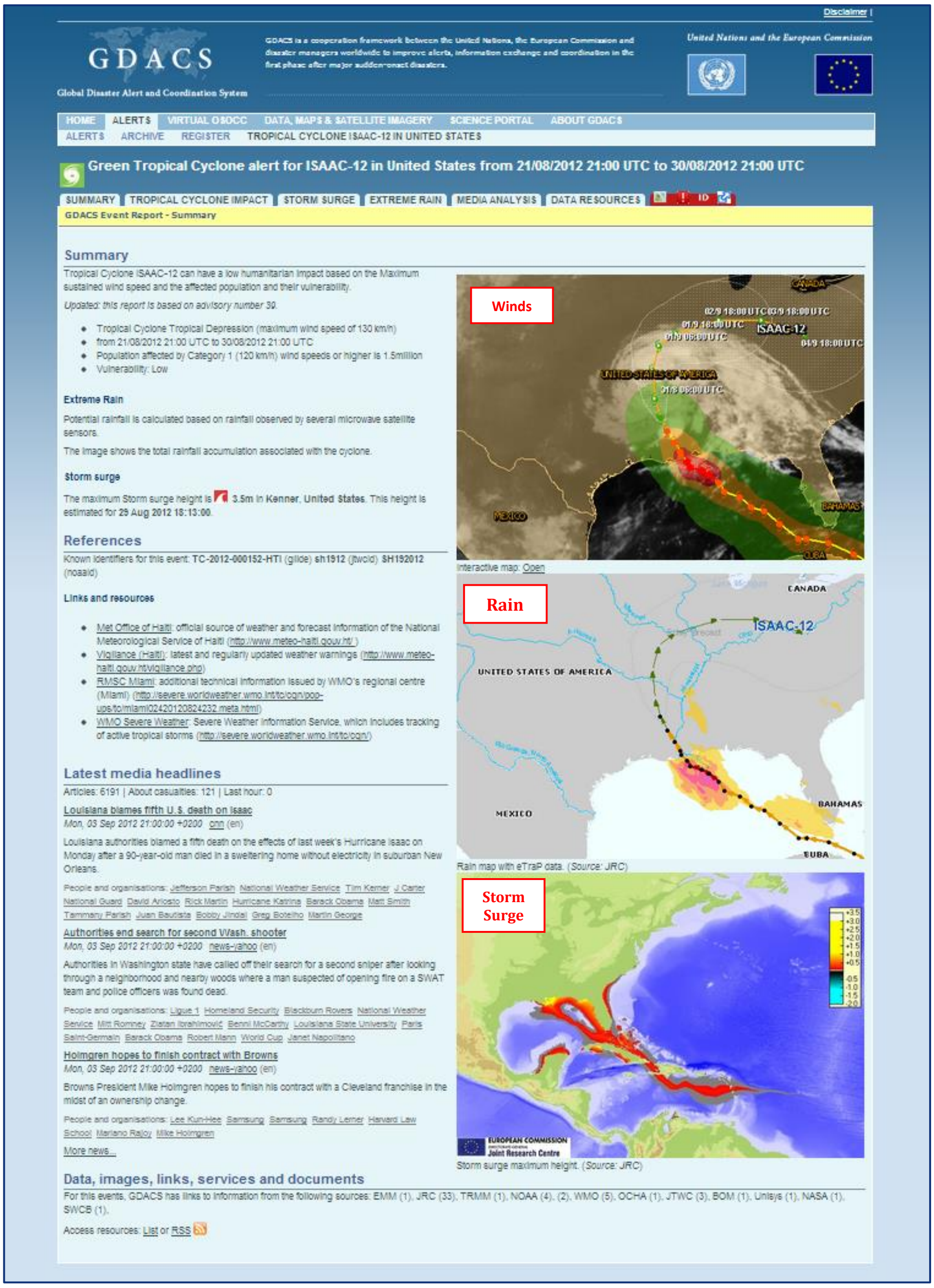

Figure 1 - TCs in GDACS

2 Tropical Cyclones bulletins

2.1 RSMC and TCWC

The most important sources of TC information are the TC bulletins provided by the Regional Specialized Meteorological Centres (RSMCs) and the Tropical Cyclone Warning Centres (TCWCs). These centres have the regional responsibility to forecast and monitor each area of TC formation (see **Figure 7**). The list of the TCWCs and RSMCs is provided in Annex 1.

Every 6-12 hours the TC warning centres publish a TC bulletin, including several TC information as: track, wind speed and wind radii[3]. The information and format included in each bulletin vary from center to center and it is not always in the same format. A brief description of one of this bulletin is presented below. This TC bulletin is the one of the NOAA National Hurricane Center's (NHC), that is the center responsible for the Atlantic and the eastern Pacific Ocean and is currently used as data source in GDACS.

> **NOAA NHC bulletin:** NHC issues tropical and subtropical cyclones advisories every six hours (at 03:00, 09:00, 15:00, and 21:00 UTC) for the areas of the Atlantic and eastern Pacific Oceans. The NHC bulletin contains a list of all current watches and warnings on a tropical or subtropical cyclone, as well as the current latitude and longitude coordinates, intensity, system motion and wind radii. The intensity includes the analysis of the central pressure (Pc, it is not forecasted), and the maximum sustained (1-min average) surface wind (Vmax) analysed and forecasted for 12, 24, 36, 48 and 72 h. The advisory may also include information on any pertinent storm tides associated with the cyclone.
>
> More information at: http://www.nhc.noaa.gov/.

2.2 Other organisations

In addition to the RSMCs and TCWCs other organizations provides specific TC information (e.g. Joint Typhoon Warning Center - JTWC, NOAA Hurricane Weather Forecast Research and Forecast System – HWRF, European Centre for Medium Weather Forecast-ECMWF). A brief description of the JTWC bulletin that is currently used in GDACS is presented below.

> **JTWC bulletin:** JTWC is the U.S. Department of Defence agency responsible for issuing tropical cyclone warnings for the Pacific and Indian Oceans. TC bulletins are issued for the Northwest Pacific Ocean, North Indian Ocean, Southwest Pacific Ocean, Southern Indian Ocean, Central North Pacific Ocean. JTWC products are available by 03:00, 09:00, 15:00 or 21:00 UTC (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 every twelve hours). The bulletins include position of TC centre, the maximum sustained wind based on 1-min average and the wind radii.
>
> More information at: www.usno.navy.mil/JTWC/.

[3] Wind radii represents the maximum radial extent – in nautical miles - of winds reaching 34, 50, and 64 knots in each quadrant (NE, SE, SW, and NW). These data are provided in each TC bulletin issued by the TC warning centres at least every six hours. The thresholds of the velocity (34, 50, 64kt) could vary from centre to centre

3 Tropical Cyclones data in GDACS

3.1 Previous TC data: August 2007 – September 2014

The TC bulletins provided by the RSMCs and TCWCs include several TC information (eg. Track, Vmax, wind radii), but are not available in a single standard format, so it is difficult to use these data in an automatic system like GDACS. To overcome this problem, PDC set up an automatic routine in 2007, which includes the NOAA and JTWC bulletins into a single database. The NOAA bulletins include the Atlantic, Eastern Pacific and Central Pacific basins[4], while the JTWC bulletin the rest of the basins. The TCs data were then published as a Web Feature Service (WFS), which is a service used to publish geospatial data. This allows other applications to query records using standards-based protocols. PDC implemented the WFS service with ESRI's ArcIMS WFS connector. The PDC data contained most of the elements reported in the official TC bulletins, but the data was structured in different layers, including geographical elements (as points, lines or polygons) and attributes. JRC downloaded regularly the data from PDC, as part of the GDACS geoprocessing tool called AsgardLite. This system called the WFS service and processed the resulting XML. The data was processed and then stored in a spatial database (ArcSDE / ESRI Spatial Database Engine, upon a Microsoft SQL Server database). This allowed the creation of interactive maps through the JRC Web Mapping Service (WMS), needed for the maps of the TC reports. The PDC information was stored in different layers in the JRC database, more suitable to the mapping needs of GDACS. In October 2014, the PDC created a new ArcGIS Server and the ArcIMS system was no longer available, therefore the JRC decided to develop its own system, described in Section 3.2.
More information can be found in Vernaccini et al. (2007) and at: http://www.pdc.org

The system described above was used in GDACS for the **wind impact** and as input for the JRC **storm surge** system, while for the **rain impact**, the JRC developed a system using as input two different products: the NOAA "Ensemble Tropical Rainfall Potential" (eTRaP) data and the National Aeronautics and Space Administration (NASA) "Tropical Rainfall Measuring Mission" (TRMM). A brief description of these data is presented below, while an analysis on these products can be found in Probst et al. (2012).

NOAA Ensemble Tropical Rainfall Potential – eTRaP: The ensemble Tropical Rainfall Potential (eTRaP) has been developed to improve short-range forecasts of heavy rainfall in TC and combines all single-pass Tropical Rainfall Potential (TRaP) produced to form a simple ensemble. The TRaP is a 24-h rain forecast based on estimated rain rates from microwave sensors aboard several satellites. The TRaP became operational at National Environmental Satellite, Data, and Information Service (NESDIS) in 2003 and was followed by ensemble TRaP. More information can be found in Ebert et al. (2011), while the data are available at: http://www.ssd.noaa.gov/PS/TROP/etrap.html.

NASA Tropical Rainfall Measuring Mission" (TRMM): NASA-TRMM is a joint mission between NASA and the Japan Aerospace Exploration (JAXA) Agency lunched in 1997 to study rainfall for weather and climate research. The precipitation-relevant instruments on the TRMM satellite included the Precipitation Radar (PR), TRMM Microwave Image (TMI), and Visible and Infrared Scanner (VIRS). A number of TRMM Multi-satellite Precipitation Analysis (TMPA) products with different temporal resolutions were available for a geographical coverage from 50° S to 50° N. The TRMM satellite ended collecting data on 15 April 2015. More in information can be found at https://trmm.gsfc.nasa.gov/.

[4] The center responsible for the TC information in the Atlantic and Eastern Pacific is the NOAA NHC while for the Central Pacific is the Central Pacific Hurricane Center (CPHC).

3.2 Current TC data: October 2014 - present

In 2014, JRC set up a new automatic routine, independent from the one of PDC, which includes the data of JTWC and NOAA into a single database, covering all TCs basins. The NOAA data are used for the Atlantic, Northeast and North Central Pacific basin, while the JTWC data for all the other basins, like in the PDC routine (see Section 3.1 and **Figure 2**). JRC started using this routine at the beginning of October 2014.

NOAA data:

1. **Atlantic** basin (including North Atlantic Ocean, Gulf of Mexico and Caribbean Sea)
2. **Northeast Pacific** basin (from Mexico to 140W)
3. **North central Pacific** Basin (from 140W to 180W)

JTWC data:

4. **Northwest Pacific** basin (from 180W to Asia including the South China Sea)
5. **North Indian** basin (including the Bay of Bengal and the Arabian Sea)
6. **Southwest Indian** basin (from Africa to about 100E)
7. Southeast Indian/Australian basin (100E to 142E)
8. **Australian/Southwest Pacific** basin (142E to about 120W)

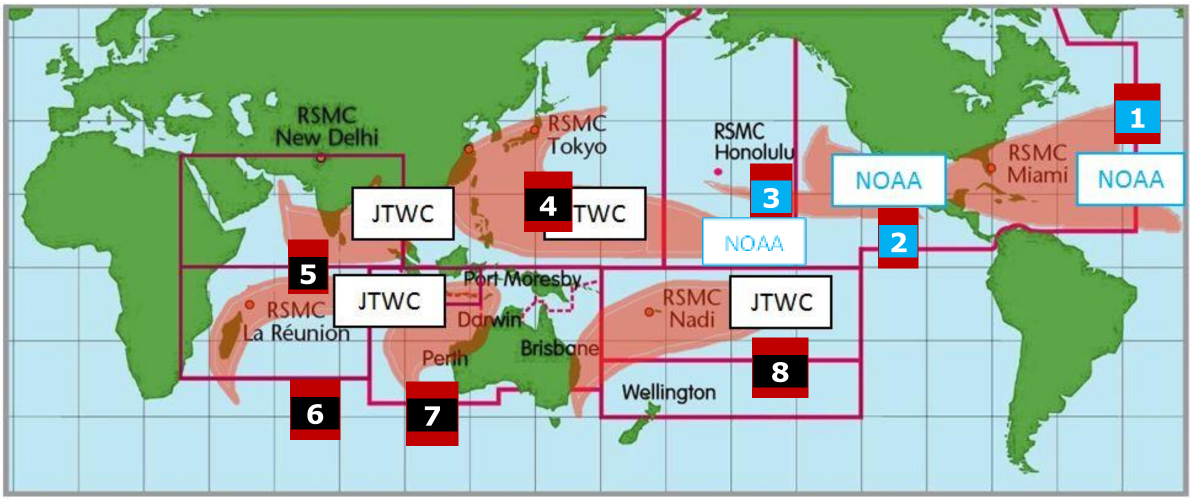

Figure 2 - Data sources used in the GDACS database for each TC basin.
Background source: WMO and NOAA, see http://www.aoml.noaa.gov/hrd/tcfaq/F1.html

NOAA and JTWC use a different method to calculate the "Uncertainty Cone[5] ", that it is also slightly different from the method of PDC (see Annex 2). Therefore, the JRC developed a method similar to the PDC method described in Section 3.2.1.

The new routines described in the next Sections are used for the **wind** and **storm surge** impact in GDACS, while for the **rain impact** GDACS is still using the NOAA eTRaP product described in Section 3.1. The JRC has also recently implemented a new routine to use the NASA Global Precipitation Measurement (GPM) instead of the TRMM data, since the TRMM satellite ended collecting data on 15 April 2015. More information on the NASA GPM can be found at: https://pmm.nasa.gov/gpm

A scheme of the data sources used in the current GDACS system is in **Figure 3**.

[5] The uncertainty cone is a polygonal shape around the forecast points for a tropical cyclone's advisory that represents the probable track of its center.

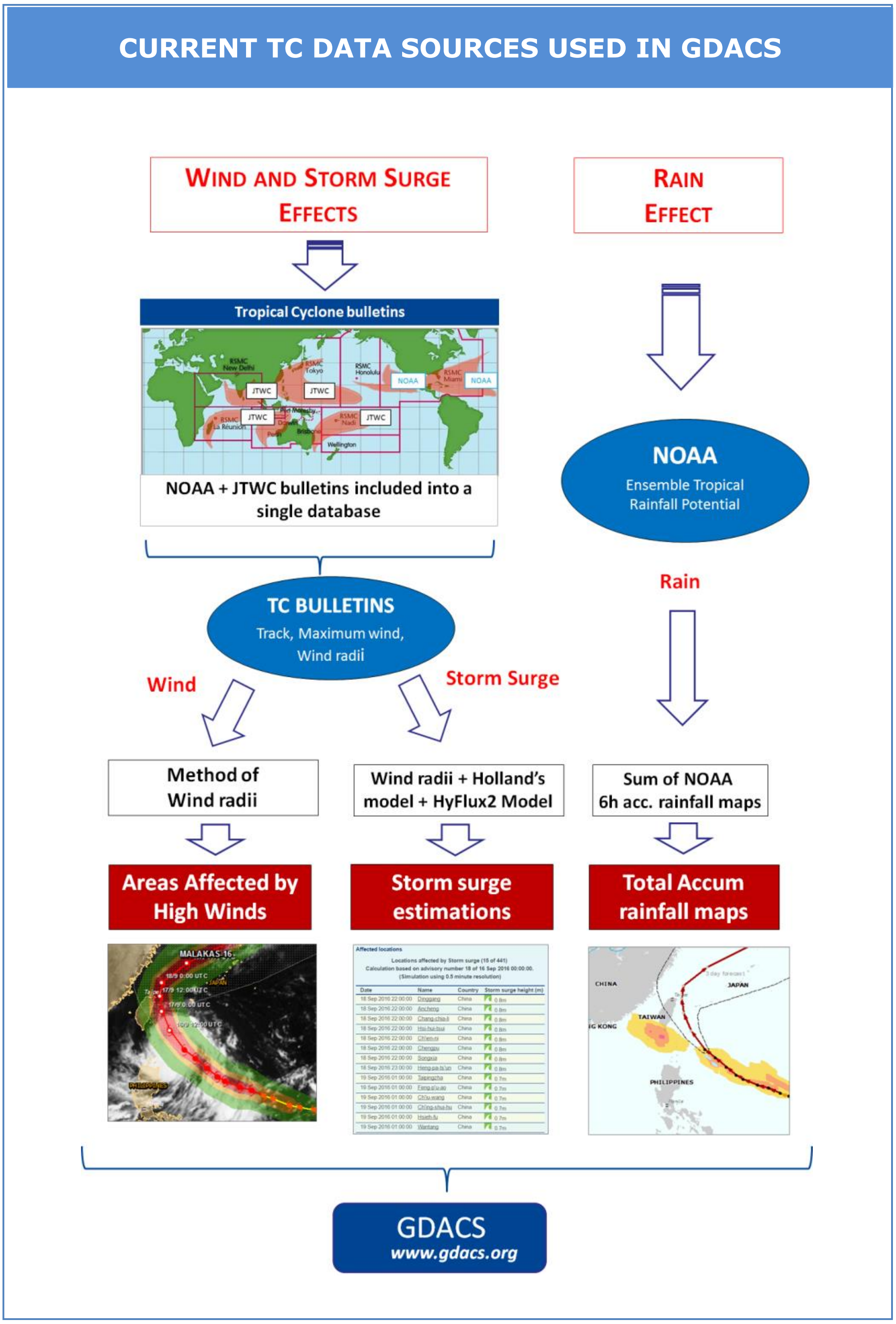

Figure 3 - Current TC data surces used in the system in GDACS.

3.2.1 JRC automatic routines for JTWC and NOAA data

The format of the JTWC data is different from the one of NOAA; therefore two separate routines have been created by the JRC in order to include these data in one single database.

The routines are scheduled every 30 minutes and they check the reference url to get the latest information to compare with the bulletin previously saved, and if the latest one has a new information the system process the new data.

<u>ROUTINE FOR THE NOAA data:</u>

The sources of the RSS for the NOAA data used in GDACS are the following:

- Central Pacific basin: http://www.prh.noaa.gov/cphc/index-cp.xml
- Eastern Pacific basin: http://www.nhc.noaa.gov/index-ep.xml
- Atlantic, Caribbean, and the Gulf of Mexico: http://www.nhc.noaa.gov/index-at.xml

Not all the information available included in these RSS fields are considered, but only the one that has in the ***<title>*** the following words:

- "Forecast Advisory"
- "Forecast/Advisory"
- "Forecast-Advisory"

The TC information (NOAA advisories) are included inside the tag ***<pre> </pre>***.

The NOAA module scraper checks the url listed above for the TC basins of Central Pacific, Eastern Pacific, Atlantic-Caribbean and it looks for the text inside the tag ***<pre></pre>*** (TC information). If the TC bulletin is available, the main TC information will be extracted in order to compare the bulletin to the one stored in the JRC bulletin archive (*Stormname*, *Universalid* and *Bulletinnumber* are the keys) and if it is a new information, the basic data are elaborated and stored into the database in three tables: *TCEvent*, *TCBulletin*, *TCTracks.* The new record inserted will be marked as *"unprocessed"* to allow the next step, in order to get the right information to process the wind radii buffers and the other TC information.

<u>ROUTINE FOR THE JTWC DATA:</u>

The JTWC data are available for the TCs basins except for the basin of the Atlantic.

- <u>Before 2 May 2016:</u> The files **.tcw** of the JTWC were downloaded from the following website: http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/warnings/. Note: the files that started with "***e***" and the ones that had the third character equal to "***9***" were not considered.

Filename	Last Modified	Filesize	Filetype
wp2214.gif	01-Dec-2014 07:40	54998	file
wp2214.kmz	01-Dec-2014 07:23	435109	file
wp2214.tcw	01-Dec-2014 07:39	5504	file
wp2214fix.txt	01-Dec-2014 12:10	398	file
wp2214prog.txt	01-Dec-2014 07:59	2317	file
wp2214web.txt	01-Dec-2014 07:39	4605	file

Table 1- JTWC data.

The JTWC module scraper checked the page indicated above to find the file having the extension equal to **.tcw**, that contained in the firsts lines the main and complete information about the bulletin (i.e. the **.txt** files didn't include the information about the date of bulletin).

- After 2 May 2016: On 2 May 2016, the JTWC changed the website and the parameters included in Table 1 were not available anymore, therefore the JRC developed a new procedure using the rss feed: https://metoc.ndbc.noaa.gov/RSSFeeds-portlet/img/jtwc/jtwc.rss. This procedure identifies the key " **.tcw"** and uses the JTWC ID (e.g. *ep1016*) of the TC in order to have the link for the specific bulletin, see example below:

  Rss feed:

```
<ul>
   <li>
      <a href='https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/products/ep1016web.txt'
      target='newwin'>TC Warning Text</a>
   </li>
   <li>
      <a href='https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/products/ep1016.gif' target='newwin'>TC
      Warning Graphic</a>
   </li>
   <li>
      <a href='https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/products/ep1016.tcw'
      target='newwin'>JMV 3.0 Data</a>
   </li>
   <li>
      <a href='https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/products/ep1016.kmz'
      target='newwin'>Google Earth Overlay</a> <img src='https://metoc.ndbc.noaa.gov/ProductFeeds-
      portlet/img/jtwc/img/kml.jpg'>
   </li>
</ul>
```

  JTWC ID TC:

  https://metoc.ndbc.noaa.gov/ProductFeeds-portlet/img/jtwc/products/**ep1016.tcw**.

  The module identifies the keys of the bulletin (*Stormname*, *Universalid* and *Bulletinnumber*) and if the bulletin exists, the main TC information is extracted to compare the bulletin to the one stored in the JRC archive of the TCs (*Stormname*, *Universalid* and *Bulletinnumber* are the keys) and if it is a "new information", the data are elaborated and stored into the database in three tables: *TCEvent*, *TCBulletin*, *TCTracks*. The new record inserted is marked as "*unprocessed*" to allow the next step to get the right information to process the wind radii buffers and the other information.

The new NOAA and JTWC routines described above have been tested for several months in 2014, comparing the new data with the previous, giving the same results. Therefore the JRC started using officially the "new system" in GDACS in October 2014. The "old system", using the new PDC server, continued running on Sep-Dec 2014, but only the TC data obtained with the new JRC routine were shown in GDACS.

Next Steps: ***Join the scraper module***

JTWC and NOAA don't provide TC information for all the TC basins, therefore JRC decided to include the data of both sources in the database, in order to cover all the TC basins. For the eastern and central Pacific basins (see basins 2-3, **Figure 2**), JRC decided to use the NOAA data, because it is the center responsible for these two basins (see Annex 1), however also JTWC provides data for these two basins and the JRC can include also this information, having two different reports for each TC as well as two parallel processing / analysis and alert for each TC. Moreover, in some case a TC can start in one basin and moves into another one, leaving the competence of monitoring from one source to another. For example, NOAA provides data for the central Pacific basin, but not for the western Pacific, while JTWC provides data for both TC basins. The objective is to maintain the continuity of the TC tracks through the different basins.

3.2.2 Cone of Uncertainty

The cone of uncertainty is a polygonal shape around the forecasted points of a TC that represents the probable track of its center in the next days (three to five days forecast). There are several methods developed to calculate the Uncertainty Cone of a TC track. An overview on the methods used by NOAA, JTWC and PDC is shown below, while more information are in Annex 2.

- **NOAA:** The cone represents the probable track of the center of a tropical cyclone, and is formed by enclosing the area swept out by a set of circles along the forecast track (at 12, 24, 36 h, etc). The size of each circle is set up that two-thirds of historical official forecast errors over a 5-year sample are within the circle (see: http://www.nhc.noaa.gov/aboutcone.shtml).
- **JTWC**: The JTWC creates an Area of Gale Force Winds introducing the forecast track error. This area is calculated by adding the JTWC 5-year running mean forecast track error to the forecast 34 knot wind radii at each forecast time. The shading highlights the area that may be affected by wind speeds exceeding 34 knots for a given JTWC forecast, based on historical track forecast errors (see: http://www.usno.navy.mil/JTWC/frequently-asked-questions-1/frequently-asked-questions#aou).
- **PDC**: The Cone of Uncertainty (Potential Track Area) is a polygonal shape around the forecast points for a TC advisory that represents the average error in the forecasted locations over the last 10 years. The cone shape algorithm is set to draw circles along the forecasted path of the TC and the total cone shape is obtained joining all the circles (see: http://ghin.pdc.org/ghin/catalog/main/home.page .

Note: all these methods are "Climatology-Based". They don't consider the uncertainty in the track forecast based on the spread of the numerical models or other forecast models at a particular forecast time.

In GDACS, the cone of uncertainty for the TCs is calculated with a method similar to the one of PDC (see Annex 2). This system is based on the average error in the forecasted locations over the last 10 years. In 2015, the JRC has started using the new NOAA data for the Atlantic and Eastern Pacific Ocean, in order to have a more updated uncertainty cone. The new values used for the Atlantic and Eastern Pacific basins are shown in the table beow. The JRC is currently updating the uncertainty cone also in the other TC basins.

TIME (h)	DISTANCE			
	ATLANTIC BASIN		EASTERN PACIFIC BASIN	
	nm	Km	nm	Km
12	30	56	26	48
24	49	91	42	78
36	66	122	55	102
48	84	156	70	130
72	115	213	100	185
96	165	306	137	254
120	237	439	172	319

Table 2 - Radii of the forecasting circles, based on the NOAA data (as of 2016)

3.3 Future TC data: NOAA-HWRF and ECMWF-HRES

JRC developed the TC system used in GDACS in 2007 and the storm surge system in 2011. At that time the global numerical weather forecast models couldn't resolve the high wind and pressure gradients inside a TC due to their coarse resolution, while a TC weather forecast model was not globally available. Recently, the global forecasting models and the TC models have improved their resolutions and are now globally available. These models provide wind, pressure and rainfall data that could be used in GDACS and in the JRC storm surge system.

The JRC is assessing the possibility to use these products, especially the TC products based on the NOAA Hurricane Weather Research and Forecast (HWRF) model and the outputs of the global high resolution model (HRES) of the European Centre for Medium Weather Forecast (ECMWF). A brief description of these products is presented below:

NOAA Hurricane Weather Research and Forecast (HWRF) model: The development of the Hurricane Weather Research and Forecast (HWRF) model began in 2002 at the National Centers for Environmental Prediction (NCEP) - Environmental Modeling Center (EMC) in collaboration with the Geophysical Fluid Dynamics Laboratory (GFDL) scientists of NOAA and the University of Rhode Island. HWRF is a non-hydrostatic coupled ocean-atmosphere model, which utilizes highly advanced physics of the atmosphere, ocean and wave. It makes use of a wide variety of observations from satellites, data buoys, and hurricane hunter aircraft. The ocean initialization system uses observed altimeter observations, while boundary layer and deep convection are obtained from NCEP GFS. Over the last few years, the HWRF model has been notably improved, implementing several major upgrades to both the atmospheric and ocean model components along with several product enhancements. The latest version of HWRF model has a multiply-nested grid system: 18, 6, 2 km of resolutions. The TC forecasts are produced every six hours (00, 06, 12, and 18 UTC) and several parameters are included (e.g. winds, pressure and rainfall).

More information: http://www.nws.noaa.gov/os/notification/tin15-25hwrf_cca.html

Active TCs: http://www.emc.ncep.noaa.gov/gc_wmb/vxt/HWRF/index.php

ECMWF Weather Deterministic Forecast – HRES:

Before March 2016: the HRES horizontal resolution corresponded to a grid of 0.125° x 0.125° lat / long (≈16 km), while its vertical resolution was equal to 137 levels. This deterministic single-model HRES configuration runs every 12 hours and provides 10-days forecasts available on a global scale.

After March 2016, the ECMWF has started using a new grid, with up to 904 million prediction points. The new cycle has reduced the horizontal grid spacing for high-resolution from 16 km to just 9 km, while the vertical grid remained unchanged.

More information at: http://www.ecmwf.int/en/forecasts

As described above, there are several new products that the JRC could use to improve the impact of the three dangerous effects in GDACS. A scheme of the new possible data sources for the GDACS system is presented in **Figure 4**, while two examples of using the HWRF data are in **Figure 5** and **Figure 6**. More information on the new systems that the JRC is implementing can be found in Probst et al. (2016).

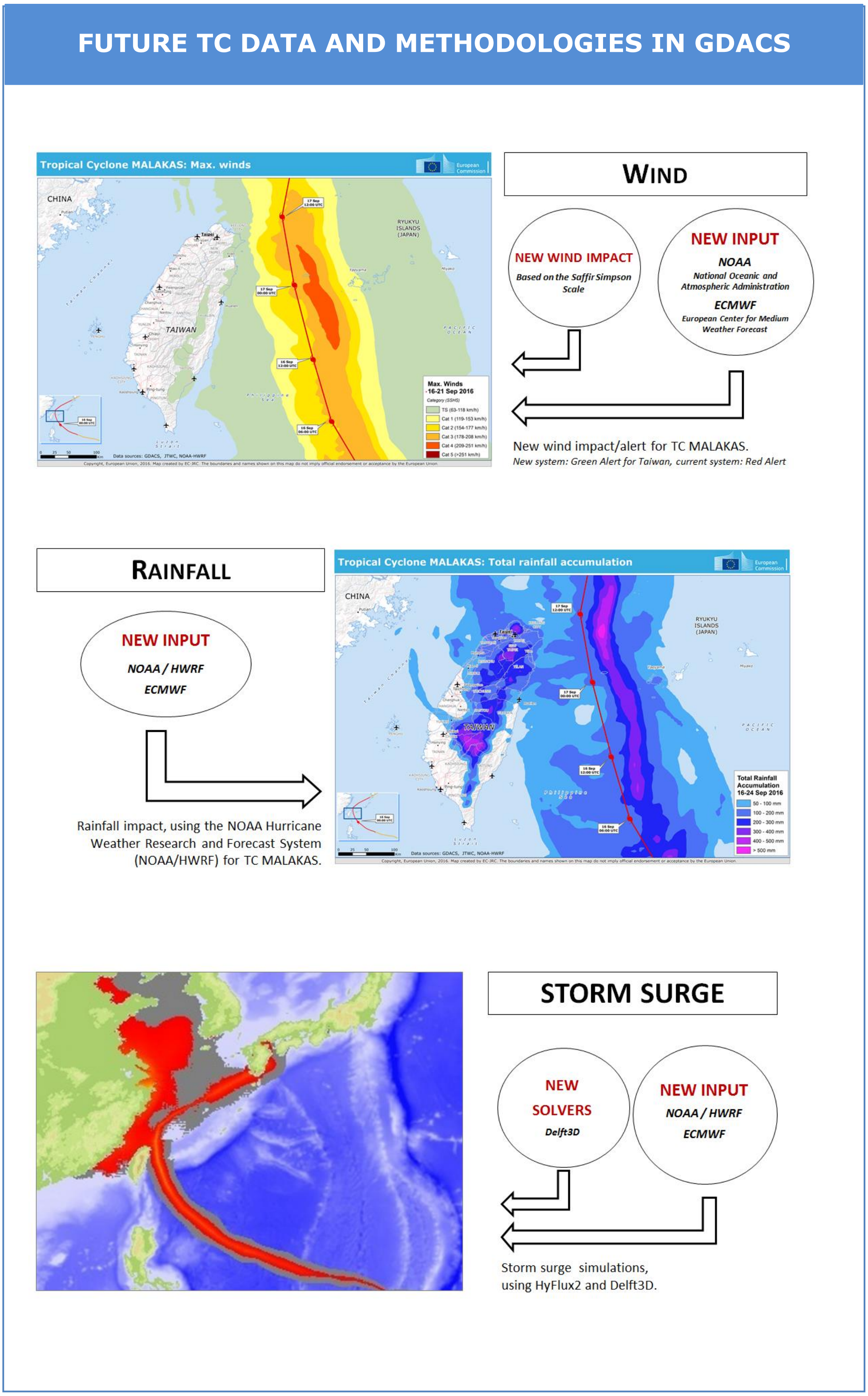

Figure 4 - New Tropical Cyclones data sources that could be used in GDACS

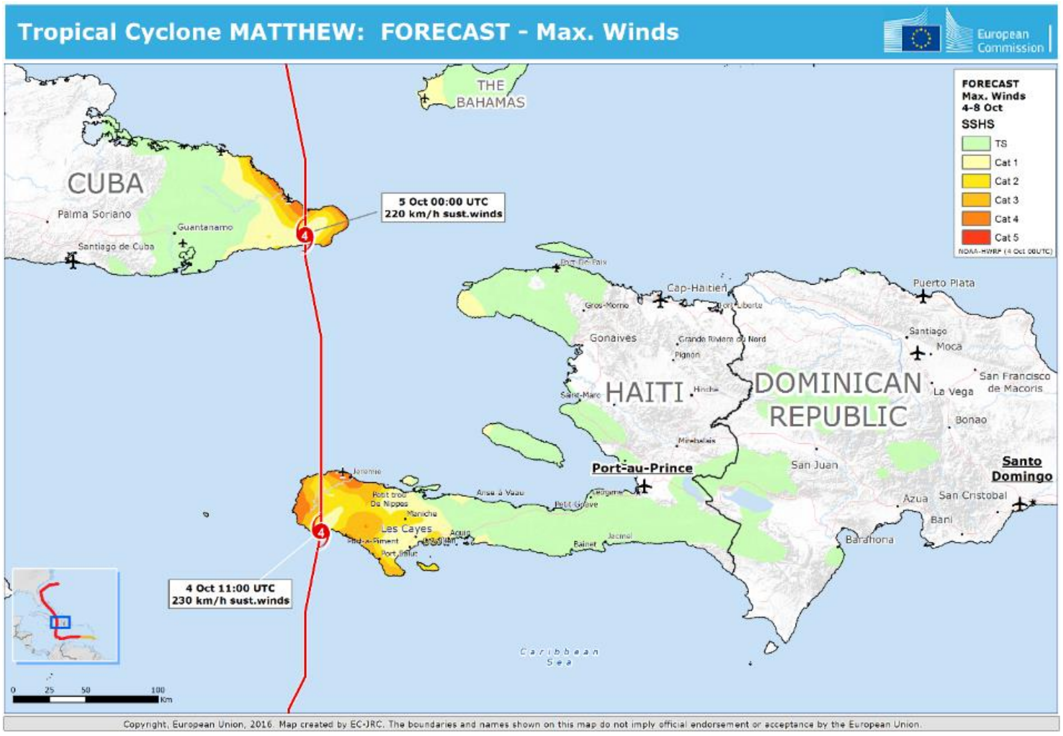

Figure 5 - Forecast of the maximum winds for TC MATTHEW using the data of NOAA-HWRF (as of 4 Oct 2016,00:00 UTC).

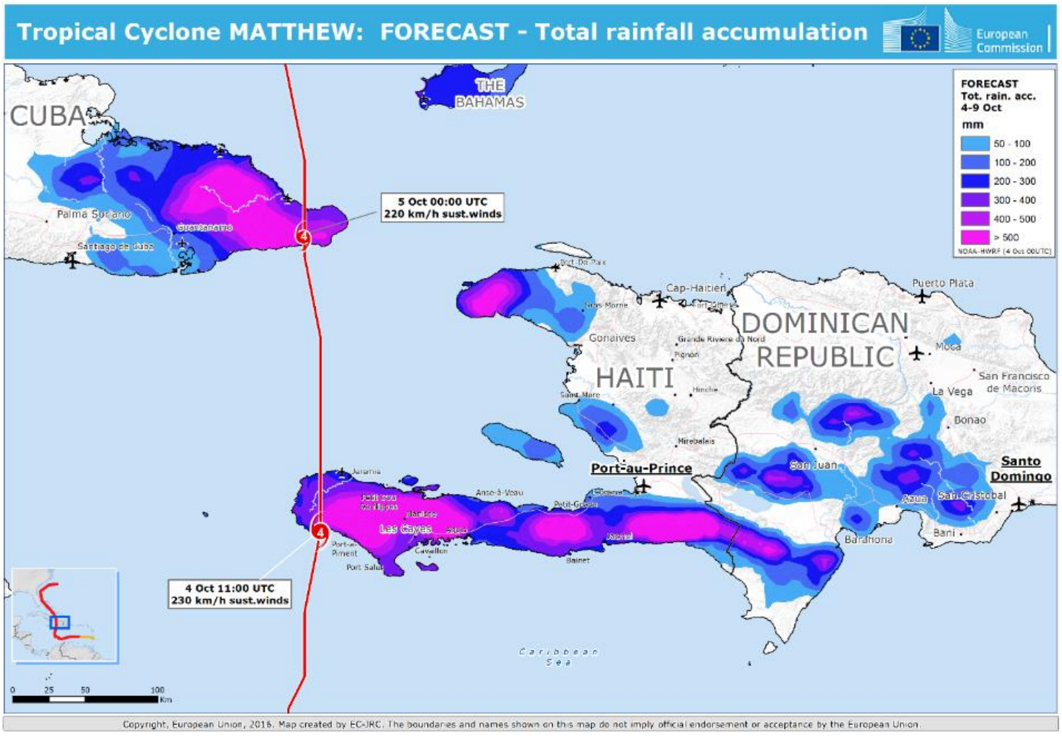

Figure 6 - Forecast of the total rainfall accumulation for the TC MATTHEW using the data of NOAA HWRF (as of 4 Oct 2016, 00:00 UTC).

4 Conclusions

The Global Disasters Alert and Coordination System (GDACS) automatically invokes ad hoc numerical models to analyse the level of the hazard of natural disasters like earthquakes, tsunamis, tropical cyclones, floods and volcanoes. The Tropical Cyclones (TCs) are among the most damaging events, due to their three dangerous effects: strong winds, heavy rains and storm surge. GDACS includes all these effects, using various sources of data. This report has described all the TC data sources used by GDACS over the last 10 years, as well as the methods that the JRC developed to include these data.

The most important sources of TC information are the TC bulletins provided by the Regional Specialized Meteorological Centres (RSMCs) and the Tropical Cyclone Warning Centres (TCWCs). These centres have the regional responsibility to forecast and monitor each area of TC formation. Every 6-12 hours the these centres publish a TC bulletin, including several TC information as: track, wind speed and wind radii. In addition to these centers other organizations, like the Joint Typhoon Warning Center (JTWC), provide the TC information.

In 2007, the Pacific Disaster Centre (PDC) set up an automatic routine which includes the TC bulletins from the Joint Typhoon Warning Center (JTWC) and National Oceanic and Atmospheric Administration (NOAA) into a single database, covering all the TC basins. The JRC used this source of information for several years for the TCs in GDACS and in the JRC storm surge model. In 2014 the JRC set up a new automatic routine, without using anymore the PDC's system, including directly the data of the JTWC and NOAA into a single database, covering all the TCs basins. In addition to these TC products, there several are new product that the JRC could use.

JRC developed the TC system used in GDACS in 2007 and the storm surge system in 2011. At that time the global numerical weather forecast models couldn't resolve the high wind and pressure gradients inside a TC due to their coarse resolution, while a TC weather forecast model was not globally available. Recently, the global forecasting models and TC models have improved their resolutions and are now globally available. These models provide wind, pressure and rainfall data that could be used in GDACS and in the JRC storm surge system. The JRC is currently testing these new sources of information to improve the GDACS alert system. A brief description of these new products has been presented in this report, while more information on the new system developed by the JRC using these two data sources can be found in Probst et al. (2016).

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Authors

Pamela Probst and Alessandro Annunziato

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ANNEX

Annex 1. Tropical Cyclone Basins and Warning Centres

The Tropical Cyclones (TCs) formed in particular areas of the globe, named tropical cyclone "basins" (see http://www.aoml.noaa.gov/hrd/tcfaq/F1.html and **Figure 7**)

1. **Atlantic** basin (including the North Atlantic Ocean, the Gulf of Mexico, the Caribbean Sea)
2. **Northeast Pacific** basin (from Mexico to 140W)
3. **North central Pacific** Basin (from 140W to 180W)
4. **Northwest Pacific** basin (from 180W to Asia including the South China Sea)
5. **North Indian** basin (including the Bay of Bengal and the Arabian Sea)
6. **Southwest Indian** basin (from Africa to about 100E)
7. **Southeast Indian/Australian basin** (100E to 142E)
8. **Australian/Southwest Pacific basin** (142E to about 120W)

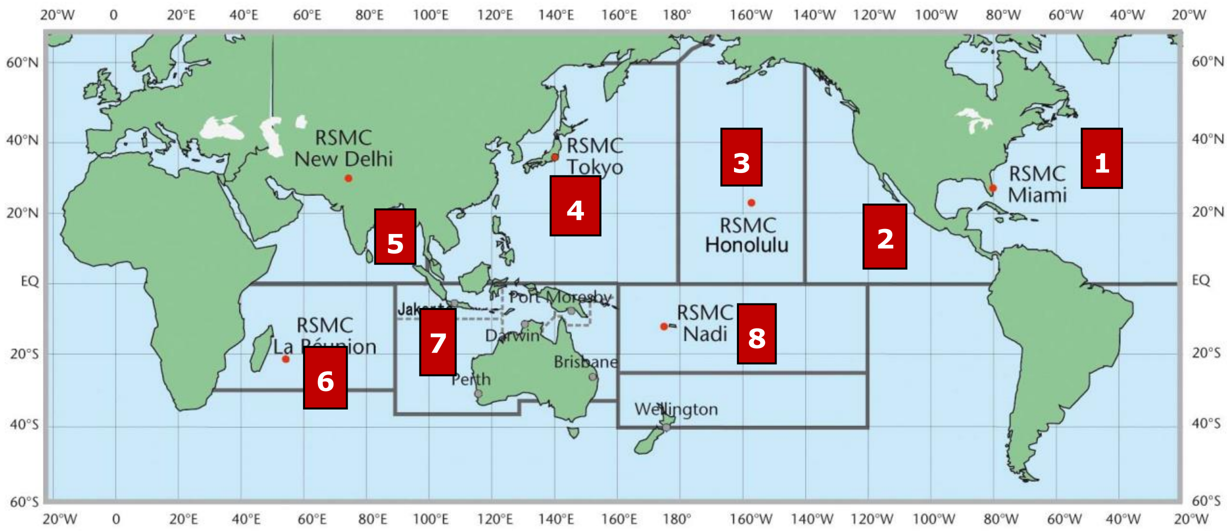

Figure 7 - TC "basins" and Warning Centres responsible for monitoring / forecasting

(source: WMO: http://www.wmo.int/pages/prog/www/tcp/Advisories-RSMCs.html)

The 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), listed in Tables **Table 3**-**Table 4**, have the regional responsibility to forecast and monitor each of the TC basins (see all the TC basins in **Figure 7**). These centers provide information on TC position, intensity and other TC parameters (i.e. wind radii) on all TCs everywhere in the world. The RSMCs are responsible for tracking and issuing bulletins, warnings, and advisories about TCs in their designated areas of responsibility and additionally the TCWCs provide information for the other regions (see http://severe.worldweather.wmo.int/TCFW/ and http://www.wmo.int/pages/prog/www/tcp/Advisories-RSMCs.html)

RSMC	ORGANIZATION	AREA
MIAMI-HURRICANE CENTER www.nhc.noaa.gov/index.shtml	NOAA/NWS, USA	Caribbean Sea Gulf of Mexico North Atlantic North Pacific Oceans
HONOLULU-HURRICANE CENTER www.prh.noaa.gov/hnl/cphc/	NOAA/NWS, USA	Central North Pacific Ocean
TOKYO-TYPHOON CENTER www.jma.go.jp/en/typh/	Japan Meteorological Agency	Western North Pacific Ocean South China Sea
TROPICAL CYCLONES NEW DELHI www.imd.gov.in	India Meteorological Department	Bay of Bengal Arabian Sea
LA REUNION - TROPICAL CYCLONE CENTRE www.meteo.fr/temps/domtom/La_Reunion/	Météo-France	South-West Indian Ocean
NADI-TROPICAL CYCLONE CENTRE www.met.gov.fj/advisories.html	Fiji Meteorological Service	South-West Pacific Ocean

Table 3 - List of the Regional Specialized Meteorological Centres (RSMCs).

TCWC	ORGANIZATION	AREA
PERTH http://www.bom.gov.au/weather/cyclone/	Bureau of Meteorology, Australia	South-East Indian Ocean
DARWIN http://www.bom.gov.au/cyclone/index.shtml	Bureau of Meteorology, Australia	Arafura Sea Gulf of Carpenteria
BRISBANE http://www.bom.gov.au/cyclone/index.shtml	Bureau of Meteorology, Australia	Coral Sea
WELLINGTON http://www.metservice.com/warnings/home.	Meteorological Service of New Zealand, Ltd.	Tasman Sea
JAKARTA http://meteo.bmkg.go.id/siklon/	Indonesian Meteorological and Geophysical Agency, Indonesia	Tasman Sea

Table 4 - List of the Tropical Cyclone Warning Centres (TCWCs).

Annex 2. How to calculate the cone of uncertainty

There are several methods used to calculate the cone of uncertainty of the forecast track. The methods used by PDC, NOAA, JTWC are shown below.

<u>NOAA Process</u>

> *"NOAA NHC uses a track forecast cone for the graphical representation of the uncertainty in its forecasts of the TC's future location. The cone represents the probable position of the center of the tropical cyclone and is made by drawing a set of circles centered at each forecast point—12, 24, 36, 48, and 72 hours for a three-day forecast, as well as 96 and 120 hours for a five-day forecast. The radius of each circle is equal to encompass 2/3 of the historical official forecast errors for the preceding five-year period. The cone is then constructed by drawing a tangent line that connects the outside boundary of all the circles." (Source: NOAA)*

Forecast Period (hours)	2/3 Probability Circle Atlantic Basin	2/3 Probability Circle Eastern North Pacific Basin
12	30	26
24	49	42
36	66	55
48	84	70
72	115	100
96	165	137
120	237	172

Table 5 - Radii of NHC forecast cone circles for 2016, based on error statistics from 2011-2015.

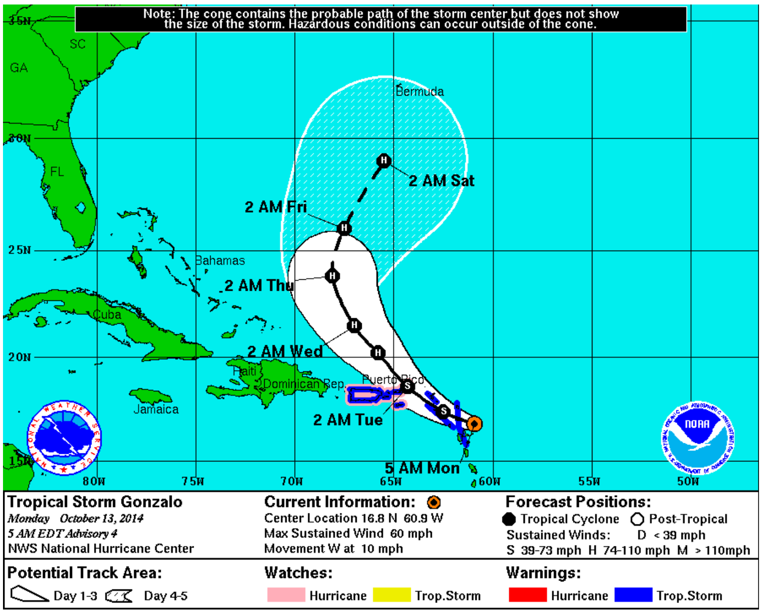

Figure 8 - NOAA uncertainty cone

Source: NOAA - http://www.nhc.noaa.gov/aboutcone.shtml

JTWC Process

"The JTWC creates an Area of Gale Force Winds introducing the forecast track error. This area is calculated by adding the JTWC 5-year running mean forecast track error to the forecast 34 knot wind radii at each forecast time. Since JTWC does not forecast wind radii for the 96- and 120-hour forecast times, this area is calculated by adding the 72-hour 34 knot radii to the forecast track error at those times. Thus, the shading highlights the area that may be affected by wind speeds exceeding 34 knots for a given JTWC forecast, based on historical track forecast errors. However, this calculation does NOT account for uncertainty in the track forecast based on the spread of the numerical model spread or other forecast guidance at a particular forecast time". (Source: JTWC)

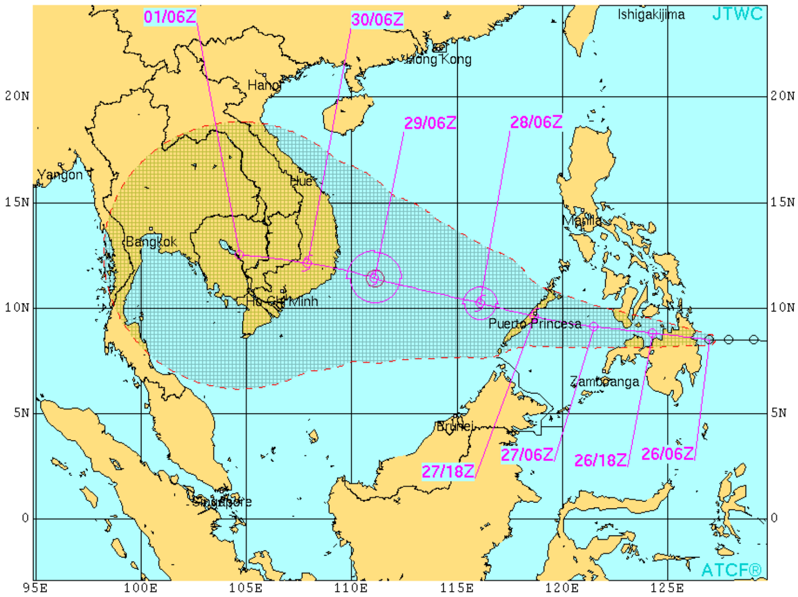

Figure 9 - JTWC Area of Gale Force Winds (source: JTWC)

PDC Process

"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. Historically, a given storm has a 60 to 70 % chance of staying within the cone of uncertainty during a 3 day time period." (Source: PDC)

"The cone shape algorithm is set to draw circles along the forecasted path of the storm. The radius of each circle drawn is slightly bigger than the last. Each new circle is joined with the main cone shape. The circles are close enough together that the edge of each circle drawn gives the appearance of a smooth line. The joining of all the circles gives the total cone shape. The distances (nautical miles) used to calculate the cone of uncertainty features are shown in the table below. The three-day cone is constructed with the above methodology using only the forecast points out to and including 72 hours. The five-day cone is constructed with the above methodology using all the forecast points available". *(PDC Global Hazard Information Network).*

List of abbreviations and definitions

ECMWF	European Centre for Medium Weather Forecast
GDACS	Global Disasters Alerts and Coordination System
GFS	Global Forecasting System
GPM	Global Precipitation Measurement
HWRF	Hurricane Weather Research and Forecast System
JRC	Joint Research Centre
JTWC	Joint Typhoon Warning Center
NESDIS	National Environmental Satellite, Data, and Information Service
NHC	National Hurricane Centre
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PDC	Pacific Disaster Centre
RSMC	Regional Specialized Meteorological Centres
SSHS	Saffir Simpson Hurricane Scale
TC	Tropical Cyclone
TCWC	Tropical Cyclone Warning Centres
TRMM	Tropical Rainfall Measuring Mission
WMO	World Meteorological Organization
WFS	Web Feature Service
WMS	Web Mapping Service
WRF	Weather Research and Forecasting

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