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Multi-hazard Early Warning System Global Disaster Alert and Coordination System (GDACS)

Methods for Anticipation and Rapid Impact Estimation
User Manual (version 2)

Masante, D., Barantiev, D., Destro, E., Mastronunzio, M.,
Paris, S., Proietti, C., Salvitti, V., Santini, M.

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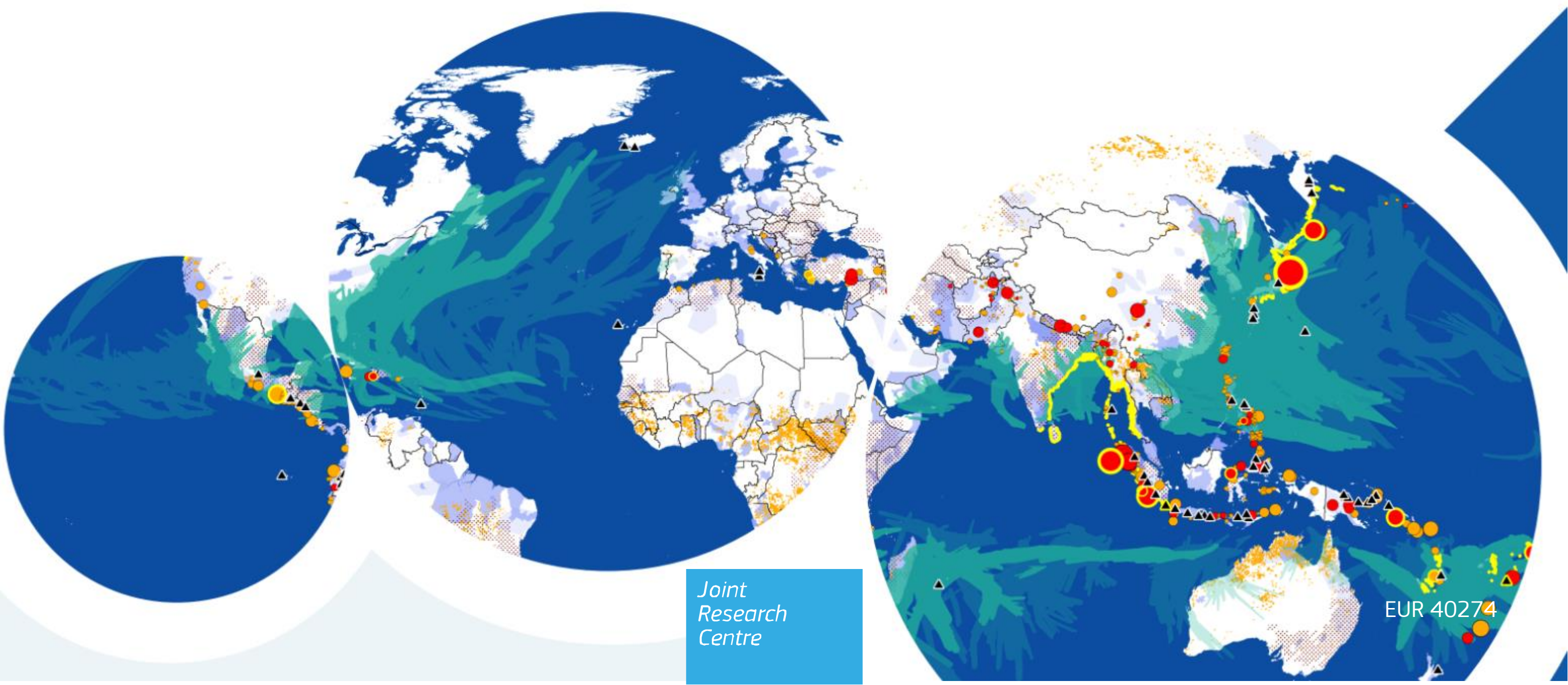

Joint Research Centre

EUR 40274

Contact information
Name: Marzia Santini
Email: marzia.santini@ec.europa.eu

JRC Science Hub
https://joint-research-centre.ec.europa.eu

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Authors

Masante D. - JRC.E.1 Disaster Risk Management, European Commission, Ispra, IT

Barantiev D. - JRC.E.1 Disaster Risk Management, European Commission, Ispra, IT

Destro E. – ArcadiaSIT, external consultant to the European Commission, JRC.E.1 Disaster Risk Management, Ispra, IT

Mastronunzio M. – Engineering Ingegneria Informatica, external consultant to the European Commission, JRC.E.1 Disaster Risk Management, Ispra, IT

Paris S. – Fincons SpA, external consultant to the European Commission, JRC.E.1 Disaster Risk Management, Ispra, IT

Proietti C. – Fincons SpA, external consultant to the European Commission, JRC.E.1 Disaster Risk Management, Ispra, IT

Salvitti V. – ArcadiaSIT, external consultant to the European Commission, JRC.E.1 Disaster Risk Management, Ispra, IT

Santini M. - JRC.E.1 Disaster Risk Management, European Commission, Ispra, IT

Abstract

This report presents the updates and describes the Multi-Hazard and Early Warning System component (MHEWS) of the Global Disaster Alert and Coordination System (GDACS). GDACS is made of three major components, of which the EC Joint Research Centre is the main contributor for the MHEWS component. This report focusses on the methodology underpinning the GDACS score employed across the seven hazards covered by the MHEWS. For all of them, the potential for triggering international humanitarian assistance is the key criteria upon which all events are evaluated. To do so, the magnitude/intensity of the natural phenomenon are combined and evaluated against the number of exposed people and the coping capacity or vulnerability of the country/region affected. The MHEWS interface and functionalities are presented concisely, as website components are under constant development.

1 Introduction

The international humanitarian community needs to understand and anticipate the impacts of an adverse event as soon as possible, in order to improve preparedness and response, and to take informed operational decisions, especially in case of large-scale disasters.

The European Commission (Joint Research Centre (JRC), the) and Directorate-General for European Civil Protection and Humanitarian Aid Operations - DG ECHO), the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) and United Nations Satellite Centre (UNOSAT) launched the Global Disaster Alert and Coordination System[1] (GDACS) in 2004, as a cooperation platform to provide disaster early warning and coordination services to humanitarian actors.

Immediately after major sudden-onset disasters induced by natural hazards, the affected country and a multitude of international actors collect and analyse information in order to plan their response. This activity is typically carried out simultaneously with varying speed, relevance and accuracy, using multiple information channels and applying different procedures. This stage may result in duplication of efforts, information gaps, overlaps or even inappropriate response, occasionally associated with high costs and delays.

GDACS services aim at facilitating information exchange among all actors, in support of decision-making and coordination. GDACS builds on the collective knowledge of disaster managers worldwide and the joint capacity of all relevant disaster information systems. It provides real-time access to web-based disaster information systems and related coordination tools.

The GDACS initiative combines science-based information from different independent systems into a single Multi-Hazard Early Warning System (MHEWS), in line with the target of the Sendai Framework for Disaster Risk Reduction[2], which aims at increasing the availability of and access to multi-hazard early warning systems. Moreover, it provides disaster risk information and assessments to people by 2030, supporting the "Early Warnings for All" - the UN Global Early Warning Initiative[3], which aims to develop a global system to enhance knowledge on risks, impacts, consequences, and available response options, as well as to develop capacities to anticipate and manage disaster risks across scales.

One of GDACS's main tasks is the dissemination of automatic notifications in case of earthquakes, tsunamis and tropical cyclones. Notifications are sent to the subscribers of GDACS. Furthermore, the system monitors in a semi-automated way drought, floods, forest fires and volcanoes, totalling seven hazards. The goal is to ensure timely warning in case of severe events that may require international assistance.

European Commission

The European Commission is the executive body of the European Union and supports GDACS through the Directorate-General for European Civil Protection and Humanitarian Aid Operations[4] (DG ECHO) and the Joint Research Centre[5] (DG JRC).

DG ECHO aims to preserve life, prevent and alleviate human suffering and safeguard the integrity and dignity of populations on behalf of the European Union. It achieves this through support to humanitarian actions, the Union Civil Protection Mechanism (UCPM) and the Emergency Response Coordination Centre (ERCC), aimed at enhancing cooperation in the prevention, preparedness, and response to natural or human-induced disasters, as well as satellite and media information analysis, sense-making and management systems for international crisis management.

The JRC is the European Commission's science and knowledge service and it performs research and development also in the area of disaster risk management, including early warning and information systems. JRC serves as the scientific lead in developing the GDACS multi-hazard and early warning system (MHEWS) component. The JRC works closely with the scientific partners as well as with European Commission services, EU institutions and agencies and policy organisations in Europe and internationally for performing crisis

1 https://gdacs.org/
2 https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
3 https://earlywarningsforall.org/site/early-warnings-all
4 https://civil-protection-humanitarian-aid.ec.europa.eu/index_en
5 https://joint-research-centre.ec.europa.eu/index_en

management research and designing specialised early warning and information systems, including under the Copernicus Emergency Management Service.

The United Nations Office for the Coordination of Humanitarian Affairs[6] (UN OCHA) is the leading global actor in ensuring better preparation for, as well as rapid and coherent response to, natural disasters and other emergencies as defined by General Assembly resolution 46/182 of 19 December 1991. UN OCHA is responsible for developing, mobilising and coordinating the deployment of its international rapid response capacities, to provide assistance to countries affected by natural disasters and other emergencies. OCHA is the primary contributor to the GDACS Virtual OSOCC (VOSOCC) component, as real-time coordination platform to support international coordination in the first disaster phase, the registration of mobilizing international response teams (USAR, EMT, etc), and the mobilization of OCHA's rapid response rosters.

The United Nations Satellite Centre[7] (UNOSAT) is part of the United Nations Institute for Training and Research (UNITAR), with a mandate to provide United Nations funds, programmes and specialised agencies with satellite analysis, training and capacity development at their request. It supports UN Member States with satellite imagery analysis over their respective territories and provides training and capacity development in the use of geospatial information technologies. It provides rapid mapping and analysis during emergencies, such as natural disasters and conflicts, helping governments and aid organizations coordinate relief efforts. UNOSAT is the primary contributor to GDACS Satellite Mapping Coordination System (SMCS) component.

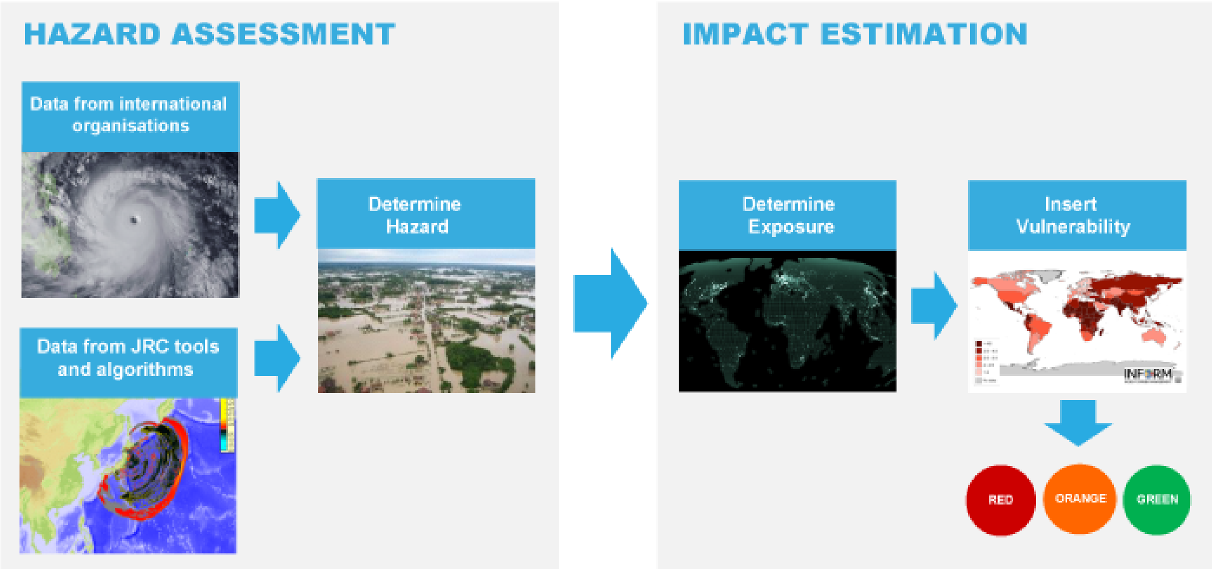
The Union Civil Protection Mechanism (UCPM) supports the work conducted by the European Commission (DG ECHO and JRC) on actions related to early warning systems. In this context, UCPM has supported the development of GDACS and in particular its MHEWS component in order to enhance the ERCC's and the wider disaster management community's preparedness capacity and situational awareness. In general, the UCPM supports the development of specialised early warning and information systems to help the ERCC monitor the global situation. It also complements the early warning and information systems of Member States in their hazard and disaster impact assessment by contributing to early analysis and action in real-time.

6 https://www.unocha.org
7 https://unosat.org/

2 GDACS services and components

The GDACS platform offers the following three information systems and online coordination tools. The **Multi-Hazard and Early Warning System** (MHEWS), a platform dedicated to monitoring natural disasters (Fig. 1), it includes a notification service, issuing information and updates to ongoing events to the subscribers (primarily earthquakes or tropical cyclones). The automatic risk estimates and analysis at the basis of the notifications are provided by the JRC. All the information is openly accessible through the GDACS platform interfaces and can be directly integrated into other web portals through RSS feeds or GDACS API.

Figure 1. A conceptual scheme of GDACS MHEWS service flow



Source: GDACS

The **Virtual OSOCC**[8] (Virtual On-Site Operations Coordination Centre) is a GDACS component managed by OCHA, typically activated in major sudden-onset disasters to support international coordination during the first phase of a disaster. The platform has about 9,000 registered users and its primary purpose is to facilitate information exchange among disaster responders, to encourage real-time information exchange during emergencies, allowing better coordination of the international response operations to disasters and avoiding duplication while ensuring complementarity. Moreover, the Virtual OSOCC may host virtual crisis response exercises involving multiple stakeholders, to prepare for coordinated response in case of a real emergency.
Access to Virtual OSOCC is restricted to disaster managers from governments and disaster response organizations worldwide, and information updates from the affected country and international responders are moderated by a dedicated team. A comprehensive manual is found on its webpage[9].

The GDACS **Satellite Mapping Coordination System**[10] (SMCS) provides a communication and coordination platform where organizations may monitor and inform stakeholders of their completed, current, and planned mapping activities for ongoing emergencies. In the field of Earth Observation (EO), the multiplication of actors and capacities necessitates of coordination, with the dual objective of, on one side, maximising uptake by the civil protection, crisis management and humanitarian communities of EO products and, on the other side, ensuring the best use of available mapping resources by avoiding duplication of efforts.
Maps and satellite imagery from several providers are shared on the Virtual OSOCC trough the GDACS Satellite Mapping and Coordination System (SMCS). There, participants can monitor and inform partners of their completed, current and future mapping activities during an emergency. This service is facilitated by the United Nations Institute for Training and Research (UNITAR) United Nations Satellite Centre (UNOSAT).

8 https://vosocc.unocha.org/
9 https://vosocc.unocha.org/GetFile.aspx?file=att36103_h4t800.pdf
10 https://smcs.unosat.org/home

3 The GDACS multi-hazard and early warning system (MHEWS)

The multi-hazard and early warning system is the component of GDACS that monitors, in real-time and near real-time, potential disasters or ongoing disasters around the world, covering seven hazards: droughts, earthquakes, tsunamis, floods, forest fires, tropical cyclones, and volcanic eruptions.

With the goal of providing a quick and clear estimate of the impact of disasters, including the severity and the potential humanitarian consequences, GDACS MHEWS classifies any relevant event with a three color-coded scale and a related numerical score ranging from 0 to 3. The colours are harmonized and applicable to any type of hazard, with a focus on the need for international humanitarian support. They are briefly described below:

GREEN: Moderate event with potential or minor impacts, but unlikely to require international humanitarian aid. Monitoring is needed to detect any worsening, even in absence of impacts. Score ranges from 0.1 to 0.99.

ORANGE: Severe event with potential serious impacts, so that some degree of international humanitarian assistance may be needed. Score ranges from 1 to 1.99.

RED: Major event with heavy impacts, and possibly resulting in a humanitarian crisis. International assistance is likely to be needed. Score ranges from 2 to 3.

Beyond these general definitions, each hazard type has its own specificities, and the meaning of numeric score and colours are further explained in the sections dedicated to each of the hazards. GDACS automatic classification (and notifications) cannot always predict the severity of humanitarian impacts of a natural disaster, since the algorithms are empirical in nature, often based on scattered data and high uncertainty there-in. While this fact highlights the urgent need for more and better impact data collection worldwide, the GDACS goal remains to provide at least a quick and actionable approximation of impacts, through its simple traffic-light system.

3.1 Impact assessment

GDACS events are produced automatically or semi-automatically for each hazard independently, using dedicated algorithms and the data available, with expert supervision. Every event on GDACS features a score and colour, based on the estimated risk that the given event poses to the exposed population and affected area. The following risk components are considered:

1. The intensity of the physical hazard, such as wind speed, earthquake magnitude, wildfire extent, etc.;
2. The exposure to this hazard in terms of the population and infrastructure potentially affected by it;
3. The vulnerability of the potentially affected countries or subnational units (when available), estimated with socio-economic variables.

As a result, events with the same intensity can result in different GDACS levels, depending on where they take place. For example, a shallow M6.5 earthquake under an uninhabited desert might get the "green" class. However, an earthquake of the same magnitude under a densely populated area would probably trigger a “red” class event in a vulnerable country, or an “orange” category for a country with safer building standards and quicker response capability.

3.2 Scope of GDACS automatic estimation

Impact estimation can only be as good as the data available at the onset of the event. For example, a preliminary error of 40 km in the epicentre of an earthquake can significantly alter the number of people potentially affected and consequently the alert level issued by GDACS. The predicted track of a tropical cyclone is not always accurate and a deviation of 50 km in landfall is quite common. This can change the number of people affected by the winds from hundreds of thousands to zero, making a previously issued red level obsolete. These are unavoidable limitations in early warning systems and GDACS users are advised to take them into consideration.

GDACS notifications are not meant to override or replace alerts or information from local or national civil protection authorities. Expert assessment of the situation and evacuation and response plans must always be carried out by competent decision-makers in designated positions of authority. Instead, GDACS provides the international humanitarian response community and any other national or international entity, as well as any interested citizen, with a global situational awareness platform about ongoing or imminent natural disasters.

3.3 MHEWS website

The main gateway to GDACS activities is the GDACS website[11], which hosts the MHEWS web pages. Below it follows a quick guide to the different sections of MHEWS website.

Figure 2. Top banner of GDACS homepage

Source: GDACS.

The top banner (Fig. 2) provides a direct access to the main components of GDACS and its functionalities, further explained in the following section:

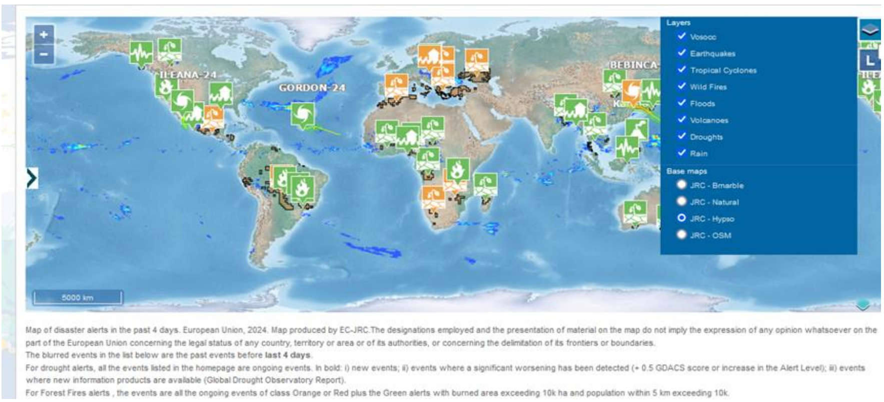
- HOME: directs to the MHEWS homepage, with the list and dynamic map of the ongoing events by hazard, plus some additional items.
- ALERTS: provides an easy graphical user interface to access the full database of GDACS, including all the events.
- VIRTUAL OSOCC: redirects the user to the dedicated website of GDACS Virtual OSOCC component[12], managed by UN OCHA.
- MAPS & SATELLITE IMAGERY: redirects the user to the dedicated website of GDACS SMCS component[13], managed by UNITAR/UNOSAT.
- KNOWLEDGE: this section displays background info about all the methodologies and documents needed to understand and use GDACS MHEWS data and indicators.
- ABOUT: provides a brief introduction to the GDACS initiative, its partners and the context.

3.3.1 MHEWS homepage

Below the different sections of the home page are explained.

In the MHEWS homepage a **dynamic map** allows the user to explore the ongoing events around the world (Figure 3), located through a specific icon. Only the active events that are equal or less than four days old are displayed (except for drought whose events are always shown and updated less frequently). Users can switch off any hazard through the dynamic panel.

Figure 3. Map view of GDACS homepage.



Source: GDACS.

11 https://gdacs.org
12 https://vosocc.unocha.org/
13 https://smcs.unosat.org/home

On top of the hazard themes, a rainfall theme of the last 24 hours and a selection of base maps are provided.

The **events section** lists all the active and recent events (Figure 4) in bold. The blurred events are the active events older than **4 days**, with some exceptions.

For droughts, all the events listed in the homepage are ongoing events, and specifically in bold: i) new events; ii) events where a significant worsening has been detected (+ 0.5 GDACS score or increase in the GDACS Level); iii) events where new information products are available (Global Drought Observatory Report).

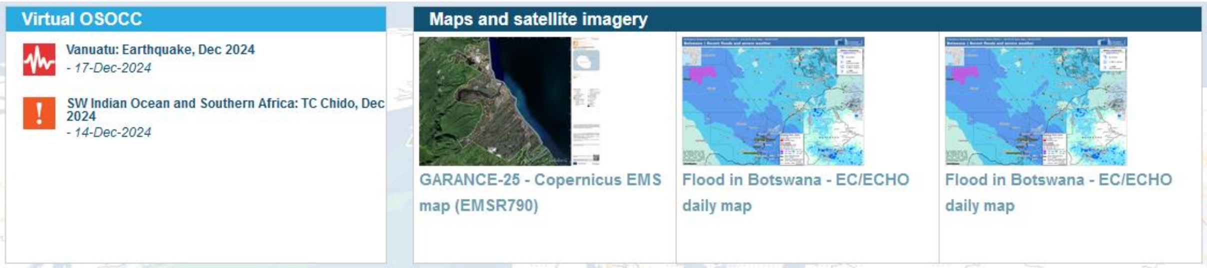
For Forest Fires, the events are all the ongoing events of class Orange or Red plus the Green level with burned area exceeding 10k ha and population within 5 km exceeding 10k.

Figure 4. snapshot of GDACS events list in homepage

Source: GDACS

The “Virtual OSOCC” and the “maps and satellite imagery” panels provide quick access to the products released by these GDACS components and related activations (Figure 5).

Figure 5. Panel in GDACS homepage showing activity by SMCS and VOSOCC components



Source: GDACS.

The “GDACS News” panel shows products or summaries of relevant natural disasters of any kind, provided by partners like ECHO (Figure 6).

Figure 6. News on ongoing disasters, primarily from ECHO

Source: GDACS

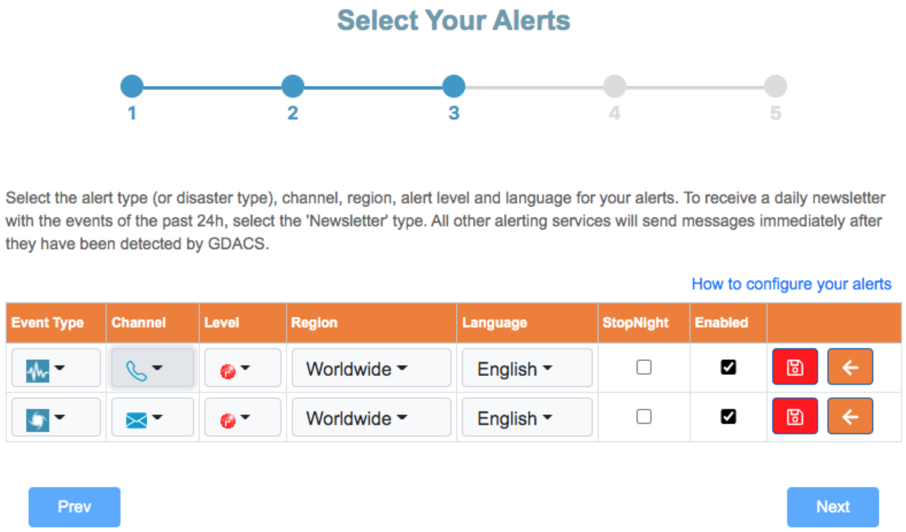
3.4 GDACS notifications

GDACS provides a service for automated early warning and notifications on natural disasters by both email and SMS. Currently, the service covers earthquakes and tropical cyclones. Notifications are also issued for possible subsequent tsunamis in the case of earthquakes and volcanic eruptions.

Subscription to GDACS automatic notifications requires an account, which users can request on the GDACS website[14]. To register, the user needs to:

1. Create username and password
2. Enter preferred means of communication from the possible options
3. Select the hazard of interest and level (Figure 7)

Figure 7. Snapshot of a GDACS user subscription step, to select notifications of interest and mean of communication



Source: GDACS.

Users can also define sub-continental/regional area of interest and the language of the notifications (English, French, Spanish).

The notifcations contain the basic information about the event: time and location, severity and magnitude, relevant web links, as in the example of Figure 8.

14 https://gdacs.org/gdacsregister/Register

Figure 8. Example of GDACS notification message by email

GDACS
Global Disaster Alert and Coordination System

United Nations and the European Commission

Red alert for Tropical Cyclone MAN-YI-24

Alert level

The alert level for the forecasted track (next 72h) is **Red**.

The overall alert level is **Red** for Guam, Philippines

This tropical cyclone can have a **high** humanitarian impact based on the storm strength and the affected population in the past and forecasted path.

Please see methodology for more explanations on thresholds.

In particular **Guam, Philippines** are affected by high winds up to **231** km/h (64 m/s or 144mph).

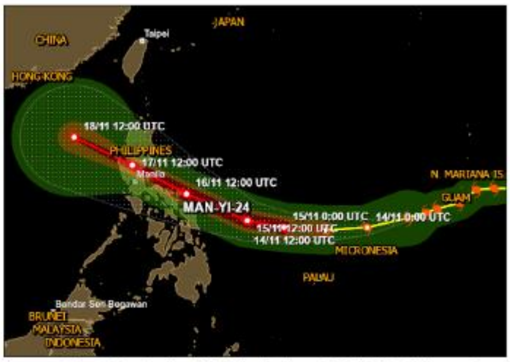
Current Storm Status

Analysis based on advisory number 19 for MAN-YI-24, published on 13 Nov 2024 12:00

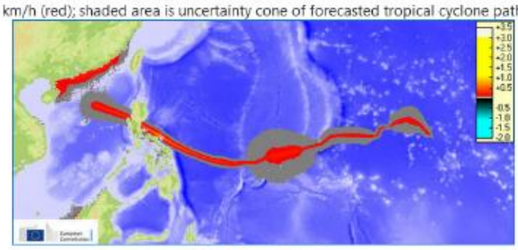
- The storm is: **active**
- Current country: **Guam, Philippines**
- Current position: **Lat:11.9 Lon:141.2**
- Alert level at current position: **Red**
- Basin: **NWPacific**
- Current strength: **Tropical Storm**
- Maximum sustained winds: **65** km/h (current), **231** km/h (next 5 days)

GDACS report created on 13 Nov 2024 16:23.

For a more complete report including information on storm surge and extreme rainfall, please go to http://www.gdacs.org/Cyclones/report.aspx?eventid=1001124&eventtype=TC.



Legend: areas affected by winds of 63-92 km/h (green), 93-118 km/h (orange) and >118 km/h (red); shaded area is uncertainty cone of forecasted tropical cyclone path.



Click for detailed report

Legend: areas affected by storm surge <1m (red), >1m (yellow) (source: JRC)

Source: GDACS.

3.5 Data access and resources

Registered and non-registered users can subscribe to GDACS notifications through its RSS feed by providing the associated URL[15] to RSS readers, or by clicking on the RSS icon on the GDACS Website. The RSS feed contains geographical information (GeoRSS) for eventual use in geographic software. A KML file with the latest events and polygons of interest, such as the track of tropical cyclones, for use in Google Earth is also available. To obtain the file, click on the KML icon on the GDACS Website.

The data are available also by other Application Programming Interface (API) endpoint that provides data in json/geojson format for the most recent 100 event data in the last 4 days[16], while for a custom extraction the method *SEARCH* is available at the dedicated endpoint[17] and described at "swagger" link[18].

GDACS can also share an API as well as Web Mapping Services (WMS) with organizations wishing to include GDACS events and information in geographical software.

15 https://www.gdacs.org/xml/rss.xml
16 https://www.gdacs.org/gdacsapi/api/Events/geteventlist/EVENTS4APP
17 https://www.gdacs.org/gdacsapi/api/Events/geteventlist/SEARCH
18 https://www.gdacs.org/gdacsapi/swagger/index.html

4 MHEWS hazards and methodology

4.1 Exposed population

The population dataset currently used across all hazards to estimate the population exposure is the Global Human Settlement Layer[19], as the Exposure Mapping component of the Copernicus Emergency Management Services[20].

4.2 Critical Infrastructures

The impact of natural disasters on critical infrastructures is a crucial information for effective disaster management. For every event, GDACS provides a list of potentially exposed critical infrastructures of the following categories: power plants, airports, ports and dams, derived from multiple sources[21].

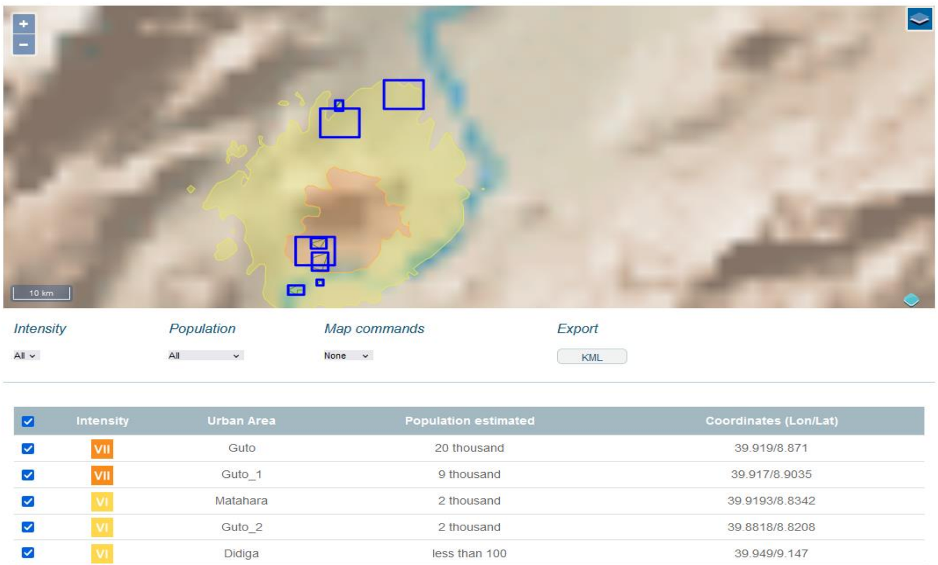
4.3 Areas of interest

A key task in impact assessment and response planning is to locate the most affected areas and the population exposed. Satellite mapping is widely used by humanitarian organisations and disaster managers to rapidly and remotely assess the impact of disasters, and a lot is invested to improve the timeliness and reliability of the satellite-based impact assessments. GDACS implements an automatic procedure to detect such areas and facilitate the prompt acquisition of satellite images (i.e. Areas of Interest - AoI).

The hazard data (e.g. shakemaps for earthquakes, or wind force, precipitation and storm surge for tropical cyclones) are automatically combined with the Global Human Settlement Layer (GHSL) to identify the most exposed areas. The use of this series of AoIs allows to focus the acquisitions on the urbanised areas and impact assessment at settlement level. For the earthquakes, the data is the shakemap intensity, produced by USGS. For tropical cyclones the definition of the AoI comes from their three components (winds, rainfall and storm surge) using as input different atmospheric data (NOAA-HWRF, NOAA-GFS, ECMWF-HRES, NASA-GPM).

In GDACS, AoI are reached through the "Impact" section of a specific event, where a link to the AoI dedicated page (e.g. Figure 9) is under "Affected areas" section.

Figure 9. Sample view of GDACS *area of interest* dedicated section, in case of earthquake



	Intensity	Urban Area	Population estimated	Coordinates (Lon/Lat)
	VII	Guto	20 thousand	39.919/8.871
	VII	Guto_1	9 thousand	39.917/8.9035
	VI	Matahara	2 thousand	39.9193/8.8342
	VI	Guto_2	2 thousand	39.8818/8.8208
	VI	Didiga	less than 100	39.949/9.147

Source: GDACS.

19 https://human-settlement.emergency.copernicus.eu/
20 https://emergency.copernicus.eu/
21 Global Power Plant Database, TeleAtlas, Global Discovery

4.4 Earthquakes

4.4.1 Description and methodology

The earthquake impact estimations considered by GDACS are the highest estimates between those caused by ground motion and by the ensuing tsunami. To assess the potential impact by shaking, GDACS combines:

1. Gridded data corresponding to the earthquake intensity calculations (USGS Shakemaps),
2. Gridded data of the exposed population (sourced from JRC Global Human Settlement Layer, GHSL)
3. Country humanitarian vulnerability based on human losses from past events
4. Coping capacity of the affected country or countries (INFORM index)

These four data components are processed by a model referred as to the "Shakemap" model and return an overall score ranging from 0 to 3.

The GDACS "**Shakemap**" impact estimations are based on the geographical distribution of the earthquake's Modified Mercalli scale intensity[5] (MMI). A map of the intensity of earthquakes stronger than Mw 5.5 is normally available a few minutes after the event from the United States Geological Survey (USGS). An automatic routine has been implemented in GDACS to launch a shakemap calculation using the USGS software in case the shakemap is not made available by USGS within a reasonable time or the magnitude is too low for USGS to issue a shakemap.

The GDACS shakemap-based score and notification relies on a humanitarian vulnerability score, derived by the number of people exposed in each MMI grade, from VII (Very Strong Shaking) upwards, calibrated by the casualties recorded for all seismic events since 2006 (sources: DG ECHO Daily Flash, EM-DAT). In some countries with more than 3 or 4 earthquakes recorded, more detailed Country-specific coefficients are used. This score has been then re-calibrated separately for each country to obtain country-specific correction from the global trend ("country seismic vulnerability"). In addition to the global score, there are also country-specific scores which have been re-calibrated separately.

As soon as the shakemap is available from one of the competent seismological centres[6], the following procedure is triggered to assign the GDACS score.

A first preliminary score (*raw score*) is calculated weighting the population exposed (1) and factoring into a formula with fixed empirical coefficients (2), where the latter have been obtained empirically by a multi-parametric linear regression model on the number of fatalities against the MMI of the earthquake:

$$(1)\ \text{Scaled Population} = \sum 10^{-8} * e^{(2.3026*MMI)} * \text{Population}$$

In case the MMI value is lower than VII, a reduction factor is applied as follows:

$$(2)\ \text{Scaled Population} = [\sum 10^{-8} * e^{(2.3026*MMI)} * \text{Population}] * 10^{3*(MMI-VII)}$$

A country-specific correction is applied to this score, based on the calibration of the number of casualties by previous earthquakes of similar entity, in the same country since 2006. For most cases this correction is the addition or subtraction of a numerical "Country Shakemap Vulnerability"[7] that can range from -1 to +1. Alternatively, in countries with more than 3 or 4 earthquakes recorded since 2006, a linear correction model is applied and the "Shakemap" Score is calculated as follows, with country-specific coefficients C1 and C2 applied, from a linear model of casualties as a function of earthquake intensity fitted for each country.

$$(3)\ \text{Shakemap Score} = [(-0.59 + C1_{Shakemap}) + (0.53 + C2_{Shakemap}) * \log10(\text{Scaled Population})] + \text{Country Shakemap Vulnerability}$$

At this step, the score lower than 1 corresponds roughly, according to the calibration, to number of casualties less than 10. A score between 1 and 2, corresponds to number of casualties between 10 and 100. A score higher than 2, corresponds to more than 100 casualties.

To calculate the final GDACS score a factor derived from the INFORM Lack of Coping Capacity (LCC) dimension of the INFORM index is applied (yearly updated). A normalisation is applied to the original country-specific INFORM LCC (resulting in values vary by 1.5 of South Sudan to 0.5 of Switzerland, see table). If the score obtained from shakemap scores in (3) and (4) is above 2 (corresponding roughly to 300 casualties) and the final score is less than 1, due to the country-specific coping capacity, the final alert score is rounded upwards to 1. This allows to avoid over-estimation of the coping capacity of a country.
The formula for the overall GDACS score follows:

*(4) GDACS Score = Shakemap Score * INFORM LCC*

The dependency on the USGS Shakemap product has occasionally resulted in delays due to the time required for its release. To address this issue and ensure the timely dissemination of critical information on the GDACS event website, the **"Rapid Impact**" methodology was introduced. This approach conducts impact estimations employing the same principles as the "Shakemap"-based framework. However, instead of relying on the USGS shakemap product, it utilizes a shakemap generated by the JRC, which employs the USGS shakemap model with default configurations for shakemap product generation. The system is configured to execute automatically upon receipt of new bulletins containing magnitude and hypocentral data provided by seismological institutes. These results are published on the website for informational purposes only and are not used for notifications.

4.4.2 Outputs and GDACS score

The GDACS shakemap-based notification relies on a score derived by the number of people exposed in each MMI grade, calibrated by the casualties recorded for all seismic events since 2006 (source: DG ECHO Daily Flash, EM-DAT). This score has been then re-calibrated separately for each country to obtain country-specific correction from the global trend ("country seismic vulnerability"). In addition to the global score, there are also country-specific scores which have been re-calibrated separately.

It is worth mentioning that these alerts do not consider a possible tsunami. Alerting score for the tsunami is calculated separately (see below). If an earthquake generates a tsunami, the alert level is set to whichever of the two hazards scores the highest.

The GDACS class is attributed according to the following thresholds. In case the event involves 2 or more countries, the highest coefficients within MMI>=7 are considered.
To match the GDACS colour coding, the alert score is transformed into a GDACS level according to the thresholds of Figure 10.

Figure 10. Table of GDACS levels and scores

GDACS Alert Level	GDACS score (Shakemap)
RED	≥2
ORANGE	≥1 - 2
GREEN	0 - 1

Source: GDACS.

The timeliness of the GDACS impact estimation system is highly dependent on how long it takes the shakemap for publication. The average time delay from the shake to the publication on GDACS is 23.6 minutes, so the system currently waits up to 25 minutes for the publication of a shakemap product.

For earthquakes (and tsunamis), the most important aspects are timeliness of alerts and avoiding false alerts. The first aspect has been improved steadily by forging agreements with regional seismological institutes around the world to push data to GDACS (rather than GDACS scraping data from their web sites).

The second aspect is ensured by GDACS's earthquake vulnerability score, which effectively lowers the alert level for countries able to cope with disasters, and includes the wave-height-based notification approach for tsunamis (reducing tsunami false alerts by 90%).

4.5 Tsunami

4.5.1 Description and methodology

The JRC Tsunami Assessment System integrates several components, needed to evaluate the tsunami as a consequence of an earthquake event, detected by the seismic networks with the following parameters, extracted in 15 to 30 minutes after the earthquake: epicentre (latitude and longitude), magnitude, depth.

The fault form and the fault movement are not known until a few hours after the earthquake, i.e. the time needed to analyse the seismic waves far from the epicentre. The JRC Tsunami calculation system therefore estimates the fault length, height and direction, which will influence the initial water displacement, initializes the calculation space (bathymetry and deformation) and launches the propagation calculation using the HySea model, developed by Malaga University "Differential Equations, Numerical Analysis and Applications" (EDANYA) group. The original bathymetry used is General Bathymetric Chart of the Oceans (GEBCO) 30", but then the cell size is adapted to a faster computing time and a suitable description of the fault. A small earthquake, e.g. under M6.5, will have a relatively small fault plane of few km and therefore the cell size has to be small enough to describe well the deformation (obtained using Okada model). As the number of cells is kept almost constant to about 1000 x 1000 as a maximum the overall extent for such a small event is small. If the magnitude is high, e.g. M8.0 then the size of the fault increases and it is possible to enlarge the cell size and thus the calculation extent.

The GDACS tsunami alert model is triggered by earthquakes occurring under or near the sea, specifically by any event of magnitude larger than Mw 6.2 occurring under water, or when the distance of the inland epicentre from the coast is less than 40 km. In case a new estimation of the earthquake is done (location, magnitude or depth) a new tsunami calculation is triggered, taking about 2-3 minutes to complete.

The logic for the tsunami alert is based on: the magnitude of the earthquake, the depth of the earthquake, the maximum wave height at any coast reached by the tsunami.
In case the HySea calculation system failed to calculate on the fly a potential event, a tsunami database of pre-calculated parameters is queried, and outputs are used to look up a tsunami wave height from the JRC Tsunami Database (containing over 132000 scenarios).

For each earthquake of magnitude exceeding 6.5 occurring in a location with positive water depth (from ETOPO30), the tsunami database is queried for the closest matching scenario. Scenarios have been calculated for 13800 locations covering tsunamigenic areas (from NOAA[22]) for magnitudes ranging from 6.5M to 9.5M with steps of 0.25M. If a scenario is available, the corresponding maximum wave height at a coast is retrieved.

4.5.2 Outputs and score

The GDACS Alert Score for tsunami relies on the maximum wave height at a coast. As for the Seismic notification model, the score is transformed into a level according to the thresholds of Figure 11.

If the maximum wave height is greater or equal than 3m, the GDACS score for tsunami is red; if the height is greater or equal than 1m, the score is orange; otherwise, the score is green. These values are then corrected for earthquake depth in the same way as for earthquakes.

GDACS automatic notifications cannot always reliably provide a proxy for the humanitarian impact of tsunamis, as it is inherently very difficult to predict even by very sophisticated probabilistic seismic risk assessment tools that consider detailed exposure and vulnerability data, gathered over long time-periods.

22 https://www.noaa.gov/jetstream/tsunamis/tsunami-locations

Figure 11. GDACS levels and corresponding thresholds for tsunamis

GDACS Alert Level	GDACS Alert score [Tsunami]	Maximum wave height at coast (m)
RED	Above 2	≥3
ORANGE	from 1 to 2	≥1 & <3
GREEN	from 0 to 1	>0 & <1

Source: GDACS.

The bathymetry is chosen to limit the computing time, which means that as the magnitude of the event increases, the resolution decreases in order to reduce the computing time and cover the whole geographical domain involved. In case of very large events, *ad-hoc* calculations should be performed and used to better estimate the impacts.

4.6 Volcanoes

4.6.1 Description and methodology

Volcanic eruptions do not often cause humanitarian disasters but have the potential of causing extreme ones. Currently, a global monitoring system that collect and harmonise volcanic information at the global scale does not exist. So, in case of eruptions, events are logged in GDACS manually, by interpreting the information released by authoritative institutions, scientific organisations and complemented by media reports.

Nearly all volcanic eruptions are multifaceted events: they pose a threat to human lives and physical assets through direct exposure to lava, pyroclastic flows, different kinds of tephra, toxic gas emanations, ash clouds, slope instability and potential subsequent tsunami and many other. Eruptions not only can last several weeks, months or years, but may have consequences outside of the eruptive phase, such as an increased lahar risk in the rainy season after an eruption, in areas covered by volcanic ash.

These complex dynamics and the variety of phenomena make the automatic definition of a GDACS hazard indicator very challenging. Moreover, the available information on individual volcanoes is heterogenous: not all volcanoes are monitored and the data collected can be very different. Around the world, many volcanoes have their own alerting systems and specific thresholds, set by national authorities and volcano observatories. For this reason, the GDACS system cannot automatically integrate the alert code issued by the local competent authorities, without expert assessment beforehand. A significant number of volcanoes lack systematic observation programs entirely.

The GDACS information system for the Volcano status is based on the Volcano Ash Advisories (VAAs), the weekly reports from the Smithsonian Institution, and the DG ECHO Daily Flash, which collects information from various sources with direct access to the location affected, especially in case of confirmed impacts.

As a primary source of information, GDACS monitors the VAA bulletins issued daily by the Volcanic Ash Advisory Centres[23] (VAACs). They are automatically stored in the GDACS database and provided through the GDACS Alert session when there is a significant increase of the ash cloud emission (i.e. a class change in the VAA bulletin). Albeit VAACs are primarily targeted at the aviation sector, they provide a consistent global coverage and monitor the volcanic clouds, a good proxy for the "size" of the ongoing eruption.

Concerning the specific volcanic activity, GDACS relies on the weekly reports issued by the Smithsonian Institution[24]. If the report highlights a significant increase in the volcanic activity, GDACS experts combine it to the VAA, for a comprehensive overview.

The GDACS system currently does not provide an explicit impact estimation from the monitoring data. Instead, it lists the total population living within a certain distance of the volcano (2, 5, 10, 20, 30, 50, 75 and 100km). The distances coincide with the usual evacuation radii for eruptions, which in turn are roughly correlated with

23 The nine VAACs (Volcanic Ash Advisory Centers), have been designated by the International Civil Aviation Organization (ICAO) to provide their expertise to civil aviation in case of significant volcanic eruptions. They are a basic part of the IAVW. (International Airways Volcano Watch). The VAAC includes the sub sources in the code's list (TOULOUSE, BUENOS AIRES, WELLINGTON, WASHINGTON, MONTREAL, LONDON, ANCHORAGE, TOKYO, DARWIN) (http://www.bom.gov.au/products/Volc_ash_recent.shtml)

24 https://volcano.si.edu/reports_weekly.cfm

different types of eruption-related hazards. This approach is inspired by the Volcano Population Index[25] (VPI), a method of evaluating exposure to volcanic risk.
To add information on the actual impacts, GDACS digests the DG ECHO Daily Flash, which, in case of risky eruptions worldwide, provides a daily update of the situation. The Daily Flash lists also several sources that may be used to complement the GDACS analysis of the eruption (including information from the national authorities).
The lack of automatic inclusion of impacts in GDACS such as lava flow estimation or ash fall prediction should be weighted, since both events can be important to estimate the risk from a volcanic eruption. Also, the possibility of landslide that could cause a tsunami is included only manually afterwards, when it is known from evidence that has occurred (e.g. Tonga eruption in January 2022).

4.6.2 Outputs and score

GDACS classifies an event according to the following criteria, without attributing an actual numerical score:

- GREEN level is manually introduced as a default rating, as soon as significant increase of the ash cloud emission is provided by the VAAC, and/or a significant increase of the volcanic activity is reported by the weekly reports of Smithsonian Institution, or by the DG ECHO Daily Flash bulletin. The GDACS score is fixed to 0.5.
- ORANGE level is attributed if, on top of green class, an activation of international response mechanisms is triggered, in sight of potential impacts. GDACS score is set at 1.5.
- RED class is introduced as soon as a significant volcanic event is evaluated by the JRC analytical team as having the potential to cause a severe impact, enough to trigger the attention of the international humanitarian community, and fatalities are recorded. GDACS score is assigned as 2.5.

4.6.3 Ongoing developments in anticipation and impact analysis

The development of a prototype for automated volcanic hazard alerts, aiming to fill the gap in global, near real-time monitoring and information dissemination on volcanic activity, is ongoing by the Joint Research Centre.

GDACS's prototype for volcanic hazard details especially focusses in automating hazard and exposure factors. The hazard component utilizes near real-time data from the International Civil Aviation Organization (ICAO) and an updated list of active volcanoes from the Smithsonian Institution's Global Volcanism Program (GVP). The exposure metric is based on the Global Human Settlement Layer (GHSL) and considers population data weighted by proximity to volcanoes.
The prototype involves monitoring Volcanic Ash Advisories (VAA), which are crucial for aviation safety and are indicators of volcanic activity. The frequency of VAA issuance can serve as a proxy for a volcano's activity level. Therefore, a methodology was established to estimate the Volcanic Explosivity Index (VEI) from the plume height reported in VAA, although limitations exist when plume height information is missing or when the eruption magnitude exceeds the detectable range. The six-year period from 2018 to 2024 saw almost 60.000 VAA for 127 volcanoes, indicating significant eruptive activity.

GDACS introduces the normalized Population Exposure Index (PEI), which assesses the potential impact of volcanic eruptions on populations by considering the weighted population within various distance categories from the volcano and normalizing it against the VEI.

A preliminary GDACS score has been developed to categorize the potential humanitarian impact of volcanic eruptions, aligned with the scoring system used for earthquakes and based on the magnitude of the eruption and the normalized weighted population exposure.
Future development needs to integrate vulnerability and coping capacity into the algorithm and enhance the accuracy of the GDACS Score. Cases like the La Palma 2021 and Hunga Tonga 2022 eruptions indicate the need for such additional factors in the alert system. The work carried out points towards a refinement of vulnerability definition, using the Volcano Fatality Index (VFI) and to incorporate country-specific coping capacities from INFORM Risk into the impact estimation algorithm, emphasizing the importance of comprehensive data sources and methodologies for an effective volcanic alert system.

25 Ewert, J.W.; Harpel, G.J. In harm's way: Population and volcanic risk. Geotimes 2004, 49, 14–17

The inclusion of indirect phenomena, such as tsunamigenic potential and effusive eruptions in urban areas, as well as augmenting the system with other data sources like satellites and artificial intelligence, is under evaluation.
The prototype for automated volcanic hazard alerts is under testing and validation at the time of writing. Once this phase will be completed, its integration in the MHEWS component of GDACS will be considered by the GDACS Governing Board.

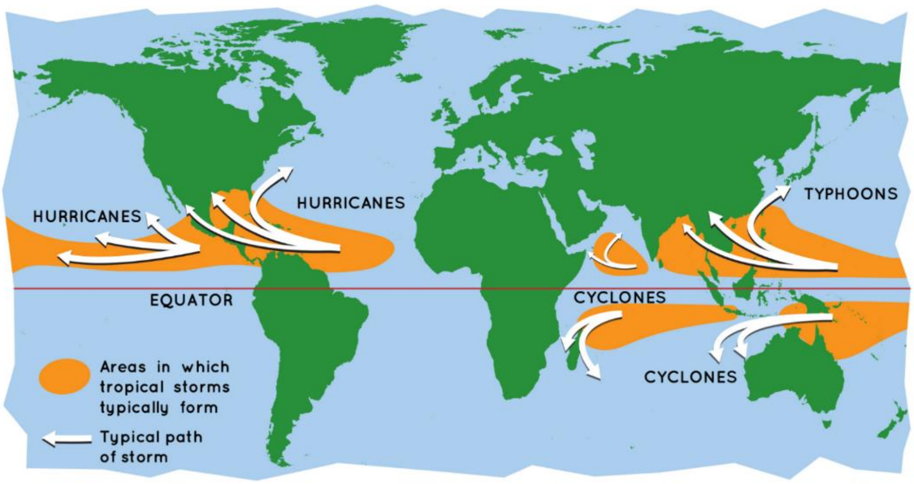
4.7 Tropical Cyclones

4.7.1 Description and methodology

Tropical Cyclones (TCs) are highly destructive natural disasters that cause significant damage and fatalities in many countries yearly. The impacts are primarily due to strong winds, heavy rain, and storm surge. Strong winds can damage infrastructure and cause injuries and deaths through destruction. Extreme rainfall leads to floods, landslides, and drowning. A storm surge, caused by strong winds and low atmospheric pressure, also results in coastal inundations, further exacerbating the destruction.

Tropical cyclones are generated in specific areas of the Earth's oceans (Figure 12), often follow roughly similar paths and are highly seasonal, meaning that certain countries are most at risk during certain times of the year.

Figure 12. Areas subject to tropical cyclones. They are often indicated with a different term in certain areas.



Source: NASA.

The World Meteorological Organization (WMO) has designated a series of observatories as the Regional Specialized Meteorological Centres[26] (RSMC) in charge of information and warning in case of TC by issuing regular bulletins. These are the authoritative sources when it comes to TC information. However, there is no standardised way of reporting, neither in terms of terminology nor characterisation of the wind speed scale, or even the way to determine the winds intensity for a given TC in the TC vortex. Different RSMCs have different standards[27], one of the challenges that the GDACS system is trying to overcome.

Other data sources, in addition to the RSMCs, also contribute to the generation of important TC information. For instance, the Joint Typhoon Warning Center[28] (JTWC) of the US Navy, the Global Forecasting System[29] (GFS) and the Hurricane Weather Research and Forecast[30] (HWRF) models, both operated by the US National Oceanic and Atmospheric Administration (NOAA), as well as the European Centre for Medium-Range Weather Forecasts[31]

26 https://severeweather.wmo.int/rsmcs.html
27 https://community.wmo.int/classification-tropical-cyclones
28 https://www.metoc.navy.mil/jtwc/jtwc.html
29 https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast
30 https://www.aoml.noaa.gov/hurricane-weather-research-forecast-model/
31 https://www.ecmwf.int/

(ECMWF) model. The information emitted by these different sources can be roughly put into two groups: bulletins (plain text descriptions of cyclone forecasts, including a tabular listing of key wind field parameters at the current and forecasted timesteps, and the coordinates in latitude longitude of the modelled forecasted points that represent the timesteps, i.e. the so-termed "eye-of-the-cyclone") and gridded numerical model data. All the sources generally use different data formats and forecast timesteps and ranges.

In GDACS, TC bulletins from the National Hurricane Center (NHC) of NOAA (for the Caribbean Sea, Gulf of Mexico, North Atlantic, Eastern North Pacific and Central North Pacific), Meteo France-La Réunion (for the South-Westerntsern Indian Ocean) and the Joint Typhoon Warning Center (JTWC) are automatically added to a database at the JRC. With these sources, the system covers all TCs basins worldwide with information from different bulletin types. GDACS uses the TC bulletins to estimate the wind impact of the TCs. The classification used in GDACS for wind is based on the equivalent category of the Saffir-Simpson Hurricane Wind Scale[32] (SSHS) using 1-min sustained winds. The JRC alert system uses these data and methodology to disseminate GDACS notifications via SMSs and emails.

Although the bulletins list wind field information for each of the four cardinal quadrants (describing an asymmetrical wind field), the GDACS system takes only the maximum of the four values, discarding the rest, to build a maximalist symmetrical wind field. A custom algorithm modulates the wind radii data to prevent large jumps between timesteps. This algorithm, in particular, kicks in when there is a steep drop in wind speed between one timestep and the next, which is often the case when a TC reaches land. On the one hand, this can generate overestimations of wind speed and inconsistencies between the intensity of the cyclone and the maximum wind speed reported by GDACS. However, the discontinuous nature of the bulletins necessitates this approach to avoid severely underestimating a major TC.

JRC has developed and implemented an additional tool to analyze the risk of the TCs and evaluate their potential impacts, utilizing Numerical Weather Prediction (NWP) models such as the NOAA's Hurricane Weather Research and Forecast (HWRF) meso-meteorological model and the Global Forecasting System (GFS) model, and the global high-resolution model of the European Centre for Medium Weather Forecast (ECMWF). These different numerical meso-meteorological and global models produce meteorological data in binary formats (GRIB[33]) that this additional system uses, like gridded meteorological parameters. The NWP products have the advantage of directly providing the TC wind and pressure fields. The implemented tool calculates the highest wind intensity in a given pixel over the duration of the period of interest. The data undergoes no further conversion to any of the inputs.

At present, the GDACS alert levels for the TCs are based on wind force only, with a risk matrix that includes hazard (TC 1-min sustained wind speed), exposed population (from JRC GHSL) and vulnerability of the exposed country (Table 5).
The GDACS class for incoming TC is calculated by evaluating the population's exposure to high wind speeds and then modulating the resulting alert level based on the estimated vulnerability and/or lack of coping capacity of the affected country.
Exposure is measured by evaluating the amount of population within the 64kt and 34kt wind buffers (pop_{64kt} and pop_{34kt}, respectively) and verifying if it exceeds a certain amount or a percentage of the total population of the country (pop_{tot}), which is likely in the case of smaller countries, particularly island nations. The exposure thresholds vary with the storm class according to the Saffir-Simpson scale. This is to compensate for the fact that the highest wind buffer provided by NOAA/JTWC bulletins is the 64kt one, which corresponds to Tropical Cyclone strength winds but does not distinguish between TC categories.
The JRC maintains a list of country vulnerability values and updates it[34] updates its vulnerability and coping capacity values. Vulnerability is divided into three classes: low, medium, and high. This Vulnerability Indicator integrates the Human Development Index[35] (HDI) with the data on rural populations, specifically the percentage of the population in rural areas and those living below 10m low elevation in coastal zones. It also introduces a new index, the Rural Population Index (RPI), for the rural population by averaging the values of the two selected indicators. The quartile method ranked the countries by HDI and RPI, and the arithmetic mean aggregated the scores for the two-dimensional indices into a composite index. Each country is finally assigned to 3 classes: (1) High Vulnerability, (2) Medium Vulnerability, and (3) Low Vulnerability. When a TC affects several countries

32 https://www.weather.gov/mfl/saffirsimpson
33 GRIdded Binary or General Regularly-distributed Information in Binary form and Network Common Data Form
34 https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Warning
35 https://hdr.undp.org/data-center/human-development-index#/indicies/HDI

simultaneously, the highest vulnerability class out of all the affected countries is considered for issuing the general alert.

For the heavy rains associated with TC, GDACS uses the NOAA Ensemble Tropical Rainfall Potential (eTRaP) data and the National Aeronautics and Space Administration (NASA) - Global Precipitation Measurement (GPM) data.

4.7.2 Storm Surge

GDACS does not treat storm surges as a separate hazard but as a complement to the TC information and analysis. As such, a severity scale with three classes is provided based on the maximum storm surge height, with no further considerations of the vulnerability or exposure of coastal areas affected and no numerical score associated with the colour (Figure 13).

The JRC initially developed the storm surge system for the TCs, including the atmospheric forcing in JRC HyFlux2 used for tsunami modelling[36]. This system includes a Monte Carlo method based on Holland's parametric model, using wind data from the bulletins issued by JTWC, NHC-NOAA[37] or Meteo France-La Réunion as input. In addition, the software Delft3D[38] is currently implemented to analyse gridded sources and simulate storm surges. Using the forecasted track, the calculations identify the populated places affected by storm surge up to three days in advance. When forecasts change, the associated storm surge estimation and the severity alert class change accordingly. All links, data, statistics, and maps on GDACS refer to the latest model run.

Since the storm surge calculations in GDACS do not include additional wave, tide and river effects, it is important to note that the storm surge may be higher in a delta river. The torrential rains that may affect the mountain areas during the passage of a Tropical Cyclone may increase the river flow, and the incoming storm surge could block the outflow. This could create floods in the surrounding areas of the cities close to a delta river.

4.7.3 Outputs and score

The GDACS Alert score is currently based only on the wind effect. A GDACS storm surge alert level is also estimated, but this is not considered in the overall GDACS score from TCs.
The class determines the latter numerical score, which corresponds to scores of 0.5, 1.5, and 2.5, respectively, represented by the colours green, orange, and red.

As explained, the alert level is derived by calculating the population exposure by comparing a population layer with the wind category layer (Table 5).

When the GDACS system uses the tropical cyclone advisory bulletins, it can provide impact reports five days before landfall. The GDACS results experience fluctuations in alert levels due to the uncertainty in the meteorological forecasts. Therefore, to prevent excessive false warnings and frequent changes in the warning level, GDACS RED alerts are reduced to ORANGE in the presence of a predicted maximum score more than three days in advance.

Table 1 GDACS Tropical Cyclone look-up table to assign GDACS levels

Storm Class	Vulnerability	Population	ALERT
Tropical Depression	low/med/high	any	GREEN
Tropical Storm	high	pop_{34} > 10M	ORANGE
	low/med	else	GREEN
Cat. 1 Tropical Cyclone	low	any	GREEN
	med	pop_{64kt} > (100k or 10% pop_{tot})	ORANGE
	med	else	GREEN

36 https://publications.jrc.ec.europa.eu/repository/handle/JRC36005
37 https://www.nhc.noaa.gov/index.shtml
38 https://oss.deltares.nl/web/delft3d

	high	pop_{64kt} >1M	RED
	high	pop_{64kt} > (100k or 10% pop_{tot}) OR pop_{34kt} >10M	ORANGE
	high	else	GREEN
Cat. 2 Tropical Cyclone	low	Any	GREEN
	med	pop_{64kt} > (50k or >10% pop_{tot})	ORANGE
	med	else	GREEN
	high	pop_{64kt} >1M	RED
	high	pop_{64kt} > (50k or >10% pop_{tot}) OR pop_{34kt} >10M	ORANGE
	high	else	GREEN
Cat. 3 Tropical Cyclone	low	pop_{64kt} > 500k	ORANGE
	low	else	GREEN
	med/high	pop_{64kt} > (100k or >10% pop_{tot})	RED
	med/high	pop_{64kt} > 20k	ORANGE
	med/high	else	GREEN
Cat. 4+ Tropical Cyclone	low	pop_{64kt} > 1M	RED
	low	pop_{64kt} > (100k or >10% pop_{tot})	ORANGE
	low	else	GREEN
	med/high	pop_{64kt} > (100k or >10% pop_{tot})	RED
	med/high	pop_{64kt} > 20k	ORANGE
	med/high	else	GREEN

Source: GDACS.

Each time a new advisory bulletin enters GDACS, the alert messages distributed to the subscribers via the dedicated GDACS service will transmit a score level based on the most recent forecast, disregarding the earlier estimates.

As part of the tropical cyclones, the storm surge generated is also considered separately but following the GDACS “traffic-light” classification, as illustrated in Figure 13.

Figure 13. GDACS levels and corresponding thresholds for storm surge. Currently not considered within overall tropical cyclone GDACS level.

GDACS Storm Surge Alert Level	Max storm surge
Red	≥ 3 m
Orange	1 - 3 m
Green	≤ 1 m

Source: GDACS.

4.7.4 Ongoing developments in anticipation and impact analysis

To increase anticipation capability and information, the ECML at JRC has developed a prototype service for monitoring and visualising potential tropical cyclone (TC) formation (considering also potential tropical storm, i.e. a system that has not yet reached the TC intensity) at its earliest stages, namely when a system is in the "tropical disturbance" stage or is a low depression system just formed. This service is aimed at the humanitarian community to provide early warning and support in preparedness and response activities for potential tropical cyclone events.

The methodology for the pilot service involves a multi-step process. Firstly, input data is identified from various sources, including Regional Specialized Meteorological Centres (RSMCs) and the Joint Typhoon Warning Center (JTWC). These providers equip the GDACS pilot service with different data types, such as structured (e.g. JavaScript Object Notation - JSON) format files and Geographic Information System (GIS) geospatial vectors (e.g. ESRI shapefiles), and unstructured data in text format from standard broadcast bulletins or tropical weather outlooks. Structured data from RSMCs include specific details like the probability of cyclone formation, which is used to identify and track potential cyclone events and their evolution. For unstructured data, particularly from the JTWC, an Artificial Intelligence (AI) approach is employed to extract relevant information from text bulletins and convert it into a structured format conducive to identify tropical disturbances and tracing their evolution.

The prototype service's interface features a global map visualizing the cyclogenesis identified in the last four days and a table listing the main properties of all disturbances monitored. The table's main properties include data source, identifier, dates of start monitoring, and last update, as well as a link to the impact estimation of phenomena that have already passed the next phase of the TC genesis and are no longer monitored, such as disturbances. Additionally, an Application Programming Interface (API) is made available for users to access the tropical disturbance data in a structured JSON format.

The testing period of this new service allowed to record that in this way the formation of a TC can be anticipated by a few days, up to maximum a week, which is a precious advantage for humanitarian organisations to implement preparedness actions.

The service's ongoing development focuses on improving data completeness by expanding monitoring capabilities, enhancing the user experience and accessibility, and the reliability of real-time reporting.

Along with the promising capabilities of the service, some challenges need to be addressed before official release. One is to unambiguously identify individual phenomena, due to a lack of standardized identification features across different data sources. Also, untreated typographical errors in bulletins can lead to the incorrect registration of disturbances.

4.8 Floods

4.8.1 Description and methodology

The GDACS score for floods is assigned automatically, based on either specific threshold (see below) or upon expert review, which considers the impacts on people, any international support activations (e.g. Union Civil Protection Mechanism, UCPM, Copernicus Emergency Management Service, etc.) and the magnitude of the flood, measured by its return period (e.g. 20 years return period roughly corresponds to orange).

Before the experts' scrutiny, when the following thresholds are met, the flood is given at least the class orange if there are more than 100 dead or 80,000 displaced, while red class is always assigned for more than 1,000 dead or 800,000 displaced.

GDACS, by sourcing through GloFAS, uses FloodList[39] as primary and automatic source, alongside with the ECHO Daily Flash[40] and other minor (mainly media) sources, in order to collect and update impact information. The GDACS events published on the website, and the notifications sent by e-mail and SMS, incorporate information on the impacts of the flood estimated by GloFAS (Global Flood Awareness System[41]). The data provided by its global flood monitoring (GFM) include the magnitude, duration and severity of floods, and it estimates the deviation of both extent and duration compared to multi-annual statistics. Moreover, GDACS provides the localisation and the time-range of the flood, as identified by the Copernicus Global Reporting Tool[42] (GRT), developed by the JRC GloFAS Team[43]. The authorized user of GRT defines the GDACS level, thus controls how the GDACS system ingests and displays the flood. Only GRT events that have a GDACS level defined (status approved) are uploaded to GDACS.

In a hierarchical way, within each country GRT identifies from the flood events data sources (FloodLlst and DG ECHO Daily Flash) the localisation of the event, following the Open Street Map (OSM) administrative divisions[44]. The expert in charge can refine these geometries manually within GRT. Finally, this process of localisation will provide to GDACS the so-called "flood polygon" related to the event.
A list of impact parameters is provided, based on the Sendai Indicators[45], for a given country-based flood event, and collected within GDACS database as "system parameters" with key attributes. Moreover, the GRT provides as inputs also other parameters, different from the Sendai indicators. These are event name, headline and description (three different descriptive fields, that will constitute different descriptive fields in GDACS, as outputs). These descriptive filed are available in GDACS under the event summary section of a given flood event and in the impact section, under the Sendai indicator section (tab "Info").
The content of the flood event and score is validated on a weekly basis (within GRT), mostly based on the impact updates from the ECHO Daily Flash and on the categories of the Sendai indicators.

4.8.2 Outputs and score

GDACS outputs of the floods section include information on the severity, the localisation and the time-range of the flood (by means of the GDACS level as well as by means of descriptive and quantitative fields).

To a given flood collected from the GRT a unique event ID is assigned and the flood is included in the GDACS database, by country, and accessible through the dedicated section of the GDACS website. Only floods that reach at least one confirmed fatality are listed in the GDACS home page, and are kept visible there for 15 days.

The Flood alert level is based on the impact information, specifically on the number of fatalities and displaced population, but not the overall affected people in the area. For floods, at present the numerical score can only get one of three values, corresponding to the respective class: 0.5 for green events, 1.5 for orange events and 2.5 for red events. GDACS alert levels are indicated below:

— RED alert for more than 1,000 fatalities or 800,000 displaced people, or in case of major international humanitarian activations to meet severe emergency needs, and at least some fatalities were assessed.

39 https://floodlist.com/
40 https://erccportal.jrc.ec.europa.eu/ECHO-Products/Echo-Flash
41 https://global-flood.emergency.copernicus.eu/
42 https://grt.globalfloods.eu/
43 GRT feeds all floods events displayed in GDACS; it is a web portal for experts, where all available floods events are collected and handled by country . All countries are grouped in the proper continent section: by this structure the GRT portal provides a regional and global overview of current flood events. Moreover, the selectable timeframe is accessible for past floods events. GloFAS automatically compiles flood events extracting them from FloodList, then the authorized users (dissemination centres or GDACS experts) review each unassigned GRT event, by comparing the information available by other sources against the automatic GRT inserted event. This expert supervision is also perfomed on already confirmed flood events, in order to update and/or integrate them with confirmed estimates from other sources.
44 https://help.openstreetmap.org/questions/54632/getting-administrative-boundaries-of-a-given-country-for-all-its-admin_level
45 https://www.preventionweb.net/sendai-framework/sendai-framework-indicators

— ORANGE alert if there are more than 100 fatalities or 80,000 displaced people, or if any international humanitarian activation is triggered, even in absence of casualties.

— GREEN alert for all other floods, including the ones with no fatalities and/or on displaced people (e.g. only rescued people or damaged houses).

4.9 Droughts

4.9.1 Description and methodology

GDACS combines an automated procedure with expert-validated information from authoritative institutions, media and scientific organisations.
The indicator for the spatial delineation of a drought event is the Risk of Drought Impact in Agriculture[46] (RDrI-Agri), as produced by the Global Drought Observatory[47] (GDO). The indicator is calibrated primarily, but not exclusively, around agricultural drought. It combines physical indicators of drought hazard with exposure and vulnerability of a region/country, according to the well-known framework of risk as a function of hazard exposure and vulnerability.
Therefore, the RDrI synthesizes the severity of a drought accounting for the socio-economic conditions of the affected regions, inferring the severity of potential impacts from the event. The exposure and vulnerability blocks of the indicator are semi-static (i.e. change every few years only), but the hazard component is dynamic, being updated every ten days, to scan for new droughts globally in near-real-time.

Since the focus of GDACS is on the humanitarian consequences of natural disasters, the GDACS index for drought should reflect the humanitarian severity (potential impact) of a given event. This requirement is satisfied only partly by the RDrI-Agri, as the calibration of the indicator is much looser than required by GDACS requirements to highlight only the events of potential interest for humanitarian actors. So, the RDrI is evaluated further by drought experts at the JRC Global Drought Observatory (GDO), to narrow down the events to the most relevant ones only, worth displaying on GDACS.

The procedure starts from the global RDrI-Agri indicator, which is extracted automatically every ten days and stripped of its lowest risk class, out of three possible values (Low, Medium, High). An algorithm then checks whether the remaining patches on the map (i.e., candidate drought events) match two simple criteria:

— The event is at least one month old, i.e. it is flagged as drought by GDO for at least three updates in a row, before being considered for GDACS, to avoid very short dry spells and potential false positives.

— The event extends over an area of at least 3 square decimal degrees in “Medium” class of RDrI-Agri indicator or, alternatively, over a single map “cell” of RDrI class “High”. As mentioned, the first class of risk (Low) is not considered, no matter for how long it lasted or its geographical extension.

Both requirements must be met to pass the candidate drought events to the next evaluation stage. If so, the algorithm produces a layer of spatial polygons outlining the extent of the drought. If the process identifies a new location previously not flagged as under drought, it tries to associate it to an adjacent existing drought event, before promoting as a new one. A few attributes are added to the output, including a unique identifier for the event and the country or sub-national region where the drought occurs.

The algorithm typically produces many candidate “drought events”, which necessarily need to be validated and often merged or discarded before release on GDACS. Experts from the GDO team evaluate the spatial polygons issued by the unsupervised stage described above, at every update (ten days). They prioritize higher scores according to RDrI, for which the evaluation is particularly careful. First, they confirm the area affected, also considering coherent geographical and climatic domains. For instance, they might merge events relatively close in space and linked to the same climate or atmospheric circulation, or vice versa split in different events patches geographically close but separated by natural boundaries (e.g. mountain chains) or with diverging precipitation regimes. Knowing the potential specificity of droughts in certain regions, they look at the various indicators produced by GDO, to characterize the drought. After the evaluation, at least the "green” GDACS level is attributed

46 https://data.jrc.ec.europa.eu/dataset/b4727c91-955f-4e2f-b0cf-dd64145b57e7
47 https://drought.emergency.copernicus.eu/tumbo/gdo/map/

to events deemed to be relevant, and confirmed for publication on GDACS, while for events of class "orange" and "red" specific evidence of significant impacts is required.

If one event gets split geographically in several patches at some point in time, a common situation when a big drought builds up or fades away, it is still treated as a single event, unless the drought expert in charge of validation decides to override the default and label any of the patches as separate events.

The input data are provided entirely by the GDO through a dedicated API, checked every 10 minutes by GDACS.

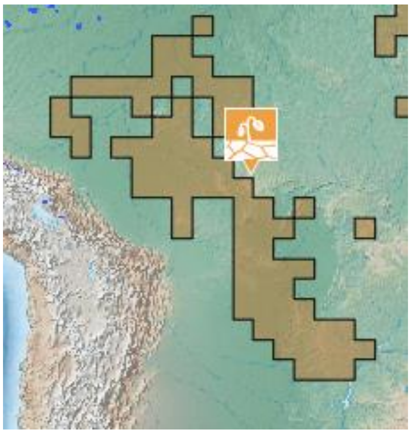
4.9.2 Outputs and score

The data published on GDACS MHEWS are entirely taken from the GDO feed dedicated to GDACS, without further data processing. The output data consists of the GDACS scoring and ancillary info, through RDrI-Agri[29] elaborated with dedicated algorithms and expert knowledge as explained above.
The data are provided to GDACS in json format and contain an array of drought events with all the information needed to update the GDACS event data structure.
Drought events are issued according to the common three-colors scale, whose meaning is explained as follows:

GREEN	A confirmed drought, but no evidence of impacts or mild/intermediate impacts associated to a high coping capacity. Monitoring is required to identify possible worsening. No specific action would be envisaged by international aid providers.
ORANGE	A drought with relevant impacts to the economy or assets, but not to people, at least not life threatening. National government provides aid in some form and official declarations of a drought/disaster are released. The drought reaches international media outlets. International humanitarian aid providers may be alerted, or international cooperation triggered.
RED	Like orange, plus very severe or life-threatening impacts to people: migrations and internal displacements, famine or starvation, violence explicitly related to water resources conflicts. International humanitarian aid is needed or has been requested/dispatched.

The GDACS score for drought is assigned and validated through expert review at GDO. The icon on the main GDACS map is placed at the geographical centroid of the event, according to the related spatial polygons, as from Figure 14.

Figure 14. Example of GDACS drought affected area.



Source: GDACS.

For reference and by no means for completeness, the Table 2 shows a breakdown of GDACS score values for the broader three-color categories, with examples, associating the impact severity of a drought event to the GDACS score value.

Table 2 GDACS drought score broad definitions, with examples

GDACS Score	Subclass description (with possible indicative conditions, not all present, nor exhaustive)	Examples
0.25	A locally confined dry spell of low or intermediate severity, without evidence of impacts.	-
0.5	A widespread meteorological drought revealed by indicators, but no evidence of impacts, or minor impacts with high coping capacity.	Italy 2017: Some isolated water supply issues, local damages to crops.
0.75	A widespread drought with minor impacts, or in presence of high coping capacity. It reaches national relevance and may reach international media too.	United Kingdom 2010/12: A long lasting event resulting in low reservoir levels, hosepipe bans, loss of yield, ecosystems damage.
1.0	Intermediate transitional value: this value is usually attributed to events fading away towards the lower class.	-
1.25	Relevant sectorial impacts in presence of high coping capacity, or mild to intermediate impacts otherwise.	Northern-Central Europe 2018: Widespread economic damages in different sectors and countries, some local water supply issues and costs for mitigation. California 2015: Severe economic damages and thousands of jobs lost in agriculture; relevant mitigation costs.
1.5	Impact to the wider economy; livestock famine and mass sale; protests; empty or not viable reservoirs.	South Africa 2017/18: Relevant economic damage, very high cost for mitigation and serious discomfort for people. Argentina/Uruguay 2018: Major economic damage for agriculture and some local water supply issues, plus a mild global impact on grain commodities.
1.75	Serious issues for water supply and remarkable population discomfort; reduced availability of grains and food price hikes; political instability.	China 2010: despite strong state support, huge damages to agriculture, millions people exposed from mild to very severe water shortages, global impact on grain prices. Sri Lanka 2017: Insufficient coping capacity, many vulnerable people exposed, rising food prices.
2.0	Local migrations/displacement; local food insecurity and food assistance required; riots.	Pakistan 2018: local food insecurity, reported deaths due to malnutrition, vulnerable rural communities displaced.
2.5	Widespread food insecurity; migrations and refugees; food and water assistance needed.	Afghanistan 2018: No coping capacity and migrations due to lack of water, with local famine.
3.0	Likely or actual widespread loss of lives, with famine and/or actual lack of water.	East Africa 2011: Famine with thousands of deaths related to malnutrition.

Source: GDACS.

For events particularly severe or extreme according to physical indicators, the GDO experts seek independent validation from national or regional climatological monitoring systems. They also proceed to query the European Media Monitor[48] (EMM) in search for evidence of impacts reported from the ground, in relation to the event. This helps to attribute a numeric score and a subclass to the event, particularly to promote an "orange event" to the red category, for which biophysical drought indicators alone can't provide sufficient information. A single source is not considered enough evidence, unless coming from official sources like governments or associated partners/agencies. A few independent sources of information are sought before accepting alleged impacts as valuable for the score attribution.

The time references present in the event summary are to be interpreted loosely, considering the slow-onset and evolution of droughts, as well as the quantitative data reported. Below a few features encountered in the interface that may need further explanation.

- *Start date* is approximated to one of three periods: beginning, middle or end of a given month, which are linked respectively to the three ten-days intervals of update within a month (called *dekads*).
- *Duration* is indicated in days, counted from the first day of the *dekad* to present.
- *Impact* is defined in very general terms, due to the multifaceted nature of drought and the specificities of the affected areas, unfit for an automatic description. The area affected is indicated in square kilometres by summing up the surface of the related spatial polygon, as presented in the map viewer.

4.10 Wildfires

4.10.1 Description and methodology

GDACS forest fires events are automatically identified by the Global Wildfire Information System[49] (GWIS) hosted at the JRC and exposed to GDACS via a dedicated API. City fires or industrial accidents resulting in fires are not included. Events are identified daily or upon request, when a relevant forest fire is having impacts that could interest the humanitarian community. Not all wildfire events generated by GWIS enter the GDACS platform. A first filter allows only the fire events that have a burnt area of at least 5 000 hectares. When a smaller wildfire could potentially cause humanitarian impacts (e.g. contiguous to urban areas), this event is manually inserted into the GDACS system upon expert judgement.
The fires information and the map are updated every day, provided enough data are made available to GWIS from imagery providers.

Burnt area information is generated by GWIS, specifically its Near-Real Time (NRT) product, based on the use of thermal anomalies from MODIS and VIIRS sensors[50] (more below). The indicator defines individual wildfire perimeters, therefore estimates the burnt area caused by the fires. GWIS uses the active fire detection provided by the NASA FIRMS[51] (Fire Information for Resource Management System).

MODIS Active fires
The MODIS sensor, on board of the TERRA and ACQUA satellites, identifies areas on the ground that are distinctly hotter than their surroundings and flags them as active fires[52]. The difference in temperature between the areas that are actively burning with respect to neighbouring areas allows active fires to be identified and mapped. The spatial resolution of the active fire detection pixel from MODIS is 1 km.

VIIRS Active fires
The VIIRS (Visible Infrared Imaging Radiometer Suite) on board the NASA/NOAA Suomi National Polar-orbiting Partnership (SNPP) uses similar algorithms to those used by MODIS to detect active fires. The VIIRS active fire products complement the MODIS active fire detection and provide an improved spatial resolution, as compared to MODIS. The spatial resolution of the active fire detection pixel for VIIRS is 375 m. Additionally, VIIRS is able to detect smaller fires and can help delineate perimeters of ongoing large fire.

48 https://emm.newsbrief.eu/NewsBrief/alertedition/en/ECnews.html
49 https://gwis.jrc.ec.europa.eu/
50 https://gwis.jrc.ec.europa.eu/about-gwis/technical-background/burnt-areas
51 https://firms.modaps.eosdis.nasa.gov/
52 https://earthdata.nasa.gov/what-is-new-collection-6-modis-active-fire-data

4.10.2 Outputs and score

The GDACS alert level is defined in a semi-automatic way, based on the expert assessment of the impacts of the wildfire. For events of at least 5000 hectares (50 square km) provided by GWIS, the green alert level is attributed automatically, even in absence of impacts. Smaller wildfires may enter GDACS as green events in case of minor impacts to people or assets, or when preparedness measures were implemented or planned in response to the wildfire (e.g. evacuation orders for threatened buildings).

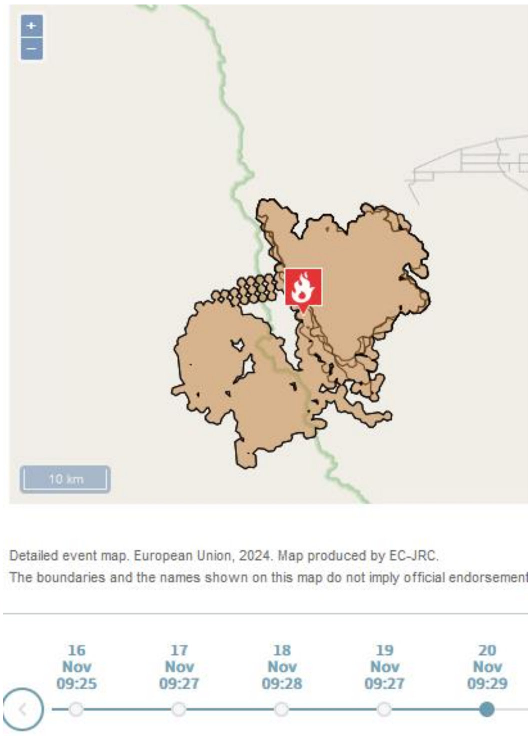
The orange level refers to wildfires of any size that impact directly the people and built-up areas, possibly resulting in some fatalities. Orange is attributed in case of UCPM activations too, with the exceptions of countries where usually UCPM is not adopted (e.g. the USA).

Red alert is assigned to a wildfire of any size that has severe impacts to people and assets, with hundreds or thousands of displaced people and often tens of fatalities. Moreover, the red class is assigned in case of UCPM activations for sizeable fires and a low coping capacity of the country or area affected.

For wildfires, at present, the numerical score can only get one of three values, corresponding to the respective class: 0.5 for green events, 1.5 for orange events and 2.5 for red events.

The area affected is reported on the map cumulatively, by overlaying all daily updates as they become available. The user can select interactively any given update to check the burned area reported for that day (Figure 15).

Figure 15. GDACS example of wildfire map with burned areas by day, overlapping as multiple areas, one for each day.



Source: GDACS.

For each Wildfire event that is transmitted to GDACS, the following attributes are specified by GWIS:

— Event ID: unique identifier of the event for reference and technical purposes

— Current episode ID: sequential number for the updates within an event

— Event name

— GDACS class: automatically set to green (manually modified upon expert assessment)

- From Date: first satellite detection of the burned area
- To Date: last satellite detection of the burned area
- Country: Country where the event is located
- Ha: hectares of burned area
- Population: exposed population within the burned area
- Landcover/land use: Land cover of the burned area (source: Climate Change Initiative – Land Cover –ESA)

Moreover, to further estimate the population at risk, the calculation of the exposed population is performed, using the following distance intervals from the burned area: 1 km, 2 km, 5 km, 10 km.

4.10.3 Ongoing developments in anticipation and impact analysis

A key instrument in the prevention and response to wildfires is the Union of Civil Protection Mechanism. While the UCPM activations are triggered by Member States according to their internal processes, the coordination and deployment of associated resources are liaised by the ERCC of the European Commission. Therefore, establishing a link between activations and the forest fires conditions on the ground may help to better anticipate the UCPM organization and response.

Looking at the time series of past fires allows to identify recurrent patterns (e.g. seasonality, variability, extremes, etc.), and the growing bulk of data collected systematically, through remote sensing data (e.g. Copernicus), represents an opportunity to evaluate in near real time the overall wildfire situation in a country, and get hints on when and where an activation may loom.

By analyzing the occurrences of past UCPM activations and co-occurring data from the ground, GDACS is developing an indicator to flag the typical conditions that occur near UCPM activations. If coupled with other correlated forecast variables, it may possibly provide anticipation capacity of activation conditions a few days before. The key challenges are to deal with the scarcity of data (i.e. number of activations) and the unpredictable chain of decisions that may or may not lead to triggering an activation, regardless of the situation on the ground; both issues affect the analysis of data.

As for all other new developments of the GDACS MHEWS algorithms, also in this case the approach is being tested and its possible integration in the operational website will be discussed by the GDACS Governing Board.

List of abbreviations and definitions

API Application Programming Interface
CEMS Copernicus Emergency Management Service
CRED Centre for Research on the Epidemiology of Disasters (Belgium)
DG ECHO Directorate-General for European Civil Protection and Humanitarian Aid Operations
ECML European Crisis Management Laboratory
ECMWF European Centre for Medium-Range Weather Forecasts
EM-DAT Emergency Events Database of CRED
EMM European Media Monitor
EO Earth Observation
ERCC Emergency Response Coordination Centre (of DG ECHO)
ERCC Emergency Relief Coordination Centre (of OCHA)
ESA European Space Agency
eTRaP Ensemble Tropical Rainfall Potential
GDACS Global Disaster Alert and Coordination System
GDO Global Droughts Observatory
GFS Global Forecast System (GFS) of NOAA
GFZ GeoForschungsZentrum (Germany)
GPM Global Precipitation Measurement
GRT Copernicus Global Reporting Tool
GWIS Global Wildfire Information System
HDI Human Development Index
HWRF Hurricane Weather Research and Forecast System
ICAO International Civil Aviation Organization
JRC European Commission's Joint Research Centre
JTWC Joint Typhoon Warning Center (USA)
KML Keyhole Markup Language
LCC Lack of Coping Capacity
OCHA United Nations Office for the Coordination of Humanitarian Affairs
MHEWS Multi-Hazard Early Warning System
MMI Modified Mercalli Scale Intensity
MODIS Moderate Resolution Imaging Spectroradiometer
NGO Non-Governmental Organisation
NOAA US National Oceanic and Atmospheric Administration (USA)
NRT Near-Real Time
OSOCC On-Site Operations Coordination Centre
PEI Population Exposure Index
RDrI-Agri Risk of Drought Impact in Agriculture
RPI Rural Population Index
RSMC Regional Specialised Meteorological Centres
RSS RDF Site Summary or Really Simple Syndication
SMCS Satellite Mapping and Coordination System
SNPP Suomi National Polar-orbiting Partnership
SSHS Saffir-Simpson Hurricane Wind Scale
TC Tropical Cyclone
UCPM Union of Civil Protection Mechanism
UNITAR United Nations Institute for Training and Research
UNOSAT United Nations Satellite Centre
USGS United States Geological Survey
VAAC Volcanic Ash Advisory Center
VEI Volcanic Explosivity Index
VIIRS Visible Infrared Imaging Radiometer Suite
VPI Volcano Population Index
WMO World Meteorological Organization

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