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Real-time Impact Estimation of Large Earthquake Using USGS ShakeMaps Through Web Processing Service

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Abstract

The Global Disaster Alert and Coordination System (GDACS) is a cooperation framework under the United Nations and the European Commission. GDACS provides alerts and impact estimations after major disasters through a multi-hazard disaster impact assessment service managed by the European Commission Joint Research Centre (JRC). The earthquake alert model is one of the main components in GDACS. The GDACS has been providing alert levels for global earthquakes based on magnitude, population and vulnerability (GDACS-EQM) since 2004. This paper describes a new method (GDACS-EQSM) for calculating alert levels of global significant earthquakes (magnitude 5.0 or larger). The output of the model is an alert score calculated though near-real-time ShakeMaps of the U.S. Geological Survey Earthquake Hazards Program (USGS); vulnerability from Index for Risk Management (INFORM); population exposed at shaking intensity level and intensity for each level, finally alert score will be converted to alert level. A comparison with GDACS-EQM showed an improvement in accuracy of reporting the correct severity; about (25%) for red alerts, (18%) orange alerts and (10%) green alerts. The model has been implemented and integrated in the GDACS based on the Open Geospatial Consortium (OGC) Web Processing Service (WPS).

Keywords: Earthquake; ShakeMaps; Disaster alert; International response; GDACS

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1. Introduction

The Global Disaster Alert and Coordination System (GDACS) is a joint initiative of the European Commission Joint Research Centre (JRC) and the United Nations Office for the Coordination of Humanitarian Affairs (OCHA). It includes disaster managers and disaster information systems worldwide and aims at filling the information and coordination gap in the first phase after major disasters. GDACS provides alerts and impact estimations after major disasters through a multi-hazard disaster impact assessment service managed by the European Commission Joint Research Centre De Groeve et al., (2006). GDACS collects near real-time information about multiple hazards and then combines them with demographic and vulnerability data to perform a statistical estimate of the disaster impact. The result of this risk analysis is distributed by the GDACS website and alerts are sent via email, fax, and SMS to subscribers in the disaster relief community, and all other persons that are interested in this information. The earthquake assessment (GDACS-EQM) tool is one of the important functionalities of the GDACS. The tool was designed in order to generate earthquake alerts in near real-time, based on factors such as magnitude in Richter scale, depth, and population density. A model for expecting number of fatalities and injuries, and the extent of economic loss can be fallen into one of three categories Jaiswal et al., (2008a), Jaiswal and Wald (2010a): empirical, analytical and hybrid methods.

The empirical method requires limited number of basic factors and those combined with mathematical models, such as De Groeve et al., (2006). The output is an alert score thatôs based on magnitude, population, depth and vulnerability. Samardjieva and Badal (2002) performed correlation analyses of 20th Century data collected from fatal earthquakes, and earthquakes of sufficient magnitude and population density. The most widely used empirical model is the U.S. Geological Surveyôs Prompt Assessment of Global Earthquakes for Response (PAGER), which is managed by the U.S. Geological Surveyôs (USGS) National Earthquake

Information Center (NEIC). Jaiswal et al., (2008a) studied the empirical approach of earthquake mortalities for more than 4,500 earthquakes worldwide since 1973. Expected earthquake motility rates for each country can be expressed on a lognormal cumulative distribution of shaking intensity and population exposed at each shaking intensity. The residual error is minimised by using data on past earthquake fatalities.

Analytical methods such as HAZUS Kircher et al., (2006) requires a high degree of accuracy and a good quantity of input data. It is difficult to apply because of the lack of input data on a global-scale. The HAZUS-MH earthquake model is designed in order to estimate losses by using national databases such as demographic of the population in study region, building structures, locations of bridges, etc. HAZUS system is becoming available on continental scale such as HAZUS-MH system for the United States FEMA (2015).

A hybrid method needs simplified parameters at the global level, such as information on building inventories and occupancy status (residential, non-residential and population in transit). The QLARM (EarthQuake Loss Assessment for Response and Mitigation) Trendafiloskiet et al., (2011) used soil amplification factors, distribution of building stock, and the population segmented into vulnerability classes in order to calculate damage and loss using vulnerability curves and loss data from past events for calibration loss estimation. Wald et al., (2008) adapted the empirical PAGER system to estimate fatality rates by incorporating population exposure, vulnerability thatôs based on collapse assessments for each building type.

Both analytical and hybrid method require at least basic building inventories and vulnerabilities of structure collapses. The advantage of both methods is not only calculate fatalities and injuries but also homelessness and economic loss Wald et al., (2008). The empirical model in PAGER needs at least four fatal earthquakes in order to collect enough data to build a country specific empirical model Jaiswal et al., (2008a). In many cases, countries have too few fatal events (213 countries) so they will be aggregated with countries that have more than four fatal earthquakes by using indicators such as the Human Development Index and climate classification.

This paper presents the GDACS-EQSM model based on ShakeMap data for calculating alert scores and alert levels in order to improve previous models GDACS-EQM. The model relies on USGS shaking intensity levels, vulnerability, and population exposure at each intensity level. Strong earthquakes are assessed based on human loss, number of injured, and economic loss. In this paper, we used over 12 years of global USGS ShakeMaps data from 2004 to Apr 2016. The historical earthquake loss data used in our model can help scientists to study the consequences of earthquakes and their trends. We use earthquake reports from two sources, USGS and EmDat, which will be discussed in section 2.

The Open Geospatial Consortium (OGC), an international voluntary consensus standards organization, It proposed standards for Web Services (OWS) such as Web Map Services (WMS), Web Feature Services (WFS) and Web Processing Services (WPS). WPS provides rule for standardizing input and output data, presents how client can request the execution of a process. Brovelli et al (2013). In order to implement GDACS-EQSM model, we used processing services WPS, which would be of large apply in risk studies.

2. Data Used and Tool

The U.S. Geological Survey (USGS) provides near-real-time shaking intensity data via ñShakeMapsò.TheUSGS ShakeMap is published on the following website (http://earthquake.usgs.gov/), ShakeMap data provides near-real-time maps of shaking intensity in terms of ground motion parameters and follows significant earthquakes within 20 minutes and within 5 minutes in the United States.

Second, the Landscan has been developed by Oak Ridge National Laboratory (ORNL Landscan). In their very first research Bhaduri et al., (2002) presented the LandScan dataset as a worldwide population database based on 30-second by 30-second grid cells. The LandScan model collects the best census counts for each country and primary geospatial input such as land cover, roads, slopes, urban areas, and village locations.

Third, the necessary earthquake document for global scale is not easy to get because earthquake catalog reports are created for different purposes, in some countries the reports were not clear. Also, up until now, there has not been any common definition of ñpeople affected by a disasterò Guha-Sapir and Vos (2010). The Emergency Events Database (EmDat) is maintained by the Center for Research on the Epidemiology of Disasters (CRED) at the Catholic University in Louvain, Belgium. EM-DAT includes earthquake disasters from around the world and has been providing important information on earthquake disaster-related deaths, injuries and economic loss since 1990. On the other hand, earthquakes with a magnitude of 6.5 or greater could cause fatalities, injuries or substantial damage are presented on USGS website (http://earthquake.usgs.gov/earthquakes/eqarchives/significant/).

Finally, De Groeve et al., (2014) described the Index for Risk Management (InfoRM). The InfoRM is known as the first global, objective and transparent tool for understanding the risk of a humanitarian crisis and disasters, which can support decisions for prevention, preparedness, and response (http://www.inform-index.org/). In this paper, we use InfoRMôs vulnerability index and lack of coping capacity (LoCC) index for natural hazard as the input parameters for calculating alert scores. InfoRMôs LoCC is used to simply understand the ability of people, organizations and systems, using available skills and resources, to face and manage adverse conditions, emergencies or disaster.

WPS software used in this study is the ZOO-Project, ZOO-Project contains set of components such as ZOO-Kernel, ZOO-ServiceProvider. The ZOO-Kernel was written in C, but WPS can be implemented in various programming languages such as Java, Python, FORTRAN, PHP, etc. Fenoy et al., (2012).

3. Model Computation

The early model for calculating alert scores and their threshold is implemented by using JRCȏs Asdard earthquake model De Groeve et al., (2006), the output of the Asgard model generates an alert score that is transformed into an alert level (Red: international humanitarian disaster, Orange medium likelihood of international humanitarian disaster, Green low international humanitarian disaster).

The historical alert data and their associated losses (killed, injured, and economic) from USGS and EmDat have been used to estimate alert thresholds for each alert level. The combination function for calculating alert scores can be expressed as follows:

$$Alert\ Score = \sum_{I=5} \sqrt[3]{ln([I-4.5]+0.5)\times Pop[i]\times Coff_I \times Vul \times LoCC} \qquad (1)$$

Where I is the shaking intensity level for example 5.5, 6.5...,8.5; and *Pop[i]* is the population at shaking intensity level i. We use LandScan 2014 data to calculate population within shaking intensities. $Coff_I$ is the coefficient of each intensity. Allen et al., (2009a) applied simple fatality model by using the following function of shaking intensity:

$$R(I) = 10^{(1.03I-10.75)} \qquad (2)$$

Where R is the fatality rate (fatalities per number of people exposed) at intensity I. The idea is to determine the ratio of $Coff_{Intensify}$ between two consecutive intensities in (2), which approximates to 10. The coefficient can be expressed as $Coff_I = \{10^{I-7}, Where\ I\ is\ shaking\ intensity\}$. Vul in (1) is the InfoRMȏs vulnerability parameter and LoCC in (1) is the LoCC of InfoRM. In this research we not only approach record number of deaths from historical earthquakes alone but also injury and economic loss (Damage Factor). The combination function of loss is defined as follows:

$$Damage\ Factor\ (DFKIE) = killed + (people\ injured)\times 10^{-1} + (economic\ loss)\times 10^{-2} \qquad (3)$$

In the computation side, the set of individual WPSs have been deployed as the chart follows:

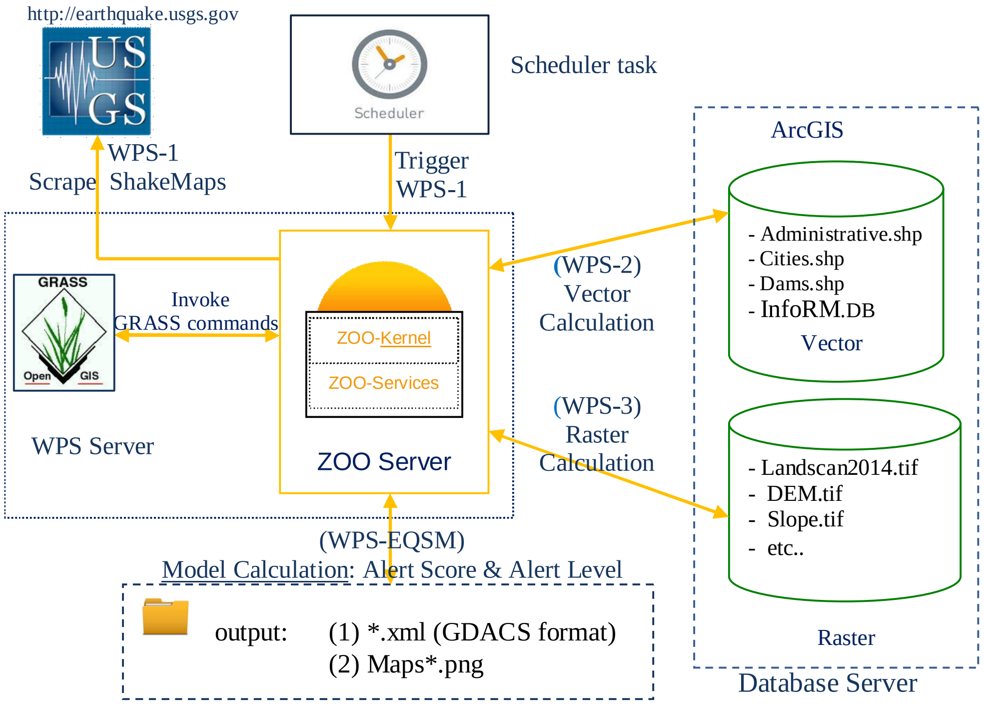


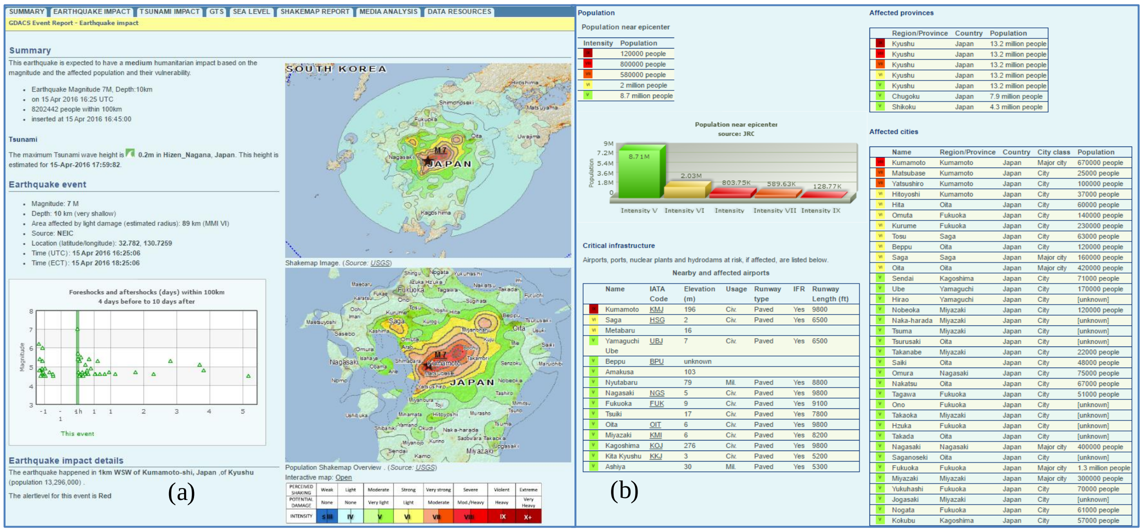
Fig. 1: Showing architecture of main component of EQSM system in GDACS based on WPSs.

The JRC calculates a new alert score and alert score to indicate the potential of the need for international intervention. As the Fig.1 those calculations (WPS-EQSM) are based on the GDACS-EQSM model and when better hazard information ShakeMap becomes available, the impact model can be developed by using (1) USGS ShakeMap; (2) population affected (WPS-3) and (3) local vulnerability of population (WPS-2). The first component is scraped (downloaded and processed) from USGS and modelled at JRC we used WPS-1. The second and third components are derived though LandScan image, geographical information system (GIS) model and InfoRM datasets.

4. Results and Discussion

Our new GDACS-EQSM model has been successfully implemented and integrated in the GDACS (www.gdacs.org) based on the ShakeMap data in the ñSHAKEMAP REPORTò page of GDACS. Implementation relied on WPS OGC standard and open source framework ZOO-Project with GRASS software. On our new ñSHAKEMAP REPORTò page, we not only present a map of events (see Fig. 2) but also a list of important geographic and demographic information such as provinces, cities, nuclear plants, ports, protected areas, and population for shaking intensities and alert levels.

Internationally, an alert level for a significant earthquake will be provided within two minutes after the ShakeMap is available by setting alert levels in green, orange and red alerts within (DFKIE=0, 1 Ò DFKIE< 1000, DFKIEÓ1000). Figure.5 shows a red alert earthquake striking in Japan on 15 Apr 2016. The ShakeMap image shows the population by various intensity levels in Fig.2a (left), the total population exposed per color-coded intensity level and population histogram in Fig.2b (right), the affected provinces and affected cities (right), and the critical infrastructure affected (bottom left). Between 2004 and April 2016, approximately 1934 earthquakes have been recorded; 1714 green alerts, 198 orange alerts and 21 red alerts (Fig.3).



GDACS Event Report - Earthquake impact

Summary

This earthquake is expected to have a **medium** humanitarian impact based on the magnitude and the affected population and their vulnerability.

- Earthquake Magnitude 7M, Depth:10km
- on 15 Apr 2016 16:25 UTC
- 8202442 people within 100km
- inserted at 15 Apr 2016 16:45:00

Tsunami

The maximum Tsunami wave height is **0.2m** in **Hizen_Nagana**, **Japan**. This height is estimated for **15-Apr-2016 17:59:82**.

Earthquake event

- Magnitude: **7** M
- Depth: **10** km (very shallow)
- Area affected by light damage (estimated radius): **89** km (MMI VI)
- Source: **NEIC**
- Location (latitude/longitude): **32.782**, **130.7259**
- Time (UTC): **15 Apr 2016 16:25:06**
- Time (ECT): **15 Apr 2016 18:25:06**

Earthquake impact details

The earthquake happened in **1km WSW of Kumamoto-shi, Japan** ,of **Kyushu** (population 13,296,000) .

The alertlevel for this event is Red

Shakemap Image. (*Source*: USGS)

Population Shakemap Overview . (*Source*: USGS)

Interactive map: Open

PERCEIVED SHAKING	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	None	None	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
INTENSITY	≤III	IV	V	VI	VII	VIII	IX	X+

Population

Population near epicenter

Intensity	Population
IX	120000 people
VIII	800000 people
VII	580000 people
VI	2 million people
V	8.7 million people

Critical infrastructure

Airports, ports, nuclear plants and hydrodams at risk, if affected, are listed below.

Nearby and affected airports

	Name	IATA Code	Elevation (m)	Usage	Runway type	IFR	Runway Length (ft)
IX	Kumamoto	KMJ	196	Civ.	Paved	Yes	9800
VI	Saga	HSG	2	Civ.	Paved	Yes	6500
VI	Metabaru		16				
V	Yamaguchi Ube	UBJ	7	Civ.	Paved	Yes	6500
V	Beppu	BPU	unknown				
V	Amakusa		103				
V	Nyutabaru		79	Mil.	Paved	Yes	8800
V	Nagasaki	NGS	5	Civ.	Paved	Yes	9800
V	Fukuoka	FUK	9	Civ.	Paved	Yes	9100
V	Tsuiki		17	Civ.	Paved	Yes	7800
V	Oita	OIT	6	Civ.	Paved	Yes	9800
V	Miyazaki	KMI	6	Civ.	Paved	Yes	8200
V	Kagoshima	KOJ	276	Civ.	Paved	Yes	9800
V	Kita Kyushu	KKJ	3	Civ.	Paved	Yes	5200
V	Ashiya		30	Mil.	Paved	Yes	5300

Affected provinces

	Region/Province	Country	Population
IX	Kyushu	Japan	13.2 million people
VIII	Kyushu	Japan	13.2 million people
VII	Kyushu	Japan	13.2 million people
VI	Kyushu	Japan	13.2 million people
V	Kyushu	Japan	13.2 million people
V	Chugoku	Japan	7.9 million people
V	Shikoku	Japan	4.3 million people

Affected cities

	Name	Region/Province	Country	City class	Population
VIII	Kumamoto	Kumamoto	Japan	Major city	670000 people
VII	Matsubase	Kumamoto	Japan	City	25000 people
VII	Yatsushiro	Kumamoto	Japan	City	100000 people
VI	Hitoyoshi	Kumamoto	Japan	City	37000 people
VI	Hita	Oita	Japan	City	60000 people
VI	Omuta	Fukuoka	Japan	City	140000 people
VI	Kurume	Fukuoka	Japan	City	230000 people
VI	Tosu	Saga	Japan	City	63000 people
VI	Beppu	Oita	Japan	City	120000 people
VI	Saga	Saga	Japan	Major city	160000 people
VI	Oita	Oita	Japan	Major city	420000 people
V	Sendai	Kagoshima	Japan	City	71000 people
V	Ube	Yamaguchi	Japan	City	170000 people
V	Hirao	Yamaguchi	Japan	City	[unknown]
V	Nobeoka	Miyazaki	Japan	City	120000 people
V	Naka-harada	Miyazaki	Japan	City	[unknown]
V	Tsuma	Miyazaki	Japan	City	[unknown]
V	Tsurusaki	Oita	Japan	City	[unknown]
V	Takanabe	Miyazaki	Japan	City	22000 people
V	Saiki	Oita	Japan	City	48000 people
V	Omura	Nagasaki	Japan	City	75000 people
V	Nakatsu	Oita	Japan	City	67000 people
V	Tagawa	Fukuoka	Japan	City	51000 people
V	Ono	Fukuoka	Japan	City	[unknown]
V	Takaoka	Miyazaki	Japan	City	[unknown]
V	Hzuka	Fukuoka	Japan	City	[unknown]
V	Takada	Oita	Japan	City	[unknown]
V	Nagasaki	Nagasaki	Japan	Major city	400000 people
V	Saganoseki	Oita	Japan	City	[unknown]
V	Fukuoka	Fukuoka	Japan	Major city	1.3 million people
V	Miyazaki	Miyazaki	Japan	Major city	300000 people
V	Yukuhashi	Fukuoka	Japan	City	70000 people
V	Jogasaki	Miyazaki	Japan	City	[unknown]
V	Nogata	Fukuoka	Japan	City	61000 people
V	Kokubu	Kagoshima	Japan	City	57000 people

Fig. 2: Example of red alert event based on ShakeMap in GDACS ñSHAKEMAP REPORTò summary report for earthquake M 7.0 in Japan on 15 Apr 2016 16:25 UTC.

The comparison in accuracy between GDACS-EQM and GDACS-EQSM, in general shows that our GDACS-EQSM model is 25 % more accurate for red alerts, 18% for orange alerts and 9% for green alerts. We have successfully estimated the alert levels of earthquakes worldwide for the last 10 years. After ShakeMap data is available, an alert level will be available within 2 minutes for strong earthquakes and less than 1 minute for almost all other events.

Furthermore, existing data on injuries and economic loss used for calibration of our model are still not robust and so work is needed to improve this dataset. Another limitation of our GDACS-EQSM model is that in some cases, USGS data on shaking intensities were missing and this caused our model to underestimate alert levels. In a few real life cases, earthquakes may not be strong but records of deaths and injuries is significant, for example in the earthquake M5.2 in Hubei-Jiangxi border region, China. Our model predicted a green alert for this earthquake, based on the ShakeMap data which reported intensity of around 5.0. However, the earthquake caused16 deaths and 8000 people injured.

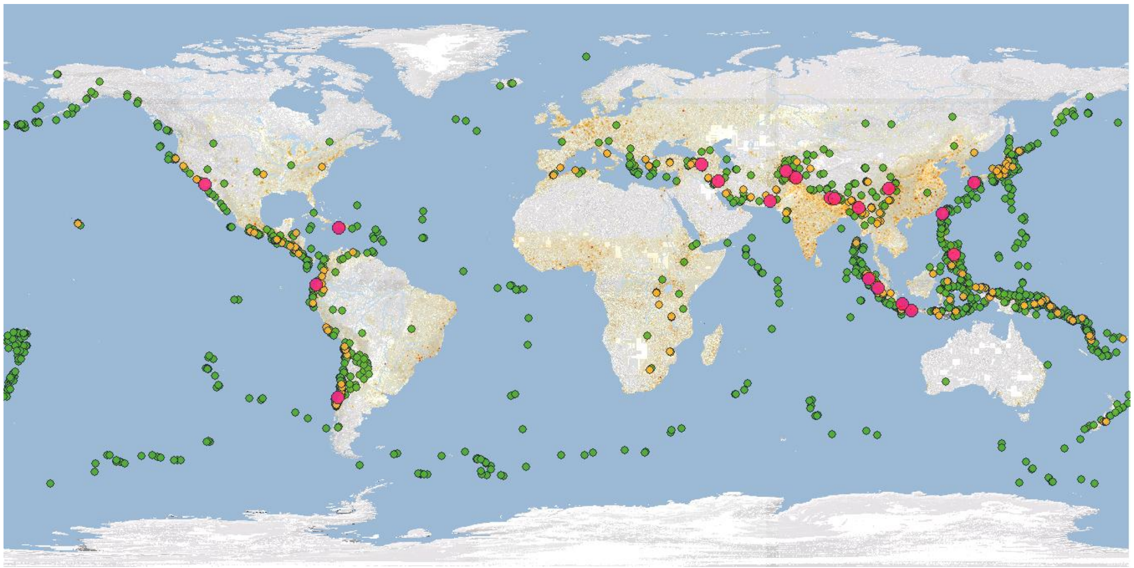


Fig. 3: Global Earthquakes and their alert levels (in red, orange, green alerts) from 2004 to August 2016.

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