# M

## MACROSEISMIC SURVEY

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### Definition

The term "macroseismic survey" refers to the process of gathering information on how strongly an earthquake was felt in different places.

### Discussion

It has long been standard practice in earthquake investigation to gather information on the distribution of effects of any recent earthquake. Indeed, before the introduction of reliable seismometers, this was really the only way to study an earthquake. Generally, the results of such a study are presented as a map of intensity, often contoured as isoseismals. A macroseismic survey generally comprises two parts. The most heavily damaged area needs to be examined firsthand, and the damage to individual buildings recorded. This task ideally should be conducted in collaboration with engineers qualified to assess the original strength of the damaged buildings. This is referred to as a field investigation of the earthquake. Data collection for the wider felt area of the earthquake, at non-damaging intensities, is usually done via questionnaires. Various strategies for the dissemination of questionnaires have been practiced in the past, including appeals for information published in newspapers, sending questionnaires to local officials, and maintaining a network of volunteer observers who can be relied on to fill in details after an earthquake has occurred. Today, the dominant method of collecting questionnaire data is over the internet. After even a moderate-sized event in a populated area, tens of thousands of responses can be collected very quickly via an institute's web site, and these can then be processed in real time using an automatic intensity assessment algorithm. This also has the great advantage that the results of the survey are visible immediately on the web site, rather than appearing only in a journal paper or bulletin some months later, and this is an excellent method of conveying seismological data to the general public in a timely and informative way.

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### Cross-references

Intensity Scales
Internet, World Wide Web and Natural Hazards
Isoseismal
Magnitude Measures
Seismograph/Seismometer

## MAGMA

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### Synonyms

Liquid rock; Molten rock

P.T. Bobrowsky (ed.), *Encyclopedia of Natural Hazards*, DOI 10.1007/978-1-4020-4399-4,

## Definition

Magma is liquid or molten "rock."

## Discussion

Magma is liquid rock which is a fluid comprised of a mixture of crystals and gas. When solidified it becomes an igneous rock. It is magma when below ground and lava when above ground. The chemical composition of magma/lava plays a major role in determining eruption characteristics and the hazard potential of a volcano. Magmas vary in composition dependent on a number of factors, in particular their plate tectonic affinity (Perfit and Davidson, 2000). Basaltic magmas are common along ocean ridges, hot spots, and continental plateaus. Magmas with higher silica contents (Andesite, Dacite, and Rhyolite) are common along subduction zones and intraplate tectonic settings. The composition, along with crystal and gas content, controls the viscosity, temperature, and explosivity of the magma. Composition combined with pressure dictates the proportions of liquid, gases, and solids. These proportions have a strong controlling influence on the style of eruption. Basaltic (or mafic) lavas have low viscosity and are the least explosive, except in certain circumstances where there is interaction with water. As magma increases in silica content (referred to as felsic or sometimes siliceous magmas [reflecting high silica content], for example, Gillespie and Styles, 1999; Rogers and Hawkesworth, 2000; Thorpe and Brown, 1993), the explosivity tends to go up because the rise in silica creates an attendant rise in viscosity. As the magma rises to the surface (and as it crystallizes with lowering temperatures, exsolving fluids), the fluid phase (dominated by $H_2O$ and $CO_2$) within the magma begins to exert pressure on the liquid phase. The exsolving bubbles, expanding as the magma rises, combined with growing crystals, increase the pressures within the magma (Scandone et al., 2007), causing a decrease in the density of the melt resulting in more rapid rise. The culmination of the ascent, high fluid pressures, and high viscosity magmas is an explosive eruption, common at stratovolcanoes. High silica, low fluid pressure magmas flow sluggishly with little or no explosive activity. Such magmas often "stall" at high crustal levels forming small stocks or sills, or larger plutons. If they egress to the surface, they flow only with great difficulty, forming domes or flow domes.

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## Cross-references

Aa Lava
Lava
Pahoehoe Lava
Plate Tectonics
Shield Volcano
Stratovolcanoes
Volcanoes and Volcanic Eruptions

# MAGNITUDE MEASURES

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## Synonyms

Earthquake measure; Earthquake severity; Earthquake size; Magnitude scale

## Definition

*Magnitude Measures*. A variety of scales and calculations to measure, characterise and catalogue the size of an earthquake in terms of the seismic waves generated and energy released by the event.

## Introduction

The size and damaging effects or severity of an earthquake are described by measurements of both magnitude and intensity. The quantification of the size of an earthquake has been considered by seismologists for many decades. A variety of different measures have been produced to estimate and report the magnitude of a seismic event. Many attempts have been made to develop a uniform scale to measure earthquake magnitude (Kanamori, 1983) but this goal has not always been achievable due to the changes in instrumentation used over time, changes in seismic data processing techniques as well as developments in the distribution of seismic monitoring stations. As a result of these influences a variety of *magnitude scales/measures* have been developed and reported which have been used at various times and locations around the world. As the science of earthquakes (seismology) has developed further advances have been made in the quantification of a seismic event. In order to provide a historical continuity of the measurements made relationships needed to be developed between the various earthquake size measuring schemes. As earthquakes are the result of complex geophysical processes it is not a simple matter to find a single measure of the size of an earthquake (Kanamori, 1978).

There are two fundamental parameters that can be used to describe the size of an earthquake. The *magnitude* of a seismic event characterises the relative size of the earthquake. It can be considered as a measure of the amount of energy released during the seismic event. For each earthquake there is only one magnitude. The *intensity* of a seismic event describes the severity of the earthquake in terms of the physicals effects on the ground, people and buildings in the area affected. For each earthquake there are many intensities depending on the location and distance from the epicentre, underlying geology, types and styles of buildings and structures present in the affected zone.

Magnitude is a logarithmic measure of the size of an earthquake based on instrumental data (Bormann et al., 2002). The measurement of magnitude is based on the amplitude of the resulting seismic waves recorded on a seismogram once the amplitudes are corrected for the decrease with distance due to geometric spreading and attenuation (Stein and Wysession, 2003).

## Seismic waves

The fault rupturing process that takes place during an earthquake generates elastic waves within the earth which propagate away from the rupture front. Different types of seismic waves are generated each with different velocities and travel paths. Two fundamental types of waves are created; compressional, longitudinal waves and shear, transverse waves. The fastest P or Primary Waves travel through the body of the earth together with the slower S or Secondary Shear Waves. At the surface of the earth these two types of motion can combine to form complex surface waves. These surface waves have much higher amplitudes than the P and S waves and are therefore much more destructive as their energy is concentrated near the earth's surface. Such surface waves can be further subdivided into Rayleigh or Love Waves which both have longer periods and arrive after the P and S waves on the seismogram. Rayleigh Waves have an elliptical motion similar to that of water waves whereas Love Waves have a motion that is horizontal and perpendicular to the direction of propagation. Near the earthquake epicentre the largest recorded wave is the short period S Wave. At greater distances the longer period Surface Waves become dominant. The various magnitude scales set out to measure the fundamental properties of these different waves in order to estimate the magnitude of the seismic event.

## Quantification of earthquake size

Earthquakes can be quantified with respect to various physical properties of the source site. These include the length of the fault that ruptures, the area of the fault, the fault displacement, particle velocity and acceleration of the fault motion, duration of faulting, amount of radiated energy as well as the complexity of the fault motion (Kanamori, 1983). It is not possible to represent all of these parameters by a single number such as the magnitude of the earthquake but the magnitude of a seismic event does have value in allowing an initial analysis and cataloguing of an earthquake to be undertaken.

The majority of *magnitude measure* scales that are in use are empirical in nature. A magnitude M is determined from the amplitude A and period T of the various seismic waves detected by a seismometer, recorded by a seismograph on a seismogram. The formulas used to derive an estimate of the earthquake magnitude contain constraints such that magnitude value scales can be correlated over a certain magnitude range (Kanamori, 1983).

The first widely used *magnitude measure* or scale was developed by Charles Richter in 1935 (Richter, 1935). This work was further developed with Beno Gutenberg in 1945 (Gutenberg, 1945a). Initially the magnitude scale was calculated on the maximum amplitude of the largest waveform detected from the seismic event. Subsequently the use of surface waves was included and then measurements of the body wave. Since this initial work many other magnitude scales have been developed for both local and global application utilising differing aspects of the seismic signal generated during an earthquake.

In order to overcome some of the localised issues of the early magnitude scales and their inability to differentiate larger magnitude earthquakes, a magnitude measure was developed that was based on a key seismic parameter, the Seismic Moment. The Seismic Moment is related to some of the key physical parameters of the fault which has ruptured during the seismic event. This Seismic Moment has been incorporated into a Moment Magnitude Scale ($M_W$) by considering the seismic energy radiated during the earthquake. The Moment Magnitude Scale is now the most frequently quoted scale in describing the size of an earthquake along with the corresponding Seismic Moment of the event.

## Seismic moment

One of the major advances in the development of magnitude scales was the concept of 'seismic moment' (Kanamori, 1978). The Seismic Moment is considered to be the most accurate and comparable measure of an earthquake and can be considered as a measure of the irreversible inelastic deformation in the fault rupture area (Kanamori, 1977). The measure is completely independent of the type of seismograph used to record the seismic event. The Seismic Moment is a parameter that measures the overall deformation at the source of the seismic event (Kanamori, 1977). It has an important bearing on global phenomena such as tectonic plate motion, polar motion and on the rotation of the earth. The Seismic Moment can be interpreted in terms of the strain energy released in an earthquake. It measures the amount of energy released rather than the size of the seismic waves which are affected by the depth of the event and the geology of the rocks that the waves pass through. The Seismic Moment is related to the final static displacement after the earthquake. The Seismic Moment $M_0$ is defined thus:

$$M_0 = \mu \bar{D} A \quad (1)$$

Where:

*$M_0$ = Seismic moment (measured in* dyn. cm *or* N.m)

*$\mu$ = Rigidity or shear modulus of the rock at the source (fault) depth*

*$\bar{D}$ = Average slip or displacement on the fault after rupture*

*A = Surface area of the fault rupture zone*

It is termed Seismic Moment as Area × Stress gives a Force, and Force × Distance gives a Moment.

## Seismic energy

Conventionally the energy E released by an earthquake has been estimated via the magnitude – energy relationship developed by Gutenberg and Richter (Gutenberg, 1956):

$$Log\, E_S = 1.5\, M_S + 11.8\, (E_S\ in\ \text{Ergs}) \quad (2)$$

$$Log\, E_S = 2.45\, m_B + 5.8\, (E_S\ in\ \text{Ergs}) \quad (3)$$

These equations hold well for most earthquakes but tend to underestimate for very large earthquakes which have a fault rupture length of 100 km or greater. Kanamori (1977, 1994) considered the change in strain energy during a seismic event with a fault rupturing. He stated that if the stress drop during an earthquake is complete the following equation holds:

$$E_S \approx \frac{\Delta\sigma}{2\mu} M_O \quad (4)$$

Where:

*$E_S$ = Seismic energy radiated by the seismic source as seismic waves*

*$M_O$ = Seismic Moment*

*$\Delta\sigma$ = Stress drop*

*$\mu$ = Rigidity or shear modulus of the rock at the source (fault) depth*

The relationship between the slip or displacement in an earthquake, its fault dimensions and its Seismic Moment is closely tied to the magnitude of the stress released by the earthquake. This is known as the stress drop, the difference between the stress before and after fault rupture. The earthquake releases the strain energy that has accumulated over time around the fault area (Stein and Wysession, 2003). The stress drop, averaged over the fault can be approximated:

$$\Delta\sigma \approx \frac{\mu \bar{D}}{L} \quad (5)$$

Where:

*$\bar{D}$ = Average slip or displacement on the fault after rupture*

*L = Fault characteristic dimension of the fault rupture*

The average slip on the fault that ruptures can also be estimated from the Seismic Moment where:

$$\bar{D} \approx \frac{c\, M_0}{\mu L^2} \quad (6)$$

Where:

*c = Fault shape factor.*

The specific relationship and values of c depend on the fault shape and fault rupture direction. This allows the stress drop to be calculated for a variety of fault morphologies.

*For a Circular Fault*:

$$\Delta\sigma \approx \frac{7}{16} \frac{M_0}{R^3} \quad (7)$$

*For a Rectangular Fault (Strike Slip)*:

$$\Delta\sigma \approx \frac{2}{\pi} \frac{M_0}{w^2 L} \quad (8)$$

*For a Rectangular Fault (Dip Slip)*:

$$\Delta\sigma \approx \frac{8}{3\pi} \frac{M_0}{w^2 L} \quad (9)$$

Where:

*R = Fault radius*

*W = Fault width*

Kanamori (1983) stated that by utilising the relationship between Seismic Moment and seismic wave energy the energy can be estimated thus:

$$E_S \approx \frac{M_O}{2\,x\,10^4} \quad as \quad \frac{\Delta\sigma}{\mu} \sim 10^{-4} \quad (10)$$

The conventional magnitude scales discussed in detail elsewhere are said to saturate when the rupture dimensions of the earthquake exceeds the wavelength of the seismic waves used for the magnitude determination, usually between 5 and 50 km (Kanamori, 1977). This saturation leads to an inaccurate estimate of the energy released in very large earthquakes. The energy can however be estimated from the calculated Seismic Moment as it is possible to correlate the seismic energy with the Moment Magnitude, $M_w$:

$$E_S \approx \frac{M_O}{2\,x\,10^4} \quad (11)$$

$$Log\, E_S = Log\,(M_0) - 4.3 \quad (12)$$

And:

$$M_W = \frac{2}{3}\, Log\, M_0 - 10.7 \quad (13)$$

So:

$$M_W = \frac{2}{3}\, Log\,(E_S.20000) - 10.7 \quad (14)$$

$$Log\,(E_S) = \frac{3}{2} M_W + 11.8\, (E_S\ in\ \text{ergs}) \quad (15)$$

To illustrate that Seismic Moment and seismic energy are different, Seismic Moment is quoted in dyn.cm (CGS units) or N.m (SI units) and seismic energy in Erg (CGS) or Joules (SI), even though the units are equivalent (Stein and Wysession, 2003). 1 erg = 1 dyn.cm and 1 erg = $10^{-7}$ J. The radiated energy is only $1/2 \times 10^4$ or 0.00005 of the Seismic Moment released. This is because the Seismic Moment is not energy per se but is related to the stress change over the earthquake source region which gives the Seismic Moment dimensions of dyn.cm:

$$\frac{dyn}{cm} \cdot cm^3 = dyn.cm \tag{16}$$

Note however that $E_S$ is not the total energy released by an earthquake. It is only the estimated amount of energy radiated as seismic waves. Other energy is released as gravitational, frictional or heat energy. $E_S$ only represents this small fraction of the total energy release during a seismic event.

## Moment magnitude scale, $M_W$

The key concept of Seismic Moment led to the development of a Moment Magnitude Scale, $M_W$ (Hanks and Kanamori, 1979) which more closely relates the measure of size to the tectonic effects of an earthquake. Traditional *magnitude measure* scales, discussed elsewhere, are said to saturate at large magnitudes leading to considerable underestimation of the size of very large earthquakes. These magnitude scales tend to only measure the localised failure along the crustal fault zone rather than the gross wide scale fault characteristics (Hanks and Kanamori, 1979). In order to represent the size of an earthquake as a dislocation phenomenon along a fault the Seismic Moment $M_0$ is considered to be the most adequate measure (Utsu, 2002). It is the most fundamental parameter that can be used to measure the strength of an earthquake caused by fault slip.

Kanamori (1977) compared the earthquake energy-moment relationship with the magnitude-energy relationship developed by Gutenberg and Richter (Gutenberg, 1956) where $E_S$ is expressed in ergs and $M_0$ in dyne.cm:

$$E_S = \frac{\Delta\sigma}{2\mu} M_O \tag{17}$$

$$Log\, E_S = 1.5\, M_S + 11.8 \tag{18}$$

As $\Delta\sigma/\mu \approx 10^{-4}$ (Kanamori, 1983):

$$Log\, M_0 = 1.5\, M_S + 16.1 \tag{19}$$

As has been stated previously $M_S$ values saturate for great earthquakes with $M_0 > 10^{29}$ dyn.cm or more such that Eqs. 2 and 3 do not hold for such large earthquakes. Kanamori (1977) and Hanks and Kanamori (1979) proposed a new Moment Magnitude Scale, $M_W$ which overcame these issues of saturation by the incorporation of the calculated Seismic Moment:

$$M_W = \frac{2}{3}\ Log\, M_0 - 10.7\ (M_0\ in\ \text{dyn.cm}) \tag{20}$$

$$M_W = \frac{2}{3}\ Log\, M_0 - 6.1\ (M_0\ in\ \text{N.m}) \tag{21}$$

The Seismic Moment does not saturate. For example the Great Alaskan Earthquake of 1964 was recorded as $M_S = 8.4$ whereas on the Moment Magnitude Scale as $M_W = 9.2$.

## Other significant magnitude scales

### Magnitude scales general form

When attempting to estimate the magnitude of a seismic event the amplitude of the seismic wave is used to determine the earthquake size once the amplitudes have been corrected for the decrease with distance from the epicentre due to geometric spread and attenuation. *Magnitudes scales* thus have the following general form:

$$M = Log\, \frac{A}{T} + F(\Delta, h) + C_S + C_R \tag{22}$$

Where:

*M = Estimated magnitude of earthquake*

*A = Amplitude of the signal recorded on the seismogram*

*T = Dominant period of the signal recorded on the seismogram*

*$F(\Delta, h)$ = A calibration function used for the correction of the variation of amplitude with the earthquakes depth (h) and distance in degrees or kilometres (Δ) from the epicentre to the seismometer recording station*

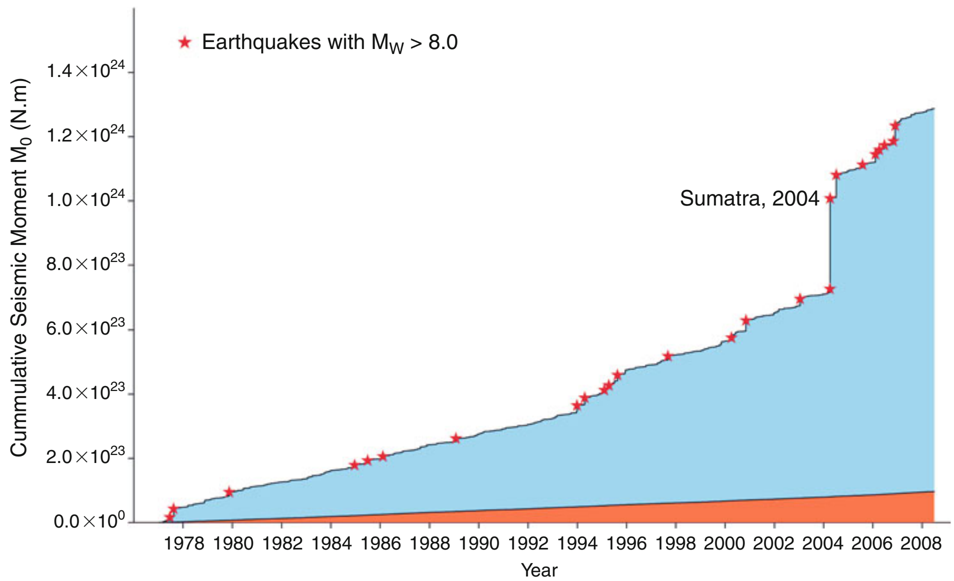
*$C_S$ = Station correction factor*

*$C_R$ = Region correction factor*

*Magnitude measurements scales* are thus logarithmic in nature. A unit increase in magnitude will correspond to a 10-fold increase in seismic wave amplitude and a 32-fold increase in associated seismic energy. Various scales have been developed for local or teleseismic (distant) events. Distance measurements for local events are usually quoted in kilometres and in degrees for more distant events ($1° = 111.19$ km).

### Local wave magnitude scale, $M_L$

The earliest *magnitude measurement* scale was introduced by Charles Richter in 1935 to assess the size of earthquakes occurring in Southern California (Richter, 1935). He developed a *local* magnitude scale ($M_L$) which is often referred to as the 'Richter Scale'. The magnitude of the earthquake was calculated from the amplitude of the seismic waves measured on a specific seismograph, the Wood Anderson Torsion Instrument. Equation 23 details the formula used along with calibration charts to calculate $M_L$. This equation is only applicable to shallow earthquakes measured in Southern California occurring within 600 km of the Wood Anderson instrument. Richter's original magnitude scale was further developed in 1945 by




**Magnitude Measures, Figure 1** Cumulative moment of all earthquakes in the Harvard University CMT catalogue from the Global Seismographic Network between 1977 and 2009. The field shaded light blue reflects the cumulative moment of earthquakes with $M_W \geq 6.5$. The field shaded *orange* reflects the cumulative moment of earthquakes with $M_W \geq 5.0$ to $< 6.5$. *Red stars* indicate the dates of earthquakes with $M_W \geq 8.0$. The contribution of the December 2004 Sumatra earthquake to the total cumulative moment is the largest step in the curve.

Gutenberg (Gutenberg, 1945a) to include seismic events of any epicentral distance from the recording station and for deeper focal depths as well as not being dependant on the type of seismograph used to record the event. A further two magnitude scales were developed from this early work, one dealing with *surface waves*, $M_S$, and another with *body waves*, $M_B$, (seismic waves that travel into and through the body of the Earth). Richter magnitudes in their original form are no longer quoted as most earthquakes do not occur in California and today Wood Anderson seismographs are rare (Stein and Wysession, 2003). $M_L$ is a good indication of the structural damage that an earthquake can cause due to the recording frequency of the Wood Anderson seismograph being close to the resonant frequency (the frequency most likely to cause damage) of many buildings at around 1 Hz.

$$M_L = Log\, A_{Max} - Log\, A_0 (Richter,\ 1935) \qquad (23)$$

To allow for possible local recording station effects (Hutton and Boore, 1987; Boore, 1989) a 'station term' is introduced:

$$M_L = Log\, A + 2.76\, Log\, \Delta - 2.48$$

Where:

*$A_{Max}$ = Peak motion on a specific instrument (Wood Anderson seismograph)*

*$A_0$ = curve correction factor for the effect of distance, tabulated in Richter (1958)*

These correction factors are only truly valid for southern California. Other site specific correction factors have been developed for other 'local scales' around the world. In the UK the British Geological Survey uses the Hutton and Boore (1987) distance correction factor when estimating $M_L$ for local UK earthquakes (Booth, 2007).

### Surface wave magnitude scale, $M_S$

The $M_S$ scale (Gutenberg, 1945a) use the amplitude of the surface seismic waves for earthquakes that are located between 2° and 160° epicentral distance from the recording station, with wave periods between 18 and 22 s and where the epicentre depth is less than 50 km. This scale will saturate at $M_S \geq 8$. A significant step in the development of the $M_S$ scale was the publication of what was termed the Moscow-Prague Formula (Karnik et al., 1962). For shallow earthquakes where surface waves are generated, the magnitude of the event can be derived thus:

$$M_S = Log\, \frac{A}{T} + 1.66\, Log\, \Delta + 3.3 \qquad (24)$$

Where:

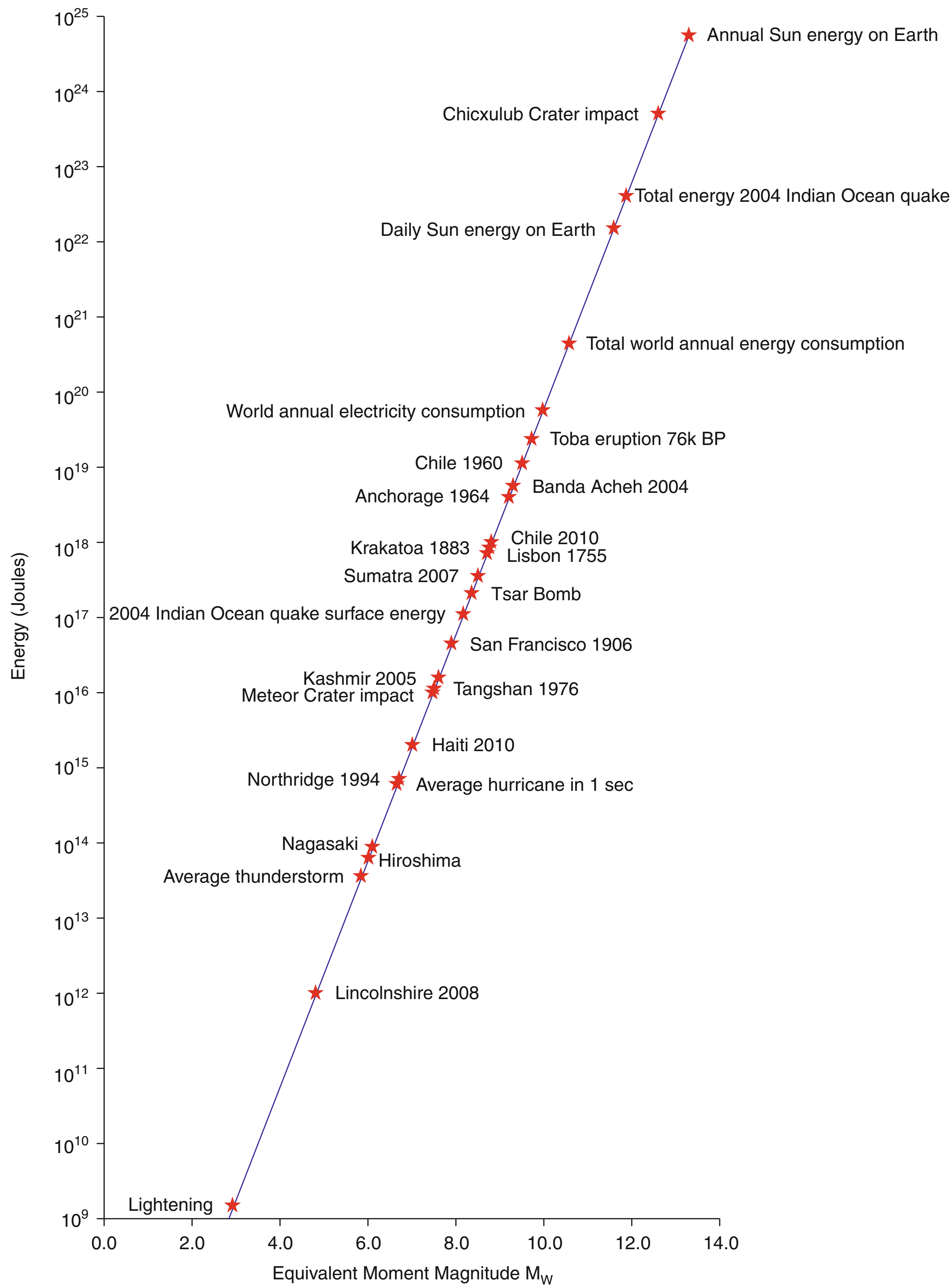
*A = Maximum amplitude of the Rayleigh Wave*

*Δ = Distance in degrees between 2° and 160°, h ≥* 50 km

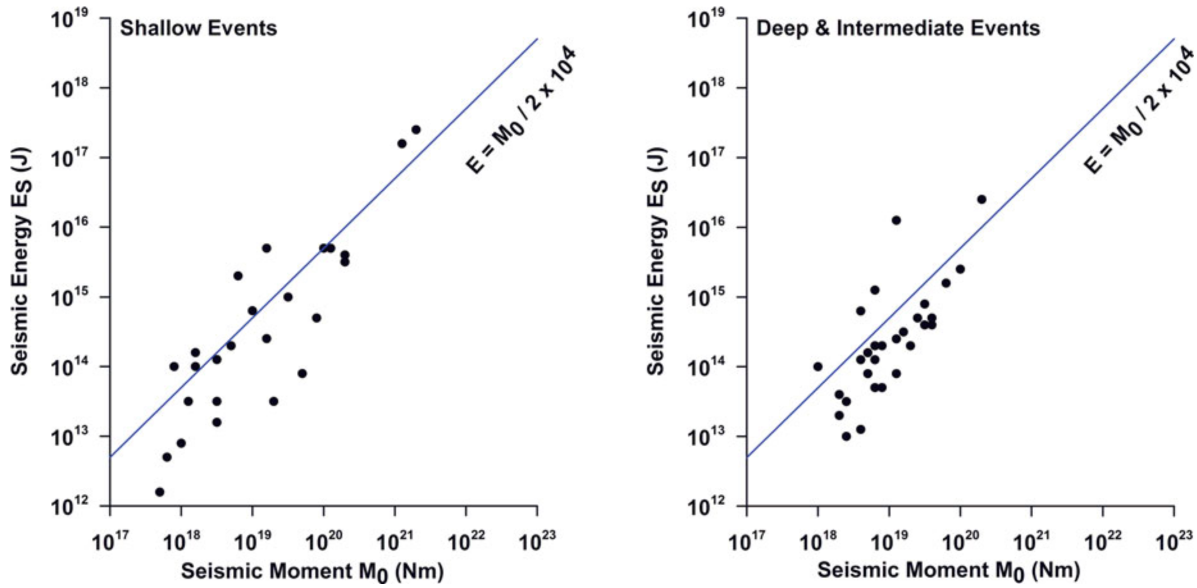
Alternatively $M_S$ can be calculated from the Rayleigh Waves with a period of 20 s, wave forms which often have the largest amplitude (Stein and Wysession, 2003):

$$M_S = Log\, A_{20} + 1.66\, Log\, \Delta + 2.0 \qquad (25)$$

The Surface Wave Scale has sometimes been referred to as the Rayleigh Wave Scale (Marshall and Basham, 1973).




**Magnitude Measures, Figure 2** A graph illustrating the equivalent Moment Magnitude $M_W$ with respect to energy released by earthquakes and other phenomena.




**Magnitude Measures, Figure 3** Relationship between seismic moment $M_0$ and energy $E_S$ for shallow events and intermediate to deep events according to Vassiliou and Kanamori (1982). The *solid line* indicates the relation $E_S = M_0//(2 \times 10^4)$ suggested by Kanamori (1977) on the basis of elastostatic considerations (Modified from Kanamori, 1983).

## Body wave magnitude scale, $m_B$ and $M_B$

In 1945 Gutenberg (1945b) utilised the seismic body waves to determine a Body Wave Magnitude which is used for earthquakes measured at distances greater than 600 km from the source:

$$M_B = Log\frac{A}{T} + F_{Old}\,(\Delta, h) + s + c \tag{26}$$

Where:

*A = maximum amplitude of the various body wave phases of the generated seismic waves*

$F_{Old}$ *= distance correction factor*

*s, c = s is the station correction and c is a correction only applied to large earthquakes* (*Abe*, 1981)

Gutenberg and Richter (1956, 2010) later revised the scale ($m_B$) by improving the distance function F and omitting the correction factor for large earthquakes:

$$m_B = Log\frac{A}{T} + F(\Delta, h) + s \tag{27}$$

In the $m_B$ scale magnitude values are compiled from the seismic wave period $\geq$0.1 and $\leq$3.0 s and where the epicentral distance is $\geq 5°$. This scale represents the size of an earthquake at its beginning. The usefulness of this scale for earthquakes with large fault dimensions and complex rupture mechanisms is limited (Kanamori, 1983). For relatively small events ($m_B \leq 5.5$) the scale is useful for the quantification of earthquakes at short wavelength periods.

## Energy magnitude scale, $M_e$

From a study of the energy radiated from a set of global shallow earthquakes Choy and Boatwright (1995) defined an Energy Magnitude, $M_e$:

$$Log\,E_S = 4.4 + 1.5\,M_e \tag{28}$$

Or

$$M_e = \frac{2}{3}Log\,E_S - 2.9 \tag{29}$$

Where:

$E_S$ *= Radiated energy* (N.m)

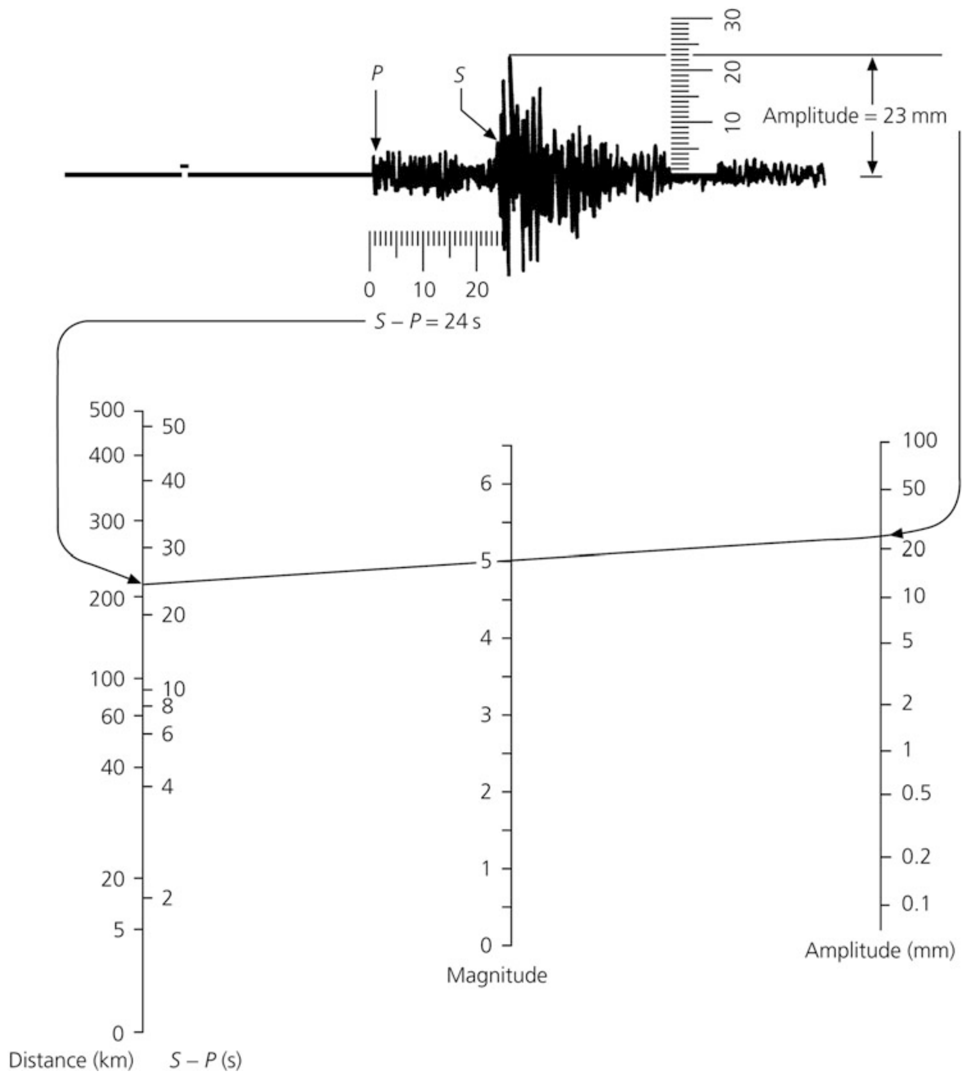
$M_e$ is explicitly derived from energy whereas in the Gutenberg – Richter energy relationship (Eqs. 2 and 3) energy is derived from magnitude (Choy et al., 2001). The energy magnitude is complimentary to Moment Magnitude for assessing seismic potential. The energy $E_s$ and Seismic Moment $M_0$ are related by the *apparent stress* if the increase in the Seismic Moment is a function of the dominant period of the data analysed but not the instrument or wave type (Boatwright and Choy, 1986):

$$\tau_a = \frac{\mu\,E_S}{M_0} \tag{30}$$

Where:

$\tau_a$ = *Average apparent stress*

$\mu$ = *Rigidity or shear modulus of the rock at the source (fault)depth*




**Magnitude Measures, Figure 4** The Richter local magnitude scale, $M_L$. The magnitude is found from the amplitude of the largest arrival and the S-P wave travel time difference (After Stein and Wysession, 2003; Bolt, 2006).

The apparent stress can also be a good indicator of the intensity of the seismic energy radiated relative to the size of the earthquake event as measured by the Seismic Moment. It is possible to estimate radiated energy from historical earthquakes. Choy and Boatwright (1995) demonstrated that in many seismic regions the average apparent stress $\tau_a$ can be regarded as the characteristic apparent stress field $\tau_c$ of the region such that:

$$M_e = \frac{2}{3}\left[Log\, M_0 + Log\, \frac{\tau_c}{\mu}\right] - 2.9 \qquad (31)$$

Where:

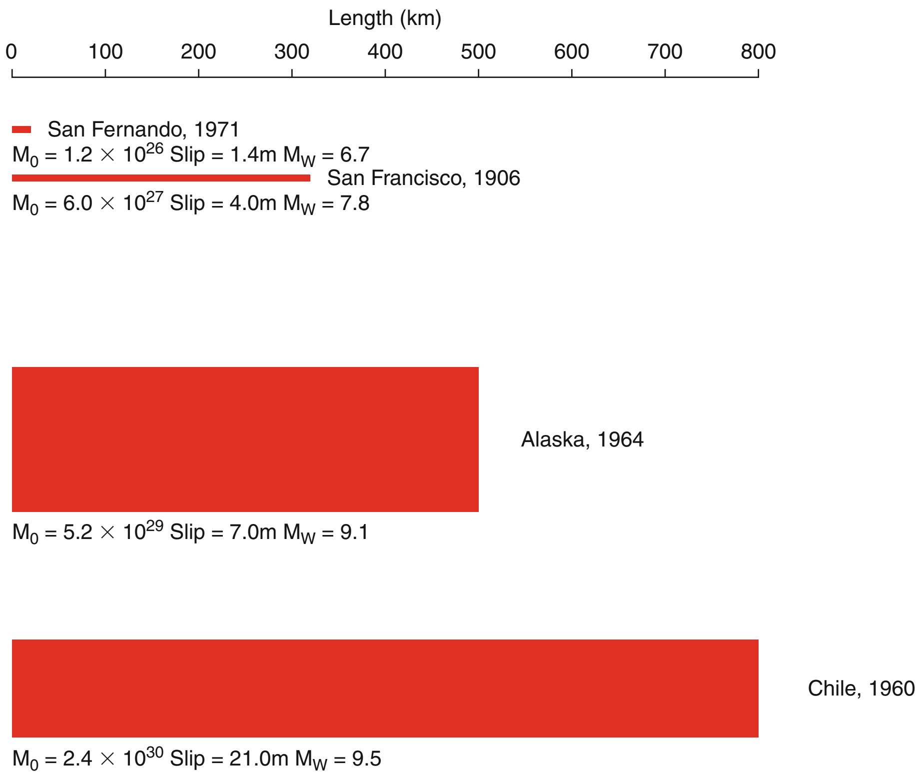
$\tau_c$ = *Characteristic apparent stress field*

This equation enables $M_e$ and $E_s$ to be estimated for an historical earthquake in a given tectonic setting and for a specific faulting type if the Seismic Moment is known (Choy et al., 2001).

## Duration magnitude scale, $M_D$

This estimate of earthquake magnitude is derived from the duration of earthquake shaking or what is termed the coda length. The coda is the tail of a seismic signal, usually with exponentially decaying amplitudes which follow a strong wave arrival. The formulas used to derive $M_D$ estimates vary for different geographical regions and for different seismographs. Duration Magnitude formulae have the following general form (Herrmann, 1975):

$$M_D = a_0 + a_1\, Log\, d + a_2\, \Delta \qquad (32)$$




**Magnitude Measures, Figure 5** Comparison of the magnitude of some significant earthquakes (After Stein and Wysession, 2003).

Where:

$d$ = *Event duration* (*seconds*)

$a_0, a_1, a_2$ = *Site specific coefficients*

Aki and Chouet (1975) demonstrated that for earthquakes at epicentral distances shorter than 100 km the total duration of a seismogram is almost independent of distance and azimuth. Thus quick magnitude estimates from local events are feasible without knowing the exact distance of the stations to the source with the removal of the distance term from the equation. For example the Northern California Seismic Network calculates $M_D$ thus (Lee et al., 1972):

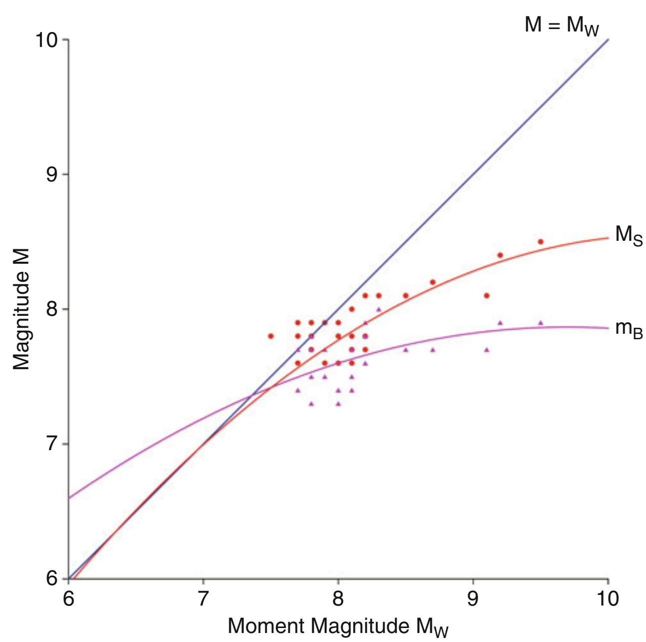
$$M_D = 2.00\,Log\,d + 0.0035\,\Delta - 0.87 \tag{33}$$

The scale can seriously underestimate magnitudes for events $M_L > 3.5$.

## Nuttli magnitude scale, $M_N$

The $M_N$ scale developed by Nuttli (1973) has been used in eastern North America and in particular Canada. The scale is based on the maximum amplitude of the Rayleigh surface waves for a frequency of 1 Hz:

$$M_N = Log\,\frac{A}{KT} + 1.66\,Log\,R - 0.1 \tag{34}$$




**Magnitude Measures, Figure 6** Relationship between magnitude scales illustrating saturation at higher magnitudes (Data from Abe and Kanamori, 1980; Kanamori, 1983).

**Magnitude Measures, Table 1** Summary of various magnitude measurement scales

| Symbol | Magnitude scale | Reference/source |
|---|---|---|
| $M_L$ | Local magnitude | Richter (1935) |
| $M_S$ | Surface wave magnitude | Gutenberg (1945a), Moscow-Prague formula (Karnik et al., 1962) |
| $M_B$ | Body wave magnitude | Gutenberg (1945b) and Gutenberg and Richter (1956, 2010) |
| $m_B$ | Body wave magnitude | Gutenberg and Richter (1956, 2010) |
| $M_D$ | Duration magnitude | Herrmann (1975) |
| $M_E$ | Energy magnitude | Choy and Boatwright (1995) and Aki and Chouet (1975) |
| $M_N$ | Nuttli magnitude | Nuttli (1973) |
| $M_{JMA}$ | Japan Meteorological Agency magnitude | Magnitude used by Japan Meteorological Agency |
| $M_W$ | Moment magnitude | Hanks and Kanamori (1979) |
| $M_{GR}$ | Gutenberg-Richter magnitude | Magnitude used in *Seismicity of the Earth*, Gutenberg and Richter (1954) |
| $M_R$ | Rothe magnitude | Magnitude used in *The Seismicity of the Earth, 1953–1965*, Rothe (1969) |
| $M_{S\ PDE}$ | Surface wave magnitude | Magnitude used in USGS preliminary determinations of epicentres catalogue |
| $M_{S\ ISC}$ | Surface wave magnitude | Magnitude used in International Seismological Centre catalogue |
| $m_{B\ PDE}$ | Body wave magnitude | Magnitude used in USGS preliminary determinations of epicentres catalogue |
| $m_{B\ ISC}$ | Body wave magnitude | Magnitude used in International Seismological Centre catalogue |
| $M_T$ | Tsunami magnitude | Abe (1989) |
| $M_K$ | Kawasumi's magnitude | Kawasumi (1951) |
| $M_U$ | Utsu magnitude | Magnitudes for earthquakes in Japan, 1885–1925, Utsu (1982) |
| $M_C$ | Large earthquake magnitude | Purcaru and Berckhemer (1978) |
| $M_N$ | Mantle wave magnitude | Brune and Engen (1969) |

Modified from Kanamori (1983) and Utsu (2002)

**Magnitude Measures, Table 2** Source parameters for some significant earthquakes

| Earthquake | Date | Body wave magnitude $m_B$ | Surface wave magnitude $M_S$ | Fault area Length × Width (km²) | Average dislocation (m) | Seismic moment $M_0$ (dyn.cm) | Moment magnitude $M_W$ |
|---|---|---|---|---|---|---|---|
| San Fernando | 1971 | 6.2 | 6.6 | 20 × 14 = 280 | 1.4 | $1.2 \times 10^{26}$ | 6.7 |
| Loma Prieta | 1989 | 6.2 | 7.1 | 40 × 15 = 600 | 1.7 | $3.0 \times 10^{26}$ | 6.9 |
| San Francisco | 1906 | | 8.2 | 320 × 15 = 4,800 | 4.0 | $6.0 \times 10^{27}$ | 7.8 |
| Alaska | 1964 | 6.2 | 8.4 | 500 × 300 = 150,000 | 7.0 | $5.2 \times 10^{29}$ | 9.1 |
| Chile | 1960 | | 8.3 | 800 × 200 = 160,000 | 21.0 | $2.4 \times 10^{30}$ | 9.5 |

After Stein and Wysession (2003)

Where:

*R = Epicentral distance*
*A = Wave amplitude*
*K = Amplitude of the seismogram*
*T = Natural period of the seismogram*

The Nuttli Magnitude Scale is used for epicentral distances >50 km and for instruments with a natural period smaller than 1.3 s. The scale has been used in preference to $M_W$ for small to moderate earthquakes as the Moment Magnitude Scale is more difficult to estimate these low magnitude events.

## Magnitude of Japanese earthquakes, $M_{JMA}$

The Japanese Meteorological Agency (JMA) has estimated the magnitude of shallow Japanese earthquakes utilising the following formula (Tsuboi, 1954):

$$M_{JMA} = Log\,(A_N^2 + A_E^2) + 1.73\,Log\,\Delta - 0.83$$

Where:

*AN, AE = Maximum ground amplitude measured on the N – S and E – W compoments of horizontal Wiechert seismographs in JMA recording stations.*

For deeper focus earthquakes in and around Japan Katsumata (2001) proposed a magnitude determination utilising regional velocity-amplitude data.

## Relationship between scales

The vast majority of magnitude scales in use today stem from the one introduced by Richter in 1935. This scale has been extended by many seismologists to apply to data produced by various observational environments (Utsu, 2002). As new scales were developed they were in principle to provide equal value estimates to the same earthquakes or to the same earthquakes which radiated equal amounts of energy. However, systematic bias exists in the newly created scales when compared to the original

Richter model. Studies have demonstrated that there are systematic differences between $M_L$, $M_S$ and $m_B$. A variety of scale interrelationship curves have been produced on order to compare and correlate various described and catalogued magnitudes. Utsu (2002) and Kanamori (1983) undertook a much more detailed analysis of various intra scale relationships (Figures 1–6, Tables 1, 2).

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http://www.isc.ac.uk/

## Cross-references

Accelerometer
Building Codes
Earthquake
Epicentre
Haiti Earthquake 2010 Psychosocial Impacts
Harmonic Tremor
Hypocentre
Indian Ocean Tsunami
Intensity Scales
Isoseismal
Mercalli, Giuseppe (1850–1914)
Primary Wave
Richter, Charles (1900–1985)
Secondary Wave (S Wave)
Seismograph/Seismometer
Seismology
Tangshan China (1976 Earthquake)
Tectonic Tremor
Tohoku, Japan, Earthquake, Tsunami and Fukushima Accident (2011)
Wenchuan, China (2008 Earthquake)

# MARGINALITY

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## Synonyms

Discrimination; Exclusion

## Definition

Marginality is a socio-spatial process of great importance in understanding and combating vulnerability to natural hazards. It severely limits the political voice and participation, economic and livelihood options, access to resources and information, as well as locational decisions of sub-groups within society. Caste, class, religious minority, and immigration status are often underlying causes of marginality.

## Discussion

Groups in society may live in places that are spatially peripheral to the majority or live in conditions that severely limit their participation in decisions that affect their lives as well as their access to resources and information. Such conditions are sometimes invisible to the majority. In a disaster, such groups often suffer greater death, injury, and economic loss (as a proportion of their already limited assets), and experience difficulty recovering. In 1978, Wisner used the term eco-demographic marginality to describe the situation of semi-pastoral people on the lower slopes of Mt. Kenya, who were politically powerless, lived in an environment undergoing degradation, and whose livelihoods depended on crops and animals of low and fluctuating value in the market. Blaikie and Brookfield (1987) adopted and subsequently expanded Wisner's notion of marginality.

Marginality is a concept with considerable utility in vulnerability assessment and planning for disaster risk reduction as well as recovery planning. Because it embraces numerous aspects of situations "on the edge," both professional planners and focus groups composed of lay people may use it to identify groups and situations that would normally not receive attention when policy, plans, and projects are focused on the needs and capabilities of the "average" person or household. Many methods such as wealth ranking exist that facilitate focus group discussion of marginality (ProVention, 2010), and this kind of situation-specificity is vital to effective project planning and programming (Wisner, 2004). It also provides understanding of what Chambers (1983) called the "deprivation trap," and thus may add a degree of reality to sometimes overly optimistic interventions that assume, for example, that everyone has time to volunteer in self-help activities or that every adult understands what it is to lobby government. Reasons for social marginality include caste, occupational, class status; religion and ethnicity; immigration status; disability; sexual orientation; and in some societies, gender and age. Political marginality may overlap with the social, but may also reflect favoritism practiced by ruling parties and historically developed center–periphery divisions of national territory. Economic marginality may be due to land and resource allocations and market dynamics that exclude or burden some, while benefiting others. However, as Perlman noted (1976), this does not imply that an economy is "dual" – a modern economy side by side with pre-modern. Indeed, in many places, marginal people are exploited for their cheap labor or commodities, and this is a reason why marginality persists and underlies much of what the United Nations (2009) has called "extensive risk" in the face of extreme natural events.

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## Cross-references

Crtical Incidence Stress Syndrome
Disaster Diplomacy
Disaster Relief
Disaster Risk Management
Disaster Risk Reduction (DRR)
Emergency Management
Emergency Planning
Exposure to Natural Hazards
Global Network of Civil Society Organizations for Disaster Reduction
Human Impact of Hazards
International Strategies for Disaster Reduction (IDNDR and ISDR)
Planning Measures and Political Aspects
Post-traumatic Stress Disorder (PTSD)
Psychological Impacts of Natural Disasters
Red Cross/Red Crescent, International Federation of
Risk
Sociology of Disasters
Susceptibility
Vulnerability

# MARINE HAZARDS

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## Synonyms

Offshore geohazards; Submarine hazards

## Definition

*Marine geohazard*. Geological site and soil conditions in the ocean bottom representing a potential source of harm.

## Introduction

Marine “geo*hazards*” (see entry *Geohazards*) are related to geological processes in the marine environment that have created regional or local site and soil conditions with a potential of developing into failure events that could cause loss of life or damage to health, environment, or assets. The failure events can be tectonic seabed displacements, seabed accelerations, and seabed instabilities ranging from local slumping to large-scale slope instability involving mass movement and debris flow and turbidity currents. Rapid, large-scale seabed displacements and downslope mass transport may generate tsunamis. Failure events where expulsion of gas, oil, water, and mud may flow uncontrolled from overpressured submarine reservoirs are often related to oil and gas production, but may also occur naturally through fractures and seeps to seabed and submarine mud volcanoes.

The event-triggering sources can be ongoing geological processes or human activities that change the seabed conditions or affects deeper strata mechanically or by pressure and temperature changes.

Marine hazards are of concern for the offshore petroleum industry with huge investments in wells, offshore structures, flowlines, and pipelines, but may also affect infrastructure related to telecommunications and electric energy transmission cables, the rapidly growing offshore wind power industry as well as fisheries. Also communities, industries, and infrastructure in the near-shore and shoreline area can be affected by submarine slide events reaching the shoreline, by earthquake or slide-generated tsunamis, and also by pollution from natural seeps and uncontrolled expulsion of oil.

## Geological processes

Consideration of large-scale geological processes like “*plate tectonics*” and long-term climate changes are important for evaluation of marine “*hazards*.” The major part of subduction zones where the oceanic crust is underthrusting continental plates is located in the oceans. This is where the most destructive earthquakes occur and the associated change in seabed level may generate tsunamis.

Long-term climate changes, especially during the last part of the Pleistocene, led to repeated “*sea level changes*” of more than 100 m. This affected the coastal zones and the continental shelves and margins on a global basis. Glacial erosion and transport of terrigenous sediments to the shelves and over the shelf edge by grounded glaciers to the continental slopes led to rapid progradation of the continental shelves along northern part of the Atlantic Ocean during glacial periods. The continental shelves and shallow water areas elsewhere were severely affected by changes in water depth and shoreline position, leading to wave, current, and river erosion and suspension of sediments. The finer fractions were transported seaward with tidal and wind-driven currents and the coarse grained sediments as hyperpycnal and turbid flows toward and locally over the shelf edge to the continental slopes.

Regional geological conditions and processes control the sedimentation rate, the thickness, and the type of marine sediments. The major river deltas of the world and the glacial fans on the margins along the North Atlantic and Arctic Seas are areas dominated by high sediment input that may lead to a combination of sloping seabed and overpressured sediments prone to slope instability and also representing a hazard for drilling operations for the petroleum industry. (In overpressured sediments, the ground water pressure is higher than hydrostatic pressures.)

Overpressures may also be generated by diagenetic changes of minerals under increased pressure and temperature transforming the mineral structure into a denser configuration under expulsion of excess water. Overpressured clayey sediments have generally lower strength, are less dense, and are more easily deformed than fully consolidated sediments.

## Earthquakes

Major "*earthquakes*" originating in the oceanic subduction zones may generate enormous tsunami catastrophes like the December 26, 2004, Sumatra event (see entry *Tsunami*) and the March 11, 2011, Tohoku events in the west cost of Japan.

For marine structures and installations, the "*earthquake*" generated ground accelerations may cause damage in the same way as for buildings and structures on land. Severe earthquakes may also trigger submarine slope failures as the sediment strength can be reduced due to cyclic stress variations during the earthquake shaking. In a worst-case scenario, the slide event may transform to a tsunami generating mass flow and cause damage to marine installations and infrastructure in the slide initiation area and in the pathway of mass flow.

Earthquake-induced fault displacements may deform and damage well casings, pipelines, cables, and structures located at or crossing the fault.

An induced earthquake is a term that is assigned to human-induced seismicity. In the marine environment, this is mainly connected to microseismicity caused by extraction of oil and gas leading to reservoir compaction, changes in the stress conditions in the reservoir and overburden sediments and along faults. With increasing reservoir compaction the likelihood of larger displacements and damage to well casings increase.

## Sediment strength and pore water pressure

### Slope stability

The stability of the seabed depends on the strength of the sediments relative to the destabilizing forces. In a slope the shear strength of the soil will have to exceed the downslope component of gravity to prevent slope failure. If other external forces (like inertia forces under earthquake loading) are acting, even higher strength will be required. Submarine slide events can be initiated either by increased downslope loading, steepening of the slope by top accumulation or toe erosion, and reduction of the shear strength of the sediments under monotonic or cyclic shear stress variations.

Soils most susceptible to large-scale instability are marine sediments with a loose mineral grain structure. These sediments are typically hemipelagic clays and sands deposited at high sedimentation rates causing overpressure generation, lower effective stresses, and thus lower strength. These soils are susceptible to increase in pore water pressure and reduced strength when subjected to rapid changes in shear stress. The combination of excess pore pressure from rapid sedimentation and pore water pressure increase during undrained shearing is the main factor in development of submarine slide events.

Enormous submarine slide area have been mapped on the continental slopes, especially in and near in the major river deltas, Nile, Niger, Amazon, etc. and glacial fans. The slope angle is typically very low, from less than 1° to a few degrees. The understanding of the geomechanical processes involved in the triggering and development of these slide events is a key element in evaluation of marine slide hazards.

Submarine landslides are generally much larger than onshore landslides (Brunetti et al., 2009). While the larger terrestrial landslides are found to fall in the range $10^6$–$10^7$ m$^3$, the larger submarine slide events are reported to have volumes of several 1,000 km$^3$. This is due to the long-term sedimentation under stable conditions not affected by yearly climate variations, but more dependent on the major sea level variations over 100,000 years.

The Storegga Slide is one of the largest submarine slide events worldwide. It is located at the mouth of the Norwegian trench next to and partly cutting into the North Sea Fan, a major glacial depocenter. The upper slide scar has a length of about 300 km, the downslope extension of the slide area is about 250 km, and the run-out distance of slide debris and turbidites is about 800 km. The estimated slide volume is in the range 3,000–3,500 km$^3$. The Storegga Slide was mapped and investigated in much detail as the Ormen Lange gas field was located in the slide scar (Solheim et al., 2005). The slide event took place about 8,200 calendar years before present and generated a major tsunami hitting the coastline of Norway, Scotland, the Faeroes, and Shetland (Bondevik et al., 2005).

The average slope angle from the toe area to the top of the upper slide scar is about 0.6°, and the slide event can be explained by existence of overpressures, a retrogressive slide process, and the sensitivity of the marine clays that formed the preferred slip planes (Kvalstad et al., 2005).

The long run-out distance of submarine landslides leads to extensive hazard zones in downslope direction and is a major source of concern for subsea installations, pipelines, and cables located below potential slide areas.

Retrogressive slide development is also observed, where the slide scar progressively moves upslope over distances of tens of kilometers.

### Mud diapirs and mud volcanoes

Overpressured soils will typically have lower strength than soils that are fully consolidated under the weight of the overburden sediments, i.e., hydrostatic pore pressure conditions. This may lead to development of deep-seated failure processes (*Deep-seated Gravitational Slope Deformation*) under the delta front where there is a decrease in overburden stress in seaward direction. This gradient in overburden stress leads to compression and formation of anticlines in the toe area of the delta and growth fault generation as the delta deposits are deformed and displaced seawards. With increasing compression, the anticlines may transform to diapirs that gradually penetrates the overburden sediments and reaches the seabed. The slopes of the diapir flanks can be high and cause slope instability.

Mud (clay) diapirs are observed in most of the major delta areas, but have also been generated in compression zones like the accretionary prisms forming in the major subduction zones and in tectonic compression zones between continental plates in the Caucasus-Caspian Sea area.

Mud diapirs may transform into "*mud volcanoes*" where overpressured water and gas transports fractures the sediment to seabed and transports sediments from deeper layers to the surface generating debris flows down the flanks of the volcano. Diapirs tend to form stratigraphic traps for oil and gas along the flanks and are thus attractive to the petroleum industry. The hazard related to slope failure and possible mud flows has to be considered when locating wells and field installations in this environment.

### Salt diapirs

Deformation of salt sheets by the weight of the overburden sediments, tectonic forces, and buoyancy effects (salt is lighter than the overburden sediments) may generate a very irregular seabed topography. The Sigsbee Escarpment in the Gulf of Mexico (GOM) is an example of the extreme morphology created by salt tectonics. The lower escarpment has a variable height, typically between 300 and 800 m with slopes typically between 8° and 25° with numerous slide scarps that locally can be even steeper. For the oil industry the irregular topography created by salt diapirs can be a serious hazard concerning slope instability, mass flow, and impact on installations (Jeanjean et al., 2003).

### Shallow gas and shallow water flow

Overpressured shallow formations represent a drilling hazard. In deep-water areas the problem is exaggerated as the window for mud weight between preventing collapse and generating fracture is narrower. If not properly evaluated and planned for in well design and drilling operations, overpressured sediments may lead to loss of fluid control followed by uncontrolled expulsion (blowout) of gas, water, and/or oil and in unconsolidated sands and uncontrolled sand production. This may lead to collapse of the reservoir and overburden sediment, cratering at the seabed, and collapse of wells and platform foundation. If gas is ignited at deck level, explosion damage and fire may totally damage the drilling platform/vessel and lead to fatalities.

### Gas hydrates

Changes in pressure and temperature may lead to dissociation of "*gas hydrates*." Methane gas hydrates may exist in the marine sediments in water depths exceeding 300–500 m dependent on the seawater temperature. The thickness of the stability zone depends on the pore water pressure and the geothermal gradient. Changes in sea level and sea water temperature caused by global "*climate change*" or locally around wells due to heat flow during oil and gas production may lead to dissociation (melting). The hydrate is transformed to water and free gas. This is associated with volume expansion and may lead to a certain weakening and fracturing of the sediments around hydrate inclusions and generate gas migration toward seabed. The process is generally slow as the melting process is endothermic and gas expansion will increase the gas/water pressure tending to stabilize the melting process. Climate-induced changes in hydrate stability have been indicated as a possible trigger mechanism for submarine slides (Kayen and Lee, 1992). Interpretation of stratigraphy and location of slip surfaces relative to the stability zone of hydrates show in many cases no connection between hydrate melting and observed slide activity. This applies to many of the largest submarine slide events, where slide initiation has occurred at large depths unaffected by climate-induced changes in hydrate stability (mass flows in the Amazon Fan, the Storegga Slide, and others). The knowledge of hydrate melting effects on sediment strength and gas migration is still rather limited.

## Identification and assessment of marine geohazards

Geohazard identification and assessment is based on interpretation of geophysical investigations of bathymetry and stratigraphy combined with geological and geotechnical boreholes with in situ testing, sampling, and laboratory testing. This allows characterization of the type and age of sediments as well as the material properties required for evaluation of the stability and run-out distance of potential slide events using analytical and numerical methods.

The likelihood of future events and size estimates are assessed using information of observed previous slide frequencies interpreted from seismic profiling, dating of post-slide sediments, and probabilistic slope stability analysis.

## Summary

Marine hazards are generally similar to natural hazards on land like earthquakes, slope failures and mass flows. One of the main differences is rooted in the marine depositional environment which allows similar conditions to develop over large areas over long time spans. This leads to submarine slide volumes that can be several orders of magnitude larger than events on land. Another difference is the sediment-water interaction vs. sediment-air interaction. This may increase the damage potential, especially with respect to tsunami generation by major earthquakes along the subduction zones and submarine slope failures generating mass flows.

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## Cross-references

Climate Change
Debris Flow
Earthquake
Erosion
Fault
Gas-Hydrates
Hazard
Induced Seismicity
Landslide (Mass Movement)
Mass Movement
Methane Release from Hydrate
Mud Volcano
Plate Tectonics
Pore-Water Pressure
Sea Level Change
Slope Stability
Subduction
Land Subsidence
Tsunami

# MASS MEDIA AND NATURAL DISASTERS

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## Introduction

Natural hazards become disasters only when they intersect human social and economic aspects (Quarantelli, 1998). Indeed the effects are exacerbated when the hazard exposes the social vulnerability of an affected community and its inability to recover without assistance (Etkin and Dore, 2003). When disasters occur, the resultant impacts are not solely limited to the geographical boundaries of the event. Today it is common for media reports and graphic images to radiate into communities and households across the globe (Bankoff, 2001). Since the 1960s, global exposure to hazards has escalated because of this enhanced media coverage and because the average number of natural disasters reported worldwide has almost doubled every decade (Pelling, 2003). Media reporting now provides an almost live experience of natural disasters that may be occurring on the other side of the world, a situation in which such a broad audience would have little or no chance of actually experiencing (CNN effect). As a consequence such imagery presented in media broadcasts may considerably affect one's social perception of environment. Such information is readily available through technological advances, globalization, the Internet, and growing number of media outlets which have access to satellite technology.

## Role of media

Among media functions played in modern society as defined by McQuail (1994), two are worth mentioning with regard to natural disasters. Most broadcasts related to hazards strongly approach the issue according to media coverage analysis. However, when the physical distance between location of the natural disaster and the location of the broadcast recipient is significant, the news itself acquires entertainment characteristics owing to the absence of reality.

Natural disasters are "attractive" as news items to media outlets since such events are easy to judge in terms of newsworthiness. The reason for this is that both reporters and editors employ professional news values in selecting and writing their news stories about topical issues. Research indicates that those newsworthy values include timeliness, conflict, prominence, significance, and human interest (Gant and Dimmick, 2000).

Not only do news reports provide audience with information about disasters, but also secondary productions from such events are meant to entertain (films, talk shows, etc.).

When considering the role of the media, it is important to recognize that the media is not just a conduit for information transfer, but it is also an "actor" and as such it is plagued with its own biases and agendas (Boykoff and Boykoff, 2004). Different communication formats, such as print media (e.g., newspaper broadsheet, tabloid, magazines, online sources) and audio/visual media (e.g., television broadcast, radio, video clips available online), play different roles in shaping social discourse. From a social impact perspective, advances in communication technology have permitted time and space to be compressed, thereby restructuring patterns of social interdependence and everyday "reality" (Thompson, 1999).

Print is constrained by space, whereas televised video is constrained by time. But due to the flexibility in their format, the space constraints of the print media are less problematic than the time constraints of televised media. Televised stories communicate less information and have a high emotional impact compared to the more detailed coverage of print stories that require greater mental effort to decode (Wanta, 1997).

International media coverage of environmental change and natural hazards plays an important role in setting and reinforcing public perceptions of issues and the social construction of events (Carvalho and Burgess, 2005; Boykoff, 2007). The news media are among the most important sources of information regarding natural hazards and other extreme events (McQuail, 1994), thereby significantly influencing how society and governments perceive and respond to hazards and disasters.

Consequently, the results of media coverage quality and quantity analysis are relevant and provide characteristics of disaster-related stories. According to them, such stories are rather poor quality scientific news as journalists have no background in science and spend little, if any, time reviewing technical documents related to natural hazards issues. Indeed they often prefer to quote a key, institutional (mainly not academic) informant. Media outlets rarely have specialists on staff for reporting general science and natural hazard-related stories (Pasquare and Pozzetti, 2007).

## Social perspective

During the process of characterizing the impact of media coverage, researchers have developed a number of theories, the most popular entitled the hypodermic model. Agenda setting theory states that the media do not directly influence what the public think, but rather the media are successful in making issues salient or significant to the wider public. Social constructionists have the perspective that suggests while the mass media plays a strong role in presenting what constitutes “news” to the public, the audience “readers” undergo a complex process of reception and consumption that minimizes the media’s potential impact on influencing public opinion (Pidgeon et al., 2003).

The real effect of media reporting appears to depend on numerous factors, among which the most important are: the nature of the recipient’s media environment, the role played by media in their daily life, the level of information acquisition, and finally the subject matter of communicated information.

Drawing on the social constructionist perspective, researchers have argued that the definition and meaning attached to risks by society are fundamentally socially constructed. Social problems are defined by four groups of claims makers: community activists, the news media, corporate interests, and government officials (Anderson, 1997; Robinson, 2002).

In contrast, the limited media influence theory proposes that people in contemporary society are psychologically diverse because of the various experiences which form their personality. People belong to different social categories based on factors such as income, age, sex, etc. These categories are described by similar subcultures, beliefs, attitudes, and values. People in modern society are not isolated but rather united by social relation bonds based on family, neighborhood, and work.

On the other hand, individual differences, societal subcultures, and patterns of social relations induce people to choose, take advantage of, and interpret varied broadcasts in a highly selective way. Thus, as reception of media coverage is extremely selective and content interpretation miscellaneous, specific broadcasts have only limited influence on recipients (DeFleur and Dennis, 1996).

## Summary

Direct media impact cannot be determined especially in the case of natural disasters. Personal experience and environment perception are essential to the human perception of reasons, frequency, and consequences of such events. Media broadcasts manage to reach a geographically varied audience. Finally, every news “reader” individually applies specific social and environmental filters against the communicated information.

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## Cross-references

Climate Change
Disaster
Internet, World Wide Web and Natural Hazards
Perception of Natural Hazards and Disasters
Risk Perception and Communication

# MASS MOVEMENT

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## Synonyms

Landslides; Mass wasting; Slope failures

## Definition

*Mass movement.* A variety of processes that result in the downward and outward movement of slope-forming materials composed of natural rocks, soil, artificial fill, or combinations of these materials.

## Introduction and significance of mass movements

Mass movements are important natural geomorphic agents that shape mountain landforms and redistribute sediment and debris to gentler terrain and water bodies. The earth mass may move in a number of ways: falling, toppling, sliding, spreading, flowing, or by their combinations. Gravity is always the primary driving mechanism, but it may be supplemented by water. Much of the Earth's landscape has been extensively modified by large-scale mass movements, but smaller mass movements have also exerted more chronic sculpting of mountainous terrain. Anthropogenic activities such as forest conversion, road and trail construction, prescribed fire, timber harvesting, residential development, grazing, mining, and mountain recreational uses have all exacerbated natural levels of mass movements, particularly those occurring in soil materials.

Most parts of the world have experienced some mass movements, although mountainous landscapes in regions of either significant tectonic activity or high rainfall are most susceptible. In particular, the circum-Pacific region is susceptible to mass movement because of the combined effects of high and intense rainfall, steep terrain, abundant earthquakes, volcanism, geological history, soil properties, and surface bedrock conditions (Sidle and Ochiai, 2006). The recent history of land cover change, proliferation of mountain road and trail systems, and concentration of people in high-hazard areas has also exacerbated soil mass movement in this region as well as increased risk of damage to property and loss of life. At particular risk today are developing nations in Southeast and East Asia, Latin America, and Africa, where montane forests are rapidly being converted to agricultural production, exotic plantations, residential development, recreation use, and pasture. Japan likely has the best documentation of historic mass movements; China, India, Pakistan, Bhutan, and Nepal have long, but incomplete histories of mass movement occurrence and damage. These East Asian regions are particularly susceptible because of prior and contemporary glaciation, tectonic uplift, frequent earthquakes, large storms, and episodic snowmelt (Sidle and Ochiai, 2006). Of the estimated 2,378 deaths attributed to mass movements worldwide from 1971 to 1974 (about 600 per year), 89% of these occurred in the circum-Pacific region.

## Trigger mechanisms

Mass movements are triggered by a number of mechanisms, the most common of which is rainfall whereby a positive pore-water pressure develops in the regolith causing a loss in shear strength and subsequent failure. In some cases, these inputs of water sufficiently decrease shear strength by reducing soil suction and increasing the slope-parallel component leading to destabilization of slopes. Large earthquakes tend to trigger more catastrophic but lesser numbers of mass soil movements compared to rainfall mechanisms due to the localized combined effects of ground shaking and acceleration, as well as dynamic pore-water-pressure response. Ground shaking and freeze-thaw action are important initiation mechanisms for mass movements in rock materials. Given the difficulties in predicting earthquakes in real time, large mass movements triggered during seismic activity are typically unexpected and have caused some of the greatest loss of life of any such disasters. Other mass movement triggering mechanisms include snowmelt, rain-on-snow, volcanic activity and collapse, undercutting of slopes by running water or waves, glacial retreat, permafrost degradation, wildfire, and stress caused by windthrow of trees.

## Types of mass movements

The term "mass movement" covers the full range of these gravitational slope-forming processes, including debris slides, debris avalanches, debris flows, rotational slumps, earthflows, soil creep, lateral spreads, solifluction, block glides, rockfalls, rockslides, volcanic collapses, lahars, dry ravel, dry creep, and rock creep. As such, the more generic term "landslides" is a subset of mass movements, because technically landslides would not include surface processes (e.g., dry ravel, dry creep) or slow plastic deformations without a specific failure plane (e.g., soil creep, rock creep). Varnes (1978) developed a widely used classification system for landslides that incorporates the type of movement (falls, topples, rotational slides, translational slides, lateral spreads, flows, and complex slope movements) together with the type of material (bedrock or engineering soils). This classification is further subdivided based on the speed of movement and has later been modified using an elaborate set of descriptors (Cruden and Varnes, 1996). As such, the Varnes classification system has been widely used by geotechnical specialists, but has not proven as useful for land managers and planners dealing with practical mass movement problems. To facilitate this technology transfer need, Sidle and Ochiai (2006) proposed a simplified categorization of mass movements that includes the role of climate (the dominant trigger mechanism), incorporates surface mass wasting and plastic deformations, recognizes the importance of combination mass movements, and follows the terminology employed by Varnes (1978) as much as possible. The five functional categories described by Sidle and Ochiai (2006) include the following: (1) shallow, rapid landslides; (2) rapid, deep slides and flows; (3) slower, deep-seated landslides; (4) slow flows and deformations; and (5) surficial mass wasting. These broad categories of mass movement tend to be associated with different climatic and precipitation patterns and certain types of damages. An important practical component of this categorization is the linkage of different land use effects with various types of mass movements. This categorization did not initially include failures in rock materials, but can easily be adapted to include these as illustrated in the examples that follow.

## Shallow, rapid mass movements

Shallow, rapid mass movements include debris slides, debris avalanches, debris flows, and shallow rockslides and falls. These mass wasting processes typically occur on relatively steep slopes ($>25°$ slope gradient) with the failure plane generally located $<2$ m below the surface and oriented approximately parallel to the land surface. As such, the volume of these failures is usually small unless they extend long distances downslope and/or progress into larger debris flows in stream channels. The length-to-depth ratios are $<0.1$. Most of these mass soil movements are triggered by individual rain storms, usually a large amount of total rainfall with a period of higher intensity (Sidle and Ochiai, 2006). Additionally, these failures can initiate during snowmelt and seismic activity. Shallow, rapid failures in soil material usually involve a hydrologic discontinuity between the underlying low-permeability substrate (e.g., bedrock, till) and the more permeable soil, which facilitates the development of high pore-water pressures during rainstorms or snowmelt that triggers the mass movement. Soils typically have low cohesion with much of the shear strength being contributed by internal angle of friction and rooting strength of vegetation. These translational soil mass movements often initiate as relatively slower moving debris slides ($<1$ m year$^{-1}$ to 0.3 m min$^{-1}$); as they progress downslope and water is incorporated they may transform into more rapid debris avalanches (0.3 m min$^{-1}$ to $>0.3$ m s$^{-1}$) and with further liquefaction that may occur in steep headwater channels they may become very rapid debris flows ($>3$ m s$^{-1}$). Given their shallow depth, these mass movements are highly affected by land cover change and can increase when woody root reinforcement declines following forest conversion, timber harvesting, fire, or disease. Shallow rockslides and falls are more related to fractures, jointing, and bedding discontinuities as these rupture surfaces often provide the weak links in an otherwise stronger rock matrix. In some weaker or highly weathered rocks, the strength of the rock matrix is the limiting feature where failure occurs. Bedding planes dipping nearly parallel to the slope and closely spaced vertical joints are particularly susceptible scenarios for rockslides and rockfalls, respectively. Characteristics of rock "fractures" that predispose slopes to rockfall and slides include smooth fracture surfaces which have a low frictional component and infilling by weaker (particularly clay-rich) material. Strength of the rock mass itself is also important, especially as it relates to weathering processes. The initiation of rockfalls and rockslides is often more complex than shallow, rapid soil mass movements and may involve earthquakes or ground shaking, pore-water pressure, freeze-thaw action, and root wedging. Cutting into steep slopes for mountain road and railway construction as well as residential development can promote the initiation of rockfall and rockslides.

## Rapid, deep-seated slides and flows

Rapid, deep slides and flows are similar to shallow, rapid mass movements except for their deeper failure plane (usually $>5$ m deep), which is often found in weathered or fractured bedrock. These consist of debris slides and avalanches, debris flows, bedrock slides, large rockfalls, and certain block glides and rapid earthflows. These mass movements typically occur after an extended rainy period (or snowmelt) followed by a large-to-moderate-sized storm. However, if interconnected preferential flow paths exist in the soil and weathered bedrock that facilitate the rapid routing of water to a failure plane, these failures may occur during an isolated rain event with a period of very high intensity (Sidle and Ochiai, 2006). The regolith material is not usually clay-rich as in slow, deep-seated mass movements. In some cases, liquefaction occurs along the sliding surface in saturated cohesionless materials just after the initial failure as a result of excess pore-water-pressure generation. Such liquefaction may lead to long-runout debris flows. In addition to rainfall and snowmelt, seismic activity can be an important trigger mechanism, particularly for bedrock slides and large rockfalls. During strong ground motion, pore-water pressures increase and the regolith may mobilize. Such large, rapid mass movements are common during major earthquakes in unstable terrain. While less common, collapses along flanks of volcanoes can be spectacular and very damaging types of rapid, deep-seated mass movements. Movement rates of rapid, deep-seated mass movements are similar to or even greater than those of shallow, rapid mass movements. Due to size and unexpected nature of occurrence of these deep, rapid earthquake-triggered failures, they can cause considerable damage, albeit much less frequent than shallow, rapid landslides. Rapid, deep slides and flows differ from shallow, rapid mass movements in that the former are less sensitive to widespread land cover change. The mechanisms of deeper-seated rockfalls and rockslides are the same as that for shallower rock failures. These mass movements can encompass entire mountainsides and have generated some of the greatest disasters related to any mass movement type.

## Slower, deep-seated landslides

Slower, deep-seated landslides generally move at rates $<1\ \mathrm{m\,day^{-1}}$ and include rotational slumps, earthflows, and lateral spreads. These mass movements all have a defined failure surface, which differentiates them from slow flows and deformations. They are generally larger than shallow, rapid mass movements and tend to move in response to multi-day or multi-week inputs of rainwater or snowmelt. Typically, once a critical threshold of groundwater accretes, movement commences with rates of movement increasing proportionally to the subsequent increases in groundwater within the failure zone. Complex preferential flow networks often develop in and around these mass movements due to the formation of tension cracks, differential movement in blocks of the failure, and internally drained features (e.g., sag ponds). These preferential flow paths can deliver substantial quantities of subsurface water to failure planes when fully connected causing surges in slumps and earthflows. In contrast, during drier periods essentially no movement may occur for months or even years. Soils and regoliths tend to be clay-rich and highly altered or weathered and exhibit plastic behavior over a wide range of water contents. Although slow, deep-seated mass movements occur throughout wide range of slope gradients, they commonly initiate on much gentler slopes ($4°–25°$) than shallow, rapid landslides (Sidle and Ochiai, 2006). Rotational slumps and earthflows often occur in combination; the initial movement typically occurs as a rotational failure, and the subsequent downslope movement of remolded material proceeds as an earthflow. Earthflows can be distinguished by a lobate shape near their terminus. Lateral flows and spreads occur in sensitive sand, silt, and clay materials, typically with gentle slope gradients. Lateral flows involve the lateral displacement of large masses of cohesive rock or soil that overlays a deformed or deforming mass of softer material (Cruden and Varnes, 1996). Initiation of lateral spreads is often due to ground shaking but can also occur when high pore-water pressure develops in the regolith during extended rainfall or snowmelt. Thereafter, liquefaction rapidly occurs at the sliding surface causing the overlying regolith to break up and spread. The rate of spreading can range from slow to quite rapid in spite of the low gradient; the largest, most rapid, and most destructive lateral spreads are triggered by large earthquakes. The general category of slow, deep-seated mass movements is not particularly susceptible to land cover change unless water is rerouted into the failure zone. These mass movements can be quite destructive, but typically do not cause fatalities due to their generally slower rate of movement; lateral spreads can be an exception.

## Slow flows and deformations

Slow flows and deformations involve the plastic deformation of soil and rock material with rates of movement generally in the range of millimeters per year (Sidle and Ochiai, 2006). Unlike slower, deep-seated landslides, these mass movements do not have a specific failure plane. This mass movement category includes the very widespread process of soil creep, rock creep, and the less important process of solifluction. Soil creep is found on most hillslopes, and while it is influenced by slope steepness and clay content, it can occur across the full range of slope gradients and has been associated with many soil textures. The most active soil creep typically occurs in landscapes where slump-earthflow processes are prevalent. Such landforms are often hummocky, and evidence of soil creep is manifested in such features as curved trees, immature fluvial drainage systems, tilted fence lines, and tension cracks in the soil. While movement can occur in both shallow and deep regoliths, rates of creep are generally more rapid near the surface. Soil creep responds to long-term inputs of water rather than individual storm events. While soil creep can be damaging to foundations or along road cuts, more devastating consequences relate to the linkage of soil creep with larger-scale landslide processes. Soil creep can cause strain softening of clay-rich regoliths and subsurface erosion in less clayey deposits leading to the initiation of deep-seated landslides. Shallow soil creep is one of the primary infilling mechanisms of geomorphic hollows following shallow mass movement. Once these sites are recharged, another landslide may occur. Rock creep is the gravitational deformation of a rock mass that proceeds gradually but continuously downslope, sometimes concentrating at a specific depth but during other times spreading over various depths beneath a slope. The disturbed rock mass causes various features such as non-tectonic folds, faults, and other types of fractures, thus degrading the rock mass to rock debris and increasing the likelihood of catastrophic slope failure (Chigira, 2002). Such gravitationally unstable conditions can be induced by tectonic uplift, glacial erosion and retreat, and coastal or fluvial undercutting of slopes. Solifluction is a specialized type of very shallow earthflow found in periglacial environments that are typically underlain by permafrost; slope gradients range from as gentle as $2°–36°$. This slow ($\leq 1\ \mathrm{m\,year^{-1}}$) mass movement type results from freeze-thaw action in fine-textured soils with most of the movement concentrated in the upper meter of the soil profile. Although confined mostly to arctic and subarctic regions, recent concerns over the effects of global warming have renewed interest in solifluction processes.

### Surficial mass movements

Even though dry ravel and dry creep are surface processes, they are considered mass movements because they are driven by gravity. These surficial mass movements involve the rolling, sliding, and bounding of surface soil grains, aggregates, and coarse fragments down steep hillsides, often forming talus cones at slope breaks (Sidle and Ochiai, 2006). Dry ravel and creep mainly initiate during active freeze-thaw periods and wetting-drying cycles. During such natural perturbations a loss of interlocking frictional resistance among soil aggregates or grains occurs loosening the material and subjecting it to downslope gravitational transport. While dry ravel and dry creep typically transport much less sediment to streams compared to other mass movements in steep terrain, they can be significant surficial processes on steep slopes with sparse vegetation covers, thin organic horizons, and/or soils that have been disturbed (particularly by fire). Under such conditions, slope gradients that approach or exceed the internal angle of friction of surface materials (≈38°–41°) typically experience active dry ravel and creep; on gentler slopes, ravel rates diminish substantially. The impacts of these surficial mass movements are generally restricted to maintenance requirements along road cuts, but in cases of extreme and widespread fire they can contribute significant sediment pulses to streams. Additionally, dry ravel is often an important infilling process after evacuation of geomorphic hollows by shallow landslides.

## Summary

Mass movements are largely episodic processes driven by gravity that can severely impact people, property, and the environment depending on their location, size, and rate of movement. These are largely triggered by rainfall, but devastating mass movements are sometimes caused by earthquakes and volcanic activity. Certain mass movement processes like soil creep can exacerbate other processes like large-scale landslides, and combination mass movements (e.g., debris slides-avalanches-flows) are common occurrences. Land use practices can exacerbate particularly shallower mass movements, with road and other excavations into hillsides being particularly problematic.

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## Cross-references

Casualties Following Natural Hazards
Collapsing Soil Hazards
Creep
Debris Avalanche (Sturzstrom)
Debris Flow
Deep-Seated Gravitational Slope Deformations
Geohazards
Lahar
Land Use, Urbanization and Natural Hazards
Landslide Impacts
Landslide (Mass Movement)
Landslide Inventory
Landslide Types
Lateral Spreading
Liquefaction
Mudflow
Pore-Water Pressure
Quick Clay
Rock Avalanche (Sturzstrom)
Rockfall
Slide and Slump
Slope Stability

# MEGACITIES AND NATURAL HAZARDS

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## Synonyms

Megalopolis; Megapolis

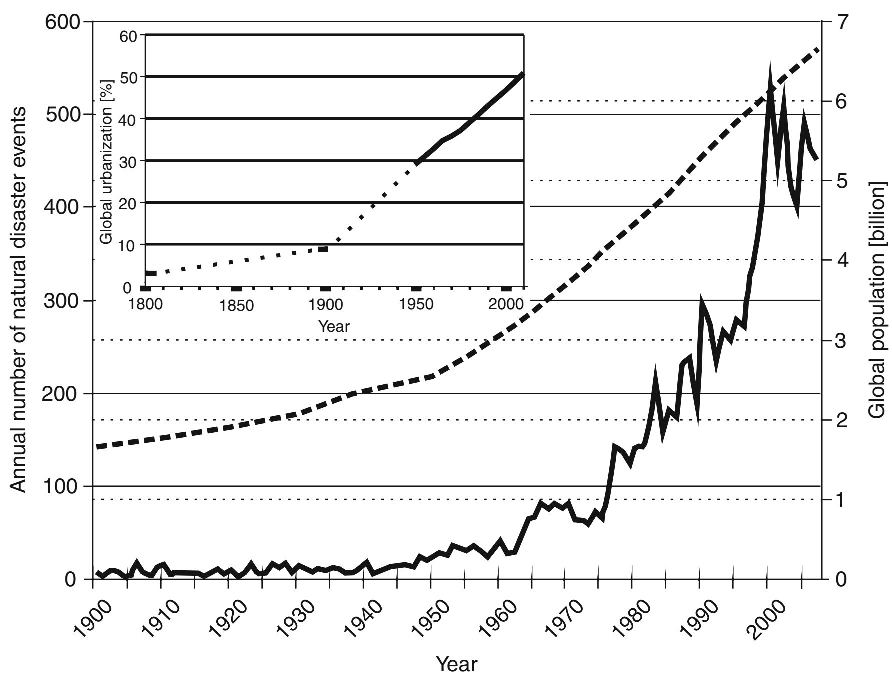
## Definition

Megacities are typically defined as metropolitan areas with more than ten million inhabitants, which show high growth dynamics and a high speed of change and development. While not necessarily facing substantially different or more severe hazards than other settlement types, their high concentration of administrative and economic functions can lead to risk that extends to the national level. However, megacities also have the best resource base to mitigate risk, and prepare for and recover from disaster events.

## Introduction

The global population has been growing continuously since about the fourteenth century (Raleigh, 1999), though by no means evenly. An abrupt increase in what had been a relatively low and steady growth rate only began toward the middle of the twentieth century, reaching a brief peak increase of some 2.2% in the early 1960s. While it had taken some 160 years for the population to grow from one to three billion (by 1960), this doubled over the next 40 years. Today, the number stands at 7 billion, and is projected to grow to 9.1 billion by 2050. This rapid increase coincided with a second trend – people moving into cities. While in 1800 about 3% of the global population was urbanized, a strong acceleration began by the beginning of the twentieth century (ca. 9%), reaching 50% by 2008 (United Nations Population Division (UNPD), 2006). Within this broad urbanization process, a number of individual cities grew disproportionally. In 1900, only 15 cities had more than one million inhabitants, three of them (London, Paris, New York) above three million (Wenzel et al., 2007). Today, more than 300 cities house in excess of one million people. Adjusting for the trend, we now define megacities as agglomerations of more than ten million people (Thouret, 1999), though at times a threshold of eight million is used (Wenzel et al., 2007). By the year 2000, already 19 cities with populations of more than ten million existed. Only 5 years later already 25 such cities were identified (Brinkhoff, 2010), with greater Tokyo (approximately 34 million people in 2010) being the largest.

The global population and urbanization growth rates over the last century (Grimm et al., 2008) also show similarities with an increasing number of disasters associated with natural hazards (e.g., Guha-Sapir et al., 2004; Figure 1) that are marked by an even more pronounced increase since about the 1960s. This suggests a relationship between population growth and urbanization with disaster incidence and damage. Considered in general terms, the coincidence is readily explained by disaster risk theory – more elements at risk (people, infrastructure, assets), exposed to (even unchanging) hazards, will likely lead to more frequent damaging events and higher losses. At a detailed level, the picture is more complicated, as specific hazard exposures and vulnerabilities have to be considered (e.g., Kerle and Alkema, 2012; see entry *Risk*). In this entry, the particular relationship between natural hazards and disasters and megacities is described, considering the role of actual hazard exposure, vulnerability, and resilience and capacity, also in light of global climate change. It particularly highlights that the absolute number of inhabitants is less relevant; instead, the functional value, as well as the political, administrative, and economic importance of megacities in their respective countries now define megacities and strongly influence the hazard risk.




**Megacities and Natural Hazards, Figure 1** Number of annual natural disasters between 1900 and 2007 in bold (primary axis, CRED 2009), and global population for the same period in hatched line (secondary axis). Inset shows estimated global urbanization rates between 1800 and today (United Nations Population Division (UNPD) 2006).

## Hazard exposure of megacities

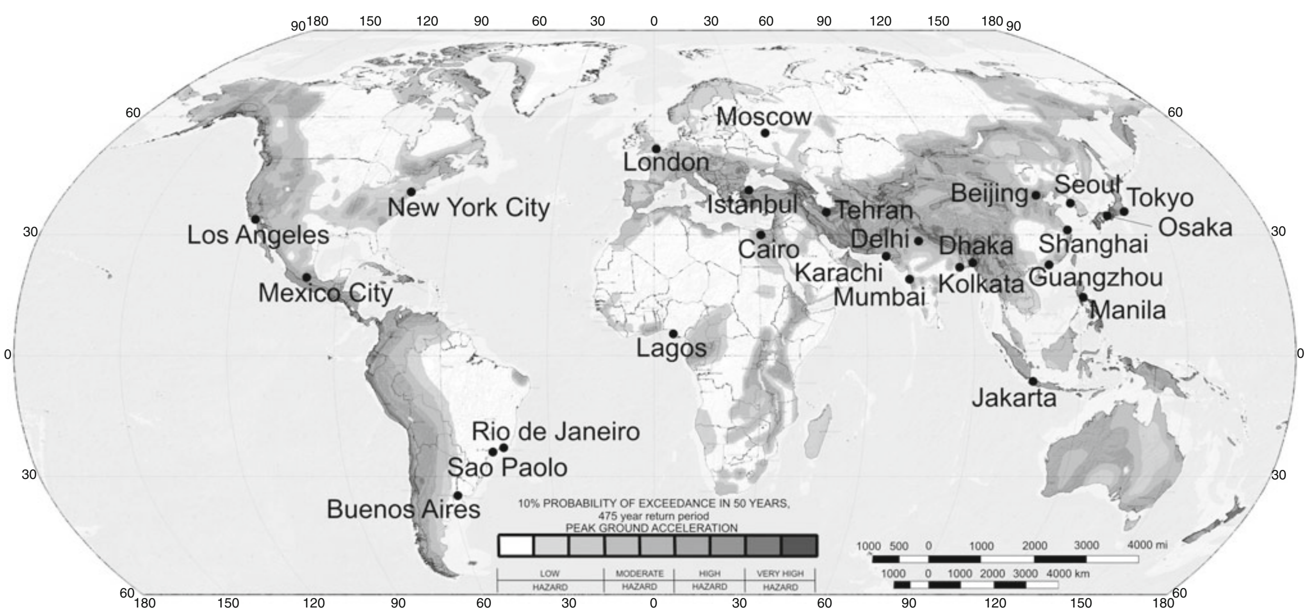
Of the 25 currently existing megacities, only six are not located in economically less developed countries (LDC). About half are exposed to substantial seismic hazard (Jackson, 2006), and all except six are situated in coastal areas (Figure 2). Those hazardous locations, however, they share with many smaller population centers. Megacities tend to occupy large areas (e.g., the Los Angeles metropolitan area covers more than 12,500 km$^2$). As such, given a comparable hazard setting, they are statistically more likely to get affected by an event than smaller cities or even rural communities. At the same time, a given event will likely affect a smaller fraction of a megacity area than it would in smaller cities or communities (Cross, 2001). Thus, in terms of direct exposure to environmental hazards, megacities do not show characteristics that significantly differ from smaller settlement types.

Disaster damage and the number of people killed or affected have been increasing in recent decades. Disaster statistics show that events affecting megacities have led to the highest monetary damages, such as the 1995 Kobe earthquake (part of greater Osaka; losses of > US$130 billion), reflecting the high accumulation of wealth. While some of these events have also killed many people (more than 6,000 during the Kobe earthquake), disasters outside megacities have been more devastating. The 1965–1967 drought in India caused some 1.5 million fatalities, whereas in 1970, a cyclone inundating coastal areas of Bangladesh killed an estimated 500,000 people. Disaster numbers, however, are strongly dependent on the specific location and extent of a disaster, and include an element of chance. With the exception of the 1923 Tokyo, 1976 Tangshan, and 1980 Mexico City earthquakes, major urban agglomerations have so far been spared by seismic events with a magnitude >7.5. However, an eventual direct hit of a megacity is seen as inevitable (Jackson, 2006), and capable of causing more than one million fatalities (Bilham, 2009). Whether a direct tsunami hit on a coastal megacity will lead to high fatality numbers or mostly infrastructure damage largely depends on the warning time. For tropical cyclones and impending volcanic eruptions, the other environmental hazards with destructive potential in megacities, the time to prepare is usually sufficient.

Damage is more usefully considered in relative rather than absolute terms. While perhaps causing less absolute physical damage in rural areas, the destroyed assets nevertheless often constitute a significant share of all possessions, especially in LDCs. Thus, in terms of economic consequence, less costly disasters outside megacities frequently have more severe and lasting effects than in large urban agglomerations that have broader means for rapid recovery.

## The effect of megacities on hazard exposure

In addition to megacities encroaching on hazardous terrain, a range of environmental changes has been documented. Ongoing and projected climate changes strongly affect various aspects of the environmental system, with consequences for hazards levels. They relate in particular to hydrometeorological hazards, such as stronger windstorms, flooding, and general precipitation




**Megacities and Natural Hazards, Figure 2** Global seismic hazard map, adapted from Global Seismic Hazard Assessment Program (GSHAP), and current megacities. About half of those are exposed to substantial seismic hazard (Jackson, 2006), and all except Sao Paulo, Mexico City, Delhi, Beijing, Moscow, and Tehran are located in coastal areas.

regime changes. Megacities themselves can also have effects on the hazards they are exposed to. Those can be effectively considered in the framework of urban ecology, which displays strong similarities with disaster risk theory (Kerle and Alkema, 2012). Several observations from an urban ecological perspective offer insights in the hazard exposure of large urban areas: (1) cities are seen as both the cause and the principal victim of environmental degradation (Weiland and Richter, 2009). As a major source of pollution, and due to their extensive resource requirements and energy consumption, they contribute to global climate change. However, with their high concentration of elements at risk and frequent location in coastal areas, these cities are also poised to be most affected by sea-level rise or stronger windstorms (Klein et al., 2003). (2) Global environmental changes are outpaced by local changes (Grimm et al., 2008). For example, urban temperature increases (urban heat islands) are faster than global warming rates, leading to rapidly rising secondary hazards (e.g., new disease vectors spreading, or increased ozone concentrations). (3) Major urban areas have ecological footprints hundreds of times their size, typically also evidenced by changes in their surrounding land cover and land use (Grimm et al., 2008). Hazard sources can be potentially far away, and the characteristics of the area in between strongly affect not only the hazard, but also vulnerability and capacity (e.g., widespread deforestation or river straightening versus comprehensive floodplain management). The threat of projected sea-level rises endangering megacities in coastal areas is at times compounded by large-scale subsidence, typically resulting from excessive groundwater extraction, such as in Jakarta or Bangkok.

## Do megacities face megarisks?

Whether megacities automatically face disproportionate disaster risks has been a matter of intense scientific debate. If megacities are not exposed to exceptional hazards compared to smaller settlements in comparable locations, what else determines their risk? Risk is principally a function of all present hazards and their potential interactions and amplifications, and the type, value, and vulnerability of all elements at risk (see entry *Risk*). Vulnerability, that is, the susceptibility to suffer loss (see entry *Vulnerability*), which differs for physical assets, people, and their social structures, and economic and environmental systems, is further offset by capacity. This is defined as "the combination of all the strengths and resources available within a community, society or organization that can reduce the level of risk, or the effects of a disaster" (UN/ISDR 2004, p. 430). Here, it becomes apparent that risk in megacities is much less a function of the absolute population number, but more of its complexity and development level (Hansjürgens et al., 2008). While a city such as Tokyo, with an exceptional physical asset base, faces a high seismic hazard, the actual risk is limited because of great efforts to reduce vulnerability (e.g., by imposing strict building codes), and to increase the capacity of the city (e.g., by empowering the population on how to respond in a seismic situation). In particular, megacities in LDCs face higher risks (Cross, 2001; Wenzel et al., 2007). This is not only due to these cities being located in poorer countries with fewer means for risk mitigation measures. Instead, the trajectory of urban development is of major importance. While most megacities in richer countries grew over centuries, allowing time for support infrastructure to develop, those in LDCs experienced their most rapid growth in recent decades. For example, while the population of greater London already exceeded six million by 1900 and since then remained largely unchanged, Mumbai grew from some 800,000 to over 23 million in the same period. This led to infrastructure and functional development drastically lagging behind urban expansion, and explains why some 60% of Mumbai's residents live in informal settlements (Wenzel et al., 2007), which are widely considered to be more vulnerable to hazards. Another point influencing risk is the exceptional importance of megacities in LDCs. While all western megacities are important economic, political, and administrative centers in their respective countries, they are not primate cities comparable to Manila, Lagos, or Jakarta. This, in turn, influences risk positively and negatively. While a disaster in a western megacity would lead to substantial damage, and potentially national and international repercussions, it is unlikely to compromise the ability of the respective country to function economically or administratively, as critical functions are decentralized and some level of redundancy exists. Megacities in LDCs tend to have far higher concentrations of economic, political, and administrative power, and as such are more vulnerable to disruption affecting the entire country (Hansjürgens et al., 2008). The risks such megacities face are, therefore, to some extent nationwide risks. On the other hand, their singular importance also facilitates acquisition of resources needed for disaster response and reconstruction, at the expense of the rest of the country.

## The assets of megacities

Many megacities, especially those that grew rapidly in recent years, are characterized by haphazard construction, insufficient infrastructure, unhygienic environments, and inadequate administrative and medical services, all with negative effects on vulnerability and capacity. Those limitations, however, are in part counterbalanced. In addition to the comparatively high ability to obtain resources for disaster response and reconstruction, their status as primate city leads to accumulation of knowledge and expertise, and a comparatively better knowledge of the existing hazards and risk. In addition, they allow an easier early warning of the population, a more timely response following an event (both with national means and international assistance), and in principle are better equipped to empower people on vulnerability reduction and disaster preparedness. The per-person cost of any risk reduction approach, be it engineering measures or installation of early warning infrastructure, is also much lower than in smaller settlements. Creating more effective disaster risk management strategies, which have to draw on all elements of the political, administrative, and societal fabric of a city, is also facilitated by the high concentration of these elements in megacities.

## Megacities and future disaster risks

The trend toward more and larger megacities is clear, with positive and negative consequences for disaster risk, posing especially high challenges for large agglomerations in LDCs. Given the generally high disaster risk, what can be effectively done to reduce it? Any form of risk mitigation and management is contingent on a solid understanding of existing risk. This is difficult as it has to include all present hazards and vulnerability types, as well as account for any present trends related to environmental degradation or climate change. This risk knowledge then forms the basis for sustainable urban development. Such planning has been performed for several megacities, such as Dhaka (Roy, 2009), Santiago de Chile (Heinrichs et al., 2012), or Istanbul (Wenzel et al., 2007), and broad recommendations for climate change adaptation in such settings have been made (Klein et al., 2003). The planning has to be integrative and consider the wider geographic setting. Given the reliance of resilient megacities on a healthy hinterland (Cross, 2001), the focus must not only be on reducing risk within the cities themselves. It is equally important to take measures that reduce the massive rural–urban migration that has been leading to a demographic imbalance that endangers the rural resource supply megacities depend on. The urban agglomerations also have to be surrounded by healthy ecosystems. Overall resilience, that is, the capacity to absorb shocks from disasters and recover, relies on proper functioning and interlinking of both human and ecological systems (Cross, 2001). As such, urban ecology considers integrative, transdisciplinary analysis of the diverse environmental, social, and political aspects as being central to urban disaster risk management, especially in megacities.

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## Cross-references


Building Codes
Buildings, Structures, and Public Safety
Climate Change
Coastal Zone, Risk Management
Costs (Economic) of Natural Hazards and Disasters
Damage and the Built Environment
High-Rise Buildings in Natural Disasters
Integrated Emergency Management System
Resilience
Risk Assessment
Tangshan, China (1976 Earthquake)
Vulnerability
Worldwide Trends in Disasters Caused by Natural Hazards


CASE STUDY

## MEGA-FIRES IN GREECE (2007)


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## Synonyms

Greek fires; Mega-fires; Very large wildfires

## The fire management policy in Greece toward the summer of 2007

Forest fire is a major natural hazard in southern Europe, which is often directly related to climate change and anomalies of meteorological conditions, in particular increased temperature and scarcity of rainfall. Long dry periods combined with other extreme weather conditions contribute to the development of forest fires that in most cases originate by anthropogenic activity and often turn into very large conflagrations. Such fires can easily burn down large forest areas, as evident in particular in the Mediterranean region.

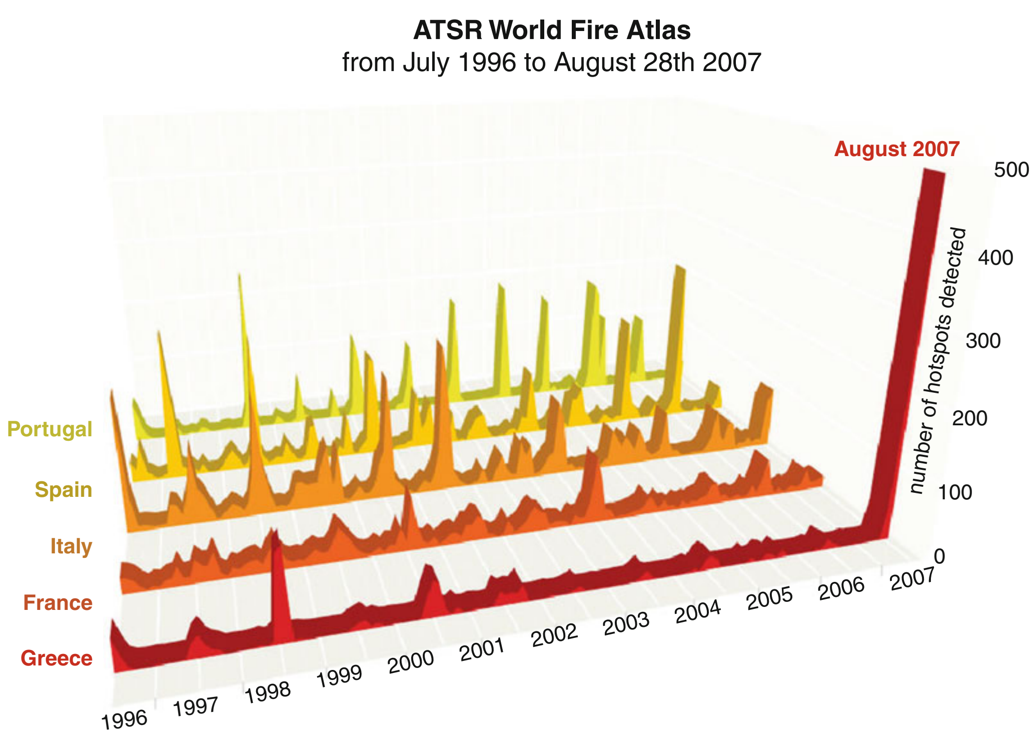
Greece is one of the EU countries most affected by the forest fires. Areas approximately 1,850,000 ha in size have been burned between 1955 and 2007, out of which 30% was burned during the last 7 years of this period. Up to 1973, fires used to occur with a relative low frequency and the average per annum area burned was 11,500 ha. One third of this area was classified as tall forests, mainly pine stands, whereas the remaining area was shrublands, pastures, and grasslands. Starting from 1974, the annually burned area increased rapidly peaking every 3–4 years (influenced by the combination of periodic favorable climatic conditions and societal fire causes). For instance, the area burned in 1974 was 36,000 ha, in 1977 some 49,000 ha, in 1985 about 80,000 ha, and in 1985 >100,000 ha (Eftichidis, 2007).

A significant increase of the burned area was recorded following the 1998 policy shift for fire suppression to the fire brigades from the forest service. This decision marked a clear change in fire management policy in Greece. Aggressive fire suppression succeeded the preventive forest management strategy previously applied with the objective of mitigating fire behavior and impact. Unfortunately, fires continued making new national records in the years 1998 (102,000 ha) and 2000 (157,000 ha). For a period of 6 years following the record year 2000, forest fires have been controlled effectively by applying a focused and aggressive fire suppression policy, giving the impression to the citizens that the problem was being managed properly. Figure 1 summarizes the statistics for fire suppression in the Mediterranean.

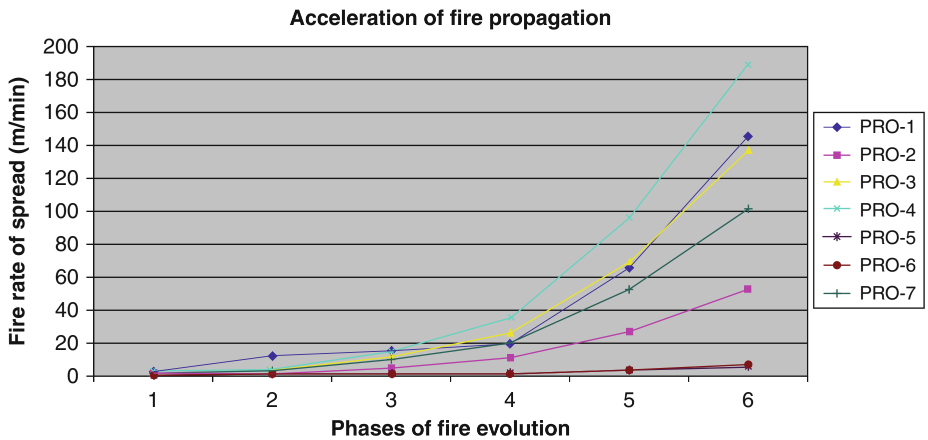
During the summer of 2007, following a long dry season, a series of fires started burning the unmanaged shrublands and pine forests in southern Greece and Peloponnese.

Fanned by favorable weather conditions and a significant volume of accumulated biomass, the 2007 fires in Peloponnese evolved to catastrophic mega-fires that burned >180,000 ha in 1 week with intensities far exceeding the capabilities of the firefighting infrastructure, including the addition of an unprecedented number of resources offered to the Greek government by several other countries.

In total, more than 3,000 fires were recorded over Greece, ravaging approximately 270,000 ha of forest,




**Mega-Fires in Greece (2007), Figure 1** Forest areas burnt in the Mediterranean countries of the EU between 1996 and 2007 (Source ATSR World Fire Atlas).




**Mega-Fires in Greece (2007), Figure 2** Local acceleration of fire propagation during very large fires.

olive groves, and farmland, according to data of the European Forest Fire Information System (EFFIS) of the JRC Ispra. On the Peloponnese, 177,265.4 ha was destroyed, consisting of 55% forests and natural lands, 41.1% agricultural lands, and 0.9% built-up areas (WWF Hellas, 2007).

The special characteristics of the 2007 forest fires, which distinguish them from past forest fires in Greece, can be summarized as follows (Xanthopoulos, 2007):

- Although the number of fires recorded was not remarkable, the extent of the burnt area was very large compared to previous years.
- Many fire episodes occurred at the same time in several locations.
- There was frequent restart of already suppressed fires.

## The mega-fires issue in Greece

Forest fires can be classified according to the suppression effort needed to contain them into initial attack, extended attack, large fires, and mega-fires. These four types cover the continuum of severity that runs from very small, short-duration, and noncomplex events to extraordinarily large, long-duration, and very complex fires. The difficulty of managing forest fires changes dramatically moving from a normal accident to a serious event (extended attack fire) or an ultracatastrophe arises and a mega-fire emerges. Mega-fires occur when multiple fire spots and individually propagating fronts of flames merge into a superfront (Brooking Institution, 2005).

In order to depict the relation of the classification with the number of fire events, we can consider that the majority of fires (approx. 95%) are suppressed during the "initial attack," whereas 4% usually evolve and require "extended attack" operations. Therefore, only 1% of the total number of fires evolves to large fires and only few of these become mega-fires.

The main physical reason for the occurrence of mega-fires is the buildup of dead woody material and accumulation of live biomass in fire-dependent forest ecosystems that can fuel high-intensity events. It is quite common to have such a fire regime following long periods of drought and repeated heat waves during the summer. The situation can be worst due to insect infestations and diseases. Mega-fires create their own local wind field which sustains their propagation, independently of the weather conditions prevailing in the area. Since spotting (starting of new fires by flying embers) is common, mega-fires combined with extreme weather conditions burn out of control and continue burning until relief in the weather or a break in fuel source occurs. Firefighting mechanisms can manage fronts with fire line intensity to 2,500 kW/m, whereas mega-fires often reach intensities to 100,000 kW/m. Therefore, efforts to extinguish such fire fronts are quite futile (Viegas and Eftichidis, 2007).

Fire behavior is normally defined by the topography, the meteorological conditions, and the type of vegetation burned. However, the time since fire ignition is another factor that contributes to extreme fire behavior. Since mega-fires are characterized by their long duration, the time lapse is responsible for eruptive behavior of the fire in many cases. Considering that fires evolve differently through time, we can define a series of six phases for describing this evolution. This consists of (1) the starting condition, (2) the phase of reduction of the fuel moisture, (3) the phase of vegetation dehydration, (4) the phase of wind generation, (5) the phase of wind flow, and (6) the phase of the fire eruption. Time evolution of these phases is different for various forest fuels as shown in Figure 2 (Viegas and Eftichidis, 2007), using the Prometheus (Riaño et al., 2002) classification of forest vegetation to fuels.

The above observation is particularly important in cases of fires approaching villages in case the fire accelerates and surprises the inhabitants without giving them time for evacuation.

Mega-fires are not defined by their physical attributes (e.g., by their size). Instead, they are recognized as "headline fires" in which operational limitations, public anxiety, media scrutiny, and political pressures collide. Beyond their impressive size, they are characterized by their complexity, their potential to overwhelm the capabilities and capacities of the fire suppression forces, and their extreme intensity and long duration. Due to the costs and damages associated with such events, mega-fires are often followed by policy or procedural changes. However, such changes are usually limited in improving firefighting operations and their sustainable hazard mitigation measures.

The 2007 forest fires of Greece record as the most catastrophic fire event in the country's history and the most catastrophic of the last few decades in Europe. The devastation includes the forests and agricultural lands, entire villages, infrastructure, and a large toll on human life (WWF Hellas, 2007). These fire events have been cited in the press as the fourth worst disaster due to forest fires worldwide since 1871 and by far the deadliest for humans in recent years.

## Causes of the mega-fires: season of 2007 in Greece

The extended Greek forest fires of 2007 took place in a summer of three continuous heat waves. The exceptionally high summer temperatures, following a winter drought, made the resinous pine forests more flammable than usual and created very favorable conditions for extensive fires.

In the search for the underlying causes of the 2007 Greek forest fires, discussions most often lead to weaknesses in Greek physical planning and development regulations, which inadvertently encourage criminal actions such as arson.

Greek officers concluded that at least some of the fires of 2007 could be attributed to arson. In the Peloponnese, suspicions of arson were reinforced by the fact that dozens of fire episodes started at the same time. Evidence suggests that the 2007 fires broke out due to a combination of criminal intent, carelessness, and accidents. In addition to arson, the lack of maintenance of the electricity pylon network; carelessness of local farmers, villagers, and forest visitors who started fires on hot days; illegal landfills left unguarded; and the inability of elderly farmers to control fires they started to maintain grazing land are frequent cited causes of fires (Xanthopoulos, 2007).

Despite significant investments and an increase of the fire suppression budget since 1998, the Greek forests suffered record-setting forest fires in which the death toll, costs, losses, and damages involved have been staggering.

However, a "successful" 6-year period of firefighting in Greece, which was due to a number of factors, was interpreted as efficiency of the fire management system based on fire suppression. Thus, the fire problem was considered finally solved or at least under control. Vegetation management programs have been ignored, and the forests were left to accumulate billions of tonnes of biomass. In addition, the high temperatures, even during the winter months, extended the growth period of the vegetation and increased the production of biomass. Due to the alternating moist and dry periods, increased volumes of cured vegetation accumulated in the forests (Eftichidis, 2007).

Given the change in the live and dead fuel moisture conditions, the fires moved to sites that in the past were less dry and where the fire used to burn surface fuels with low intensity. Currently, fires in these sites burn intensively and develop large dimensions due to high accumulation of dead vegetative material. Furthermore, the fires tend to invade areas occupied by forest species that have become more flammable and less fire-adapted in the face of worsening climatic conditions. Fir and black pine forests are good examples of this situation in Greece.

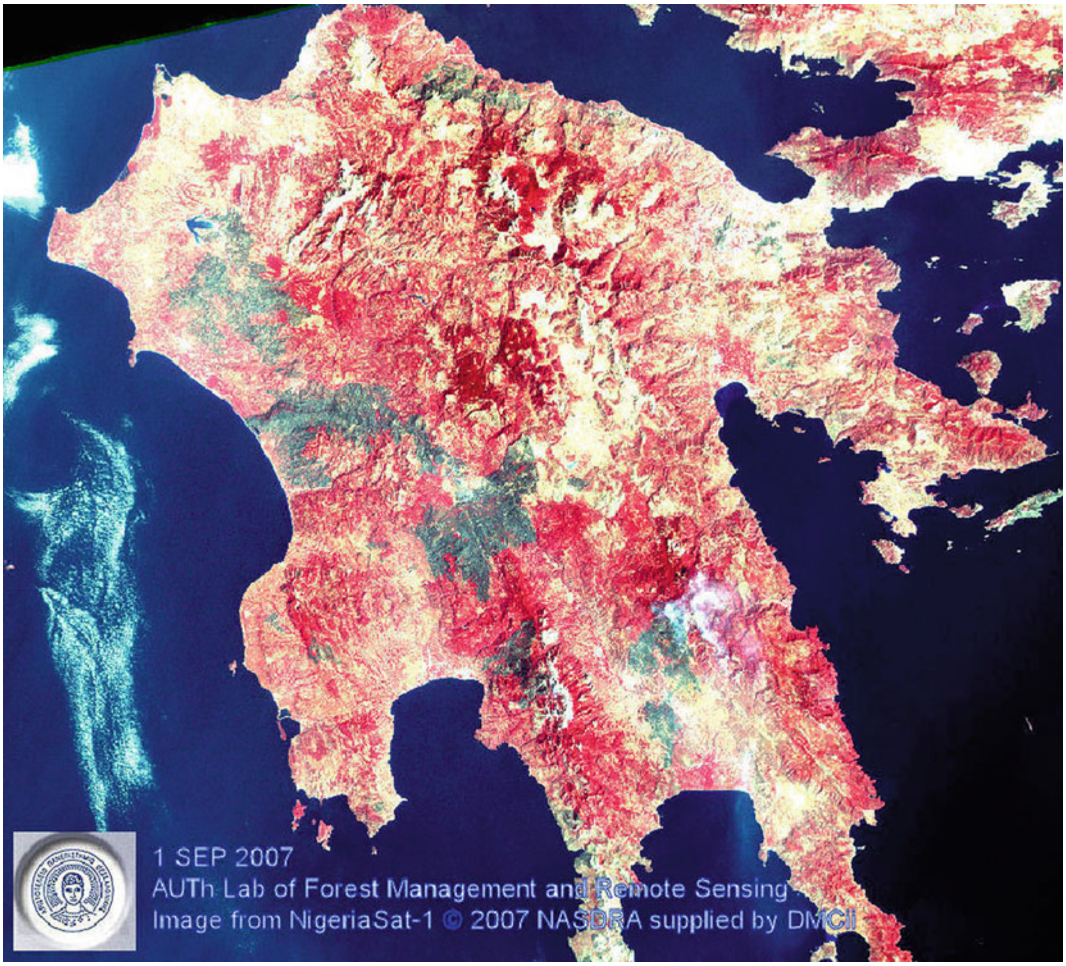
The above-mentioned conditions eventually led to a series of mega-fires in south and southwestern Greece that burned 250,000 ha, 72% of which burned during the last week of August 2007 in five adjacent fires in the region of Peloponnese (Eftichidis, 2007).

The year of 2007 was particularly dry for Greece. Measurements from the National Observatory of Athens show that high temperatures are recorded not only in the summer but during the winter months as well. A report by the National Technical University of Athens describes the winter of 2007 as the warmest in 100 years of collected data. The summer was affected by three heat waves with continuous temperatures as high as 42–45°C for several days at a time.

During the first heat wave, in the eastern part of Greece, the weather station of the city of Pyrgos, one of the most affected areas in Peloponnese, recorded for the first time in its history maximum temperatures of 38.5°C and 41.1°C, respectively, for the 24th and 25th of June. The second heat wave was worse and lasted 10 days from July 17–26, with two peaks according to the Pyrgos meteo station data, first the 18/7 (39.7°C) and second the 25/7 (43.4°C which was also a historical record for the last 50 years). The last heat wave (22–25 August with temperatures ranging from 38°C up to 42.3°C) occurred just before the firestorm started. These persistent heat waves dehydrated the forest vegetation and prepared the environment for the mega-fire that followed (Eftichidis, 2007).

The wind speed in the area of Pyrgos during the dates of the fire (24–27 August) reached 30.6 km/h, whereas day temperature was constantly above 40°C. The humidity of the air fell below 12% during the warmer hours of the day, reaching 40% after midnight.

The majority of the fires in Peloponnese started the night of 23 August and involved several parts of south and west Peloponnese, including the regions of Messinia, Arcadia, Laconia, Ilia, and Achaia. The 24th of August was the 80th day without rain in the area of Pyrgos. On the 25th of August, a state of emergency was declared, and international assistance was requested to fight the fires. On the 29th of August, due to the change of the weather, the fires began to die, and the fire brigades succeeded to contain most of them within the next 2 days. A distribution of the burned areas in the region of Peloponnese is shown in Figure 3. According to the calculations made by the Remote Sensing Laboratory of the




**Mega-Fires in Greece (2007), Figure 3** Footprint of the areas burnt in Peloponnese during August 2007 (Source: Remote sensing Laboratory of the Aristotelian University of Thessaloniki).

Aristotelian University of Thessaloniki using satellite data of resolution 30 × 30 m, the total burned area is 177,265 ha. An area of 78,104 ha was agricultural land, whereas 1,634 ha corresponded to structures and infrastructures (villages, roads, installations, etc.).

The evolution of the fire ignitions during this period is shown in Figure 4. It is evident that most of the fire ignitions occurred in the first 2 days of the firestorm (24 and 25 August), whereas significant new fires continued to start until 28 August (Eftichidis, 2007). The situation far exceeded the capabilities of the Greek firefighting forces. Reinforcements and help provided by several other countries for the firefighting operations was not able to control the high-intensity fires in progress.

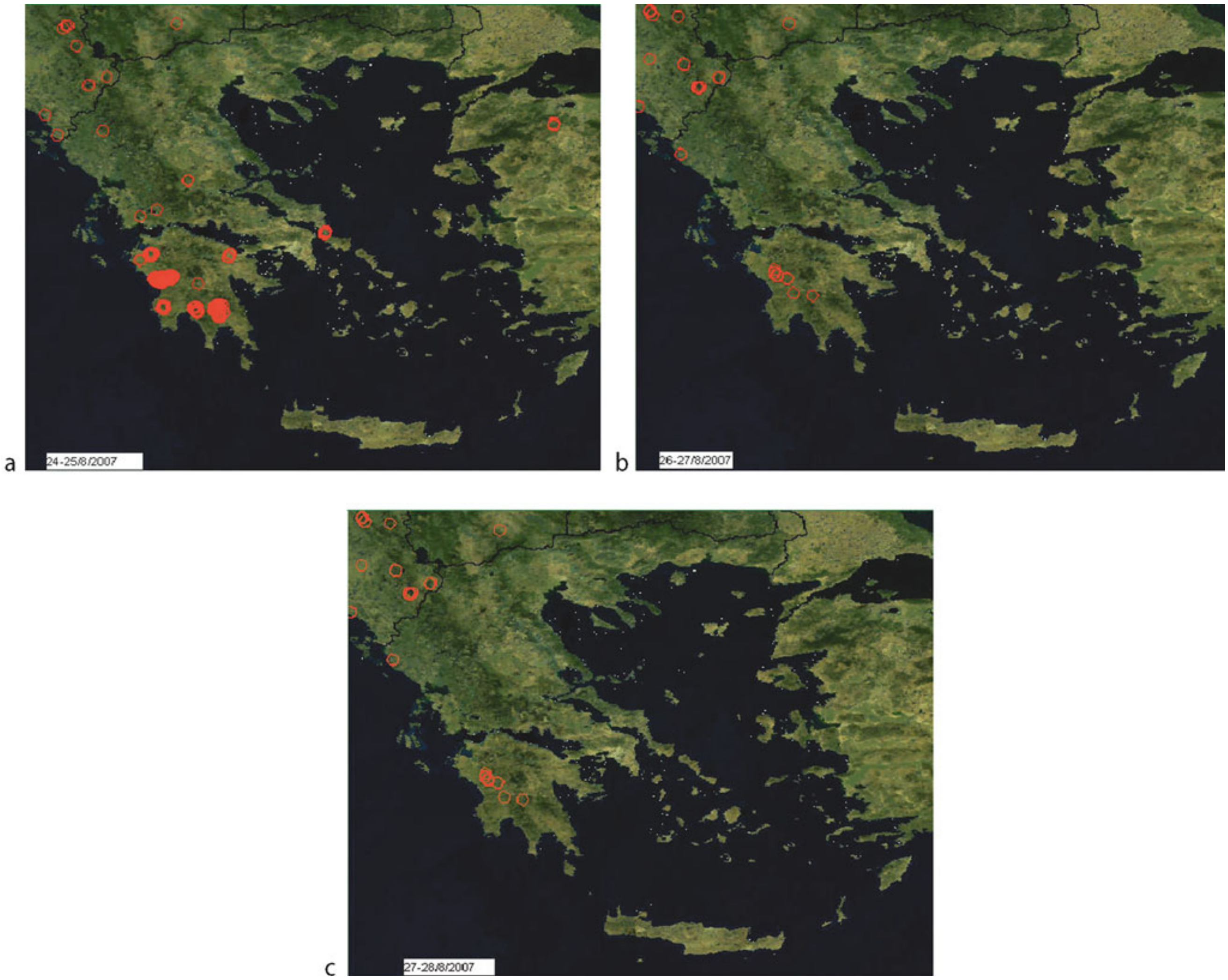
The data of the mega-fires of Peloponnese are shown in the next table (Table 1).

The fires burned hundreds of square kilometers of pine and fir forests, open forested areas, shrublands, olive groves, vineyards, as well as vast number of isolated residences, installations, and houses in the villages. Several regions faced breakdowns in telecommunications, electricity, and water supplies.

As can be seen from the data in Table 1, the fires of Megalopoli, Zacharo, and Pyrgos and the fires in dry sites were more extensive than the fires that burned in higher altitudes and more humid sites such as the mountains of Taygetos and Parnon. The extent of the fires is also related to the forest species of the regions. In Taygetos and Parnon, stands of fir trees burned more slowly than pine stands that burned elsewhere.

The extent of the 2007 situation was completely new in comparison to the historic forest fire patterns. The extreme intensity of these fires made their control impossible even when they reached areas that are normally used as fire control points.

Damages were unprecedented and of extreme severity. Many people evacuated their homes to move to safer places. Unfortunately, most of the inhabitants of the villages, in particular aged people, refused to leave their houses and belongings, and a number of individuals died as a consequence.




**Mega-Fires in Greece (2007), Figure 4** Fire ignitions in Peloponnese during the dates 24–28/8/2007 (Source NASA).

**Mega-Fires in Greece (2007), Table 1** Burned areas by mega-fires in Greece, summer 2007 (Source: MODIS burned area products)

| Fire name | Burned area (ha) | Growth duration |
|---|---|---|
| Mnt. Taygetos | 11,357 | 24–27/8/2007 |
| Mnt. Parnon | 20,681 | 23–30/8/2007 |
| Megalopoli | 42,350 | 24–27/8/2007 |
| Zacharo | 45,809 | 24–30/8/2007 |
| Pyrgos | 42,652 | 24–30/8/2007 |
| *Total* | *162,849* | |

There were also cases of people who did not evacuate in a timely manner, due to the unpredictable speed of the fire propagation as well as due to lack of coordination of the evacuation operations during the first days of the fires. Some of these people were trapped and killed in car accidents while trying to escape from the burning villages. The death toll of the mega-fires of the summer 2007 in southern Greece was more than 70 people, which is a high number of victims in worldwide wildfire history.

Flames engulfed the archeological site of Olympia, home of the first Olympic Games, and the temple of Apollo Epikourios, a 2,500-year-old monument near the town of Andritsaina in southwestern Peloponnese. Thus, the situation was made extremely complex, requiring the authorities to evacuate villages, save archeological sites, and protect human property rather than just extinguishing the flames.

## Effects of the 2007 fires

The mega-fires of the summer 2007 in Greece had significant environmental impact due to the large extent and the erratic behavior of the fire. Biodiversity in several protected areas belonging to the Natura 2000 network covering some 30,132 ha (WWF Hellas, 2007) was affected. On the Peloponnese, WWF recorded impacts at seven important Sites of Community Importance and significant impacts to the biotopes of certain species of special ecological importance, for example, the golden jackal (70% of its population lived in these protected areas of the Peloponnese), 4 out of 5 species of endemic lizards, land turtles, and other animals. The potential for recovery of these biotopes depends on the effective protection of these areas from any future change in land use (WWF Hellas, 2007).

Another notable ecological impact of the 2007 forest fires occurred in the National Park of Mount Parnitha near Athens. A significant part of the nucleus of the National Park and of the Parnitha true -fir (*Abies cephalonica*) forest was burned. The destruction in much of the Parnitha National Park is irreversible in the midterm since true-fir forests are not adapted to fire events. The forest fire in Parnitha also caused damage to the populations of several protected birds, mammals (especially deer – the National Park of Parnitha hosted the most important population of *Cervus elaphus* in the country), and other vertebrates and invertebrates (WWF Hellas, 2007).

The 2007 forest fires influenced the local climate of the fire-afflicted areas in Greece. These impacts consisted of a rise of average local temperatures, extension of the summer period, and a reduction of the volume and at the same time increased intensity of rainfall.

Following the catastrophic fires on the Peloponnese and Evia in August 2007, the Greek government declared a state of emergency and allocated about €300 million for emergency relief. However, the final cost of the fires is likely to have been higher. Tourism and agriculture were hard-hit, and the regeneration of forests will take many years. An independent estimate by the international assessment firm Standard & Poor's evaluated the damage in the range of €3–€5 billion, corresponding to 1.4–2.4% of the country's GDP (Xanthopoulos, 2007).

Especially on the Peloponnese, the impacts of forest fires to the local economy are considered to have been very high. The on-site inspections recorded extensive damage to entire villages, thousands of houses, livestock, the road network, and to telecommunications, electricity, and irrigation networks.

The tourism sector is also expected to have been affected significantly. Tourism on the Peloponnese was almost exclusively based on the natural environment and the traditional human settlements as primary attractions for the thousands of foreign and Greek visitors. If unplanned development of the human settlements and encroachment on natural areas is not effectively prevented during the reconstruction phase, the region is expected to experience a degradation of its tourism potential (WWF Hellas, 2007).

As concerns the agricultural sector, it should be kept in mind that the Peloponnese hosted 35% of the country's livestock and 30% of the country's olive groves (Bassi and Kettunen, 2007).

Indeed, the 78,043 ha of agricultural land ruined on the Peloponnese were primarily olive groves. In the prefecture of Ilia alone, 50% of the olive production potential was totally incinerated (WWF Hellas, 2007). Such damage should be seen in relation to the main source of income in this area. In this prefecture, 50% of the workforce was in the primary sector. At the same time, this prefecture has the lowest GDP/capita of all prefectures affected by the August fires (approximately half of the national average GDP/capita).

The extensive damage to olive trees and livestock is bound to change the agricultural production balance on a national level and will require extensive compensation for agricultural damage. Indeed, many farmers will have to live on European subsidies and national compensation for several years. For many, there will not be full compensation for damages, and they will be called upon to decide whether to make a new start or abandon their way of life (Bassi and Kettunen, 2007).

The most significant social impact of the 2007 fires was the deaths of 76 people (Xanthopoulos, 2007). The fires also left thousands of people homeless and unemployed (WWF Hellas, 2007).

The quality of life of the inhabitants in fire-affected areas will also be undermined by damage to the landscape. It is estimated that the destruction of the natural vegetation cover will be followed by a disturbance of the soil and water balance and, most likely, by floods and landslides in the future (WWF Hellas, 2007).

## Conclusions

The mega-fire phenomenon appears to be increasing in frequency and destruction worldwide. The potential influence of the climate change in the future on the rate of fuel accumulation is of concern. The increase in temperatures and the decrease in rainfall shall contribute to the growing forest fuel load that will be available for future fires. In particular, the problem will be exacerbated in cases where human activity mixes with forest vegetation. There is no question that the forest fire season of summer 2007 was very difficult for Greece. However, the circumstances cannot be considered unique, and it would be overly simplistic to solely attribute the disaster to extreme weather conditions resulting from climate change (Xanthopoulos, 2007). Scientific study indicates that the main underlying causes lie in the lack of appropriate preventive forest management and of a fire prevention policy, the weakness of state mechanisms for effective forest fire suppression, and the lack of organized hazard management plans in the event of mega-fires. Above all, the perception that protection from forest fires is equivalent to forest fire suppression is to blame for the tragic fire events of 2007.

There are several reasons that the mega-fire phenomenon has been growing during the last few decades. For instance, the management of the vegetation in noncommercial forests and the impact of climate change on the accumulation of biomass and to the moisture status of the forest vegetation. These two factors are reinforced by uncontrolled urban growth in the wildland urban interface and the relative large investments in fire suppression infrastructure and policies. In addition, public expectations for the land discourage or exclude activities that might reduce fuel loadings (Williams, 2007)

Fire suppression can be successful during years of mild fire seasons, contributing thus to the accumulation of flammable biomass that will be available to the fire in the dry years that will follow with extreme weather conditions. This leads to the paradox of increasing the risk while investing in mitigation. Mega-fires are not occurring due to a lack in funding. The worst fires on record in the USA coincide with the highest preparedness budgets ever seen (Williams, 2007).

Sustainable management of the vegetation is a key issue in addressing the problem of accumulation of biomass and the artificial structure of the tree stands due to human-centered forest protection plans. These facts lie behind the intensity and the size of mega-fires and define the chances for control. Therefore, the wise management of the fire problem should be reinforced through sustainable forest management for mitigation purposes (Eftichidis, 2007).

Mega-fires have to be addressed as a hybrid of civil protection and environmental issues since they impact natural resources, but at the same time, they threaten the lives of citizens, consume agricultural production, destroy properties, and create severe postfire social problems.

Land planning organizations have to find ways for reducing exposure and improving the coping capacity of rural population to forest fire, in order to limit the disastrous consequences of mega-fires.

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## Cross-references


Forest and Range Fires
Forest Fire Regimes
Mega-Fires in Greece (2007)


## MERCALLI, GIUSEPPE (1850–1914)


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Giuseppe Mercalli was born in Milan, Italy, on May 20, 1850. In 1872, he was ordained a Roman Catholic priest and in 1874 became a professor of Natural Sciences. He devoted his life to the study of *volcanoes* and *earthquakes* and, at the same time, was a dedicated schoolteacher for over 35 years, writing several natural science handbooks. Until he became director of the Vesuvius Observatory in 1911, he taught at the Catholic seminary of Monza and at the Lyceums of Reggio Calabria (1888) and Naples (1892). He was lecturer at the Universities of Catania and Naples.

A pupil of the geologist Antonio Stoppani, he started his scientific activity by studying Quaternary Alpine glacial deposits, but soon expanded his interests to volcanological and seismological research that made him famous. In 1883, his monograph "Vulcani e fenomeni vulcanici" was published, concerning Italian *volcanoes* and related phenomena. In this work he presented his observations and studies on the Eolian Islands, the Phlegrean Fields, Etna and *Vesuvius*, and also on Italian *earthquakes*, and their correlation with *volcanoes*. He compiled a catalog of Italian *earthquakes* from 1450 BC to 1881, highlighting the existence of *seismic districts*, where seismic activity is more frequent and characteristic. He drew four seismic maps, representing the first scientific synthesis of Italian seismicity. This work was a milestone for seismologists of that time, like Mercalli's monographs on the Ischia (1883), Liguria (1887), Ponza (1892), and Andalusia (1881) *earthquakes*. Other geological and seismic monographs were published in 1897 on Piemonte and Liguria and on Calabria and Messina, followed by the studies on the 1905, 1907, and 1908 Calabrian *earthquakes*.

He revised the De Rossi-Forel *intensity scale* and in 1900 the ten degree Mercalli scale was officially adopted in Italy. In the course of time it was modified by several seismologists but Mercalli's name was maintained: the *Modified Mercalli scale* is today used worldwide.

Mercalli studied some Etna eruptions and the Eolian islands, in particular Stromboli and Vulcano, but the main subject of his investigations was certainly *Vesuvius*, to which he dedicated over 20 years of his life. Moreover, he summed up his ponderous studies on active *volcanoes* of the world in the volume "I vulcani attivi della Terra", printed in 1907, which actually represents the first Italian treatise on volcanology. He not only provided a precise description of the observed phenomena but also introduced classifications, stating the specific characteristics of the different eruptive apparatus and their manifestations.

During the night of March 18–19, 1914, a fire put an end to Mercalli's life, one that had been entirely dedicated to science.

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## Cross-references

Earthquake
Eruption Types (Volcanic)
Intensity Scales
Modified Mercalli (MM) Scale
Seismology
Vesuvius
Volcanoes and Volcanic Eruptions

# METEORITE

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## Synonyms

Asteroid; Bolide; Meteor; Meteoroid

## Definition

A meteorite is a mass of solid material (either stony or metallic) on the surface of the Earth that came from space.

## Discussion

The word meteorite is used for such an object on the surface of the Earth. In space, it is called a meteoroid if small or an asteroid if large (there is no strict dividing line between a meteoroid and an asteroid: typically, a diameter of about 1 km is used, but usage varies within wide limits). A meteor is the bright streak in the sky that accompanies the entry of a meteoroid into the Earth's atmosphere. A meteor that exhibits one or more bright explosions is called a bolide.

Most meteorites originate in the asteroid belt between Mars and Jupiter, but a few come from the surfaces of larger planets, such as Mars or the Moon. Some volatile-rich types may come from comets. Meteorites are classified as stony, iron (metallic), and stony-iron. Stony meteorites, which are about 40 times more abundant in space than irons, are further classified as either chondrites (the most abundant type, with many subclasses of chondrite) or as achondrites. Chondrites contain small, mm to cm diameter, spherical inclusions that are more or less distinct in the body of the meteorite. Freshly fallen meteorites are enclosed in a glassy crust of melted material, the fusion crust, which forms by friction with the air as the meteoroid enters the Earth's atmosphere at high speed.

Meteorites are described as either finds or falls, depending upon the circumstances of their discovery. They are conventionally named after the post office nearest to the point at which they are recovered, such as Allende (fell in 1969 near the town of Allende, Chihuahua, Mexico). In the case of the recently discovered meteorites in Antarctica, names are given that refer to the location, year, and order in which they were cataloged, such as ALH84001 (found near the Allen Hills Moraine in 1984 and the first to be cataloged).

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## Cross-references

Asteroid
Asteroid Impact
Asteroid Impact Mitigation
Asteroid Impact Predictions
Comet
Impact Airblast
Impact Ejecta
Impact Fireball
Impact Firestorms
Impact Tsunami
Impact Winter

# METHANE RELEASE FROM HYDRATE

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## Synonyms

Climate-induced dissociation of methane hydrate; Release of methane from hydrate caused by global warming

## Definition

The release of methane gas from methane hydrate, which is a clathrate (a solid in which water molecules form a cage enclosing methane molecules), occurs when an increase in pressure or a decrease in pressure create conditions that cause hydrate to break down into its separate constituents of water and gas. A natural increase in temperature can be caused by a warming climate, and reduction in pressure, for hydrate beneath the seabed, by a fall in sea level.

## Discussion

Methane hydrate is stable under conditions of low temperature and high pressure such as those found on land in regions of permafrost or under the ocean in water deeper than 300–600 m, depending on the water temperature. The concentration of methane in the ocean is usually far too low for hydrate to form, but in the sediment and rocks beneath the seabed, methane concentration can be high enough to form hydrate. The thickness of the gas hydrate stability zone (GHSZ), in which hydrate can form and exist stably, is limited by the increase of temperature with depth within the Earth. Methane from deeper hydrocarbon reservoirs or generated by bacteria from the organic material in the sediment migrates upward, as free gas or dissolved in water, into the GHSZ, where it forms hydrate. The amount of carbon in hydrate beneath the seabed is probably equal to the carbon in all other sources of natural gas and petroleum in the Earth.

An increase in seabed temperature reduces the extent of the GHSZ. In deep water, the seabed remains in the GHSZ, whereas the downward propagation of the temperature increase causes the base of the GHSZ to migrate upward, releasing methane, which may reenter the GHSZ and form hydrate again, limiting the amount that may escape into the ocean. Where the GHSZ in shallower water is removed completely by warming, the methane released is free to migrate through the sediment to the seabed. The upper continental slope is most prone to methane release by this mechanism, because temperature change is greatest in the upper water column. Although hydrate is absent from most continental shelves, because they are too shallow for the GHSZ to occur, it exists in rocks and sediment beneath the shelf in the Arctic because of the low temperature caused by the presence of permafrost created during the last glacial period when large parts of the shelf were subaerial. There, sea-level rise reinforces the effect of increasing water temperature by flooding low-lying land with water that is warmer than the average temperature of the land surface. Permafrost retards the escape of methane released from hydrate, because the extra heat required to melt the ice slows down the increase of temperature, and because ice impedes the flow of gas. This can impose time lags of hundreds of years between the onset of warming and methane escape.

Over recent years, there has been increasing evidence that methane released from hydrate as a consequence of warming enters the ocean, but little evidence that much of it enters the atmosphere to contribute to global warming. It appears that the rate of release of methane is generally too slow to overcome its solution in the ocean, where, after oxidation, it contributes to ocean acidification. Catastrophic gas venting or submarine landslides of hydrate-rich sediment might, however, be effective in releasing large amounts of methane over short periods of time. Submarine slides have been widely cited as an agent of ancient increases in atmospheric methane but their potency has still to be proven. It has been proposed that the release of gas from rapid dissociation of hydrate creates zones of over-pressured gas in sediment beneath continental slopes, reducing sediment strength and increasing the likelihood of submarine slides, which can cause tsunamis.

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## Cross-references

Climate Change
Displacement Wave, Landslide Triggered Tsunami
Gas-Hydrates
Marine Hazards
Permafrost
Release Rate
Sea Level Change
Tsunami

## MINING SUBSIDENCE INDUCED FAULT REACTIVATION

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### Synonyms

Break lines; Fault steps

## Definition

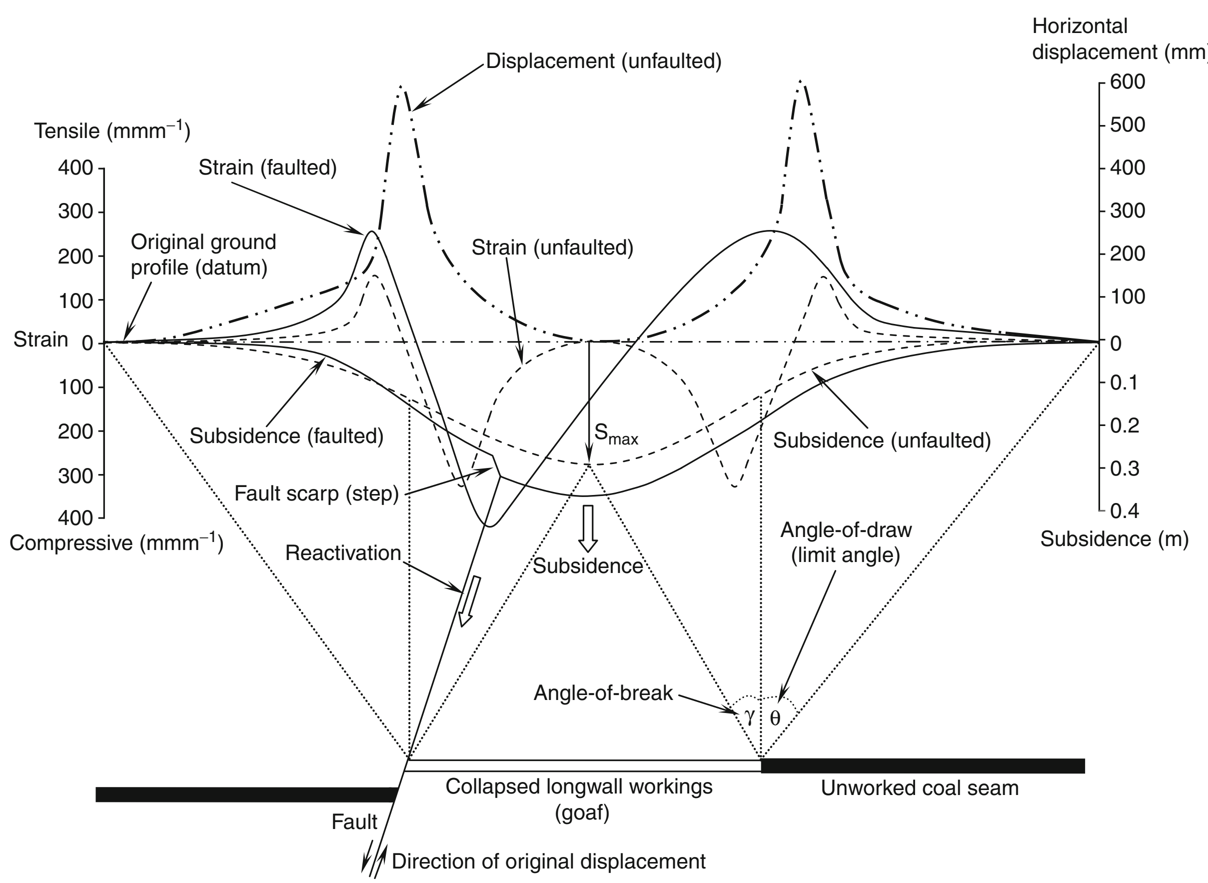
Faults are naturally occurring discontinuities in rock or soil where there has been observable and measurable displacement by shearing and/or dilation. Faults located in areas prone to mining subsidence, caused by the longwall extraction of coal, are susceptible to reactivation. This may result in the generation of a fault scarp along the ground surface (also referred to by some mining and subsidence engineers as a "step" or "break line").

## Summary

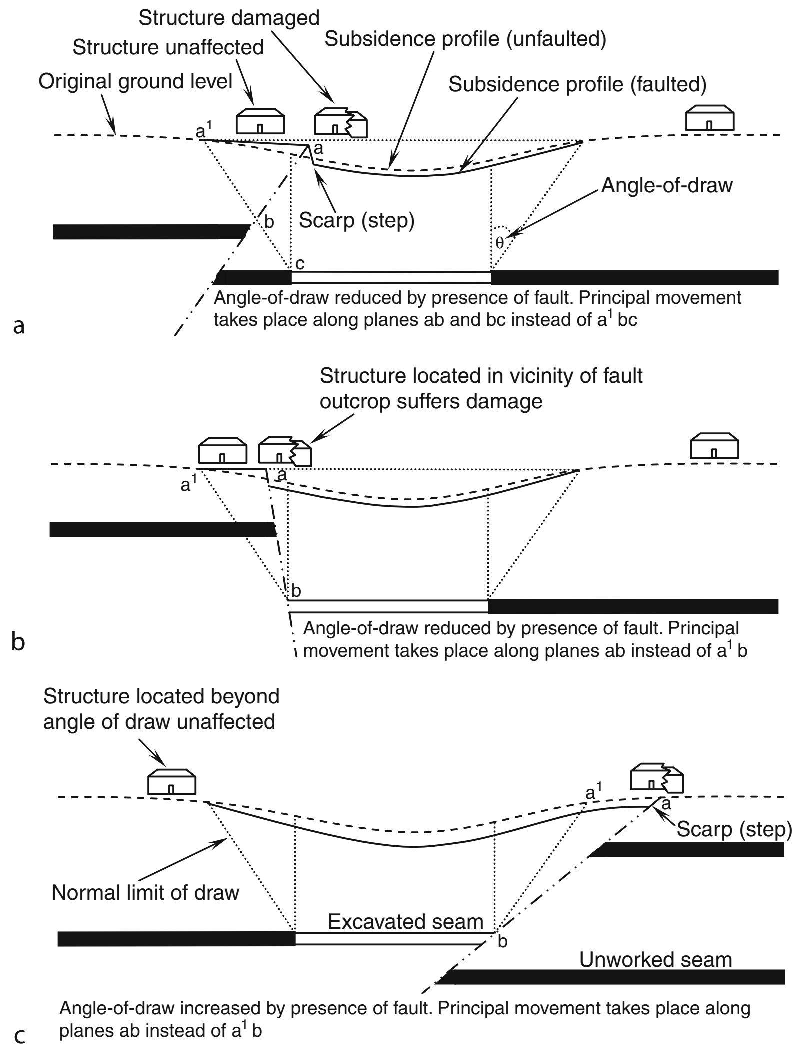
Mining subsidence-induced fault reactivation may generate a scarp, graben, fissure, or zone of compression along the ground surface (Figures 1 and 2). This is significant because it may cause physical damage to structures (buildings, houses, industrial premises, bridges, dams, pylons, and towers), services and utilities (sewers, water conveyances, gas mains, pipelines, and communications cables), and transport networks (tracks, roads, motorways, railways, rivers, and canals) (Figures 3–6).

The topographic expression of reactivated faults may vary considerably from subtle deflections and flexures barely recognizable across agricultural land or road side verges, to distinct, high-angled fault scarp walls, upto approximately 3–4 m high and 4 km long. In areas of high relief, reactivated faults may influence the first time failure of slopes and the reactivation of landslides (Figures 7–9). More commonly, fault scarps are less than a meter high, less than a meter wide, and vary in length from just a few meters to a few hundreds of meters long.

Reactivated faults do not always appear at their expected outcrop position as inferred on geological maps. This may be attributed to the acceptable mapping tolerances (since geological maps provide an estimate of their likely outcrop position on the ground surface). This is often complicated by the variable nature of the strata, surficial deposits, or made ground, which a fault displaces. Greater thicknesses of surficial




**Mining Subsidence Induced Fault Reactivation, Figure 1** Schematic model to illustrate fault reactivation during the mining of a horizontal coal seam by the longwall-mining method. Fault reactivation generates a fault scarp (or step) in the subsidence profile (trough) and disrupts the distribution of the horizontal displacements and strains. High compressive ground strains tend to occur at the fault scarp (but not always, these may also be tensile, generating a fissure) (After Donnelly, 2009).




**Mining Subsidence Induced Fault Reactivation, Figure 2** The influence of faults on mining subsidence and the angle-of-draw. (**a** and **b**) Any structures located in the vicinity of fault outcrops during their reactivation will almost certainly physical damage. When workings are located in the footwall of the fault, any structure located in the hanging wall may be safeguarded as the fault absorbs most of the ground strains (although this is not always the case). In examples (**a** and **b**), the presence of the fault has reduced the angle-of-draw (and therefore area-of-influence) in the hanging wall. (**c**) Faults may also extend the angle-of-draw, beyond that which would otherwise prevail in the absence of any faults (After Donnelly, 2009).

deposits tend to reduce the severity of a fault scarp, but influence a much broader area. Where the cover is thin or absent a distinct, high-angled fault scarp may develop, but where these are thicker a less distinct, broad, open flexure will be generated. Fault scarps are normally temporary features of the ground surface and may be destroyed soon after their generation by, for example, repairs to roads and structures, the ploughing of agricultural land, or by processes of weathering and erosion. In some instances, reactivated faults have reduced the amount of subsidence on the unworked side of a fault by absorbing ground strains and safeguarding houses, structures, and land that may have been otherwise damaged.

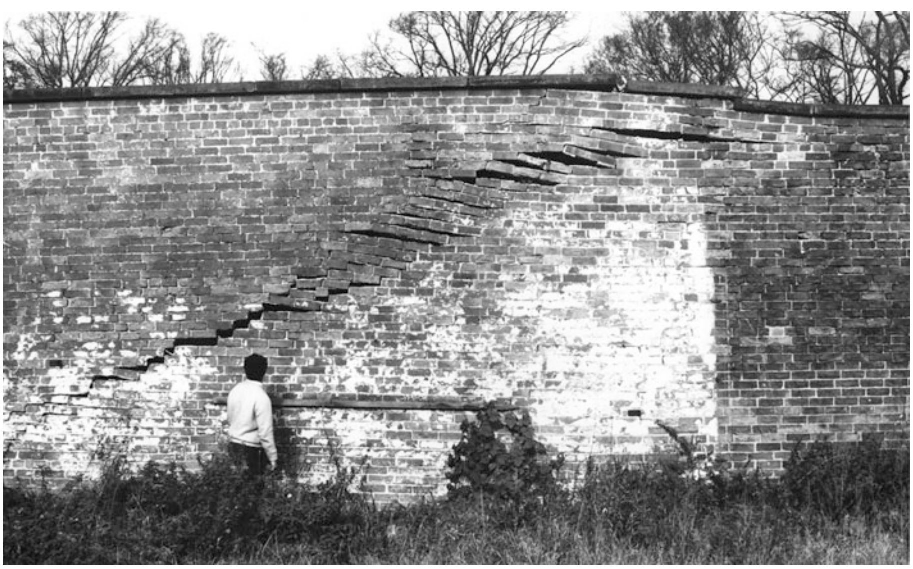
Faults are capable of several phases of reactivation each time they are influenced during longwall coal mining operations, separated by periods of relative stability. Fault reactivation has been documented since the middle part of the nineteenth century throughout the United Kingdom and in many other coal mining regions around the world.

Although fault reactivation, in certain circumstances, may continue for periods of time (weeks to several years) after "normal" subsidence has been completed, movements along most faults does eventually stop in the majority of cases investigated.

The mechanisms of mining subsidence-induced fault reactivation are only partially understood. Since ground movements along faults have been observed and recorded to take place over weeks, months, and years, aseismic creep appears to be the dominant mechanism. However, brittle shear failure may be possible where the fault displaces strong sandstone or limestone. There is currently no strong evidence to suggest that coal mining-induced fault reactivation induces seismicity (earthquakes), although this is difficult to prove.

**Mining Subsidence Induced Fault Reactivation, Figure 3** Damage to houses caused by the mining-induced reactivation of the Hopton Fault, Oulton, Staffordshire, UK (Photograph © Laurance Donnelly).

**Mining Subsidence Induced Fault Reactivation, Figure 5** Barlaston church, Staffordshire, UK, was severely damaged by mining-induced fault reactivation. (Photograph © Laurance Donnelly).



**Mining Subsidence Induced Fault Reactivation, Figure 4** Compression to a 5.0 m high retaining wall, caused by fault reactivation and subsidence, Eastwood Hall, Nottinghamshire, UK (Photograph after Whittaker and Reddish, 1989).

**Mining Subsidence Induced Fault Reactivation, Figure 6** Reactivation of the Inkersall Fault, Derbyshire, generating a graben, which caused widespread damage to two schools, houses, roads, and walls in the late 1980s and 1990s (Photograph © Laurance Donnelly).

**Mining Subsidence Induced Fault Reactivation, Figure 7** Air Photograph to demonstrate how the reactivation of the Tableland fault and associated network of complex fissures can influence the geomorphology of entire moorland slopes, South Wales Coalfield (after Donnelly, 1994).

**Mining Subsidence Induced Fault Reactivation, Figure 8** The 3–4 m high and 4 km long Tableland Fault scarp, which has influenced the Darren Goch landslide and displaced stream valleys, South Wales Coalfield (Photograph © Laurance Donnelly).

**Mining Subsidence Induced Fault Reactivation, Figure 9** A typical South Wales fault scarp representing several phases of reactivation, probably initiated by valley deglaciation and exacerbated by mining subsidence. These form distinct, extensive topographic features, which may reach at least 4 m high and 3–4 km long. These influence surface drainage and groundwater flow and landsliding (including first time failures and reactivation of existing landslides) (Photograph © Laurance Donnelly).

It would be prudent on all engineering sites containing geological faults in active and former mining areas to investigate their potential effects on ground stability, mine gas emissions, or groundwater/mine water discharges, before development and construction is carried out. It is recommended that this be undertaken at the desk study and ground investigation stage of a project to reduce the risks for unforeseen ground conditions. The ground may then be suitably treated, or appropriate foundations designed, prior to any construction or developments taking place. Further information on mining-induced fault reactivation is present in Donnelly, 2006, 2009; Donnelly and Rees, 2001; Bell and Donnelly, 2006.

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## Cross-references

Creep
Critical Infrastructure
Fault
Land Subsidence
Landslide
Mass Movement
Risk Assessment
Subsidence Induced by Underground Extraction

# MISCONCEPTIONS ABOUT NATURAL DISASTERS


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## Definitions

*Adaptability.* The ability to adapt – in this context, to unexpected or altered behavior of natural systems.

*Mitigation.* Measures taken by society to reduce the consequences of a disaster.

*Natural disaster.* An event in which the behavior of part of Earth's natural systems causes severe consequences to society, usually greater than local in scale.

*Natural hazard.* A natural system with the potential to damage society; alternatively, any natural process with the ability to damage society *even if society is not yet present in the area*.

*Resilience.* The ability to resume normal functioning after a disaster.

*Risk.* (noun) Probability; probability multiplied by consequence; (verb) to take a chance.

*Sustainability.* The ability to be sustained – requires specification of *what* is to be sustained, at what *level of intensity*, for what specified *time period*, and what are the *indicators of unsustainability.* Needless to say, these requirements are usually ignored.

*Vulnerability.* The degree to which society can be affected by disasters.

## Introduction

As a result of many years of thinking about natural disasters, teaching students about natural disasters and trying to help communities avert natural disasters, I have come to a number of realizations about the nature and causes of hazards and disasters. These can be summarized as follows:

(a) People cause natural disasters by behaving in ways that make society vulnerable to infrequent high-magnitude natural events.
(b) More people and more development means more and bigger natural disasters.
(c) "Natural hazards" can usefully be defined as processes of nature with the potential to cause damage to society.
(d) Altering the behavior of natural systems usually results in increasing the probability of a natural disaster.
(e) Maintaining altered behavior of natural systems creates significant long-term costs to society.
(f) People behave according to their world views.
(g) Scientists are often poor communicators, especially with nonscientists.
(h) Whatever can happen, will happen one day; that could be today.
(i) Scientists should do what they are good at – science.
(j) Communities must make their own disaster-management decisions.

These realizations sometimes conflict with more conventional thinking about disaster mitigation, among both scientists ("experts") and lay people. I make no claim whatsoever that my views are "right" for anyone else – but I do think that, even if they are wrong, they are at the very least a useful set of discussion points to stimulate fundamental thinking about how to better reduce the impacts of natural disasters. The following list of "misconceptions" – perhaps better thought of as challenges – sets my realizations (which are at present "true" for me) against the background of conventional or traditional practices and thinking.

## Misconceptions

### That we know what we are talking about

Discussions about natural disasters are frequently plagued by the different meanings that different people attach to words such as "hazard," "disaster," "risk," and so on. The word "hazard" is particularly broadly interpreted; to some, hazard is synonymous with risk as the numerical probability of a specific event happening in a specified time interval; to others, it is synonymous with "natural process," such as a landslide occurring on an uninhabited island. Many other interpretations occur between (and even beyond) these extreme examples. Again, "risk" is sometimes defined as the product of probability and consequence, whereas to others it is simply numerical probability as noted above. Similar confusion is possible with the terms "vulnerability," "catastrophe," "disaster," "resilience," and many others.

This is not the place to propose specific meanings for words (with the exception of two examples suggested below); it is, however, appropriate to note that in order to make substantial progress in mitigating inevitable future natural disasters, the meanings of words used either in print or orally must be made completely clear by the user. If this is not done, audiences should ask for it to be done. Experience has shown that such requests are often a complete surprise to the user of the words, and indeed may be treated as an insult; this probably indicates that the user is not clear about the meaning. In any case, continued discussion in the presence of unresolved conflicting interpretations of word meanings is usually unproductive and thus a waste of time.

As examples of how it is possible to unequivocally define potentially confusing words, I offer the following:

"Sustainable" – a specified activity is sustainable at a specified level for a specified time if it does not result in unacceptable consequences (to whom?).

"Natural hazard" – a natural process that currently has the potential to be deleterious to society.

### That natural disasters are caused by misbehavior of nature

Natural disaster is a term commonly used to describe severe damage and/or deaths in communities affected by events such as tornadoes, earthquakes, tsunami, volcanic eruptions, storms, etc. It is important to understand that the *events* are simply part of the normal behavior of the Earth's natural systems; they were going on for billions of years before humans evolved, and will continue for billions of years into the future. There is no element of natural misbehavior involved. Events that cause natural disasters are usually somewhat rare on the timescales commonly considered by communities, and are therefore sometimes unexpected, but the only element of misbehavior that can be identified is that the communities did not expect the event to occur and were therefore unprepared – i.e., human misbehavior.

### That natural disasters can be prevented by altering the behavior of nature

This misconception arises from the idea that nature misbehaves; if it does then its behavior can be corrected. It is telling to note that the German language term for river engineering is "*Flußkorrektion*" – literally "river correction," implying that the form of the river prior to engineering was incorrect. This is undoubtedly a consequence of the definition of Civil Engineering up until the 1970s: "Harnessing the great powers of nature for the benefit of man," reflecting the idea that "man" has dominion over nature.

Certainly engineering has been vital in developing resources for (hu)mans' use, and modification to the everyday behavior of natural systems can be sustainable. To modify the infrequent events that are the usual trigger for natural disasters, though, is a much more challenging task for a number of reasons:

(a) Data describing infrequent events are usually sparse, so those events are poorly known and understood and the design of control measures to that extent is unreliable.
(b) These infrequent events are characterized by greater magnitude and power than the more frequent, lower-intensity events to which communities are accustomed, so control is correspondingly more difficult.
(c) Fiscal constraints commonly limit the magnitude of event that is able to be "controlled"; but a greater (superdesign) event can occur at any time, and when it does occur it will cause a natural disaster in spite of engineering controls.
(d) Implementation of works to alter the behavior of nature inevitably generates the public perception that there can be no more disasters in that place, so development accelerates, leading to greater costs when the inevitable superdesign event occurs.

Natural disasters cannot be prevented; given Earth's ever-increasing population and occupancy of available land, natural disasters will increase in frequency. The impacts of future natural disasters can be reduced only by better knowledge of their trigger events and careful preparation by communities to reduce their own vulnerability.

### That humans are powerless against nature

This is a more recent misconception than most of the others. It is a reaction to the realization that, in many places where geological activity is intense, the forces involved are simply too large for humans to counter. It appears to follow that there is nothing we can do to prevent natural disasters.

It is certainly true that little or nothing can be done to alter the behavior of earthquakes, volcanoes, glaciers, and other large-scale physical processes, and, as outlined elsewhere in this entry, *reliable* modification of infrequent, intense natural process is not achievable. The natural processes that trigger disasters will therefore continue to occur. This does not make society powerless to reduce the impacts of disasters, however. A disaster occurs when a community is affected by an extreme natural process; but there is nothing to prevent the community from modifying *its own* behavior so as to become less vulnerable to the disaster. What is required is that society becomes aware of the likely consequences of the trigger event, and is prepared to adapt its own behavior in the light of those effects. We may in principle be unable to control nature, but we are in principle able to control ourselves.

## The increase in meteorological disasters is caused by climate change

There seems to be a general awareness that natural disasters triggered by storms are increasing in frequency and magnitude (e.g., Hurricane Katrina, recent storms in Japan and the Philippines). This has been cited as evidence that anthropogenic climate change is both real and rapid, and is causing extreme meteorological events to increase in intensity. The hard factual evidence for this is pretty much nonexistent; the storm sequences of recent years lie within the natural event variability that would be expected with a stable climate, even if they may be unusual in that context. Recent storminess is not yet evidence for climate change.

What is clearly evident is the exponential increase in damage costs of weather-related disasters from the 1960s to the present day, as evidenced in many reports. This coincides with the dramatic rise in human population and investment value over the same period – the more there is to lose, the greater will be the losses.

## Statistical data on natural behavior can be used to design reliable disaster countermeasures based on cost-benefit analysis

This is the classical natural hazard management concept; if we design to manage the most likely event, then over time net benefit will be maximized. There are a number of flaws in this concept. For example, the probability of the most likely event is much less than the sum of the probabilities of the other events, so the most likely event is in fact *un*likely to occur – it is much more likely that some other event will occur. For example, in 1,000 throws of a six-sided die, the most likely number of sixes is 166.7 (1,000/6). This is of course impossible, because 0.7 of a "six" cannot occur; the most likely possible number (167) of sixes is also much less likely to occur than some other result. Many of these flaws result from the fact that in dealing with disaster-triggering events, we are always dealing with a small sample. This is not only a small dataset describing the infrequent (and therefore few) recorded trigger events, but also the small number of events that will occur in the future in the timescale of relevance.

Events capable of causing disasters are by definition infrequent; if they were frequent, humans would alter their behavior so that the natural hazards were not disastrous. Thus, if we are planning to mitigate disasters at a given site over, say, the next hundred years, we can expect a small number of trigger events – certainly fewer than five, possibly none at all. Here is the point: *Statistical predictions about a small sample of events are intrinsically imprecise*. If a dice is rolled 6,000 times, we expect close to 1,000 sixes; say between 950 and 1,050, which is 1,000 $\pm$ 5%. If the same dice is rolled six times, however, we expect close to 1 six; so the best-case scenario is 1 $\pm$ 1 or 1 $\pm$ 100%. Even if we have a million years of event data from the past, the fact that we are predicting *into* a small sample space makes the prediction intrinsically imprecise.

The other fact that makes cost-benefit analysis of doubtful value is that net benefit equals unmitigated damage cost minus mitigated damage cost. Now both unmitigated and mitigated damage costs are large and imprecise numbers; this means that subtracting one from the other to get net benefit gives a much smaller and much more imprecise number – so imprecise in fact that using it as a design discriminator is often unrealistic.

## Natural disasters are always big

The word "disaster" intrinsically implies something big – bigger than an "incident," say, or a "mishap" (but smaller than a "cataclysm" or a "catastrophe"). As with much terminology, however, its meaning depends on one's point of view. A minor mudslide that kills an unemployed peasant is completely unworthy of notice to the vast majority of a population, but to the close relatives of the dead man it is clearly an event that will change their lives, and could realistically be called catastrophic; for the local community in which the man had lived for many years it is a disaster.

## People resist hazard mitigation because they are ignorant

It is a common experience among hazard managers that persuading people to take sensible precautions against disasters is difficult. Even persuading them to accept the fact of the existence of a hazard of which they were previously unaware can be tremendously difficult. In such cases an easy solution to the problem is to label the people stupid; but this is both untrue and unproductive.

People usually behave according to what they think is the right thing to do; their view of the right thing to do may be the result of ignorance or prejudice, but it is not the result of stupidity. Ignorance and prejudice can be altered by good communication; but by definition, stupidity cannot.

At another level, peoples' behavior aligns with their view of how the world operates. Hence, before they have experienced a natural disaster, people will resist being required to carry out hazard assessments and mitigation measures – whereas after the disaster they may blame the authorities who failed to protect them. This is not stupidity, it is the result of a change of world view.

The point of this is that informing people about potential natural disasters is always unwelcome, and the information will be resisted. In order to communicate it effectively, the "expert" needs to understand the world view of the people, and to be overtly empathetic about the psychological impact the information can have. Such empathy is not possible with people one has (even to oneself) labeled "stupid."

### Worst-case scenarios are scaremongering and problematic

It is not uncommon for natural hazards scientists to be accused of scaremongering when outlining the potential impacts of extreme natural events on communities, together with the comment that this is not a constructive way to go about communicating science to society. It is indeed the case that simply stating that a community has a 1% per year chance of being devastated by a landslide is likely to create a situation where further communication is difficult; nevertheless, if that information is correct then it needs to be made available so that the community can make decisions about how to manage the situation. The reality is that

(a) Every worst-case scenario can occur, and given long enough will occur.
(b) The worst-case scenario can occur tomorrow.

Thus any disaster-management planner who does not convey such information to a community is not carrying out their duty – in fact any official whose estimate of the likely disaster magnitude is exceeded has failed.

How, then, can such information be conveyed without engendering a non-constructive reaction? This needs forethought – it is too late when standing before the microphone in the Community Hall. It is necessary to establish mutual trust between the community and the official before real communication can occur, so considerable groundwork is required. The whole topic of effectively communicating hazards science to communities and their leaders, so that it can be useful in decision making, is being seriously addressed nowadays (e.g., http://www.usgs.gov/science_impact/index.html) and is possibly one of the most important factors in advancing disaster management worldwide.

A useful aspect of considering a worst-case scenario is that any action a community takes to mitigate its impact will be much more effective against any (much more likely) lesser event. It also has the effect of making a community actively aware of the nature of the landscape they use.

### Scientists know best

Reducing the impact of a potential disaster is a task that requires knowledge of the physical aspects of the disaster and knowledge of the social functioning of the community it impacts. Scientists acquire the former through research, but they do not have the latter; I would even venture to suggest that the people with the best potential knowledge of how the community functions are not sociologists or social scientists, but *the community itself*. It is not uncommon, especially where less-developed communities are receiving aid to reduce disasters, to find that scientists exceed their brief of understanding and communicating science, and carry on to state what actions the community should take to mitigate disasters.

I submit that this is not the best way to operate. Especially in dealing with communities of people whose culture is not that of science, or even that of the land of origin of the scientists, all that scientists can usefully do is make information easily available; how that information is used by the community is a decision that can only be made by the community. In doing this, the community accepts responsibility for its resilience to disaster. The community may choose to seek further advice from the scientists, but the latter group should, in my opinion, refrain at all times from trying to influence decision making (difficult though this may be).

This is not just cultural correctness: It is a pragmatic way of ensuring that the disaster-management decisions made are acceptable to the community, and therefore are carried out. There is a long list of situations where solutions have been imposed on communities, found not to be acceptable by the communities and simply not implemented; or, if implementation was part of the job, the works or procedures put in place were not maintained and lapsed through neglect. Rarely does the agency responsible for the solution return to assess its effectiveness. By contrast, when the community is the decision maker, the community will ensure implementation goes ahead and that maintenance occurs.

## Conclusions

As noted at the outset, these "misconceptions" are both personal to myself and intended for discussion; however, the purpose is very serious. Of all the tertiary programs I have been involved in, disaster management is the one with far and away the greatest potential to benefit society – and, if it is done poorly, to do the opposite. *Disaster mismanagement kills people*. Natural processes do not obey the theories of scientists; if the theories are sound, they more or less represent natural processes. In disaster management the best possible information is always required; nature cannot be influenced by theory, policy, or blind faith. Hence, it is imperative that we think deeply about the behavior of nature and of communities; we take nothing on trust, however eminent the source; and we are open to admitting that our present ideas might be wrong.

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## Cross-references

Civil Protection and Crisis Management
Classification of Natural Disasters
Community Management of Hazards
Disaster Risk Reduction
Education and Training for Emergency Preparedness
Emergency Planning
Exposure to Natural Hazards
Frequency and Magnitude of Events
Hazardousness of Place
Humanity as an Agent of Geological Disaster
Land-Use Planning
Land Use, Urbanization and Natural Hazards
Mitigation
Myths and Misconceptions
Natural Hazard
Perception of Natural Hazards and Disasters
Recurrence Interval
Resilience
Risk Assessment
Sociology of Disasters
Uncertainty
Vulnerability

# MITIGATION

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## Synonym

Risk reduction

## Definition

Mitigation is the planning and execution of measures designed to reduce the risk to acceptable or tolerable levels.

## Introduction

Risk mitigation is an important component of risk management. To develop effective risk mitigation measures, one should understand the key determinants of risk; that is hazard and vulnerability.

## Risk mitigation strategies

Risk mitigation strategies for natural hazards aim at either reducing the hazard, or reducing the vulnerability and exposure of the population, infrastructure, and other elements at risk. They can broadly be categorized into the following groups:

- Physical measures to reduce the frequency and/or severity of the hazard
- Land-use planning
- Early warning systems (and emergency evacuation plans) (*early warning systems*)
- Risk communication (*risk perception/communication*) and public awareness campaigns
- Legislation and enforcement of building codes
- Measures to pool and transfer the risks such as natural hazard insurance

Public awareness campaigns are effective in reducing the vulnerability of the exposed population for all types of natural hazards.

Physical measures may be used to stop, delay, or reduce the impact of certain types of natural hazards such as debris flow, flash flood, river flood (*flood protection*), storm surge, and tsunami. On land, these may include "soft" measures in the form of drainage, erosion protection, vegetation, ground improvement; or "hard" structures like dikes, embankments, and vertical concrete or stone block wall. Offshore, the man-made physical barriers like jetties, moles or breakwaters, or even submerged embankments could be constructed to reduce the impact of cyclone, storm surge, and tsunami.

A well functioning and efficient early warning system, including well-designed escape routes and safe areas, is probably the best way to prevent loss of life due to tsunami, flood, storm surge, cyclone, volcanic eruption, and certain classes of landslides. To develop a reliable early warning system, the physical processes and mechanisms need to be understood and methods need to be developed for measuring, modeling, and predicting the natural hazard of concern, for example, landslide or tsunami. Design of functional networks of escape routes and safe places is strongly dependent on the local context.

The most effective method for mitigating the earthquake risk is to construct buildings and other infrastructure to withstand the earthquake-induced load effects. In seismically active regions, important structures should not be placed in areas that are exposed to earthquake-induced landslides and ground failure, unless measures to improve the ground and/or stabilize the slope(s) are implemented. Obviously relevant legislation and enforcement of building codes must be in place for this mitigation strategy to be successful.

## Identification of appropriate mitigation strategy

For a given hazard and element at risk, a number of viable mitigation measures may be available. The identification of the optimal risk mitigation strategy involves:

1. Identification of possible hazard scenarios and hazard levels
2. Analysis of possible consequences (loss of life, monetary losses, damage to the environment, etc.) for the different scenarios (*risk assessment*)
3. Assessment of possible measures to reduce the hazard
4. Assessment of possible measures to reduce or eliminate the potential adverse consequences
5. Recommendation of specific measure(s) on the basis of technical evaluations and discussions with the stakeholders
6. Transfer of knowledge and communication with authorities and society

Any mitigation strategy needs to be part of a community's integrated land-use planning and subjected to analyses that assess and circumvent its potential negative environmental impacts. The optimal risk mitigation strategy is not always the most appropriate one. The exposed population and other stakeholders must be involved in the decision-making process that leads to the choice of the most appropriate risk mitigation strategy.

## Summary

Mitigation is an important component of risk management and it refers to the planning and execution of measures designed to reduce the risk. Risk mitigation strategies for natural hazards may focus on reducing the hazard, or on reducing the vulnerability and exposure of the population, infrastructure, and other elements at risk. To identify the most appropriate risk mitigation strategy, the exposed population and other stakeholders must be involved in the decision-making process.

## Cross-references

Breakwater
Building Codes
Debris Flow
Disaster Risk Management
Early Warning Systems
Flash Flood
Flood Protection
Hazard
Insurance
Land-Use Planning
Risk
Risk Assessment
Risk Perception and Communication
Surge
Tsunami
Volcanoes and Volcanic Eruptions
Vulnerability

# MODIFIED MERCALLI (MM) SCALE

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## Definition

The Modified Mercalli Scale is one of the several scales used in the world to estimate the intensity of earthquakes (see entry *Intensity Scales*). It is a tool to evaluate the severity of historical earthquakes in many regions of the world, and it is currently adopted in the USA and other countries for *macroseismic surveys*. Note that there are different versions of MM Scale, all with 12 degrees. The first one was devised by Wood and Neumann in 1931 (see Table 1), modifying and condensing the Mercalli-Cancani scale, as formulated by Sieberg in 1923. This scale is a hierarchical classification of observed effects; the diagnostic effects for the lower degrees are essentially those on people, for the intermediate and higher degrees those on objects and buildings, and for the highest degrees (XI and XII) those on the environment.

Afterward, *Richter* proposed a new version, the MM Scale of 1956 (Richter, 1958), which takes into account four different classes of masonry, defined according to quality of workmanship, construction materials employed, and resistance against lateral forces. Later on, other MM scales have been produced, such as the versions by Brazee (1979) and Stover and Coffman (1993), the variant by Dengler and McPherson (1993) addressed to sparsely populated areas, or the revisions carried out by Dowrick (1996) and Hancox et al. (2002) for New Zealand, etc.

Therefore, when using MM intensity values, it is necessary to specify the scale version.

**Modified Mercalli (MM) Scale, Table 1** Modified Mercalli intensity scale of 1931 (From Wood and Neumann 1931)

| | |
|---|---|
| I | *Not felt* – or, except rarely under especially favorable circumstances |
| | Under certain conditions, at and outside the boundary of the area in which a great shock is felt: |
| | Sometimes birds, animals, reported uneasy or disturbed; |
| | Sometimes dizziness or nausea experienced; |
| | Sometimes trees, structures, liquids, bodies of water, may sway –doors may swing, very slowly |
| II | *Felt indoors by few, especially on upper floors*, or by sensitive, or nervous persons |
| | Also, as in grade I, but often more noticeably: |
| | Sometimes *hanging objects may swing*, especially when delicately suspended; |
| | Sometimes trees, structures, liquids, bodies of water, may sway; doors may swing, very slowly; |
| | Sometimes birds, animals, reported uneasy or disturbed; |
| | Sometimes dizziness or nausea experienced |
| III | *Felt indoors by several, motion usually rapid vibration* |
| | Sometimes not recognized to be an earthquake at first |
| | *Duration estimated* in some cases |
| | Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away |
| | *Hanging objects may swing slightly* |
| | Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly |
| IV | *Felt indoors by many, outdoors by few* |
| | *Awakened few*, especially light sleepers |
| | *Frightened no one*, unless apprehensive from previous experience. Vibration like that due to passing of heavy, or heavily loaded trucks. Sensation like heavy body striking building, or falling of heavy objects inside |
| | *Rattling of dishes, windows, doors*; glassware and crockery clink and clash |
| | *Creaking of walls, frame*, especially in the upper range of this grade |
| | *Hanging objects swung*, in numerous instances |
| | Disturbed liquids in open vessels *slightly* |
| | Rocked standing motor cars noticeably |
| V | *Felt indoors by practically all, outdoors by many or most: outdoors direction estimated* |
| | *Awakened many* or most |
| | *Frightened few* – slight excitement, a few ran outdoors |
| | Buildings trembled throughout |
| | *Broke dishes*, glassware, to some extent |
| | *Cracked windows* – in some cases, but not generally |
| | *Overturned vases, small or unstable objects*, in many instances, with occasional fall |
| | *Hanging objects, doors, swing* generally or considerably |
| | Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly |
| | *Pendulum clocks stopped*, started or ran fast, or slow |
| | *Moved small objects, furnishings*, the latter to slight extent. *Spilled liquids* in small amounts from well-filled open containers. *Trees, bushes, shaken slightly* |
| VI | *Felt by all*, indoors and outdoors |
| | *Frightened many*, excitement general, some alarm, many ran outdoors. *Awakened all* |
| | Persons made to move unsteadily |
| | *Trees, bushes, shaken slightly to moderately* |
| | Liquid set in strong motion |
| | Small bells rang – church, chapel, school, etc |
| | *Damage slight* in poorly built buildings |
| | *Fall of plaster* in small amount |
| | *Cracked plaster* somewhat, especially fine cracks in *chimneys* in some instances |
| | *Broke dishes*, glassware, in considerable quantity, also some windows |
| | *Fall of knickknacks, books, pictures* |
| | *Overturned furniture* in many instances |
| | *Moved furnishings* of moderately heavy kind |
| VII | *Frightened all* – general alarm, all ran outdoors |
| | Some, or many, found it difficult to stand |
| | Noticed by persons driving motor cars |
| | *Trees and bushes shaken moderately to strongly* |
| | Waves on ponds, lakes, and running water |
| | Water turbid from mud stirred up |
| | Incaving to some extent of sand or gravel stream banks |
| | Rang large church bells, etc |
| | Suspended objects made to quiver |
| | *Damage negligible* in buildings of good design and construction, *slight* to moderate in well-built ordinary buildings, *considerable* in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc |
| | *Cracked chimneys* to considerable extent, *walls* to some extent. *Fall of plaster* in considerable to large amount, also some stucco. *Broke numerous windows, furniture* to some extent |

**Modified Mercalli (MM) Scale, Table 1** (Continued)

| | |
|---|---|
| | Shook down loosened brickwork and tiles |
| | Broke weak chimneys at the roofline (sometimes damaging roofs). *Fall of cornices* from towers and high buildings |
| | Dislodged bricks and stones |
| | *Overturned heavy furniture*, with damage from breaking |
| | *Damage considerable* to concrete irrigation ditches |
| VIII | *Fright general* – alarm approaches panic |
| | Disturbed persons driving motor cars |
| | *Trees shaken strongly* – branches, trunks, broken off, especially palm trees |
| | Ejected sand and mud in small amounts |
| | Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters |
| | *Damage slight* in structures (brick) built especially to withstand earthquakes |
| | *Considerable* in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling |
| | *Fall of walls* |
| | *Cracked, broke, solid stone walls seriously* |
| | *Wet ground* to some extent, also ground on steep slopes |
| | *Twisting, fall of chimneys, columns, monuments* also factory stacks, towers |
| | *Moved conspicuously, overturned, very heavy furniture* |
| IX | Panic general |
| | *Cracked ground conspicuously* |
| | *Damage considerable* in (masonry) structures built especially to withstand earthquakes: |
| | Threw out of plumb some wood-frame houses built especially to withstand earthquakes; |
| | *Great* in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken |
| X | *Cracked ground*, especially where loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks |
| | Landslides considerable from river banks and steep coasts |
| | Shifted sand and mud horizontally on beaches and flat land |
| | Changed level of water in wells |
| | Threw water on banks of canals, lakes, rivers, etc |
| | *Damage serious* to dams, dikes, embankments |
| | *Severe* to well-built wooden structures and bridges, some destroyed |
| | Developed dangerous cracks in excellent brick walls |
| | Destroyed most masonry and frame structures, also their foundations |
| | Bent railroad rails slightly |
| | Tore apart, or crushed endwise, pipe lines buried in earth |
| | Open cracks and broad wavy folds in cement pavements and asphalt road surfaces |
| XI | Disturbances in ground many and widespread, varying with ground material |
| | Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud |
| | Caused sea waves (“tidal” waves) of significant magnitude |
| | *Damage severe* to wood-frame structures, especially near shock centers |
| | *Great* to dams, dikes, embankments, often for long distances |
| | Few, if any (masonry), structures remained standing |
| | Destroyed large well-built bridges by the wrecking of supporting piers, or pillars |
| | Affected yielding wooden bridges less |
| | Bent railroad rails greatly, and thrust them endwise |
| | Put pipe lines buried in earth completely out of service |
| XII | *Damage total* – practically all works of construction damaged greatly or destroyed |
| | Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive |
| | Wrenched loose, tore off, large rock masses |
| | Fault slips in firm rock, with notable horizontal and vertical offset displacements |
| | Water channels, surface and underground, disturbed and modified greatly |
| | Dammed lakes, produced waterfalls, deflected rivers, etc |
| | Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level |
| | Threw objects upward into the air |

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## Cross-references

Building Failure
Earthquake
Earthquake Damage
Intensity Scales
Isoseismal
Macroseismic Survey
Mercalli, Giuseppe
Richter, Charles F.
Seismology

# MONITORING NATURAL HAZARDS


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## Synonyms

Observation; Surveillance; Watching

## Definition

The verb “to monitor” comes from the Latin “monere” which means to warn. In geosciences, it means to watch carefully at a hazardous situation and to observe its evolution and changes over a period of time. It is also used to define the activity of a device that measures periodically or continuously sensitive states and specific parameters.

## Introduction

Hazard monitoring is based on the acquisition and the interpretation of a signal indicating changes in behavior or properties of a hazardous phenomenon or the occurrence of events. This ranges from acquiring basic meteorological data to advanced ground movement measurements. Hazards monitoring began sometime ago, when the Babylonians first tried to forecast weather. When Aristotle wrote his treatise *Meteorologica*, the Chinese were also aware of weather observations (NASA, 2012a). Pliny the Elder studied in details the eruption of the Vesuvius in August 79 AD, providing one of the first scientific observations of a natural catastrophe. Presently, the evolution and the precision of monitoring are closely linked to the development of new technologies. A very interesting example highlighting the importance of technological development is provided by hurricane statistics. The number of hurricanes had often been underestimated because of the lack of information prior to the appearance of satellite imagery: many hurricanes that did not reach the coasts were simply not registered (Landsea, 2007). Today, the development of telecommunications and electronics has made easier the adoption of monitoring systems. In addition, satellite remote sensing has improved greatly the detection of changes at Earth surface. Nevertheless, monitoring remains a costly activity, implying that actually only few hazard types and locations are monitored. Moreover, as dangerous phenomena are usually complex, several parameters have to be monitored, and in most cases one single variable is not a sufficient criterion to provide reliable warnings.

Monitoring can be either linked to an early warning system, leading to act directly within the society, or used to record hazardous events to provide data for hazard assessment and a better understanding of the phenomenon. Some of the monitoring results are public and accessible at no cost, such as earthquake data, whereas meteorological data are often sold because they are profitable due to their direct impact on society (such as agriculture, air traffic, news, and tourism). In any case, with the boom of Internet, more and more free data is accessible in many countries.

In the following, we describe briefly the most common sensor types used for monitoring several hazards and further discuss monitoring aspects.

## Instruments and measured variables

Originally, monitoring was mainly done by simple human observations or with limited devices, and some were performed manually, such as the first rain gauges. Now, even if some monitoring is still based on observations, as for snow avalanches, it is mainly instrumented, and many sensors are also used for remote-sensing techniques. The great advance in computer sciences and communication technologies has increased the accessibility to instruments, by improving technology and reducing costs.

Climatic variables are monitored by satellite and meteorological stations. According to the World Meteorological Organization (WMO, 2012a), the global observing system (GOS) acquires *“meteorological, climatological,* *hydrological and marine and oceanographic data from more than 15 satellites, 100 moored buoys, 600 drifting buoys, 3,000 aircraft, 7,300 ships and some 10,000 land-based stations."*

Hazard monitoring consists primarily of treating a signal in order to obtain information about movement, moisture, temperature, pressure, or physical properties (Table 1). A monitoring sensor is local when it records properties at its own location (thermometer, rain gauge, etc.). Remote sensors are used to collect properties of distant objects. Remote-sensing techniques can be active (a signal is sent and received) or passive (only receiving). For instance, InSAR (interferometric synthetic aperture radar) is an active remote-sensing method to detect ground movement, whether Earth surface temperatures can be measured from satellites by passive remote sensing analyzing specific bands of the electromagnetic spectrum (Jensen, 2007). Currently, satellites using microwaves or bands in the visible and infrared spectra permit one to quantify environmental variables such as rainfall, $CO_2$, water vapor, cloud fraction, and land temperature (NASA, 2012b).

Two important advances in the last 20 years now allow one to measure ground movements, one key factor for many natural hazards: (1) the GNSS (Global Navigation Satellite System), which allows measuring 3D displacements, and (2) the satellite and terrestrial InSAR techniques that permit one to map very accurate displacements using two successive radar images by comparing the phase signal. Of course, local direct measurements of displacements such as extensometers, tide float gauges, or inclinometers are still very much used and complement these recent techniques.

The final goal of hazard monitoring is to provide information about physical parameters directly or indirectly interpreted in order to evaluate the level of risk. The following presents some of the most current methods used to monitor the main hazards affecting human activities.

## Meteorological monitoring

Monitoring meteorological variables is mainly dedicated to weather forecasting but also to the understanding of climate change. It covers phenomena from local to global scale. Spatial and temporal scales of the phenomena are linked. Local and extreme events, such as tornadoes, hail, or thunderstorms, last only a few minutes to hours, and their location and intensity cannot be forecasted in advance. These kind of events are the topics of short-range forecasting, or nowcasting, that rely on observations and measurements of the phenomena after its initiation, as, for instance, by means of satellite or ground-based radar data. Regional events, such as heavy precipitation over a mountain range, strong winds over a country, or hurricanes, can usually be foreseen a few days in advance. These are forecasted at medium range by numerical weather forecast models that rely on the actual state of the atmosphere, assessed by radiosounding balloons, meteorological stations, or satellite images. The global scale is related to climate changes and is monitored by temperature measurements (Figure 1), sea level rise tracking, and various other indices.

Weather monitoring is thus dedicated to forecasting but also to increase the knowledge about the phenomena. Most of the data acquired during an event are then used by the scientific community for various applications, such as statistical analyses, improvement of the understanding of the processes, or development of more reliable models.

### Monitoring of local extreme events

The short-range forecasting, often referred to as nowcasting, focuses on the pending few hours and the local scale. It strongly relies on monitoring to anticipate the displacements of the occurring hazard.

Thunderstorms with intense precipitation or hail are usually tracked by means of ground-based precipitation radars. The returning radar pulses provide the spatial distribution of the hydrometeors and so the intensity of the precipitation. The diameter of the raindrops or the hail may be approximated based on the reflectivity factor or the signal attenuation. The main advantage of radar measurements is that it provides real-time precipitation information on a large area, but there are several issues for precipitation estimation. The first one is that the drops are detected on a wide range of altitudes and the calculated intensity may not match ground observations due to wind or evaporation (Shuttleworth, 2012). Another issue is for mountainous regions, as mountain ranges are responsible for beam shielding (Germann et al., 2006). However, various algorithms and correction methods exist to make the radar data valuable for nowcasting. The goal of such forecasting is to assess the motion and the evolution of precipitation patterns (Austin and Bellon, 1974). While it was initially just an extrapolation of the patterns, it is becoming more sophisticated by use of numerical forecasting models that are initialized with radar data (Wilson et al., 1998).

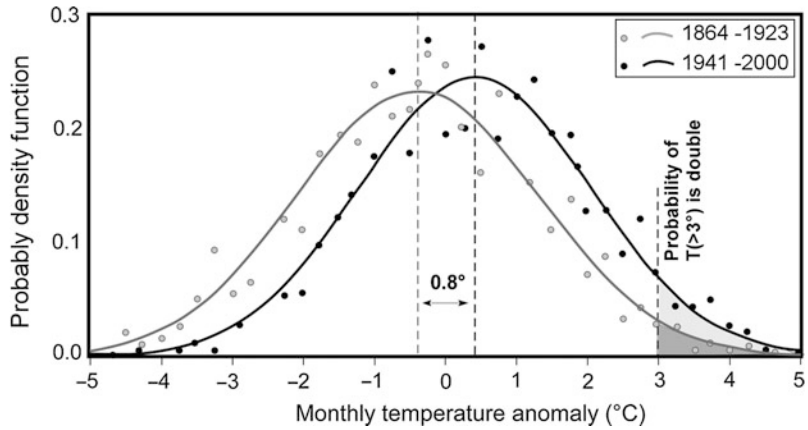
Tornado detection is possible using a Doppler radar, which uses the Doppler effect on the reflected pulse to assess the velocity of hydrometeors, according to the radial axis. By displaying the motion within a storm, it becomes possible to identify a tornado vortex signature (Donaldson, 1970; Brown et al., 1978), which is characterized by an intense and concentrated rotation. With this approach, the presence of tornado genesis can be identified before a tornado touches the ground. The US government deployed a network of 158 Doppler radars for tornadoes monitoring between 1990 and 1997 (NOAA website).

### Monitoring of regional meteorological variables

Today's weather forecasts are mainly based on numerical weather prediction (NWP) models. However, these models rely on data assimilation, which is a statistical

**Monitoring Natural Hazards, Table 1** Description of the most common sensors used to monitor natural hazards

| Sensors | Monitored variables | Principles | Monitored phenomenon |
|---|---|---|---|
| *Pressure measurement* | Pressure (air, water), in situ stress measurement | Barometer: used a height of fluid in vacuum to compensate the atmospheric pressure<br>Pressure transducer: convert a material deformation electrical signal | Atmospheric circulation, water table, Earth crust deformations |
| *Radar* (RAdio Detecting And Ranging) | Distance to a hard object and velocity | Reflection of an emitted microwave by an object and received by an antenna. The Doppler effect permits to estimate the speed of an object | Precipitation imaging, river discharge (velocity), sea level rise, tornadoes |
| *Laser* (Light Amplification by Stimulated Emission of Radiation) and *Lidar* (Light Detection And Ranging) | Distance to a surface and orientation | The Laser consists in amplifying coherent light by using the principle of stimulated emission, creating a narrow beam that can be reflected by surfaces. The Lidar uses the principle of range finder by evaluation of the distance by the time of flight or the phase comparison. The direction of the beam is recorder in order to obtain the 3D coordinates. Information on the reflectivity can be also obtained | Landslides movements and characterization, local atmospheric circulations |
| *Thermometer* | Temperature | The measurement is realized using changes of the properties of materials under temperature variations such as volume (mercury), or the electric resistance such as thermistors or thermocouple which produce a current proportional to the temperature between two different materials | Climate, weather forecasts, volcano |
| *Accelerometer and seismometer* | Acceleration, velocity, displacement | Measurement of ground acceleration using transforming movement into electrical signal | Earthquake, surface deformation (landslides) |
| *Wind sensor* | Wind speed and direction | Anemometer is a rotating device entrained by wind such as cup. Anemometers usually use three half spheres like rotating along a vertical axe. The windvanes is a device which is orientated parallel to the wind. Measurement of ultrasonic wave by several sensors permits to obtain the wind velocity and direction | Weather, hurricanes, tornadoes |
| *Rain gauge* | Amount of precipitation throughout time | The traditional rain gauges are tipping-bucket, like a container that is emptied each time the unitary volume that can be measured is reached. Precipitations can also be measured using rain drop impact counts | Weather, bad weather |
| *InSAR* (interferometric synthetic aperture radar) | Topography, small surface displacement using radar | By using ground-based or satellite InSAR images, it is possible to extract a distance to the ground and a very accurate changes between two images down to millimeter resolution in the direction of line of site. This is based on microwave interference | Earth surface deformation: Earthquakes, volcanoes, landslides, subsidence |
| *GNSS* (Global Navigation Satellite System) | Ground position | The principle is to acquire several highly precise travel times of microwaves from at least two satellites (with highly precise positions) and to compute the distance and location to calculate the best position (can be improved include the phase information). Highest accuracy is obtained by using differential GNSS method which computes difference with a well-known GNSS position. This remove several error such atmospheric and ionosphere one. The position resolution reaches a few millimeters | Earthquakes, volcanoes, landslides, subsidence |




**Monitoring Natural Hazards, Figure 1** Statistics of Swiss monthly temperature differences to the average over the whole period. This shows a shift of 0.8°C. The probability to get a monthly temperature 3°C greater than the average temperature is at least twice for the period 1941–2000 compare to 1864–1923 (Modified from Schär et al., 2004).

combination of observations and short-range forecasts, to adjust the initial conditions to the current state of the atmosphere (Daley, 1993; Kalnay, 2003). Data such as temperature, pressure, humidity, and wind are acquired by weather stations, or radiosounding balloons to get a profile of the troposphere (Malardel, 2005).

Air temperature, barometric pressure, wind speed, and direction are commonly measured at weather stations, but also with costal or drifting weather buoys. Some boats and aircrafts are also equipped with sensors acquiring various atmospheric variables.

Rain gauge stations provide point precipitation measurement. It is the first and most common way to measure precipitation, and so it has the advantage that long time series exist. However, these are subject to systematic errors (values lower by about 5–10%) related to the wind and to the choice of the gauge site (over exposure to the wind in open area or shade effect from obstacles around) and gauge design (Shuttleworth, 2012). The height of the gauge is a defined parameter and balances the effect of the wind that decreases closer to the ground, and of the splash-in that increases nearer to the ground. The rain gauges evolved to reduce errors linked to the wind, to evaporation, and to condensation, and changed from manual measurements toward automatic recording.

Weather station networks are organized at a national or regional scale. In 1995, the World Meteorological Organization proposed a resolution (Resolution 40) to “facilitate worldwide co-operation in the establishment of observing networks and to promote the exchange of meteorological and related information in the interest of all nations” (WMO, 2012b). This database contains time series from all over the world.

Precipitation assessment by remote sensing is not as accurate as ground-based measurements, but it provides information in area where no or few observations exist. It is likely to be the only way for precipitation measurement to be possible at a global scale (Shuttleworth, 2012). The Tropical Rainfall Measuring Mission (TRMM) satellite with precipitation radar onboard allows measuring the vertical structure of precipitation (Iguchi et al., 2000; Kawanishi et al., 2000). Precipitation can also be derived from visible and infrared satellite data (Griffith et al., 1978; Vicente et al., 1998).

In addition, the meteorological satellites such as meteosat-9 (www.eumetsat.int) deliver images in visible or infrared spectra providing important data to the meteorologist. It is also a very important source of information in case of the development of severe hazards, such as hurricanes.

## Monitoring of climate and climate change

Climate studies rely on long series of high-quality climate records (Figure 1). The most analyzed parameter is the air temperature. Scientists use data recorded at weather stations over decades and employ different methods to reconstruct past data before the beginning of the measurements. Data reconstruction, rescue, and homogenization are still important topics today.

Some satellites have radiometers on board to monitor clouds and thermal emissions from the Earth and Sea Surface Temperature (SST) (NASA, 2012a). For instance, SST can be measured using the calibrated infrared Moderate Resolution Imaging Spectroradiometer (MODIS) installed on Observing System satellites Terra (Minnett et al., 2002). The sea level can be measured using a Radar altimeter of the Jason-2 satellite, which permits one to provide inputs for El Niño or hurricane monitoring. Sea level rise is mainly caused by climate change and is currently about 3.4 ± 0.4 mm/year (Nerem et al., 2010).

## Floods monitoring

Floods have several origins often linked to intense precipitation, massive snowmelt, tsunamis, hurricanes, or storm surges, but several are related to other hazards like landslides and rockfalls. The main instrumental setups to forecast floods are weather stations, with a particular emphasis on the rain gauge, weather radars, and meteorological models.

The direct monitoring of floods is done by measuring rivers discharge and/or lakes and sea level. The river discharge is linked to the measurement of the stage (or level), which is the water height above a defined elevation, by a stage-discharge relation. The stages of rivers or lakes are measured by float, ultrasonic, or pressure gauges (Olson and Norris, 2007; Shaw, 1994). The stage-discharge relation has to be updated frequently because of erosion and deposition problems. This relationship is established using current-meters based on rotor or acoustic Doppler velocimeter which establishes the velocity contours of the river section (Olson and Norris, 2007; Shaw, 1994). Radars are also used and seem to be a promising way to obtain discharge (Costa et al., 2006), by using ground-penetrating radar (GPR; the echo of emitted microwave permit to get the river bed profile) coupled with a Doppler velocimeter in order to get the discharge estimation.

In several lowland areas, flood monitoring includes the embankment monitoring that means stability analysis as for landslides. The survey of affected flood area is performed by man-made mapping, aerial photography, or satellite imaging when the flood area is wide, as in Bihar (India) in August 2008 (UNOSAT, 2012).

## Earthquake monitoring

Earthquakes monitoring has two objectives: one to provide data for hazard assessment and the other to develop some aspects for prediction. The main recent technologic advances are GNSS and InSAR techniques that allow one to observe the deformation of the Earth's crust before (interseismic), during (coseismic), and after (post-seismic) an earthquake (Figure 2). This permits, for instance, to expect large earthquakes like in the Cascadia Subduction Zone (Hyndman and Wang, 1995), California, and Turkey (Stein et al., 1997).

The displacements recorded by several seismometers provide the necessary information to estimate the location of an earthquake, its magnitude or the energy released. The statistics of the magnitude for defined zones lead to define the Guntherber-Richter law which may be used to obtain the probability of occurrence for earthquakes of a magnitude larger than a given value. In addition, fine analysis using inversion methods of wave signal provides information to characterize the surface of failure (Ji et al., 2002).

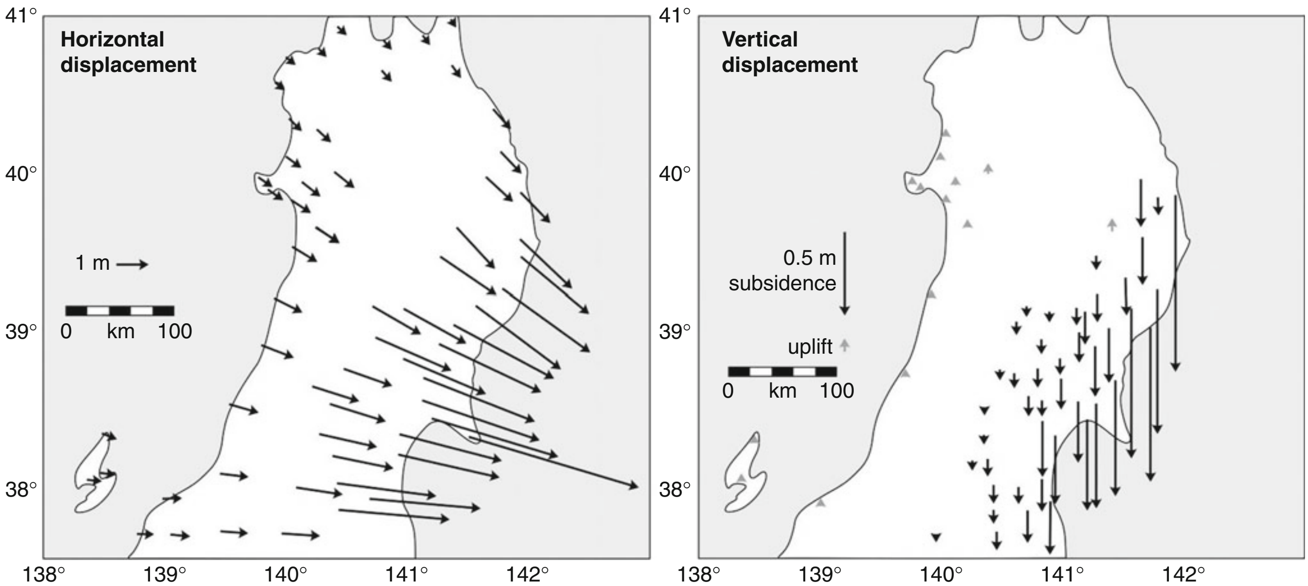
The use of monitoring to predict events within a few days or hours is not yet possible because of the variability of geodynamical contexts. For example, a monitored variable may display opposite signals depending on the context, such as radon which can increase before earthquakes as in Kobe in 1995 (Igarashi et al., 1995) but which can also decrease (Kuo et al., 2006). The amplitude of the signal is thus not significant. The observation of an enhanced activity close to a fault (foreshocks) can be used as signal, but this activity increase does not necessarily lead to earthquakes.

The forecast is still not accurate, but observed ground deformations coupled with history of earthquakes permit one to estimate the probability that large earthquakes occur at a location within a period of time (Stein et al., 1997). The two most promising methods are the following: (1) The first is to characterize the ground mechanical properties using ambient seismic noise. The post-seismic period leads to significant seismic velocity changes (Brenguier et al., 2008), indicating most probably stress field modification, but it seems from recent results that it can also be observed before the earthquake. (2) The second is to analyze ionospheric anomalies of the total electron content that are detected before earthquakes by GNSS systems (Heki, 2011).

## Tsunamis monitoring

Tsunamis can have different origins including earthquakes, large volcanic eruptions, submarine landslides, rock falling into water, etc. The indirect monitoring is related to the triggering factors of the phenomenon, which are mainly earthquakes or landslides. The Åknes rockslide in Norway is an example of indirect monitoring applied to mountainside instability of significant volume that can fall into a fjord and generate a tsunami. The monitoring of the instability is part of a full early warning system including the evacuation of villages located on the coast within a few minutes (Blikra, 2008).

The direct monitoring of tsunamis is the record of the wave propagation and can be fundamental for different reasons: a large earthquake does not lead necessarily to a tsunami, then the alarm should be canceled if the closest gauges do not indicate any wave (Joseph, 2011); the wave can occur later than expected; the occurrence of landslides (submarines or not) are not always detected. In addition to tide gauges, several seafloor sensors (pressure) are located near the coastal areas of continents and islands, but also in the middle of the ocean (Joseph, 2011). The most advanced monitoring system is the Deep-Ocean Assessment and Reporting of Tsunamis (DART II), and it consists of a surface buoy localized by GNSS and communicating the pressure recorded at the bottom of the ocean by a pressure sensor. The communication with a satellite is bidirectional (Meinig et al., 2005). Such devices are being deployed all over the world (NOAA, 2012) showing great results, like the satellite altimeters that




**Monitoring Natural Hazards, Figure 2** Coseismic crustal deformation of the Tohoku Earthquake. Horizontal and vertical displacement. These displacements are defined by the difference between the positions on the day before the mainshock (March 10) and those after the mainshock, March 11 (Modified and simplified after RCPEVE, 2012).

recorded accurately the 2004 Sumatra tsunami wave all around the world (Smith et al., 2005).

## Volcanoes monitoring

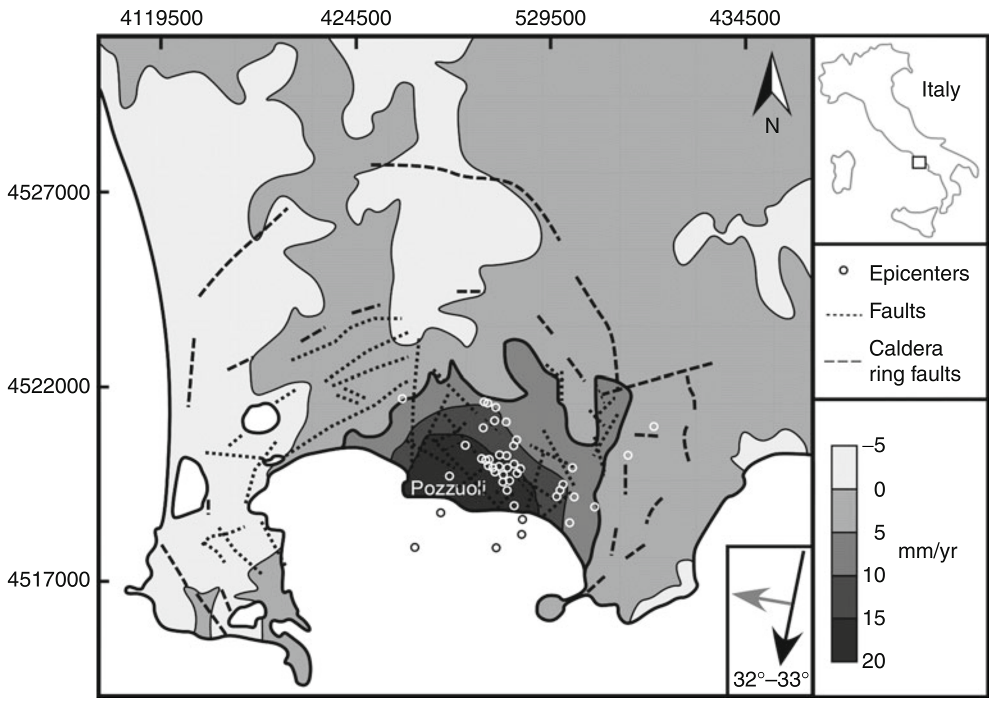
Volcanoes are one of the most spectacular natural hazards on Earth and can be the most disastrous. As an example, the eruption of the Krakatau (Indonesia) in 1883 killed some 30,000 people, releasing a significant volume of ash that briefly affected climate (Durant et al., 2010) and generated a large tsunami wave (Gleckler et al., 2006). As eruption types are so diverse, their monitoring is not easy. Several activities can provide precursory signs, linked to magma movements which change the properties of the ground. The first activity signs that are usually monitored by seismographs are tremors indicating stress adjustments. These stress changes induce ground deformations that can be observed by high precision tiltmeters, indicating changes in slope of the surface. Currently, GNSS are commonly used (Figure 3); they can provide continuous 3D displacements and have partially replaced the electronic distance meter (EDM) laser beam. In addition, since the early works of Massonnet et al. (1995), the InSAR technique allows one to observe deformation of volcanoes, providing information on their behaviors. Any change in the ground can influence measurable parameters such as gravity, temperature, and magnetic field. All those variables can be monitored. The change in gas composition in fumaroles is frequently reported, especially an increase in $CO_2$ content or a change in the ration F/Cl. Nevertheless, it is quite difficult to monitor gases because they follow preferential paths up to the surface that can change during a precursory period (McNutt et al., 2000). At Etna volcano, ambient seismic noise signature has been recognized as a potential precursor that can be monitored in order to forecast an eruption (Brenguier et al., 2008).

The monitoring of volcanoes does not only involve the volcano itself, but also ash that can disturb aerial traffic or have an impact on the agriculture. Sulfur dioxide, ash, and aerosols (sulfuric acid) are mostly monitored by satellite imaging (ultraviolet and infrared sensors) which is not designed directly for that purpose (Prata, 2009). As those processes are closely linked to atmosphere movements, many of the monitoring techniques of weather forecasting are also used.

## Landslides monitoring

Landslides are easily observed because they are moving masses affecting and deforming the relief. As a consequence, the main variables to monitor are the movement and parameters that are modifying the stress or the properties of the material that is under deformation (SafeLand, 2010). Except in the case of earthquakes or exceptional precipitation, the displacement is the main parameter to monitor. In most of the cases, the failure is preceded by an acceleration of movements. Depending on the material geometry and the volume involved, the failure may be forecasted (Crosta and Agliardi, 2003), and this acceleration can sometime be directly correlated with groundwater level using a mechanical model (Corominas et al., 2005).

Two types of landslides must be distinguished: shallow and deep-seated landslides. The first are too small and too localized to be easily monitored, but today several




**Monitoring Natural Hazards, Figure 3** PS-InSAR™ showing uplift along the line of sight with data from descending orbit on October 2005–November 2006. Observe the correlation between uplifts, structures, and seismic activity (Modified and synthetized after Vilardo et al., 2010).

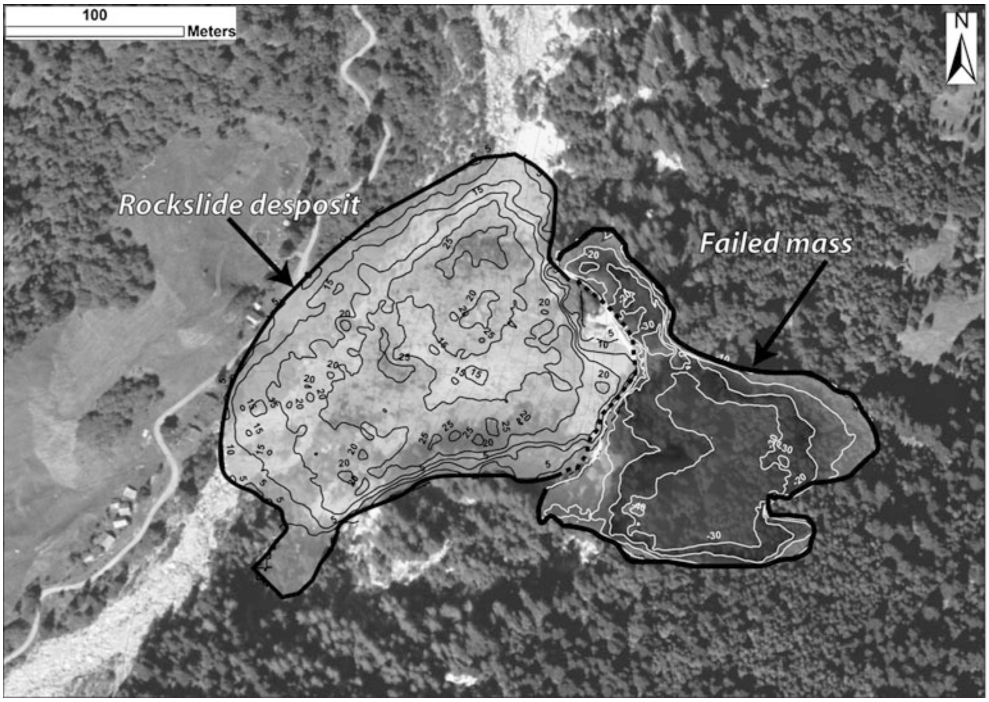
attempts are made to create early warnings for shallow landslides (Sassa et al. 2009). The deep-seated failures are usually sufficiently large to display significant movements before catastrophic failure.

## Large landslides monitoring

The main instruments used to monitor large landslides are dedicated to movements. Physically, extensometers can be used to measure displacements and crack meters can be used to observe the opening of cracks. When boreholes are available, manual inclinometer or permanent inclinometer columns may be used, providing the deformation profiles and often the failure surface where most of the deformation concentrates. These devices are often used for early warning system, as for the site of Åknes (Norway) (Blikra, 2008). As water plays an important role in controlling movements of a landslide, boreholes can be used to measure the level of the water table (manually or by measuring the groundwater pressure).

Surface movements can be followed using targets and total station (laser distance meter), but today, if the required conditions of visibility are appropriate, permanent GNSS can be used for a permanent monitoring of the movements (Gili et al., 2000). The disadvantage of these methods is that they are point measurements only. By using advanced satellite InSAR techniques (PS-InSAR, SBAS, etc.), a significant percentage of landslides can be imaged and monitored. In addition, time series of displacement of ground reflectors can be obtained. One of the last evolutions of the InSAR is the SqueeSAR™ method that enhances significantly the capability of tracking ground displacement (Ferretti et al., 2011). Unfortunately, satellite InSAR is not suitable for early warning because satellites take several days to pass over an area a second time. If no appropriate reflective object exists on the monitored surface (for instance due to forest cover), the InSAR method can be applied only if corner reflectors are installed on the ground, providing movements on selected points only (Singhroy et al., 2011). With ground-based InSAR (GB-InSAR), it is possible to follow the movements of the surface of a landslide or rockslide, when it is visible in the direction of the line of sight. This is very useful to observe the deformation evolution of the front of landslides (Tarchi et al., 2003).

The Lidar technique provides full 3D point clouds in the case of terrestrial Laser scanner (TLS), which allows characterizing rock slopes and landslides (Safeland, 2010; Jaboyedoff et al., 2012). It permits one to monitor and to follow the full evolution of a landslide surface that is moving, to understand mechanisms of failure (Oppikofer et al., 2008) and also to monitor rock fall by comparison of successive acquisitions (Figure 4). The airborne Laser scanner (ALS) is less accurate but




**Monitoring Natural Hazards, Figure 4** Map of the deposit and failed mass thickness of the of the Val Canaria rockslide (Ticino, Southern Swiss Alps). This map based on the comparison of the airborne and terrestrial Lidar digital elevation model taken before and after the 27.10.2009 rockslide event (modified after Pedrazzini et al., 2011; the aerial picture and airborne Lidar are provided by swisstopo).

permits one to estimate differences between digital elevation models.

For most landslides, several different sensors are required to establish an early warning system (Blikra, 2008; Froese and Moreno, 2011). Since a few years ago, photogrammetry and image correlation have developed, leading to very promising results (Travelletti et al., 2012). Geophysics methods are also improving their capabilities to image the underground. One of the most interesting recent developments is ambient seismic noise analysis. For a rock mass, it indicates a decrease of the natural frequency before failures and for landslides, a decrease of the surface wave velocity (Mainsant et al., 2012).

### Debris flow and shallow-landslides monitoring

Shallow landslides and debris flow landslides are mostly dependent on precipitation. As a consequence, the main monitored variables are precipitation intensity, and duration (Baum and Godt, 2010; Jakob et al., 2011). Saturation, soil moisture, and antecedent precipitation are variables that are also often monitored. In the case of shallow landslides, the exact location cannot be determined, thus the entire area is considered as hazardous if some thresholds are exceeded. It must be noted that an early warning system designed for rainfall-induced landslides is operational in Hong Kong and has been continuously improved since 1977 (Chan et al., 2003; Sassa et al., 2009).

In the case of debris flows, sensitive catchments can be equipped in order to issue warnings. The seismic sensors and ultrasonic gauges permit one to deduce velocity and peak discharge (Marchi et al., 2002).

Monitoring shallow landslides and debris flows is still a topic of research under development because the triggering and the localization of such phenomena are not yet well understood.

## Snow avalanche monitoring

Snow avalanches are seasonal events and depend strongly on climate variables such as previous precipitation, snowpack depth and strength, and temperatures. As a consequence, snow avalanches monitoring concentrates essentially on hazard level quantification. This is mainly performed using human observations (SLF, 2012) and weather stations equipped by ultrasonic snow depth sensors. Observed variables are strongly dependant on local physiographic conditions. In addition to monitored data, the observers perform snow hardness tests in order to detect the potential mechanical weakness in the snowpack (Pielmeier and Schneebeli, 2002). The conditions for avalanches are so diverse (wet snow, large amount of fresh snow, etc.), that up to now, human intervention in the monitoring remains the main method to monitor and forecast this hazard.

## Other monitoring

There are other hazards to monitor. Some require the integration of meteorological data in the monitoring design. For instance, a drought corresponds to a period of abnormally dry weather leading to a deficit of water in the hydrologic cycle and finally leading to problems (but the definition of drought is not unique). Forest fires are consequences of dryness, with origins that are often not natural, but anthropogenic. Hail storms are also hazardous phenomenon that can lead to serious damage; hail monitoring is mainly based on human observation and meteorological radar. Lightnings are monitored using an electromagnetic sensors network. All the sensors detecting one specific lightning provide the distance to it. The location is then deduced by searching the best agreement between all the detected distances to sensors.

## Future of monitoring as a demand of the society

The monitoring of natural hazards is often a tedious task because if the physics well describes the single phenomenon, in natural environments, the occurrence of an event is controlled by several simultaneous phenomena. It implies that, for the analysis and prediction of events, a number of different variables are required to be able to describe all possible cases.

The power of computer science, communication technologies, and the improving quality of sensors, combined with decreasing prices, make the monitoring of environmental data more precise and easy. This leads to new understanding of natural hazards and also to the implementation of early warning systems that will permit one to manage territories in a safer way. In addition, nowcasting, as proposed by World Meteorological Organization, is now an objective of this organization to provide forecasts in less than 6 h. Such developments are mainly possible because of computer power available almost everywhere and a generalized ability to communicate rapidly by anybody with the "smartphone" technology.

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## Cross-references

Accelerometer
Airphoto and Satellite Imagery
Avalanches
Climate Change
Debris flow
Deep-Seated Gravitational Slope Deformations
Doppler Weather Radar
Earthquake
Earthquake Prediction and Forecasting
El Niño/Southern Oscillation
Eruption Types (Volcanic)
Flash Flood
Flood Hazard and Disaster
Hurricane (Cyclone, Typhoon)
Hydrograph, Flood
Inclinometer
North Anatolian Fault
Piezometer
Pore-water Pressure
Remote Sensing of Natural Hazards and Disasters
Rock Avalanche
Rockfall
San Andreas Fault
Santorini
Seismic Gap
Seismograph/Seismometer
Slope Stability
Tiltmeters
Tohoku, Japan, Earthquake, Tsunami and Fukushima Accident (2011)
Tsunami

# MONSOONS

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## Synonyms

Mausam; Rainy season; Wet season

## Definition

The term "monsoon" is derived from the Arabic word "mausam," which means season. Halley (1686) defined monsoon as the seasonal reversal of steady and sustained surface winds, which blow from the northeast during winter and from the southwest during summer. In spite of this original definition rooted in atmospheric circulation, rainfall is another variable that has been widely used to define monsoon.

## Discussion

Although there is no universal definition, monsoons are atmospheric systems with certain well-defined characteristics (Webster 1987). All monsoons have a life cycle characterized by distinct onset, maintenance, and demise phases. They feature abundant rainfall during summer and dry conditions during winter. The strongest monsoon, the Asian summer monsoon (Ramage 1971), affects about half of the world's population. Monsoons are also found in other tropical–subtropical land areas, including Australia, Africa, South America, and North America (Webster 1987; Nogues-Paegle et al., 2002; Sultan et al., 2003; Higgins et al., 2006).

Monsoon variability is influenced by various weather and climate phenomena, including synoptic-scale disturbances, tropical waves and cyclones, and tropical intraseasonal variations that contribute to active and break periods. Interannual and longer variations of monsoons are due to both internal dynamics of the coupled atmosphere–ocean–land system and interactions of monsoons with other climate phenomena such as El Niño-Southern Oscillation, snow cover, and the Pacific Decadal Oscillation.

Although the major cause of monsoons is the thermal contrast between land and ocean, the discernable features of monsoons vary from region to region. The monsoon climate over many Asian countries is characterized by wet and hot conditions in summer but dry and cold conditions in winter, corresponding to a pronounced seasonal reversal of surface winds. However, regions close to the equator usually experience two rainy seasons. Over eastern Africa, the monsoon rainfall is characterized by "long rain" in March–May and "short rain" in October–December. The North American monsoon is characterized by distinct rainfall maxima over western Mexico and the southwestern United States and by an accompanying upper-level anticyclone over the higher terrain of northwestern Mexico. The South American monsoon features a pronounced wet season (November–March) and a dry season (April–September) over central Brazil. An intense upper-tropospheric anticyclonic circulation, located over eastern Bolivia, appears during the wet season.

Monsoon variability is often related to floods, drought, and other hazardous extreme weather and climate events. Excessive monsoon rainfall causes floods and landslides and hence considerable social and economic impacts. Alternately, insufficient monsoon rainfall leads to drought, and therefore scarcer fresh water supplies. Monsoon depressions and tropical storms with high winds and tidal surges are often embedded within the large-scale monsoon circulation, posing threats to human lives and property. Monsoon behavior, such as the intensity and duration, influences economic planning and development, water resource management, agriculture (planting and harvesting), and emergency response. Because of the significant societal and economic impacts of monsoons, it is important to continue to improve understanding towards more realistic simulation and prediction of monsoons.

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## Cross-references


Challenges to Agriculture
Cloud Seeding
Doppler Weather Radar
Drought
El Niño-Southern Oscillation
Erosion
Flash Flood
Hydrometeorological Hazards
Storm Surges


CASE STUDY

# MONTSERRAT ERUPTIONS


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Montserrat is a small volcanically active island in the Caribbean situated on the Lesser Antilles island arc. The island's main volcano is called the Soufrière Hills and this volcano has been erupting since 1995.

## 1995–1998

In 1995 after 40 years of quiescence a relatively small lava dome was extruded. This dome grew at 4 $m^3$/s until 1997 when the dome collapsed producing multiple pyroclastic flows. These burning clouds of ash destroyed the previously evacuated capital city of Plymouth in March 1997 and killed 19 people in June 1997. The volcano continued to erupt until 1998 showing a cyclic seismic and dome growth behavior that was used by scientists at the newly established Montserrat Volcano Observatory (MVO) to provide short-term forecasts (McNutt et al., 2000). This initial period of activity changed Montserrat dramatically, destroying the prosperous south and forcing residents to relocate to the rugged and difficult north (Figure 1). In 1998 the pre-eruption population of 11,000 had reduced to just 4,000 as long-term evacuations, loss of livelihoods, and personal danger forced the people of Montserrat to transmigrate, mainly to the United Kingdom (Aspinall and Cooke, 1998).

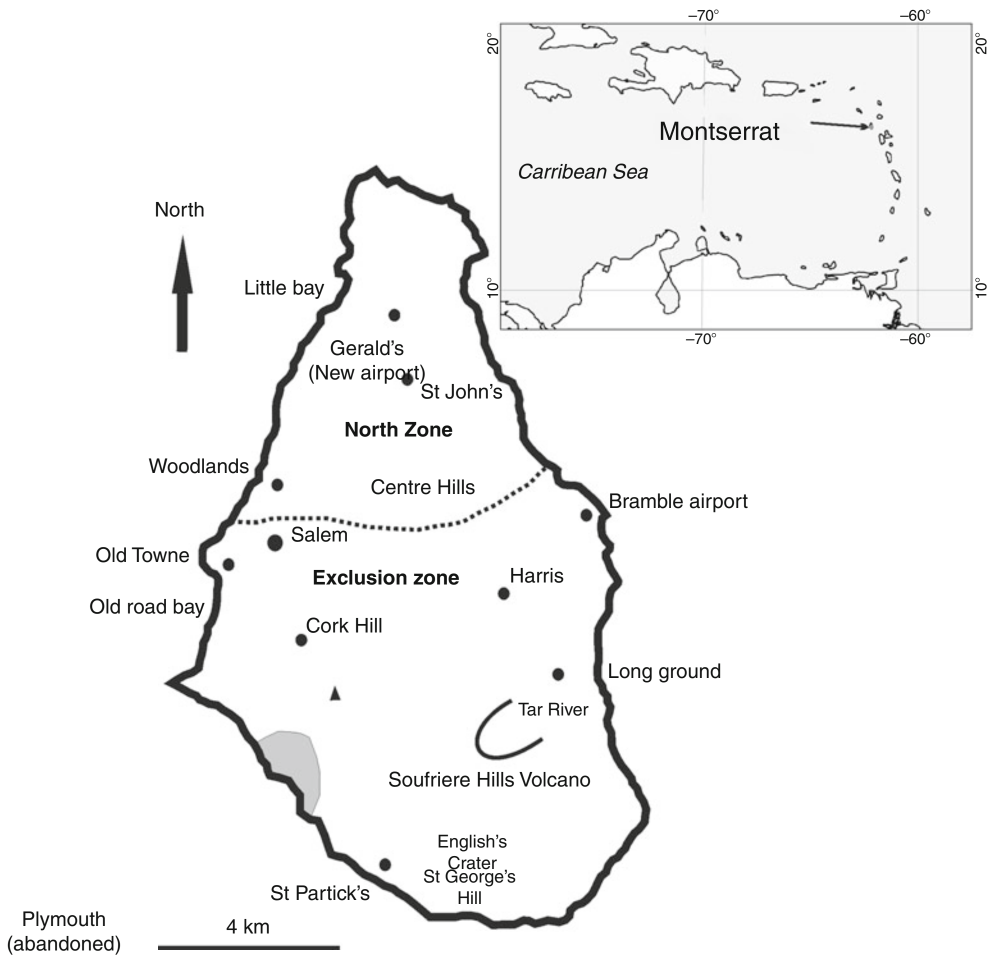
## 1998–2003

As the people gradually abandoned hope the volcano continued to erupt. Between 1998 and 2003, Andesitic lava domes continued to grow and collapse, for example, in 2000 a 29 million $m^3$ dome collapsed generating a magmatic eruption and over 40 pyroclastic flows (Carn et al., 2004). In 2003, the volcano produced the largest dome collapse ever recorded in historical time with 210 million $m^3$ of material giving way, and 170 million $m^3$ collapsing in just 2 hours of activity (Herd et al., 2005). Figure 2 shows the smoking crater that was left behind. This major collapse followed 2 years of dome growth, caused a tsunami, a previously unrecorded pressure wave, a shock wave, and tephra fall that caused extensive damage on Montserrat and neighboring islands (Herd et al., 2005).

## 2003-Onwards

The Soufriere Hills is now the best monitored volcano complex in the Caribbean with an array of technologically advanced monitoring equipment and a permanent scientific team. But recent changes in seismicity, which previously aided eruption forecasts, have led to changes of procedure at the MVO and increased pressure to find more accurate precursors (Luckett et al., 2008).

As the physical monitoring of the volcano continues, so does the struggle of the Montserrat people (Figure 3). Relocation to the northern regions caused long term social issues, including a lack of cultural building considerations and inferior agricultural land causing residents to return to the dangerous regions to farm. Transmigration also caused multiple stresses and unanticipated concerns, for example, there was a lower standard of schooling in the UK compared with pre-eruption standards on the island (Kelman and Mather, 2008). As the eruption continues the future of the remaining Montserratians is unclear, they require a sustainable livelihood in order to remain on the island but with limited space and imminent danger this may be difficult to achieve. Scientists and local authorities are under extreme pressure to protect the remaining Montserratians from further suffering.




**Montserrat Eruptions, Figure 1** Location of Montserrat Island and the Soufriere Hills Volcano. This map also marks the exclusion zone that covers the majority of the southern island.

**Montserrat Eruptions, Figure 2** A view of the crater taken in December 2004 (*Catherine Lowe*).

**Montserrat Eruptions, Figure 3** A minibus used for tourism is caught in a lahar in November 2004. This image demonstrates the difficulties in maintaining a sustainable livelihood on an active volcanic island (*Catherine Lowe*).

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## Cross-references

Base Surge
Civil Protection and Crisis Management
Community Management of Hazards
Disaster Risk Reduction
Early Warning Systems
Eruption Types (Volcanic)
Evacuation
Galeras Volcano, Colombia
Human impact of hazards
Krakatoa (Krakatau)
Magma
Mt. Pinatubo
Nevado del Ruiz Volcano, Colombia
Nuee Ardente
Pyroclastic Flow
Santorini
Tsunami
Volcanoes and Volcanic Eruptions

# MORTALITY AND INJURY IN NATURAL DISASTERS

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## Synonyms

Casualties; Fatalities

## Definition

*Disaster.* An event that causes significant damage, destruction, or loss of life where local response capacity is overwhelmed and outside assistance is required.

*Natural disaster.* Disasters resulting from the effects of naturally occurring hazards such as earthquakes, volcanoes, floods, or extreme climatic events.

*Natural disaster mortality.* Deaths resulting from a natural disaster, most often those that are immediate and directly attributable to the event.

*Natural disaster injury.* Physical damage or harm to the body caused by a natural disaster.

## Natural disaster mortality and injury in the twentieth century and beyond

Since the beginning of the twentieth century, natural disasters have resulted in over 22.6 million deaths and 6.6 million injuries, and have affected the lives of more than 5.4 billion people (CRED, 2010). While the number of natural disasters reported and the size of populations affected have followed an increasing trend, fatalities have declined as a result of advances in early warning systems, disaster preparedness, and improvements in emergency management and response. However, human vulnerability to natural hazards is escalating, primarily due to the increasing population density and land use change which suggests that the human toll of future natural disasters will rise (Huppert and Sparks, 2006; United Nations, 1988). Poverty is a major risk factor for mortality and injury in natural disasters, and the size of impoverished populations in high-risk areas is likely to increase in future years (Eshghi and Larson, 2008).

A rapid-onset natural disaster is an event that is triggered by an instant shock. Most natural disasters are classified as rapid-onset events though it is important to note that in some cases there is enough warning time to allow for evacuation and other mitigation measures. In contrast, a slow-onset natural disaster unfolds over a longer time period where the hazard is felt as an ongoing stress over days, months, or even years (UNDP, 2004). Natural disaster impacts on human populations from 1900 to date are summarized in Table 1. More than half (52%) of reported deaths in natural disasters since the beginning of the twentieth century are attributable to drought. The significance of drought-related deaths is historically underappreciated where many casualties are secondary or indirect and are uncounted. Floods and earthquakes are also large contributors to natural disaster mortality, accounting for 31% and 10% of deaths, respectively. Natural disaster injuries were overwhelmingly caused by three types of events: earthquakes (33%), extreme temperature events (28%), and floods (20%).

## Drought

More than half of disaster-related deaths since the beginning of the twentieth century are attributed to drought, a slow-onset natural disaster that has devastating long-term effects on communities. Drought is a frequent phenomenon that is sometimes associated with famine; however, famines are rare, complex, and often the result of multiple underlying causes including chronic poverty, economic inequalities, and conflicts (Sen, 1982).

Some of the worst famines in the recent history include the 1943 Bengal famine, the Great Leap Forward famine in China from 1958 to 1961, the 1974 famine in Bangladesh, and regional famines in the Sahel during the mid-1970s and mid-1980s (CRED, 2006). In recent decades, drought-related mortality has been concentrated in Africa where in many cases drought-related impacts are exacerbated by conflict and other preexisting cultural and political tensions. Both starvation and disease epidemics are primary causes of drought mortality; however, many secondary deaths where drought is a causal factor go unreported (CRED, 2010). While drought-related mortality is complex, multicausal, and likely to be underestimated, numerous methodologies and long-term development strategies exist that seek to reduce the impacts of drought (Dreze and Sen, 1990; FEWS, 2010). Compared to other types of natural disasters, droughts clearly resulted in the greatest number of deaths in the past century, however, drought-related mortality has substantially decreased in recent history where between 1990 and 2009, there were 37 droughts with a total of 4,472 deaths reported (CRED, 2010).

**Mortality and Injury in Natural Disasters, Table 1** Mortality and injury associated with natural disasters, 1900–2009[a]

| | Mortality | | Injuries | |
|---|---|---|---|---|
| Hazard type | N | % | N | % |
| *All geophysical events* | *2,414,208* | *10.7* | *2,191,887* | *33.0* |
| Earthquake[a] | 2,313,294 | 10.2 | 2,180,226 | 32.8 |
| Volcano | 95,979 | 0.4 | 11,152 | 0.2 |
| Mass movement dry | 4,935 | 0.0 | 509 | 0.0 |
| *Meteorological events (storms)* | *1,374,993* | *6.1* | *1,294,556* | *19.5* |
| *All hydrological events* | *6,968,301* | *30.9* | *1,303,199* | *19.6* |
| Flood | 6,913,134 | 30.6 | 1,293,919 | 19.5 |
| Mass movement wet | 55,167 | 0.2 | 9,280 | 0.1 |
| *All climatological events* | *11,821,088* | *52.4* | *1,856,696* | *27.9* |
| Drought | 11,708,271 | 51.9 | – | 0.0 |
| Extreme temperature | 109,344 | 0.5 | 1,852,761 | 27.9 |
| Wildfire | 3,473 | 0.0 | 3,935 | 0.1 |
| *Total* | *22,578,590* | *100* | *6,646,338* | *100* |

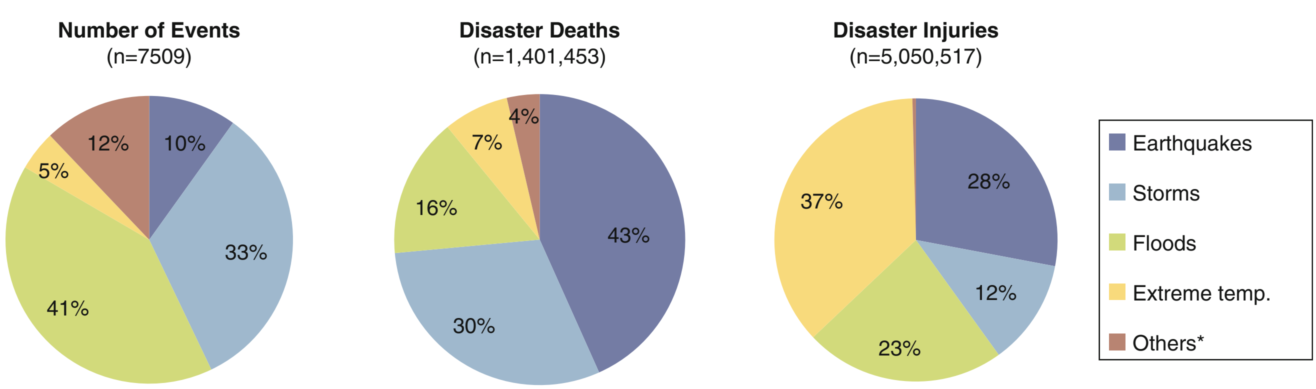
Source: CRED, 2010
[a]Includes mortality and injury from earthquake-induced tsunamis

## Mortality and injury in rapid-onset natural disasters, 1980–2009

Rapid population growth and changing trends in natural disasters over time suggest that earthquakes and storms will have the greatest impacts on human populations in the coming decades. Rapid-onset natural disasters, including earthquakes, volcanoes, meteorological events, floods, mass movements, and wildfires, caused over 1.4 million deaths and 5.0 million injuries within the past three decades. Deaths and injuries in rapid-onset natural disasters in the past 30 years are summarized in Figure 1 and Table 2. Earthquakes, which accounted for only 10% of events, resulted in 43% of deaths and 28% of injuries. Storms, including cyclones and hurricanes, comprised 33% of events and were the cause of 30% of deaths and 12% injuries. The most common event, floods, was associated with 16% of mortality and 23% of injuries. Extreme temperature events, which accounted for 5% of rapid-onset natural disaster events, resulted in 7% of deaths and 37% of injuries. Injury reporting is likely more complete in extreme temperature events than other types of disasters, particularly those in the middle- and low-income countries where the majority of mortality and injury occur, because the vast majority of extreme temperature events are in high-income countries where better health information systems ensure more accurate reporting. Other disaster types, including volcanic eruptions, mass movements, and wildfires, accounted for 12% of events collectively but contributed only 4% of mortality and <1% of reported injuries (CRED, 2010).

## Earthquakes

Earthquakes are concentrated in Asia which is the most populous continent with approximately 60% of the world's population (UN, 2010). Over the past century,




**Mortality and Injury in Natural Disasters, Figure 1** *Rapid-onset natural disasters and their impact on human populations, 1980–2009* (Source CRED, 2010. **Others include volcanoes, wet and dry mass movements, and wildfires*).

**Mortality and Injury in Natural Disasters, Table 2** Casualties in rapid-onset disasters, 1980–2009

| Hazard type | Total number of casualties | | Average per event | |
|---|---|---|---|---|
| | Deaths | Injuries | Deaths | Injuries |
| Earthquakes | 617,201 | 1,412,010 | 827 | 1,893 |
| Storms | 430,131 | 611,538 | 174 | 247 |
| Floods | 199,481 | 1,155,699 | 66 | 380 |
| Extreme temperature | 103,475 | 1,852,161 | 307 | 5,496 |
| Others[a] | 51,165 | 19,079 | 56 | 21 |
| *Overall* | 1,401,453 | 5,050,517 | 187 | 673 |

Source: CRED, 2010
[a]Include volcanoes, wet and dry mass movements, and wildfires

53% of earthquakes and 75% of earthquake mortality were in Asia, and their impact in this region has been increasing in the recent decades in parallel with rapid population growth and industrialization. In the past 30 years, 86% of earthquake deaths were in Asia. An average of 827 deaths and 1893 injuries were reported per earthquake disaster between 1980 and 2009. Earthquake-induced tsunamis, which were reported in 3% of earthquakes in the past 30 years, contributed 60% of all earthquake-related fatalities, primarily due to the catastrophic Indian Ocean tsunami in 2004 which resulted in 227,000 deaths and affected over 2.4 million people in the coastal areas of Indonesia, Sri Lanka, India, and Thailand (CRED, 2010). Other recent devastating earthquakes include the 2008 Sichuan earthquake which killed an estimated 87,476 Chinese and the 2010 Haiti earthquake where mortality estimates range from 45,000 to above 300,000 with CRED reporting 22,570 deaths (CRED, 2010; BBC, 2011). The primary cause of death in earthquakes is building collapse, and direct mortality is both rapid, occurring within hours, and delayed where deaths occur within several days of the earthquake (Kunii et al., 1995). Instantaneous deaths are caused by severe crush injuries or trauma-induced hemorrhage; other causes of rapid death include asphyxia from dust inhalation or chest compression, hypovolemic shock, or drowning in earthquake-induced tsunamis. Delayed deaths can be caused by hypothermia, hyperthermia, dehydration, crush syndrome, and sepsis (Safar et al., 1988). In the aftermath of most earthquakes, the majority of people requiring medical assistance have minor injuries including superficial lacerations, sprains, and bruises; fractures and injuries requiring surgery and hospitalization are less common (Noji, 1997). The greatest demand for emergency medical services is within the day following the earthquake, and most of the injured can be treated on an outpatient basis; within 3–5 days, the demand for medical attention at hospital emergency departments usually returns to normal (Schultz et al., 1996; Oda et al., 1997).

## Storms

Meteorological events, which include hurricanes, tropical cyclones, local storms, and winter storms, occurred predominantly in Asia (39% of events) and the Americas (32% of events) over the past 30 years; however, their impact is concentrated in Asia where 90% of deaths were reported. An average of 174 deaths and 247 injuries were reported due to meteorological events between 1980 and 2009. Tropical cyclones are by far the most deadly type of meteorological event and accounted for 94% of storm fatalities, or an estimated 428,734 deaths, in the past 30 years. There were an average of 342 deaths per tropical cyclone, and mortality was concentrated in Asia where more than 91% of tropical cyclone deaths were reported. The most devastating recent tropical cyclones include the 1991 Bangladesh cyclone which killed 138,866 people and cyclone Nargis which resulted in an estimated 138,366 deaths in Myanmar in 2008 (CRED, 2010). The majority of storm-related deaths are drownings associated with storm surges; other causes of mortality and injury include burial in collapsed structures, blunt trauma, and storm-induced mudslides (French, 1989; Noji, 2000). Most care seekers after floods suffer from lacerations and can be treated on an outpatient basis; closed fracture and other penetrating injuries are also common (Noji, 1993, 2000).

## Floods

Geographically, floods in the past 30 years have been concentrated in Asia (42%), the Americas (23%), Africa (21%), and Europe (14%). However, flood mortality occurred predominantly in Asia and the Americas, which accounted for 65% and 25% of flood deaths, respectively; India and Bangladesh have particularly high levels of flood mortality (NRC, 1987; CRED, 2010). The average flood between 1980 and 2009 resulted in 66 deaths and 380 injuries. General floods accounted for 59% of floods and 48% of flood mortality. Flash floods, which comprised 14% of flood events, were the most deadly type of flood, and accounted for 27% of flood mortality (50,764 deaths) with an average of 121 deaths per flash flood. The deadliest recent flash flood in Venezuela killed an estimated 30,000 people in 1999. Other recent high-mortality floods were in China (3,656 deaths in 1998 and 2,755 deaths in 1996), Haiti (2,665 deaths in 2004), Somalia (2,311 deaths in 1997), and India (1,811 deaths in 1998 and 2001 deaths in 1994) (CRED, 2010). Flood deaths and injuries are primarily the result of fast-flowing water that is laden with debris. The main cause of deaths is drowning, followed by combinations of trauma, hypothermia, and drowning (Beinin, 1985). Among flood survivors, a very low proportion of victims require emergency medical care (Noji, 2000). Injuries from floods are generally minor and include lacerations, infection of wounds, skin rashes, and ulcers (PAHO, 1981).

## Extreme temperature events

Extreme temperature events which include heat waves and also extreme winter conditions and cold waves are mostly frequently reported in Europe (45%), Asia (31%), and the Americas (20%). The average extreme temperature event during the past 30 years resulted in 307 deaths and 5,496 injuries. Extreme heat events, which accounted for 36% of extreme temperature events, accounted for 89,046 deaths (87%), while more common extreme cold events (64% of events) resulted in 13,755 deaths (13%). There were an average of 707 deaths per extreme heat event and 62 deaths per extreme cold event over the past 30 years. Overall, 87% of heat wave fatalities were concentrated in Europe, while cold wave deaths were prevalent in both Asia (53%) and Europe (32%). It is important to consider that reporting of deaths and injuries may be more complete in extreme temperature events because extreme temperature events are predominantly reported in more developed countries with better information systems; furthermore as compared to other types of rapid-onset natural disasters, they do not cause infrastructure damage and widespread societal disruption. In extreme temperature events, hyperthermia (heat) and hypothermia (cold) deaths are either direct or indirect causes of mortality and injury. Hyperthermia cases are likely to be underreported because heat-related illness can exacerbate the existing medical conditions and can be difficult to identify; in addition there is variation in criteria used to identify heat-related deaths (MMWR, 2006). In heat waves, where risk of mortality is greater, numerous underlying demographic and physiological characteristics have been identified as risk factors for death, and risk of respiratory death is increased (Davido et al., 2006; Hertel et al., 2009).

## Conclusion

One of the difficulties in assessing natural disaster injury and mortality is that information for many events is unreported or casualty estimates are inaccurate; this is particularly true for injuries that are undocumented for a majority of events. As a result, the true impact of natural disasters on human populations is likely to be substantially greater than the recorded impact, especially in events that occurred before substantial improvements in natural disaster reporting that were observed in the 1970s (CRED, 2010; Ehsghi and Larson, 2008). Understanding the causes of death and injury in natural disasters is important for planning disaster response. Morbidity and mortality patterns for certain types of natural disasters have been identified and can be used to plan the type of relief supplies, equipment, and personnel that will be required in the early stages of disaster response (Noji, 2000). Many factors contribute to the outcome of a natural hazard, including if the hazard evolves into a disaster and the resulting level of impact on human populations. While all natural disasters are unique and require a response that is tailored to the specific event, mortality and injury patterns can be anticipated and used to inform emergency medical relief and the planning and management of the ensuing humanitarian response.

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Casualties Following Natural Hazards
Drought
Economic Valuation of Life
Flood Hazards and Disaster
Galeras Volcano, Colombia
Geological/Geophysical Disasters
Haiti Earthquake 2010 Psychosocial Impacts
Heat Wave
Hurricane Katrina
Hydrometeorological Hazards
Indian Ocean Tsunami 2004
Nevado del Ruiz, Colombia (1985)
Storms
Tangshan, China (1976 Earthquake)
Tohoku, Japan, Earthquake, Tsunami and Fukushima Accident (2011)
Tornadoes
Tsunamis
Vaiont Landslide, Italy
Vesuvius
Wenchuan, China (2008 Earthquake)

CASE STUDY

# MT PINATUBO

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Mt Pinatubo is an active stratovolcano located in Central Luzon, Philippines, that has had significant global impacts.

## The 1991 eruption

Mt Pinatubo had been quiescent for 500 years until 1990 when a nun working with traditional Aetas people living high on the volcano reported unusual activity, such as steaming cracks in the ground, to the Philippine Institute of Volcanology and Seismology (PHILVOLCS). Once these and other volcanic precursors were confirmed, PHILVOLCS in collaboration with a team from the US Geological Survey (USGS) started to monitor the activity and collate all existing geological data on previous activity.

**Mt Pinatubo, Figure 1** The pre-climactic eruption column of Mt Pinatubo taken on 12 June 1991 from Clark Air Base (This photograph has been reproduced courtesy of the Philippine Institute of Volcanology and Seismology).

Previous eruptions had been recorded in local oral histories and warned of caldera forming eruptions lasting up to 3 days (Rodolfo and Umbal, 2008), yet geological surveys for the volcano were scarce and the international team of volcanologists had very little time to estimate potential eruption size and impact. Despite this, a 5-level warning system was implemented and evacuation zones were delineated (Newhall 2000). Fortunately, because of the quick actions of the scientists and government some 85,000 people were evacuated just before one of the most powerful eruptions of the twentieth century took place on 15 June 1991 (Leone and Gaillard, 1999; Gaillard, 2008) (Figure 1).

The eruption caused widespread destruction ejecting 5 $km^3$ of magmatic material and leaving behind a 2.5 km wide caldera (see Table 1). This eruption affected 2.1 million people and despite the added danger from a coinciding typhoon, approximately, only 300 people were directly killed and the management of this eruption was considered a success. The eruption was recorded in detail within the text *Fire and Mud: Eruptions and lahars of Mount Pinatubo* edited by C. Newhall and R.S Punongbayan (1996).

## The secondary hazard and long-term social impact

The combination of widespread volcanic deposits and seasonal rains caused a secondary hazard known as lahars

**Mt Pinatubo, Table 1** A statistical summary of the main products produced by the 1991 Mt Pinatubo eruption (Source: Wolfe and Hoblitt, 1996)

| Hazard type | In detail | Size | Impact area |
|---|---|---|---|
| Tephra | Thickness deposited | 1 cm $<$ thick | 75,000 $km^2$ |
| | | 10 cm $<$ thick | 2,000 $km^2$ |
| | Total bulk volume | 3.4–4.4 $km^3$ | |
| Pyroclastic flows | Distance traveled from source | 12–16 km | 5–6 $km^2$ |
| Magma | Total volume | 5 $km^3$ | |
| Total ejecta | Total bulk volume | 8.4–10.4 $km^3$ | |
| Gas | $SO_2$ | 17 Mt | |

**Mt Pinatubo, Figure 2** The top image shows a lahar watch point in the Sacobia-Bamban River on Mt Pinatubo in 1991 and the image below was taken from the same position in 1992. In the lower image, only the roof of the watch point can be seen amongst the lahar deposits (These photographs have been reproduced courtesy of the Philippine Institute of Volcanology and Seismology).

(or volcanic mudflows) that annually threatened an area of 770 $km^2$ (Figure 2). This dangerous long-term hazard is responsible for killing nearly twice as many people than the actual eruption (Gaillard, 2008). Despite efforts to relocate residents out of lahar-prone regions some people still remain. Gaillard (2008) discusses the push and pull factors that motivate these at-risk communities to live in potentially dangerous regions on Mt Pinatubo. Push factors include victims having to pay for their new homes and services despite having no means of income in the long term evacuation centers. Pull factors include historical and cultural attachments, some declaring, "we are dead and drowned but we will never leave" (Gaillard, 2008, 323). Social and political issues caused increased difficulties in the management of lahars and relocation of evacuees, but the scale of recovery efforts indicate the difficulties faced by disaster managers. By 1997, 42,396 families had been re-homed in 23 centers around the volcano. This required 6,000 ha of land in addition to over 300 km of roads and electrical networks (Leone and Gaillard, 1999).

The economic costs of the eruption and lahar activities over the ensuing 2 years has been estimated at 11 billion pesos with 600,000 people losing their sources of income (Tayag and Punongbayan, 1994). This event demonstrates the potential physical and social impacts of such a large eruption and highlights the need for long-term disaster management in volcanic regions.

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## Cross-references


Aviation, Hazards to
Base Surge
Caldera
Early Warning Systems
Evacuation
Galeras Volcano (Colombia)
Krakatoa (Krakatau)
Lahar
Magma
Nuee Ardente
Pyroclastic Flow
Stratovolcano
Volcanoes and Volcanic Eruptions

## MUD VOLCANOES

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### Synonyms

Gas-oil volcano; Mud dome; Sedimentary volcano

### Definition

Mud volcano was defined by Kopf (2002) as a surface expression of mud that originated from depth. Depending on the geometry of the conduit and the physical properties of the extrusive, the feature may be a dome or a pie with low topographic relief (Figure 1). Mud volcanoes may be the result of a piercing structure created by a pressurized mud diapir, which breaches the Earth's surface or ocean bottom.

### Discussion

The connotations relate to formations created by geo-excreted liquids and gases; from extruded mud, and liquid. The parent material is rapidly deposited, overpressured, commonly thick argillaceous sequences of mostly Tertiary age.

The depositional environment includes ridges, plains, and intermountain falls and hollows occupied with temporary salty lakes, and plateaus with an abundance of mud domes and cones extruding mud and rock fragments (gryphons), and water-dominated pools with gas seeps (salses); offshore mud volcanoes form islands and banks on the sea floor that alter the topography and shape of the coastline.

In terms of origin, mud volcanoes are mainly present all over subduction zones and orogenic belts, where rapidly buried sediment overthrusts deeper stratum. With an increase of burial stress and temperature, a decrease in porosity and maturation of organic material are favored (Hedberg, 1974). In these conditions, trapped pore water and forming hydrocarbon gas may cause overpressure of the mud at depth (Judd and Hovland, 1997). The mud, depending on the magnitude of the buoyancy, either slowly ascends through the overburdened rock and forms mud diapirs or extrudes vigorously along zones of structural weakness such as faults and fractures and forms mud volcanoes (Brown, 1990). During rapid ascent, self-ignition of emanating methane may cause flaming eruptions and a societal hazard (Bagirov and Lerche, 1998; Ismail-Zadeh, 2006).

Mud volcanoes are used as source of natural gas. Clay from volcanoes can be used as raw material for production of ceramics and bricks. Mud from volcanoes contains medical qualities and is widely used in local spas and perfumery.

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**Mud Volcanoes, Figure 1** One of the spectacular world mud volcanoes – Bahar (Located in Azerbaijan, photo of B. Panahi).

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## Cross-references

Dispersive Soil Hazards
Expansive Soils and Clays
Liquefaction
Quick Clay
Quick Sand
Volcanoes and Volcanic Eruptions

# MUDFLOW

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## Synonyms

Debris flows; Lahars; Mudslides

## Definition

There is a wide spectrum of natural processes that take the form of a rapid mass movement of saturated soil or sediment under the action of gravitational acceleration; here the adjective "rapid" means that the typical velocity is within the 1–25 m/s range (Iverson, 1997). These mass movements are often referred to as "debris flows." Mudflows constitute an end-member of this large family: when the sediment is rich in clayey materials and poor in coarse particles (note that there is no consensus in literature on classification and the definition of mudflows may vary depending on the authors), the sediment looks like a muddy fluid (Coussot and Meunier, 1996).

## Discussion

In most cases, mudflows are initiated after long or heavy rainfalls over mountain slopes or result from the acceleration of a landsliding mass. Bank and bed erosion may also result in mudflows, in particular in rivers whose channel incises soils made up of loose soils (e.g., loess or volcanic-ash deposits). Once set in motion, mudflows can travel large distances (mostly in the 1–100 km range) and spread over gentle slopes; the mean slope gradient for observing mudflows is usually in excess of 10%, but on some occasions, mudflows were observed on shallow slopes (less than 1%).

The capacity of mudflows to travel large distance has been ascribed to their viscous behavior. There is still a vivid debate on the origins of mudflow fluidity (Ancey, 2007). Some authors provided evidence that the mud behaves like a viscoplastic fluid, that is, like a solid when the shear-stress level is low and like a viscous fluid for shear stresses in excess of a critical value (called the *yield stress*) (Coussot and Meunier, 1996). Other authors consider mud as a liquefied soil, that is, a soil within which pore pressure is sufficiently high to reduce shear strength resulting from particle friction (Iverson, 1997, 2005). Both theories have been implemented in generalized hydraulic models; a set of equations that describe flow evolution in terms of flow-depth and velocity (Huang and García, 1998).

Mudflows are a major threat in mountainous and volcanic areas, claiming thousands of lives and millions of dollars in lost property each year (e.g., Sarno and Quindici in southern Italy in May 1998, where approximately 200 people were killed).

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## Cross-references

Debris Flow
Flash Flood
Lahar
Landslide Types
Mass Movements

# MYTHS AND MISCONCEPTIONS IN DISASTERS

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## Definition and introduction

Humankind has always relied on myths to provide an answer for the unknown. Fact and imagination are interwoven to account for uncertainties. Disasters are prototypical representations of uncertain situations that must be dealt with. What is real in a myth can play its role in coping with a disaster. Equally important, though, is to separate what is imaginary about myths in disaster management. The debate on disaster myths and misconceptions has been a recurrent issue among scholars, practitioners, and other actors involved. This entry does not intend to be a comprehensive account and explanation of all myths in disaster management. This is just an introduction to a few of those myths: epidemics, looting and antisocial behavior, massive population movements, and goods donations.

One of the most popular lists of myths and misconceptions was first published by the Pan-American Health Organization in the 1980s and has been widely used, modified, and adapted ever since (Table 1).

The first 18 items were used by Alexander (2007) in a survey about disaster myths among disaster management students in Italy and USA. Despite the differences in the country of origin, background, training, and field experience, the students gave similar answers. This is illustrative of how deeply rooted some of these wrong assumptions are and how persistent in time they prove to be.

## Dead bodies, epidemics and disease: always predicted, hardly ever materialized

Shortly after nearly every disaster, the news headlines alert people to the risk of major epidemics of communicable diseases. For example, after the 2004 Asia tsunami, there were widespread fears that a second wave of deaths was to be expected, and that disease and epidemics may cause as many casualties as the tsunami itself. The forecasted disease mortality and epidemics, as in most previous similar occasions, failed to materialize.

Despite the widespread idea that dead bodies can generate epidemics after disasters, there is no evidence to support that myth (Morgan and de Ville de Goyet, 2005). The health risks of dead bodies resulting from natural hazards are very few because the immediate cause of death is trauma, not infectious disease. Dead bodies can transmit a number of diseases for a limited period of time (Morgan, 2004), and only if those diseases were already present in the host *before* death takes place.

The overrated risk of major epidemics after disasters does not imply that all health concerns in disaster response are irrelevant. Frequently, local health services are affected or destroyed, interrupting the provision of adequate community care. Also, some common diseases are frequent, but rarely in epidemic proportions. What can be expected is an increase in gastrointestinal diseases, respiratory diseases, and some vector-borne diseases such as malaria. There are no indications of massive mortality increases or large epidemic outbreaks in any of those cases. Besides, the lack of crucial data about the number of previous cases of the detected disease prevents any comparison and the determination of the trend as increasing or decreasing.

**Myths and Misconceptions in Disasters, Table 1** List of myths and misconceptions from PAHO, 2000

| |
|---|
| Myth: Disasters are truly exceptional events |
| Reality: They are a normal part of daily life and in very many cases are repetitive events |
| Myth: Disasters kill people without respect for social class or economic status |
| Reality: The poor and marginalized are more at risk of death than are rich people or the middle classes |
| Myth: Earthquakes are commonly responsible for very high death tolls |
| Reality: Collapsing buildings are responsible for the majority of deaths in seismic disasters. Whereas, it is not possible to stop earthquakes, it is possible to construct anti-seismic buildings and to organize human activities in such a way as to minimize the risk of death. In addition, the majority of earthquakes do not cause high death tolls |
| Myth: People can survive for many days when trapped under the rubble of a collapsed building |
| Reality: The vast majority of people brought out alive from the rubble are saved within 24 or perhaps even 12 h of impact |
| Myth: When disaster strikes panic is a common reaction |
| Reality: Most people behave rationally in disaster. While panic is not to be ruled out entirely, it is of such limited importance that some leading disaster sociologists regard it as insignificant or unlikely |
| Myth: People will flee in large numbers from a disaster area |
| Reality: Usually, there is a “convergence reaction” and the area fills up with people. Few of the survivors will leave and even obligatory evacuations will be short-lived |
| Myth: After disaster has struck survivors tend to be dazed and apathetic |
| Reality: Survivors rapidly start reconstruction. Activism is much more common than fatalism (this is the so-called therapeutic community). Even in the worst scenarios, only 15–30% of victims show passive or dazed reactions |
| Myth: Looting is a common and serious problem after disasters |
| Reality: Looting is rare and limited in scope. It mainly occurs when there are strong preconditions, as when a community is already deeply divided |
| Myth: Disease epidemics are an almost inevitable result of the disruption and poor health caused by major disasters |
| Reality: Generally, the level of epidemiological surveillance and health care in the disaster area is sufficient to stop any possible disease epidemic from occurring. However, the rate of diagnosis of diseases may increase as a result of improved health care |
| Myth: Disasters cause a great deal of chaos and cannot possibly be managed systematically |
| Reality: There are excellent theoretical models of how disasters function and how to manage them. After >75 years of research in the field, the general elements of disaster are well-known, and they tend to repeat themselves from one disaster to the next |
| Myth: Any kind of aid and relief is useful after disaster provided it is supplied quickly enough |
| Reality: Hasty and ill-considered relief initiatives tend to create chaos. Only certain types of assistance, goods, and services will be required. Not all useful resources that existed in the area before the disaster will be destroyed. Donation of unusable materials or manpower consumes resources of organization and accommodation that could more profitably be used to reduce the toll of the disaster |
| Myth: In order to manage a disaster well it is necessary to accept all forms of aid that are offered |
| Reality: It is better to limit acceptance of donations to goods and services that are actually needed in the disaster area |

**Myths and Misconceptions in Disasters, Table 1** (Continued)

| |
|---|
| Myth: Unburied dead bodies constitute a health hazard |
| Reality: Not even advanced decomposition causes a significant health hazard. Hasty burial demoralizes survivors and upsets arrangements for death certification, funeral rites, and, where needed, autopsy |
| Myth: Disasters usually give rise to widespread, spontaneous manifestations of antisocial behavior |
| Reality: Generally, they are characterized by great social solidarity, generosity, and self-sacrifice, perhaps even heroism |
| Myth: One should donate used clothes to the victims of disasters |
| Reality: This often leads to accumulations of huge quantities of useless garments that victims cannot or will not wear |
| Myth: Great quantities and assortments of medicines should be sent to disaster areas |
| Reality: The only medicines that are needed are those used to treat specific pathologies, have not reached their sell-by date, can be properly conserved in the disaster area, and can be properly identified in terms of their pharmacological constituents. Any other medicines are not only useless, but potentially dangerous |
| Myth: Companies, corporations, associations, and governments are always very generous when invited to send aid and relief to disaster areas |
| Reality: They may be, but in the past disaster areas have been used as dumping grounds for outdated medicines, obsolete equipment, and unusable goods, all under the cloak of apparent generosity |
| Myth: Technology will save the world from disaster |
| Reality: The problem of disasters is largely a social one. Technological resources are poorly distributed and often ineffectively used. In addition, technology is a potential source of vulnerability as well as a means of reducing it |
| Myth: There is usually a shortage of resources when disaster occurs, and this prevents them from being managed effectively |
| Reality: The shortage, if it occurs, is almost always very temporary. There is more of a problem in deploying resources well and using them efficiently than in acquiring them. Often, there is also a problem of coping with a superabundance of certain types of resources |

As rare as they may be, it is still worth commenting on the occasional outbreaks of disease after disasters caused by natural hazard. According to the Center for Disease Control and Prevention (CDC), an epidemic is the occurrence of more cases of disease than expected in a given area or among a specific group of people over a particular period of time. Floret and colleagues found that in only 3 out of more than 600 geophysical disasters recorded worldwide from 1984 to 2004, there were epidemic outbreaks: measles after the Pinatubo eruption in Philippines in 1991, coccidioidomycosis (a fungal infection caused by inhalation of spores) after an earthquake in California in 1994, and malaria after earthquake and heavy rains in Costa Rica in 1991 (Floret et al., 2006).

The cholera epidemic which developed in the aftermath of the devastating January 12, 2010 Haiti earthquake is instructive. Although perceptually linked with the disaster, it is clear that the epidemic itself was the product of a set of unusual circumstances more closely aligned with an external input and preexisting sanitary conditions (Piarroux et al., 2011).

Decision makers should keep in mind that infectious disease epidemics after disasters are very rare and that massive and indiscriminate actions to prevent unfounded health risks are not recommended. Health and disease after disasters are a major issue, and undoubtedly some illnesses increase and public health deteriorates (Noji, 1997). But the presence of infectious diseases does not justify unfounded fears of major epidemics (WHO, 2006).

## Looting and social unrest: the augmented perception of exceptional events

According to the most widespread expectation, looting is frequent after disasters, and preventative measures must be taken immediately. This perception is based on the idea that disasters change societies and communities, triggering negative actions and antisocial collective behavior. But the reality is that looting is the exception and not the norm (Auf der Heide, 2004), and when it does happen, it follows different patterns than looting associated with riots and civil unrest crises. Pro-social adaptive behavior and the willingness to help others is generally the collective reaction to be expected.

First of all, a distinction needs to be made between looting and taking essential items for survival. While looting may be considered the illicit taking of nonessential items with the sole purpose of obtaining personal profit, many researchers use the term "appropriation" when the goods taken are used to cover basic needs, such as the need for food, water, and shelter (Quarantelli, 1994). However, most of these actions are perceived and reported by media, law enforcement, or casual observers as examples of social disorder, violent behavior, and looting. Unconfirmed rumors are also assumed as proof of looting.

When actual looting occurs in disasters, it is commonly undertaken by people from outside the community, frequently by people usually involved in criminal activities, individually or in small groups, taking advantage of the sudden opportunity (Quarantelli, 1994). By contrast, looting in riots and situations of civil unrest is enacted by normally law-abiding people from the community, in a collective manner and openly undertaken with wide social support. Most of those who loot and steal after disasters also do it before disasters. The disaster itself does not act as a social transformer that triggers deep changes or significantly increases antisocial behavior.

In summary, while detailed observation of disasters and the vast majority of the scientific literature indicate that widespread looting and social disorder is a myth and actual looting is truly exceptional, the number of disasters with actual looting and its precise extent remains unclear.

## Displacement and disaster-stricken populations: the unexisting exodus

After disaster, the myth perception is that a massive displacement of those affected will follow. However, massive population displacements are not a common feature after disasters caused by natural hazards. It is in wars and armed conflicts where it is possible to find this type of exodus, with thousands or even hundreds of thousands of people painfully walking roads and paths, carrying their scarce belongings by any possible means. These displaced people will travel long distances, usually up to the first secure place they may find, and settle in quite large camps for extended periods of time.

The situation in disasters caused by natural hazards is quite otherwise. Some people may seek help from relatives outside the affected areas or in assistance camps, but most will not leave the area, or at least they will not be displaced very far away. In disasters, people will try to stay as close as possible to their homes, their neighborhoods, their villages, etc. In fact, the typical population movement more frequently observed is toward the disaster area. As early as the 1950s, this feature was identified and named "convergence behavior" (Fritz and Mathewson, 1957). People going toward the disaster-stricken zones will include concerned relatives seeking news about missing family members or aid workers. As an example, the Haiti earthquake in 2010 produced plenty of news headlines reporting massive population exodus from the capital toward the Dominican Republic by road and the USA by boats. While indeed some people attempted to reach those destinations, these actions were already commonplace in Haiti before the earthquake. And even though the difficult situation in some cities in the aftermath of the disaster may have increased attempts to leave, the reality was far from the massive exodus many predicted.

## Donations: received versus needed

Donation of all kind of commodities is indeed a very typical image after disasters. All kind of goods are donated, boxed and shipped to disaster areas. But the reality is that most such donations cause significant problems. First, there are costs linked to the logistics involved in the process: reception, classification, boxing, handling, transportation, distribution, and other related logistical elements.

Second, many donated items are inappropriate or unusable: expired medicines, unpaired shoes, extremely dirty clothes, culturally unacceptable food, winter clothes to tropical areas (or the opposite), etc. All of these situations and many others have been observed regarding donations to disaster-affected countries. The consequence is that despite the intention to help, these donations compound the situation by forcing the diversion of human resources from other essential tasks into the classification and storage of the donations.

In most occasions, the mere cost of transportation will exceed by far the value of the donated goods. Although a donated blanket seems free of charge, by the time that blanket reaches the target beneficiary, particularly if it is shipped from a long distance, the final costs will be far higher than purchasing that blanket locally. The farther the donation travels from the destination country, the higher the costs will be. Besides, massive influx of external goods, if that keeps happening beyond the first days of the disaster response, may affect local markets negatively. No one will purchase in local markets goods that the aid agencies distribute for free. Even in disasters with high levels of destruction, there will be always less-affected or unaffected neighboring areas with available sellers of basic products such as clothes, blankets, and cooking items. Certainly, price inflation may affect certain local products in disaster areas in the initial stages of an emergency. But aid organizations must strive to reject unwanted donations in kind and encourage individual donors and institutions to donate cash to well-established and recognized organizations involved in the response; the cash will be used to purchase locally as many products as possible to support the recovery of the area.

## Conclusions

Education about disasters for the public, the media, and above all, the professionals is critical for increasing our awareness about the consequences of distorted information.

Also, a new approach may be needed. Just denouncing the inappropriateness of mass burials will not solve the problem faced by authorities when they have many thousands of bodies to bury. There is a need to obtain basic data from the bodies (estimated age, clothes, old scars, taking digital pictures, etc.) and to keep records for future possible identification by relatives, or addressing the cultural and religious sensitivities through mass funerals or rituals. After these or other palliative measures have been taken, mass burials may still be hard to avoid. But certainly, authorities are better served by concentrating their efforts on activities that reduce fear, which could eventually bring some closure for the survivors.

Finally, better organized relief operations would contribute to reduce social problems caused by unsatisfied basic needs. Social unrest caused by poor access to essential items has been recorded in post-hurricane Katrina in New Orleans in 2006 and post-earthquake Haiti in 2010. Better disaster response and better organized relief distribution, which is based on better disaster preparedness, may contribute to solve this problem.

The struggle to debunk disaster myths was initiated long ago and it will not be won in the short-term. The final objective is not to destroy the myth itself but a reduction in human suffering. Myths persist because they give answers in uncertain situations. If disaster responders and societies learn to better provide certainties, explanations, and an organized response in a disaster situation, the myths will go back to being just imaginary stories.

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## Cross-references

Integrated Emergency Management System
Mass Media and Natural Disasters
Perception of Natural Hazards and Disasters
Recovery and Reconstruction After Disaster