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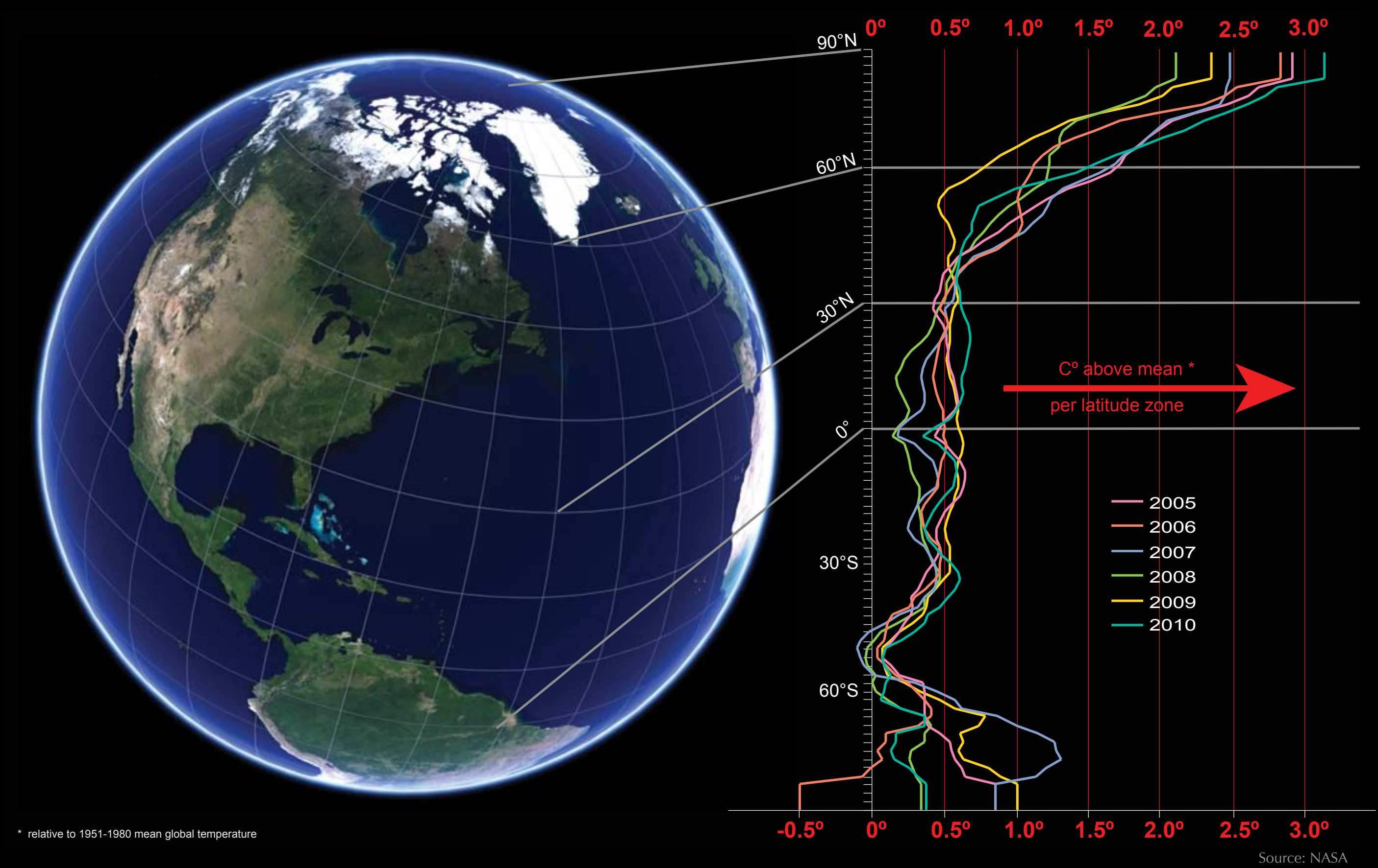
Early Warning Systems

A State of the Art Analysis and Future Directions



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Air monitoring station, Reno, Nevada, USA.

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Chapter 1: Introduction

At a time of global changes, the world is striving to face and adapt to inevitable, possibly profound, alteration. Widening of droughts in southern Europe and sub-Saharan Africa, an increasing number of disasters, severe and more frequent flooding that could imperil low-lying islands and the crowded river deltas of southern Asia, are already taking place and climate change will cause additional environmental stresses and societal crises in regions already vulnerable to natural hazards, poverty and conflicts.

A global multi-hazard early warning system is needed to inform us of pending threats. This report presents a state of the art assessment of existing monitoring/early warning systems (EWS) organized according to type of environmental threats , including air quality, wildland fires, nuclear and chemical accidents, geological hazards (earthquakes, tsunamis, volcanic eruptions, landslides), hydro-meteorological hazards (desertification, droughts, floods, impacts of climate variability, severe weather, storms, and tropical cyclones), epidemics and food insecurity. It identifies current gaps and needs with the goal of laying out guidelines for developing a global multi-hazard early warning system.

Chapter 1 introduces the basic concepts of early warning systems; Chapter 2 introduces the role of earth observation systems for disasters and environmental change; Chapter 3 focuses on existing early warning/monitoring systems; and Chapter 4 presents a global multi-hazard approach to early warning.

1.1 Early warning

Early warning (EW) is "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response", and is the integration of four main elements according to the United Nations' International Strategy for Disaster Reduction (ISDR), it integrates (UN 2006):

1. *Risk Knowledge*: Risk assessment provides essential information to set priorities for mitigation and prevention strategies and designing early warning systems.
2. *Monitoring and Predicting:* Systems with monitoring and predicting capabilities provide timely estimates of the potential risk faced by communities, economies and the environment.
3. *Disseminating Information:* Communication systems are needed for delivering warning messages to the potentially affected locations to alert local and regional governmental agencies. The messages need to be reliable, synthetic and simple to be understood by authorities and the public.
4. *Response*: Coordination, good governance and appropriate action plans are key points in effective early warning. Likewise, public awareness and education are critical aspects of disaster mitigation.

Failure of any part of the system will imply failure of the whole system. For example, accurate warnings will have no impact if the population is not prepared or if the alerts are received but not disseminated by the agencies receiving the messages.

The basic idea behind early warning is that the earlier and more accurately we are able to predict short- and long-term potential risks associated with natural and human-induced hazards, the more likely we will be able to manage and mitigate a disaster's impact on society, economies, and environment.

1.2 Types of hazards

Environmental hazards can be associated with: ongoing and rapid/sudden-onset threats and slow-onset (or "creeping") threats.

1. Ongoing and Rapid/sudden-onset: These include such hazards as: accidental oil spills, nuclear plant failures, and chemical plant accidents—such as inadvertent chemical releases to the air or into rivers and water bodies—geological hazards and hydro-meteorological hazards (except droughts).
2. Slow-onset (or "creeping"): Incremental but long-term and cumulative environmental changes that usually receive little attention in their early phases but which, over time, may cause serious crises. These include such issues as deteriorating air and water quality, soil pollution, acid rain, climate change, desertification processes (including soil erosion and land degradation), drought, ecosystems change, deforestation and forest fragmentation, loss of biodiversity and habitats, nitrogen overloading, radioactive waste, coastal erosion, pressures on living marine resources, rapid and unplanned urban growth, environment and health issues (emerging and re-emerging infectious diseases and links to environmental change), land cover/ land changes, and environmental impacts of conflict, among others. Such creeping changes are often left unaddressed as policymakers choose or need to cope

Type of Hazards	Types of Environmental Threats
1. Ongoing and rapid/sudden-onset threats	Oil spills, nuclear plant failures, and chemical plant accidents; geological hazards and hydro-meteorological hazards, except for droughts.
2. Slow-onset (or "creeping") threats	deteriorating air and water quality, soil pollution, acid rain, climate change, droughts, ecosystems change, loss of biodiversity and habitats, land cover/land changes, nitrogen overloading, radioactive waste, coastal erosion, etc.
2.1 Location specific environmental threats	Ecosystem changes, urban growth, transboundary pollutants, loss of wetlands, etc.
2.2 New emerging science	Associated with biofuels, nanotechnology, carbon cycle, climate change, etc.
2.3 Contemporary environmental threats	Electronic waste, bottled water, etc.

Table 1: Types of environmental threats.

with immediate crises. Eventually, neglected creeping changes may become urgent crises that are more costly to deal with. Slow-onset threats can be classified into location— specific environmental threats, new emerging science and contemporary environmental threats (see Table 1).

Note that rapid/sudden-onset hazards include geological threats such as earthquakes, volcanic eruptions, mudslides, and tsunamis. From a scientific point of view, geological events are the result of incremental environmental processes but it may be more effective to refer to them as quick onset. Most of the hydro-meteorological hazards (such as floods, tornadoes, storms, heat waves, etc.) may be considered rapid/sudden-onset hazards (type 1) but droughts are considered slow-onset (or "creeping") hazards (type 2).

Drought occuring in Switzerland dropped Lake Constance's water levels 55 cm.

Kecko/Flickr.com

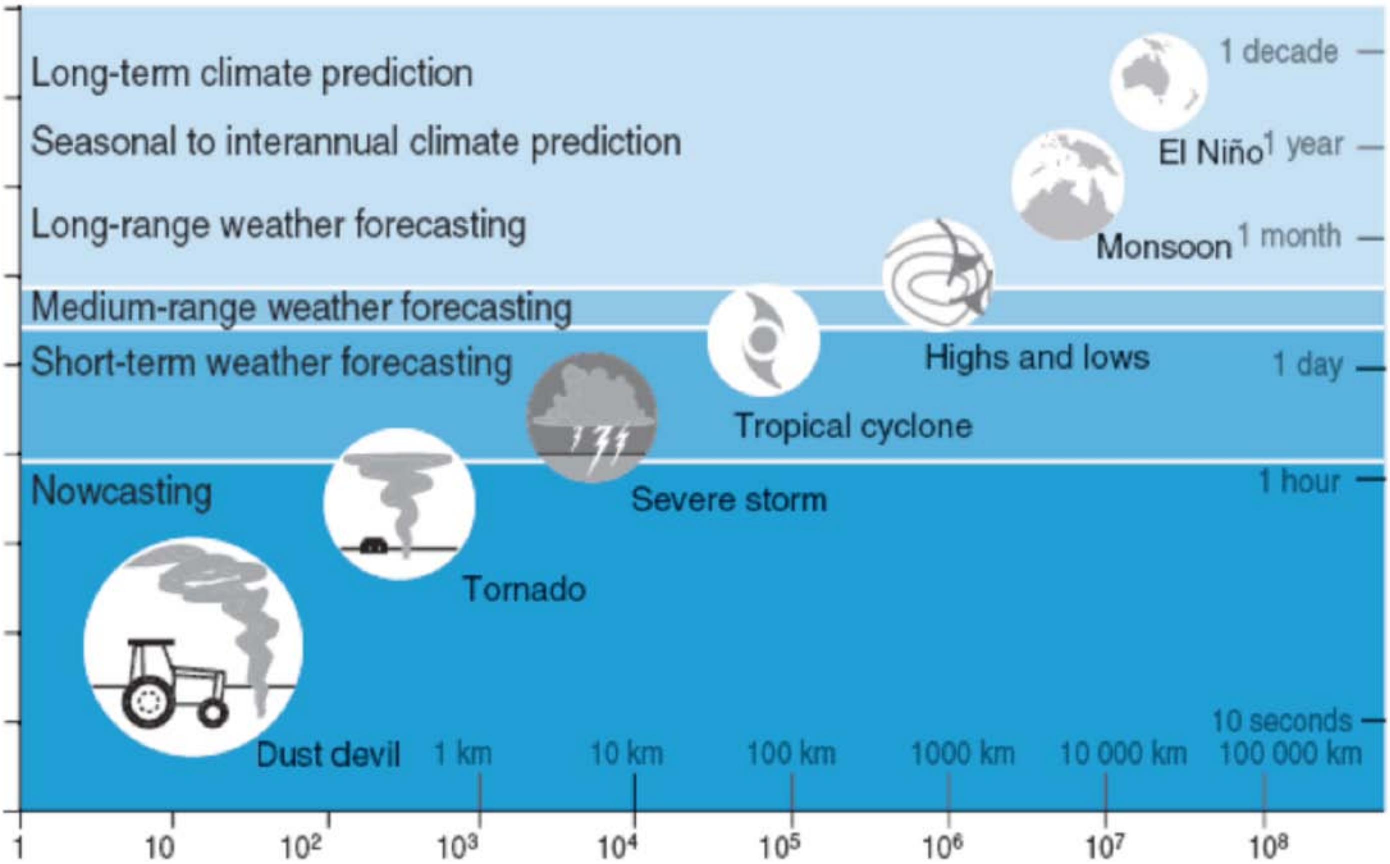


Figure 1: How early is early warning? (Golnaraghi 2005). The graph shows the timeliness of early warning systems for hydro-meteorological hazards and the area of impact (by specifying the diameter of the spherical area) for climatic hazards.

Rapid/sudden-onset and slow-onset events will provide different amounts of available warning time.

Figure 1 shows warning times for climatic hazards. Early Warning systems may provide seconds of available warning time for earthquakes to months of warning for droughts, which are the quickest and slowest onset hazards, respectively. Specifically, early warning systems provide tens of seconds of warning for earthquakes, days to hours for volcanic eruptions, and hours for tsunamis. Tornado warnings provide minutes of lead-time for response. Hurricane warning time varies from weeks to hours. The warning time provided by warning systems, increases to years or even decades of lead-time available for slow-onset threats (such as El Niño, global warming etc., as shown in Figure 1). Drought warning time is in the range of months to weeks.

Slow-onset (or creeping) changes may cause serious problems to environment and society, if preventive measures are not taken when needed. Such creeping environmental changes require effective early warning technologies due to the high potential impact of incremental cumulative changes on society and the environment.

1.3 Early warning systems: operational aspects

Early warning systems help to reduce economic losses and mitigate the number of injuries or deaths from a disaster, by providing information that allows individuals and communities to protect their lives and property. Early warning information empowers people to take action prior to a disaster. If well integrated with risk assessment studies and communication and action plans, early warning systems can lead to substantive benefits.

Effective early warning systems embrace the following aspects: risk analysis; monitoring and predicting location and intensity of the disaster; communicating alerts to authorities and to those potentially affected; and responding to the disaster. The early warning system has to address all aspects.

Monitoring and predicting is only one part of the early warning process. This step provides the input information for the early warning process that needs to be disseminated to those whose responsibility is to respond (Figure 2). Early warnings may be disseminated to targeted users (local early warning applications) or broadly to communities,

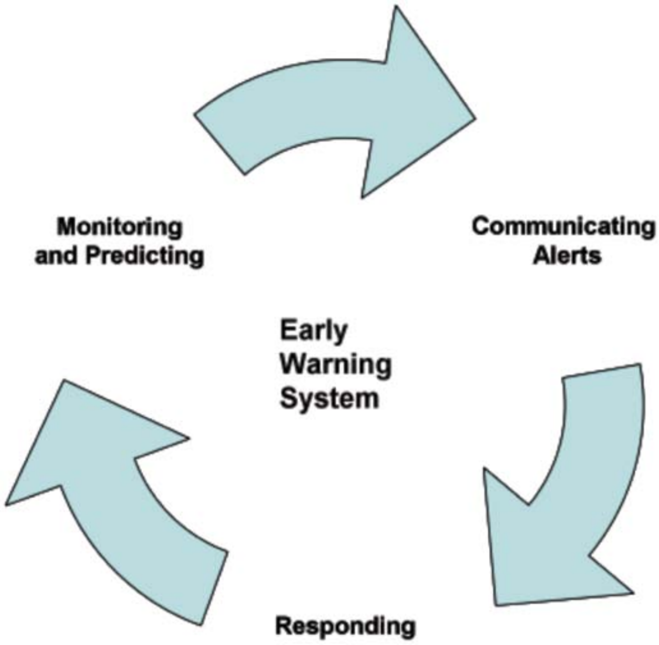


Figure 2: Early Warning System operational aspects.

regions or to media (regional or global early warning applications). This information gives the possibility of taking action to initiate mitigation or security measures before a catastrophic event occurs. When monitoring and predicting systems are associated with communication systems and response plans, they are considered early warning systems (Glantz 2003). Commonly, however, early warning systems lack one or more elements. In fact, a review of existing early warning systems shows that in most cases communication systems and adequate response plans are missing.

To be effective, warnings also must be timely so as to provide enough lead-time for responding; reliable, so that those responsible for responding to the warning will feel confident in taking action; and simple, so as to be understood. Timeliness often conflicts with the desire to have reliable predictions, which become more accurate as more observations are collected from the monitoring system (Grasso 2007). Thus, there is an inevitable trade-off between the amount of warning time available and the reliability of the predictions provided by the EWS. An initial alert signal may be sent to give the maximum amount of warning time when a minimum level of prediction accuracy has been reached. However, the prediction accuracy for the location and size of the event will continue to improve as more data are collected by the monitoring system part of the EWS network. It must be understood that every prediction, by its very nature, is associated with uncertainty. Because of the uncertainties associated with the predicted parameters that characterize the incoming disaster, it is possible that a wrong decision may be made. Two kinds of wrong decisions may occur (Grasso 2007): Missed Alarm (or False Negative), when the mitigation action is not taken when it should have been or False Alarm (or False Positive), when the mitigation action is taken when it should not have been.

Finally, the message should communicate the level of uncertainty and expected cost of taking action but also be stated in simple language so as to be understood by those who receive it. Most often, there is a communication gap between EW specialists who use technical and engineering language and the EWS users, who are generally outside of the scientific community. To avoid this, these early warnings need to be reported concisely, in layman's terms and without scientific jargon.

1.4 Communication of early warning information

An effective early warning system needs an effective communication system. Early warning communication systems have two main components (EWCII 2003):

- communication infrastructure hardware that must be reliable and robust, especially during the disaster; and
- appropriate and effective interactions among the main actors of the early warning process, such as the scientific community, stakeholders, decision makers, the public, and the media.

Redundancy of communication systems is essential for disaster management, while emergency power supplies and back-up systems are critical in order to avoid the collapse of communication systems after disasters occur. In addition, to ensure the communication systems operate reliably and effectively during and after a disaster occurs, and to avoid network congestion, frequencies and channels must be reserved and dedicated to disaster relief operations.

Many communication tools are currently available for warning dissemination, such as Short Message Service (SMS) (cellular phone text messaging), email, radio, TV and web service. Information and communication technology (ICT) is a key element in early warning, which plays an important role in disaster communication and disseminating information to organizations in charge of responding to warnings and to the public during and after a disaster (Tubtiang 2005).

Today, the decentralization of information and data through the World Wide Web makes it possible for millions of people worldwide to have easy, instantaneous access to a vast amount of diverse online information. This powerful communication medium has spread rapidly to interconnect our world, enabling near-real-time communication and data exchanges worldwide. According to the Internet World Stats database, as of December 2011, global documented Internet usage was 2.3 billion people. Thus, the Internet has become an important medium to access and deliver information worldwide in a very timely fashion.

In addition, remote sensing satellites now provide a continuous stream of data. They are capable of rapidly

EWS: Decision making procedure based on cost-benefit analysis

To improve the performance of EWS, a performance-based decision making procedure needs to be based on the expected consequences of taking action, in terms of the probability of a false and missed alarm. An innovative approach sets the threshold based on the acceptable probability of false (missed) alarms, from a cost-benefit analysis (Grasso 2007).

Consider the case of a EWS decision making strategy based on raising the alarm if a critical severity level, a, is predicted to be exceeded at a site. The decision of whether to activate the alarm or not is based on the predicted severity of the event.

A decision model that takes into account the uncertainty of the prediction and the consequences of taking action will be capable of controlling and reducing the incidence of false and missed alerts. The proposed decision making procedure intends to fill this gap. The EWS will provide the user with a real-time prediction of the severity of the event, $\hat{S}(t)$ and its error, $\varepsilon_{tot}(t)$. During the course of the event, the increase in available data will improve prediction accuracy. The prediction and its uncertainty are updated as more data come in. The actual severity of the event, ε_{tot}, is unknown and may be defined by adding the prediction error to the predicted value, $\hat{S}$.

The potential probability of false (missed) alarm is given by the probability of being less (greater) than the critical threshold; it becomes an actual probability of false (missed) alarm if the alarm is (not) raised:

$$P_{fa}(t) = P\left[S \le \mathrm{a} \,\middle|\, \hat{S}(\mathrm{t})\right] \qquad (1)$$

$$P_{ma}(t) = P\left[S > \mathrm{a} \,\middle|\, \hat{S}(\mathrm{t})\right] \qquad (2)$$

Referring to the principle of maximum entropy (Jaynes 2003), the prediction error is modeled by Gaussian distribution, representing the most uninformative distribution possible due to lack of information. Hence, at time t, the actual severity of the event, S, may be modeled with a Gaussian distribution, having a mean equal to the prediction $\hat{S}(t)$ and uncertainty equal to $\sigma_{tot}(t)$, which is the standard deviation of the prediction error $\varepsilon_{tot}(t)$. Eq. (1) and (2) may be written as follows (Grasso and others 2007):

$$P_{fa} = \int_{-\infty}^{a} \frac{1}{\sigma_{tot}(t)\sqrt{2\pi}} \exp\left[\frac{-\left(S - \hat{S}(t)\right)^2}{2\sigma_{tot}(t)^2}\right] dS = \Phi\left(\frac{a - \hat{S}(t)}{\sigma_{tot}(t)}\right) \qquad (3)$$

$$P_{ma}(t) = \int_{a}^{\infty} \frac{1}{\sigma_{tot}(t)\sqrt{2\pi}} \exp\left[\frac{-\left(S - \hat{S}(t)\right)^2}{2\sigma_{tot}(t)^2}\right] dS = 1 - \Phi\left(\frac{a - \hat{S}(t)}{\sigma_{tot}(t)}\right) \qquad (4)$$

where Φ represents the Gaussian cumulative distribution function. The tolerable level at which mitigation action should be taken can be determined from a cost-benefit analysis by minimizing the cost of taking action:

$$P_{fa} \le \beta = \frac{C_{save}}{C_{fa} + C_{save}}; \quad P_{ma} < \alpha = \frac{C_{fa}}{C_{fa} + C_{save}} \qquad (5)$$

where C_{save} are the savings due to mitigation actions and C_{fa} is the cost of false alert. Note that the tolerable levels α and β sum up to one, which directly exhibits the trade-off between the tolerable threshold probabilities for false and missed alarms. The methodology offers an effective approach for decision making under uncertainty, focusing on user requirements in terms of reliability and cost of action.

and effectively detecting hazards, such as transboundary air pollutants, wildfires, deforestation, changes in water levels, and natural hazards. With rapid advances in data collection, analysis, visualization and dissemination, including technologies such as remote sensing, Geographical Information Systems (GIS), web mapping, sensor webs, telecommunications and ever-growing Internet connectivity, it is now feasible to deliver relevant information on a regular basis to a worldwide audience relatively inexpensively. In recent years, commercial companies such as Google, Yahoo, and Microsoft have started incorporating maps and satellite imagery into their products and services, delivering compelling visual images and providing easy tools that everyone can use to add to their geographic knowledge.

Information is now available in a near-real-time mode from a variety of sources at global and local levels. In the coming years, the multi-scaled global information network will greatly improve thanks to new technological advances that facilitate the global distribution of data and information at all levels.

Globalization and rapid communication provides an unprecedented opportunity to catalyze effective action at every level by rapidly providing authorities and the general public with high-quality and scientifically credible information in a timely fashion.

The dissemination of warnings often follows a cascade process, which starts at the international or national level and then moves outwards or downwards in scale to regional and community levels (Twigg 2003). Early warnings may activate other early warnings at different authoritative levels, flowing down in responsibility roles, although all are equally necessary for effective early warning.

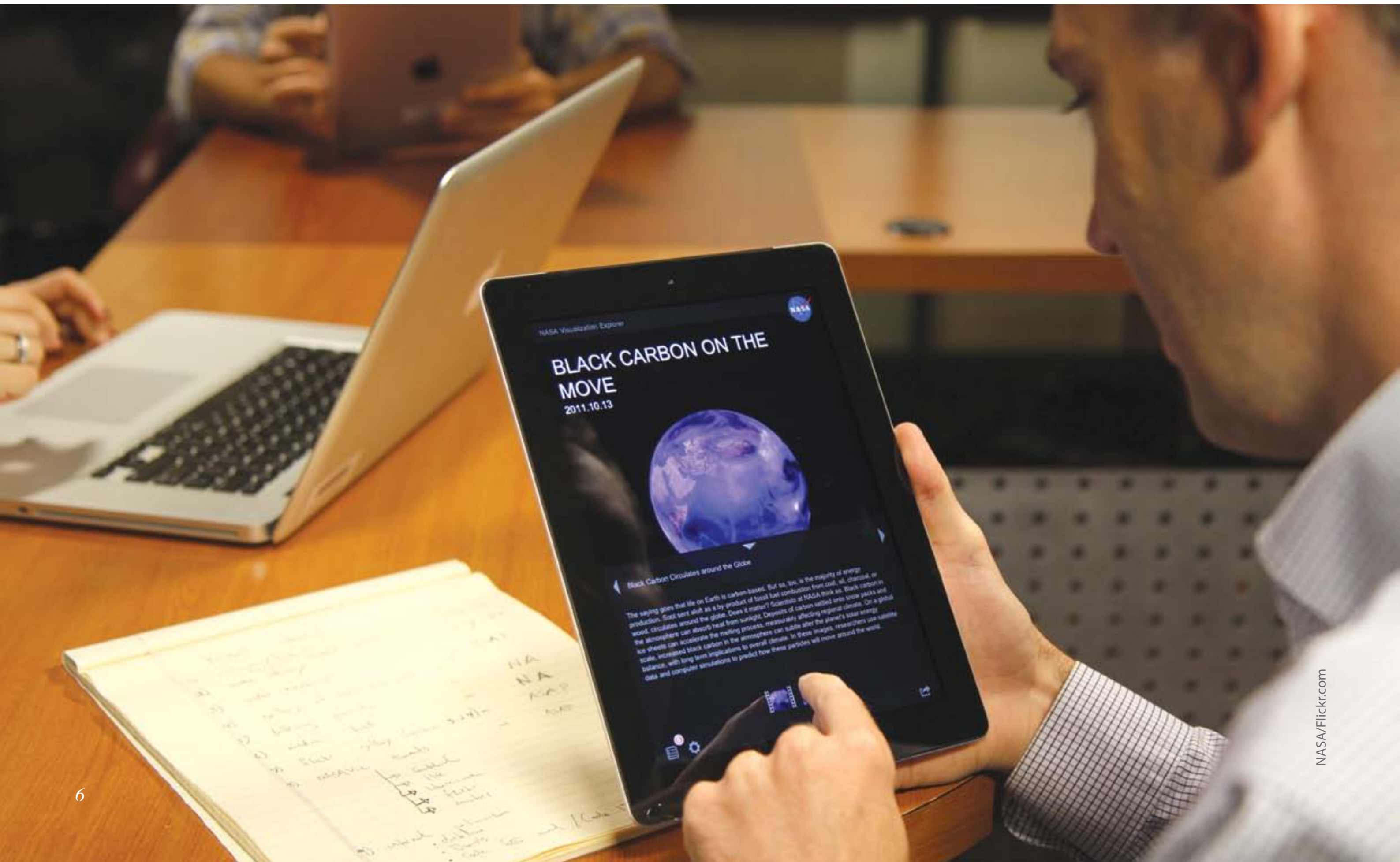
Standard protocols play a fundamental role in addressing the challenge of effective coordination and data exchange among the actors in the early warning process and it aids in the process for warning communication and dissemination. The Common Alerting Protocol (CAP), Really Simple Syndication (RSS) and Extensible Markup Language (XML) are examples of standard data interchange formats for structured information that can be applied to warning messages for a broad range of information management and warning dissemination systems.

The advantage of standard format alerts is that they are compatible with all information systems, warning systems, media, and most importantly, with new technologies such as web services. CAP, for example, defines a single standard message format for all hazards, which can activate multiple warning systems at the same time and with a single input. This guarantees consistency of warning messages and would easily replace specific application-oriented messages with a single multi-hazard message format. CAP is compatible with all types of information systems and public alerting systems (including broadcast radio and television), public and private data networks, multi-lingual warning systems and emerging technologies such as Internet Web services and existing systems such as the U.S. National Emergency Alert System and the National Oceanic and Atmospheric Organization (NOAA) Weather Radio. CAP uses Extensible Markup Language (XML), which contains information about the alert message, the specific hazard event, and appropriate responses, including the urgency of action to be taken, severity of the event, and certainty of the information.

1.5 Early warning systems and policy

For early warning systems to be effective, it is essential that they be integrated into policies for disaster mitigation. Good governance priorities include protecting the public from disasters through the implementation of disaster risk reduction policies. It is clear that natural phenomena cannot be prevented, but their human, socio-economic and environmental impacts can and should be minimized through appropriate measures, including risk and vulnerability reduction strategies, early warning, and appropriate action plans. Most often, these problems are given attention during or immediately after a disaster. Disaster risk reduction measures require long term plans and early warning should be seen as a strategy to effectively reduce the growing vulnerability of communities and assets.

Using new technology to track up-to-date environmental change.



NASA/Flickr.com

The information provided by early warning systems enables authorities and institutions at various levels to immediately and effectively respond to a disaster. It is crucial that local government, local institutions, and communities be involved in the entire policy-making process, so they are fully aware and prepared to respond with short and long-term action plans.

The early warning process, as previously described, is composed of 4 main stages: risk assessment, monitoring and predicting, disseminating and communicating warnings, and response. Within this framework, the first phase, when short- and long-term actions plans are laid out based on risk assessment analysis, is the realm of institutional and political actors. Then EW acquires a technical dimension in the monitoring and predicting phase, while in the communication phase, EW involves both technical and institutional responsibility. The response phase then involves many more sectors, such as national and local institutions, non-governmental organizations, communities, and individuals.

Below is a summary of recommendations for effective decision-making within the early warning process (Sarevitz and others 2000):

Prediction is insufficient for effective decision-making. Prediction efforts by the scientific community alone are insufficient for decision-making. The scientific community and policy-makers should outline the strategy for effective and timely decision-making by indicating what information is needed by decision-makers, how predictions will be used, how reliable the prediction must be to produce an effective response, and how to communicate this information and the tolerable prediction uncertainty so that the information can be received and understood by authorities and public. A miscommunicated or misused prediction can result in costs to society. Prediction, communication, and use of the information are necessary factors in effective decision-making within the early warning process.

Develop effective communication strategies. Wishing not to appear 'alarmist' or to avoid criticism, local and national governments have sometimes kept the public in the dark when receiving technical information regarding imminent threats. The lack of clear and easy-to-use information can sometimes confuse people and undermine their confidence in public officials. Conversely, there are quite a few cases where the public may have refused to respond to early warnings from authorities, and have therefore exposed themselves to danger or forced governments to impose removal measures. In any case, clear and balanced information is critical, even when some level of uncertainty remains. For this reason, the information's uncertainty level must be communicated to users together with the early warning (Grasso and others 2007).

Establish proper priorities. Resources must be allocated wisely and priorities should be set, based on risk assessment, for long- and short-term decision-making, such as investing in local early warning systems, education, or enhanced monitoring and observational systems. In addition, decision-makers need to be able to set priorities for timely and effective response to a disaster when it occurs based on the information received from the early warning system. Decision-makers should receive necessary training on how to use the information received when an alert is issued and what that information means.

Clarify responsibilities. Institutional networks should be developed with clear responsibilities. Complex problems such as disaster mitigation and response require multi-disciplinary research, multi-sector policy and planning, multi-stakeholder participation, and networking involving all the participants of the process, such as the scientific research community (including social sciences aspects), land use planning, environment, finance, development, education, health, energy, communications, transportation, labour, and social security and national defense. Decentralization in the decision making process could lead to optimal solutions by clarifying local government and community responsibilities.

Collaboration will improve efficiency, credibility, accountability, trust, and cost-effectiveness. This collaboration consists of joint research projects, sharing information, and participatory strategic planning and programming.

Establish and strengthen legal frameworks. Because there are numerous actors involved in early warning response plans (such as governing authorities, municipalities, townships, and local communities), the decision-making and legal framework of responsibilities should be set up in advance in order to be prepared when a disaster occurs. Hurricane Katrina in 2005 showed gaps in the legal frameworks and definition of responsibilities that exacerbated the disaster. Such ineffective decision-making must be dealt with to avoid future disasters such as the one in New Orleans.

Chapter 2: The Role of Earth Observation

Earth observation (EO), through measuring and monitoring, provides an insight and understanding into Earth's complex processes and changes. EO includes measurements that can be made directly or by sensors *in-situ* or remotely (i.e. satellite remote sensing, aerial surveys, land or ocean-based monitoring systems, Figure 3), to provide key information to models or other tools to support decision making processes. EO assists governments and civil society to identify and shape corrective and new measures to achieve sustainable development through original, scientifically valid assessments and early warning information on the recent and potential long-term consequences of human activities on the biosphere. At a time when the world community is striving to identify the impacts of human actions on the planet's life support system, time-sequenced satellite images help to determine these impacts and provide unique, visible and scientifically-convincing evidence that human actions are causing substantial changes to the Earth's environment and natural resource base (i.e. ecosystems changes, urban growth, transboundary pollutants, loss of wetlands, etc).

By enhancing the visualization of scientific information on environmental change, satellite imagery will enhance environmental management and raise the awareness of emerging environmental threats. EO provides the opportunity to explore, to discover, and to understand the world in which we live from the unique vantage point of space.

The following section discusses the potential role of EO for each type of environmental threat.

2.1 Ongoing and rapid/sudden-onset environmental threats

Oil spills

Earth observation is increasingly used to detect illegal marine discharges and oil spills. Infra-red (IR) video and photography from airborne platforms, thermal infrared imaging, airborne laser fluoro-sensors, airborne and satellite optical sensors, as well as airborne and satellite Synthetic Aperture Radar (SAR) are used for this purpose. SAR has

Figure 3: Illustration of multiple observing systems in use on the ground, at sea, in the atmosphere and from space for monitoring and researching the climate system (WMO 2011).

the advantage of also providing data during cloud cover conditions and darkness, unlike optical sensors. In addition, optical-sensor techniques applied to oil spills detection are associated to a high number of false alarms, more often cloud shadows, sun glint, and other conditions such as precipitation, fog, and the amounts of daylight present also may be erroneously associated with oil spills. For this reason, SAR is preferred over optical sensors, especially when spills cover vast areas of the marine environment, and when the oil cannot be seen or discriminated against the background. SAR detects changes in sea-surface roughness patterns modified by oil spills. The largest shortcoming of oil spills detection using SAR images is accurate discrimination between oil spills and natural films (Brekke and Soldberg 2004). To date, operational application of satellite imagery for oil spill detection still remains a challenge due to limited spatial and temporal resolution. Additionally, processing times are often too long for operational purposes, and it is still not possible to measure the thickness of the oil spill (Mansor and others 2007; U.S. Department of the Interior, Minerals Management Service 2007). Existing applications are presented in Chapter 3.

Chemical and nuclear accidents

Chemical and nuclear accidents may have disastrous consequences, such as the 1984 accident in Bhopal, India, which killed more than 2 000 and injured about 150 000, and the 1986 explosion of the reactors of the nuclear power plant in Chernobyl, Ukraine, which was the worst such accident to date, affecting part of the Soviet Union, eastern Europe, Scandinavia, and later, western Europe. Meteorological factors such as wind speed and direction, turbulence, stability layers, humidity, cloudiness, precipitation and topographical features, influence the impact of chemical and nuclear accidents and have to be taken into account in decision models. In some cases, emergencies are localized while in others, transport processes are most important. EO provides key data for monitoring and forecasting the dispersion and spread of the substance.

Geological hazards

Geohazards associated with geological processes such as earthquakes, landslides, and volcanic eruptions are mainly controlled by ground deformation. EO data allows monitoring of key physical parameters associated with geohazards, such as deformation, plate movements, seismic monitoring, baseline topographic, and geoscience mapping. EO products are useful for detection and mitigation before the event, and for damage assessment during the aftermath. For geohazards, stereo optical and radar interferometry associated with ground-based Global Positioning System (GPS) and seismic networks are used. For volcanic eruptions additional parameters are observed such as temperature and gas emissions. Ground based measurements have the advantage of being continuous in time but have limited spatial extent, while satellite observations cover wide areas but are not continuous in time. These data need to be integrated for an improved and more comprehensive approach (Committee on Earth Observation Satellites (CEOS) 2002; Integrated global observing strategy (IGOS-P) 2003).

Earthquakes

Earthquakes are due to a sudden release of stresses accumulated around the faults in the Earth's crust. This energy is released through seismic waves that travel from the origin zone, which cause the ground to shake. Severe earthquakes can affect buildings and populations. The level of damage depends on many factors, such as the intensity and depth of the earthquake, and the vulnerability of structures and their distance from the earthquake's origin.

For earthquakes, information on the location and magnitude of the event first needs to be conveyed to responsible authorities. This information is used by seismic early warning systems to activate security measures within seconds after the earthquake's origin and before strong shaking occurs at the site. Shakemaps generated within five minutes provide essential information to assess the intensity of ground shaking and the damaged areas. The combination of data from seismic networks and GPS may help to increase reliability and timeliness of this information. Earthquake frequency and probability shakemaps based on historical seismicity and base maps (geological, soil type, active faults, hydrological, DEMs), assist in the earthquake mitigation phase and need to be included in the building code design process for improved land use and building practices. For responses, additional data are needed, such as seismicity, intensity, strain, DEMs, soil type, moisture conditions, infrastructure and population, to produce post-event damage maps. Thermal information needs to continuously be monitored. This is obtained from low/medium resolution IR imagery from polar and geostationary satellites for thermal background characterization (Advanced Very High Resolution Radiometer (AVHRR), ATSR, MODIS and GOES) together with deformation from EDM and/or GPS network; borehole strainmeters; and SAR interferometry.

Landslides

Landslides are displacements of earth, rock, and debris caused by heavy rains, floods, earthquakes, volcanoes, and wildfires. Useful information for landslides and ground instability include the following: hazard zonation maps (landslides, debris flows, rockfalls, subsidence, and ground instability scenarios) during the mitigation phase, associated with landlside inventories, DEM, deformation (GPS network; SAR interferometry; other surveys such as leveling, laser scanning, aerial, etc), hydrology, geology, soil, geophysical, geotechnical, climatic, seismic zonation maps, land cover, land use, and historical archives. Forecasting the location and extent of ground instability or landslides is quite challenging. Landslides can be preceded by cracks, accelerating movement, and rock fall activity. Real-time monitoring of key parameters thus becomes essential. The observed acceleration, deformation or displacement, exceeding a theoretical pre-fixed threshold is the trigger for issuing an alert signal. An alternative approach is based on hydrologic forecasting. It should be said that for large areas site-specific monitoring is not feasible. In this case, hazard mapping associated with monitoring of high risk zones remains the best option for warning. Local rapid mapping of affected areas, updated scenarios and real-time monitoring (deformation, seismic data, and weather forecasts) assist during the response phase.

Tsunami

A tsunami is a series of ocean waves generated by sudden displacements in the sea floor, landslides, or volcanic activity. Although a tsunami cannot be prevented, the impact of a tsunami can be mitigated through community preparedness, timely warnings, and effective response. Observations of seismic activity, sea floor bathymetry, topography, sea level data (Tide Gauge observations of sea height; Real-time Tsunami Warning Buoy Data; Deep Ocean Assessment and Reporting of Tsunamis (DART) buoys and sea-level variations from the TOPEX/Poseidon and Jason, the European Space Agency's Envisat, and the U.S. Navy's Geosat Follow-On), are used in combination with tsunami models to create inundation and evacuation maps and to issue tsunami watches and warnings.

Volcanic eruptions

Volcanic eruptions may be mild, releasing steam and gases or lava flows, or they can be violent explosions that release ashes and gases into the atmosphere. Volcanic eruptions can destroy land and communities living in their path, affect air quality, and even influence the Earth's climate. Volcanic ash can impact aviation and communications.

Data needs for volcanic eruptions include hazard zonation maps, real-time seismic, deformation (Electronic Distance Measurement (EDM) and/or GPS network; leveling and tilt networks; borehole strainmeters; gravity surveys; SAR interferometry), thermal (Landsat, ASTER, Geostationary operational environmental satellites (GOES), MODIS); air borne IR cameras; medium-high resolution heat flux imagery and gas emissions (COSPEC, LICOR surveys); Satellite imagery (i.e., ASTER) and digital elevation maps (DEM). As soon as the volcanic unrest initiates, information needs to be timely and relatively high-resolution. Once the eruption starts, the flow of information has to speed up. Seismic behaviour and deformation patterns need to be observed throughout the eruption especially to detect a change of eruption site (3-6 seismometers ideally with 3-directional sensors; a regional network).

Hydro-meteorological hazards

Hydro-meteorological hazards include the wide variety of meteorological, hydrological and climate phenomena that can pose a threat to life, property and the environment. These types of hazards are monitored using the meteorological, or weather, satellite programs, beginning in the early 1960s. In the United States, NASA, NOAA, and the Department of Defense (DoD) have all been involved with developing and operating weather satellites. In Europe, ESA and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) operate the meteorological satellite system (U.S. Centennial of Flight Commission).

Data from geostationary satellite and polar microwave derived products (GOES) and polar orbiters (microwave data from the Defense Meteorological Satellite Program (DMSP), Special Sensor Microwave/Imager (SSM/I), NOAA/Advanced Microwave Sounding Unit (AMSU), and Tropical Rainfall Measuring Mission (TRMM)) are key in weather analysis and forecasting. GOES has the capability of observing the atmosphere and its cloud cover from the global scale down to the storm scale, frequently and at high resolution. Microwave data are available on only an intermittent basis, but are strongly related to cloud and atmospheric properties. The combination of GOES and Polar Orbiting Environmental Satellites (POES) is key for monitoring meteorological processes from the global scale to the synoptic scale to the mesoscale and finally to the storm scale. (Scofield and others 2002). GOES and POES weather satellites provide useful information on precipitation, moisture, temperature, winds and soil wetness, which is combined with ground observation.

Floods

Floods are often triggered by severe storms, tropical cyclones, and tornadoes. The number of floods has continued to rise steadily; together with droughts, they have become the most deadly disasters over the past decades. The increase in losses from floods is also due to climate variability, which has caused increased precipitation in parts of the Northern Hemisphere (Natural Hazards Working Group 2005). Floods can be deadly, particularly when they arrive without warning.

In particular, polar orbital and geostationary satellite data are used for flood observation. Polar orbital satellites include optical low (AVHRR), medium (Landsat, SPOT, IRS) and high resolution (IKONOS) and microwave sensors (high (SAR-RADARSAT, JERS and ERS) and low resolution passive sensors (SSMI). Meteorological satellites include GOES 8 and 10, METEOSAT, GMS, the Indian INSAT and the Russian GOMS; and polar orbitals suchh as NOAA (NOAA 15) and SSMI.

For storms, additional parameters are monitored, such as sea surface temperature, air humidity, surface wind speed, rain estimates (from DMSP/SSMI, TRMM, ERS, QuikScat, AVHRR, RADARSAT). TRMM offers unique opportunities to examine tropical cyclones. With TRMM, scientists are able to make extremely precise radar measurements of tropical storms over the oceans and identify their intensity variations, providing invaluable insights into the dynamics of tropical storms and rainfall.

Epidemics

Epidemics such as malaria and meningitis are linked to environmental factors. Satellite data can provide essential information on these factors and help to better understand diseases.

As an example, the ESA Epidemio project, launched in 2004, utilizes data from ESA's Envisat or the French Space Agency's Spot, and field data to gather information on the spread of epidemics, helping to better prepare for epidemic outbreaks. GEO, with WHO and other partners, are working together on the Meningitis Environmental Risk Information Technologies (MERIT) project to better understand the relationship between meningitis and environmental factors using remote sensing.

Wildfires

Wildfires pose a threat to lives and properties and are often connected to secondary effects such as landslides, erosion, and changes in water quality. Wildfires may be natural processes, human induced for agriculture purposes, or just the result of human negligence.

Wildfire detection using satellite technologies is possible thanks to significant temperature difference between the Earth's surface (usually not exceeding 10-25ºC) and the heat of fire (300-900ºC), which results in a thousand times difference in heat radiation generated by these objects. NOAA (AVHRR radiometer with 1 100m spatial resolution and 3 000 km swath width) and Earth Observing Satellites (EOS) (Terra and Aqua satellites with MODIS radiometer installed on them with 250, 500 and 1 000 m spatial resolution and 2 330 km swath width) are the most widely used modern satellites for operative fire monitoring (Klaver and others 1998). High-resolution sensors, such as the Landsat Thematic Mapper, SPOT multispectral scanner, or National Oceanic and Atmospheric Administration's AVHRR or MODIS, are used for fire potential definition. Sensors used for fire detection and monitoring include AVHRR, which has a thermal sensor and daily overflights, the Defense Meteorological Satellite Program's Optical Linescan System (OLS) sensor, which has daily overflights and operationally collects visible images during its nighttime pass, and the MODIS Land Rapid Response system. AVHRR and higher resolution images (SPOT, Landsat, and radar) can be used to assess the extent and impact of the fire.

2.2 Slow-onset (or "creeping") environmental threats

Air quality

Smog is the product of human and natural activities, such as industry, transportation, wildfires, volcanic eruptions, etc. and can have serious effects on human health and the environment.

A variety of EO tools are available to monitor air quality. The National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) both have instruments to monitor air quality. The Canadian MOPITT (Measurements of Pollution in the Troposphere) aboard the Terra satellite monitors the lower atmosphere to observe how it interacts with the land and ocean biospheres, distribution, transport, sources, and sinks of carbon monoxide and methane in the troposphere. The Total Ozone Mapping Spectrometer (TOMS) instrument measures the total amount of ozone in a column of atmosphere as well as cloud cover over the entire globe. Additionally, TOMS measures the amount of solar radiation escaping from the top of the atmosphere to accurately estimate the amount of ultraviolet radiation that reaches the Earth's surface. The Ozone Monitoring Instrument (OMI) on Aura will continue the TOMS record for total ozone and other atmospheric parameters related to ozone chemistry and climate. The OMI instrument distinguishes between aerosol types, such as smoke, dust, and sulphates, and can measure cloud pressure and coverage. ESA's SCHIAMACHY (Scanning Imaging Absorption Spectro-Meter for Atmospheric ChartographY) maps atmosphere over a very wide wavelength range (240 to 2 380 nm), which allows detection of trace gases, ozone and related gases, clouds and dust particles throughout the atmosphere (Athena Global 2005). The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor measures the relative amount of aerosols and the relative size of aerosol particles—solid or liquid particles suspended in the atmosphere. Examples of such aerosols include dust, sea salts, volcanic ash, and smoke. The MODIS aerosol optical depth product is a measure of how much light airborne particles prevent from passing through a column of atmosphere. New technologies are also being explored for monitoring air quality, such as mobile phones equipped with simple sensors to empower citizens to collect and share real-time air quality measurements. This technology is being developed by a consortium called Urban Atmospheres.

Water quality

The traditional methods of monitoring coastal water quality require scientists to use boats to gather water samples, typically on a monthly basis because of the high costs of these surveys. This method captures episodic events affecting water quality, such as the seasonal freshwater runoff, but is not able to monitor and detect fast changes. Satellite data provide measures of key indicators of water quality—turbidity and water clarity—to help monitor fast changes in factors that affect water quality, such as winds, tides and human influences including pollution and runoff. GeoEYE's Sea-viewing Wide Field-of-view Sensor (SeaWiFS) instrument, launched aboard the OrbView-2 satellite in 1997, collects ocean colour data used to determine factors affecting global change, particularly ocean ecology and chemistry. MODIS sensor, launched aboard the Aqua satellite in 2002, together with its counterpart instrument aboard the Terra satellite, collects measurements from the entire Earth surface every one to two days and can also provide measurements of turbidity (Hansen 2007). Overall, air and water quality monitoring coverage still appears to be irregular and adequate and available in real-time only for some contaminants (GEO 2005).

Droughts, desertification and food security

Droughts

NOAA's National Weather Service (NWS) defines a drought as "a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area."

Drought can be classified by using 4 different definitions: meteorological (deviation from normal precipitation); agricultural (abnormal soil moisture conditions); hydrological (related to abnormal water resources); and socioeconomic (when water shortage impacts people's lives and economies).

A comprehensive and integrated approach is required to monitor droughts, due to the complex nature of the problem. Although all types of droughts originate from a precipitation deficiency, it is insufficient to monitor solely this parameter to assess severity and resultant impacts (World Meteorological Organization 2006). Effective drought early warning systems must integrate precipitation and other climatic parameters with water information such as streamflow, snow pack, groundwater levels, reservoir and lake levels, and soil moisture, into a comprehensive assessment of current and future drought and water supply conditions (Svoboda and others 2002). In particular, there are 6 key parameters that are used in a composite product developed from a rich information stream, including climate indices, numerical models, and the input of regional and local experts.

These are:

1) Palmer Drought Severity Index (based on precipitation data, temperature data, division constants (water capacity of the soil, etc.) and previous history of the indices),
2) Soil Moisture Model Percentile (calculated through a hydrological model that takes observed precipitation and temperature and calculates soil moisture, evaporation and runoff. The potential evaporation is estimated from observed temperature),
3) Daily stream flow percentiles,
4) Percent of normal precipitation,
5) Standardized precipitation index, and
6) Remotely sensed vegetation health index.

Additional indicators may include the Palmer Crop Moisture Index, Keetch-Byram Drought Index, Fire Danger Index, evaporation-related observations such as relative humidity and temperature departure from normal, reservoir and lake levels, groundwater levels, field observations of surface soil moisture, and snowpack observations. Some of these indices and indicators are computed for point locations, and others are computed for climate divisions, drainage (hydrological) basins, or other geographical regions (Svoboda and others 2002). A complete list of drought products can be found on NOAA's National Environmental Satellite, Data, & Information Service (NOAA-NESDIS) web page.

Desertification

Desertification refers to the degradation of land in arid, semi-arid, and dry sub-humid areas due to climatic variations or human activity. Desertification can occur due to inappropriate land use, overgrazing, deforestation, and over-exploitation. Land degradation affects many countries worldwide and has its greatest impact in Africa.

In spite of the potential benefits of EO information, the lack of awareness of the value and availability of information, inadequate institutional resources and financial problems are the most frequent challenges to overcome in detecting desertification (Sarmap and others 2003). In 2004, through a project called DesertWatch, ESA has developed a set of indicators based principally on land surface parameters retrieved from satellite observations for monitoring land degradation and desertification. DesertWatch is being tested and applied in Mozambique, Portugal, and Brazil.

Food security

Food security was defined at the 1996 World Food Summit as existing "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life". The concept of food security includes both physical and economic access to food meeting people's needs and preferences. There are currently four systems for global agricultural monitoring, all using EO data:

- The USDA Foreign Agricultural Service's Crop Explorer.

After a crash in the price of tobacco, Malawian farmers have opted for crop diversification as a path to food security. Shot on farm estates in Chiradzulu district.

- The European Commission's Monitoring of Agriculture with Remote Sensing.
- CropWatch, developed by the Chinese Academy of Sciences' Institute for Remote Sensing Applications.
- The U.N. Food and Agriculture Organization's Global Information and Early Warning System (GIEWS).

These provide information on food availability, market prices and livelihoods.

Impact of climate variability

The observations of climate-related variables on a global scale have made it possible to document and analyze the behaviour of Earth's climate, made available through programs such as: the IOC-WMO-UNEP-ICSU Global Ocean Observing System (GOOS); the FAO-WMO-UNESCO-UNEP-ICSU Global Terrestrial Observing System (GTOS); the WMO Global Observing System (GOS) and Global Atmosphere Watch (GAW); the research observing systems and observing systems research of the WMO-IOC-ICSU World Climate Research Programme (WCRP) and other climate-relevant international programs; and WMO-UNESCO-ICSU-IOC-UNEP Global Climate Observing System (GCOS).

The Intergovernmental Panel on Climate Change (IPCC) periodically reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. Hundreds of scientists worldwide contribute to the preparation and review of these reports.

According to the recent IPCC report, the atmospheric buildup of greenhouse gases is already shaping the earth's climate and ecosystems from the poles to the tropics, which face inevitable, possibly profound, alteration. The IPCC has predicted widening droughts in southern Europe and the Middle East, sub-Saharan Africa, the American Southwest and Mexico, and flooding that could imperil low-lying islands and the crowded river deltas of southern Asia. It stressed that many of the regions facing the greatest risks are among the world's poorest. Information about the impacts of climate variability is needed by communities and resource managers to adapt and prepare for larger fluctuations as global climate change becomes more evident. This information includes evidence of changes occurring due to climate variability, such as loss of ecosystems, ice melting, coastal degradation, and severe droughts. Such information will provide policy-makers scientifically valid assessment and early warning information on the current and potential long-term consequences of human activities on the environment.

Location-specific environmental changes

(i.e., ecosystem changes, loss of biodiversity and habitats, land cover/land changes, coastal erosion, urban growth, etc.)

Landsat satellites (series 1 to 7) are extensively used to monitor location-specific environmental changes. They have the great advantage of providing repetitive, synoptic, global coverage of high-resolution multi-spectral imagery (Fadhil 2007). Landsat can be used for change detection applications to identify differences in the state of an object or phenomenon by comparing the satellite imagery at different times. Change detection is key in natural resources management (Singh 1989). Central to this theme is the characterization, monitoring and understanding of land cover and land use change, since they have a major impact on sustainable land use, biodiversity, conservation, biogeochemical cycles, as well as land-atmosphere interactions affecting climate and they are indicators of climate change, especially at a regional level (IGOS-P 2004).

The United Nations Environment Programme's (UNEP) bestselling publication *One Planet, Many People: Atlas of Our Changing Environment* (UNEP 2006), which shows before and after satellite photos to document changes to the Earth's surface over the past 30 years, proves the importance and impact of visual evidence of environmental change in hotspots. The Atlas contains some remarkable Landsat satellite imagery and illustrates the alarming rate of environmental destruction. Through the innovative use of some 271 satellite images, 215 ground photos and 66 maps, the Atlas provides visual proof of global environmental changes—both positive and negative—resulting from natural processes and human activities. Case studies include themes such as atmosphere, coastal areas, waters, forests, croplands, grasslands, urban areas, and tundra and Polar Regions. The Atlas demonstrates how our growing numbers and our consumption patterns are shrinking our natural resource base.

Chapter 3: Inventory of Early Warning Systems

The aim of this report is to identify current gaps and future needs of early warning systems through the analysis of the state of the art of existing early warning and monitoring systems for environmental hazards. Among existing early warning/monitoring systems, only systems that provide publicly accessible information and products have been included in the analysis. For the present study, several sources have been used, such as the Global Survey of Early Warning Systems (UN 2006) together with the on-line inventory of early warning systems on ISDR's Platform for the Promotion of Early Warning (PPEW) website, and several additional online sources, technical reports and scientific articles listed in the references. For each hazard type, a gap analysis has been carried out to identify critical aspects and future needs of EWS, considering aspects such as geographical coverage, and essential EWS elements such as monitoring and prediction capability, communication systems and application of early warning information in responses. Below is the outcome of the review of existing early warning/monitoring systems for each hazard type. Details of all systems, organized in tables by hazard type, are listed in the Appendix. The current gaps identified for each hazard type could be related to technological, organizational, communication or geographical coverage aspects. To assess the geographical coverage of existing systems for each hazard type, the existing systems have been imposed on the hazard's risk map. For this analysis, the maps of risks of mortality and economic loss were taken from Natural Disaster Hotspots: A Global Risk Analysis, a report from the World Bank (Dilley and others 2005).

3.1 Ongoing and rapid/sudden-onset environmental threats

Oil spills

To detect operational oil spills, satellite overpasses and aerial surveillance flights need to be used in an integrated manner. In many countries in Northern Europe, the KSAT manual approach is currently used to identify oil spills from the satellite images. KSAT has provided this operational service since 1996, and in Europe, use of satellites for oil spill detection is well established and well integrated within the national and regional oil pollution surveillance and response chains. Operational algorithms utilizing satellite-borne C-band SAR instruments (Radarsat-1, Envisat, Radarsat-2) are also being developed for oil-spill detection in the Baltic Sea area.

Chemical and nuclear accidents

Releases of a hazardous substance from industrial accidents can have immediate adverse effects on human and animal life or the environment. WMO together with IAEA provides specialized meteorological support to environmental emergency response related to nuclear accidents and radiological emergencies. The WMO network of eight specialized numerical modeling centres called Regional Specialized Meteorological Centres (RSMCs) provides predictions of the movement of contaminants in the atmosphere. The Inter-Agency Committee on the Response to Nuclear Accidents (IACRNA) of the IAEA, coordinates the international intergovernmental organizations responding to nuclear and radiological emergencies. IACRNA members are: the European Commission (EC), the European Police Office (EUROPOL), the Food and Agriculture Organization of the United Nations (FAO), IAEA, the International Civil Aviation Organization (ICAO), the International Criminal Police Organization (INTERPOL), the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (OECD/NEA), the Pan American Health Organization (PAHO), UNEP, the United Nations Office for the Co-ordination of Humanitarian Affairs (UN-OCHA), the United Nations Office for Outer Space Affairs (UNOOSA), the World Health Organization (WHO), and WMO. The Agency's goal is to provide support during incidents or emergencies by providing near real-time reporting of information through the following: the Incident and Emergency Centre (IEC), which maintains a 24 hour on-call system for rapid initial assessment, and if needed, triggers response operations; the Emergency Notification and Assistance Convention Website (ENAC) , which allows the exchange of information on nuclear accidents or radiological emergencies; and the Nuclear Event Web-based System (NEWS), which provides information on all significant events in nuclear power plants, research reactors, nuclear fuel cycle facilities and occurrences involving radiation sources or the transport of radioactive material. The Global Chemical Incident Alert and Response System of the International Programme on Chemical Safety, which is part of WHO, focuses on disease outbreaks from chemical releases and also provides technical assistance to Member States for response to chemical incidents and emergencies. Formal and informal sources are used to collect information and if necessary, additional information and verification is sought through official channels: national authorities, WHO offices, WHO Collaborating Centres, other United Nations agencies, and members of the communicable disease Global Outbreak Alert and Response Network (GOARN), Internet-based resources, particularly the Global Public Health Intelligence Network (GPHIN) and ProMED-Mail3. Based on this information, a risk assessment is carried out to determine the potential impact and if assistance needs to be offered to Member States.

Geological hazards

Earthquakes

Earthquake early warning systems are a relatively new approach to seismic risk reduction. They provide a rapid estimate of seismic parameters such as magnitude and location associated with a seismic event based on the first seconds of seismic data registered at the epicentre. This information can then be used to predict ground motion parameters of engineering interest including peak ground acceleration and spectral acceleration. Earthquake warning systems are currently operational in Mexico, Japan, Romania, Taiwan and Turkey (Espinosa Aranda and others 1995; Wu and others 1998; Wu and Teng 2002; Odaka and others 2003; Kamigaichi 2004; Nakamura 2004; Horiuchi and others 2005). Systems are under development for seismic risk mitigation in California and Italy. Local and national scale seismic early warning systems, which provide seismic information between a few seconds and tens of seconds before shaking occurs at the target site, are used for a variety of applications such as shutting down power plants, stopping trains, evacuating buildings, closing gas valves, and alerting wide segments of the population through the TV, among others.

On the global scale, multi-national initiatives, such as the U.S. Geological Survey (USGS) and GEO-FOrschungs Netz (GEOFON), operate global seismic networks for seismic monitoring but do not provide seismic early warning information. Today, the USGS in cooperation with Incorporated Research Institutions for Seismology (IRIS) operates the Global Seismic Networks (GSN), which comprises more than 100 stations providing free, real-time, open access data. GEOFON collects information from several networks and makes this information available to the public online. USGS Earthquake Notification Service (ENS) provides publicly available email notification for earthquakes worldwide within 5 minutes for earthquakes in U.S. and within 30 minutes for events worldwide. USGS also provides near-real-time maps of ground motion and shaking intensity following significant earthquakes. This product, called ShakeMap, is being used for post-earthquake response and recovery, public and scientific information, as well as for preparedness exercises and disaster planning.

Effective early warning technologies for earthquakes are much more challenging to develop than for other natural hazards because warning times range from only a few seconds in the area close to a rupturing fault to a minute or so (Heaton 1985; Allen and Kanamori 2003; Kanamori 2005). Several local and regional applications exist worldwide but no global system exists or could possibly exist for seismic early warning at global scale, due to timing constraints. Earthquake early warning systems applications must be designed at the local or regional level. Although various early warning systems exist worldwide at the local or regional scale, there are still high seismic risk areas that lack early warning applications, such as Peru, Chile, Iran, Pakistan, and India.

Landslides

Landslides cause billions of dollars in losses every year worldwide. However, most slopes are not monitored and landslide early warning systems are not yet in place.

The International Consortium on Landslides (ICL), created at the Kyoto Symposium in January 2002, is an international non-governmental and non-profit scientific organization, which is supported by the United Nations Educational, Scientific and Cultural Organization (UNESCO), the WMO, FAO, and the United Nations International Strategy for Disaster Reduction (UN/ISDR). ICL's mission is to promote landslide research for the benefit of society and the environment and promote a global, multidisciplinary program regarding landslides. ICL provides information about current landslides on its website, streaming this information from various sources such as the Geological Survey of Canada. This information does not provide any early warning since it is based on news reports after the events have occurred. Enhancing ICL's existing organizational infrastructure by improving landslide prediction capability would allow ICL to provide early warning to authorities and populations. Technologies for slopes monitoring has greatly improved, but currently only few slopes are being monitored at a global scale. The use of these technologies would be greatly beneficial for mitigating losses from landslides worldwide.

Tsunamis

The Indian Ocean tsunami of December 2004 killed 220 000 people and left 1.5 million homeless. It highlighted gaps and deficiencies in existing tsunami warning systems. In response to this disaster, in June 2005 the Intergovernmental Oceanographic Commission (IOC) secretariat was mandated by its member states to coordinate the implementation of a tsunami warning system for the Indian Ocean, the northeast Atlantic and Mediterranean, and the Caribbean. Efforts to develop these systems are ongoing. Since March 2011, the Indonesian meteorological, climatological and geophysical agency has been operating the German-Indonesian Tsunami Early Warning System for the Indian Ocean. Milestones, such as the development of the automatic data processing software and underwater communication for the transmission of pressure data from the ocean floor to a warning centre, have been reached. These systems will be part of the Global Ocean Observing System (GOOS), which will be part of GEOSS.

The Pacific basin is monitored by the Pacific Tsunami Warning System (PTWS), which was established by 26 Member States and is operated by the Pacific Tsunami Warning Center (PTWC), located near Honolulu, Hawaii.

PTWC monitors stations throughout the Pacific basin to issue tsunami warnings to Member States, serving as the regional center for Hawaii and as a national and international tsunami information center. It is part of the PTWS effort. NOAA National Weather Service operates PTWC and the Alaska Tsunami Warning Center (ATWC) in Palmer, Alaska, which serves as the regional Tsunami Warning Center for Alaska, British Columbia, Washington, Oregon, and California. PTWS monitors seismic stations operated by PTWC, USGS and ATWC to detect potentially tsunamigenic earthquakes. Such earthquakes meet specific criteria for generation of a tsunami in terms of location, depth, and magnitude. PTWS issues tsunami warnings to potentially affected areas, by providing estimates of tsunami arrival times and areas potentially most affected. If a significant tsunami is detected, the tsunami warning is extended to the Pacific basin. The International Tsunami Information Center (ITIC), under the auspices of IOC, aims to mitigate tsunami risk by providing guidance and assistance to improve education and preparedness. ITIC also provides a complete list of tsunami events worldwide. Official tsunami bulletins are released by PTWC, ATWC, and the Japan Meteorological Agency (JMA). Regional and national tsunami information centres exist worldwide; the complete list is available from IOC.

Currently, no global tsunami warning system is in place. In addition, fully operational tsunami early warning systems are needed for the Indian Ocean and the Caribbean. Initial steps have been taken in this direction. In 2010, NOAA established the Caribbean Tsunami Warning Program as the first step towards the development of a Caribbean Tsunami Warning Center. Since 2005, steps have been taken to develop an Indian Ocean tsunami system, such as establishing 26 tsunami information centres and deploying 23 real-time sea level stations and 3 deep ocean buoys in countries bordering Indian Ocean. In 2005, the United States Agency for International Development (USAID) launched the US Indian Ocean Tsunami Warning Systems Program as the US Government's direct contribution to the international effort led by the IOC. Since then, there are ongoing activities, such as Germany's five-year German-Indonesia Tsunami Early Warning System program with Indonesia, the Tsunami Regional Trust Fund established in 2005, and the United Kingdom's tsunami funds reserved for early warning capacity building.

Nevertheless, on 17 July 2006, only one month after the announcement that the Indian Ocean's tsunami warning system was operational, a tsunami in Java, Indonesia, killed hundreds of people. On that day, tsunami warnings were issued to alert Jakarta but there was not enough time to alert the coastal areas. The July 2006 tsunami disaster illustrates that there are still operational gaps to be solved in the Indian Ocean tsunami early warning system, notably in warning coastal communities on time.

Volcanic eruptions

Volcanic eruptions are always anticipated by precursor activities. In fact, seismic monitoring, ground deformation monitoring, gas monitoring, visual observations, and surveying are used to monitor volcanic activity. Volcano observatories are distributed worldwide. A complete list of volcano observatories is available at the World Organization of Volcanic Observatories (WOVO) web site. However, there is still a divide between developed and developing countries. In particular, a large number of observatories and research centres monitor volcanoes in Japan and the United States very well. Most Central and South American countries (Mexico, Guatemala, El Salvador, Nicaragua, Costa Rica, Colombia, Ecuador, Peru, Chile, Trinidad, and the Antilles) have volcano observatories that provide public access to volcanic activity information. In Africa, only two countries (Congo and Cameroon) have volcano monitoring observatories and they do not provide public access to information. Only a small number, probably fewer than 50, of the world's volcanoes are well monitored, mostly due to inadequate resources in poor countries (National Hazards Working Group 2005). There is a need to fill this gap by increasing the coverage of volcanic observatories.

Currently, there is no global early warning system for volcanic eruptions except for aviation safety. Global volcanic activity information is provided by the Smithsonian institution, which partners with the USGS under the Global Volcanism Program to provide online access to volcanic activity information, collected from volcano observatories worldwide. Reports and warnings are available on a daily basis. Weekly and monthly summary reports are also available, but these only report changes in volcanic activity level, ash advisories, and news reports. The information is also available through Google Earth. This information is essential for the aviation sector, which must be alerted to ash-producing eruptions. There are several ash advisory centres distributed worldwide, in London, Toulouse, Anchorage, Washington, Montreal, Darwin, Wellington, Tokyo, and Buenos Aires. However, there is a need to coordinate interaction and data sharing among the approximately 80 volcano observatories that make up WOVO. ESA is developing GlobVolcano, an Information System to provide earth observations for volcanic risk monitoring.

Wildfires

Early warning methodologies for wildfires are based on the prediction of precursors, such as fuel loads and lightning danger. These parameters are relevant for triggering prediction, but once the fire has begun, fire behaviour and pattern modeling are fundamental for estimating fire propagation patterns. Most industrial countries have EW capabilities in place, while most developing countries have neither fire early warning nor monitoring systems in place

(Goldammer and others 2003). Local and regional scale fire monitoring systems are available for Canada, South America, Mexico and South Africa. An interactive mapping service based on Google maps and EO imagery from INPE, the Brazilian Space Research Institute, has been available since September 2008. Individuals can contribute with information from the ground; in only 3 months the service has received 41 million reports on forest fires and illegal logging, making it one of the most successful web sites in Brazil; it has had real impact through follow up legal initiatives and Parliamentary enquiries.

Wildfire information is available worldwide through the Global Fire Monitoring Center (GFMC), a global portal for fire data products, information, and monitoring. This information is accessible to the public through the GFMC web site but is not actively disseminated. The GFMC provides global fire products through a worldwide network of cooperating institutions. GFMC fire products include: fire danger maps and forecasts, which provide assessment of fire onset risk; near real-time fire events information; an archive of global fire information; and assistance and support in the case of a fire emergency. Global fire weather forecasts are provided by the Experimental Climate Prediction Center (ECPC), which also provides national and regional scale forecasts. NOAA provides experimental, potential fire products based on estimated intensity and duration of vegetation stress, which can be used as a proxy for assessment of potential fire danger. The Webfire Mapper, part of FAO's Global Fire Information Management System (GFIMS), initially developed by the University of Maryland and financially supported by NASA, provides near real-time information on active fires worldwide, detected by the MODIS rapid response system. The Webfire Mapper integrates satellite data with GIS technologies for active fire information. This information is available to the public through the website and email alerts.

The European forest fire information system also provides information on current fire situations and forecasts for Europe and the Mediterranean area.

Although global scale fire monitoring systems exist, an internationally standardized approach is required to create a globally comprehensive early fire warning system. Integration of existing fire monitoring systems could significantly improve fire monitoring and early warning capabilities. An information network must be developed to disseminate early warnings about wild-fire danger at both the global and local levels, to quickly detect and report fires, and to enhance rapid fire detection and classification capabilities at national and regional levels. The Global Early Warning System for Wild-Fires, which is under development as part of the Global Earth Observation System of Systems (GEOSS) effort, will address these issues.

Hydro-meteorological hazards (except droughts)

Floods

Among natural hazards that are currently increasing in frequency, floods are the deadliest. This study shows there is inadequate coverage of flood warning and monitoring systems, especially in developing or least developed countries such as China, India, Bangladesh, Nepal, West Africa, and Brazil. At the local scale, there are several stand-alone warning systems, for example, in Guatemala, Honduras, El Salvador, Nicaragua, Zimbabwe, South Africa, Belize, Czech Republic, and Germany. However, they do not provide public access to information. The European Flood Alert System (EFAS), which is an initiative by EC-JRC, provides information on the possibility of river flooding occuring within the next three days. EFAS also provides an overview of current floods based on information received from the National Hydrological Services and the Global Runoff Data Center in Germany.

Floods are monitored worldwide from the Dartmouth Flood Observatory, which provides public access to major flood information, satellite images and estimated discharge. Orbital remote sensing (Advanced Scanning Microradiometer (AMSR-E and QuickScat)) is used to detect and map major floods worldwide. Satellite microwave sensors can monitor, at a global scale and on a daily basis, increases of floodplain water surface without cloud interference. The Dartmouth Flood Observatory provides estimated discharge and satellite images of major floods worldwide but does not provide forecasts of flood conditions or precipitation amounts that could allow flood warnings to be issued days in advance of events. NOAA provides observed hydrologic conditions of major US river basins and predicted values of precipitation for rivers in the United States. NOAA also provides information on excessive rainfall that could lead to flash-flooding and if necessary warnings are issued within six hours in advance. IFnet Global Flood Alert System (GFAS) uses global satellite precipitation estimates for flood forecasting and warning. The GFAS website publishes useful public information for flood forecasting and warning, such as precipitation probability estimates, but the system is currently running on a trial basis. At a global scale, flood monitoring systems are more developed than flood early warning systems. For this reason, existing technologies for flood monitoring must be improved to increase prediction capabilities and flood warning lead times.

Severe weather, storms and tropical cyclones

At the global level, the World Weather Watch (WWW) and Hydrology and Water Resources Programmes coordinated by WMO provide global collection, analysis and distribution of weather observations, forecasts and warnings. The WWW is composed of the Global Observing System (GOS), which provides the observed meteorological data; the Global Telecommunications System (GTS), which reports observations, forecasts and other products and the Global Data Processing System (GDPS), which provides weather analyses, forecasts and other products. The WWW is an operational framework of coordinated national systems, operated by national governments.

The Tropical Cyclone Programme (TCP) is also part of the WWW. TCP is in charge of issuing tropical cyclones and hurricanes forecasts, warnings and advisories, and seeks to promote and coordinate efforts to mitigate risks associated with tropical cyclones. TCP has established tropical cyclone committees that extend across regional bodies (Regional Specialized Meteorological Centres (RSMC)), which, together with National Meteorological and Hydrological Services (NMHSs), monitor tropical cyclones globally and issue official warnings to the Regional Meteorological Services of countries at risk. Regional bodies worldwide have adopted standardized WMO-TCP operational plans and manuals, which promote internationally accepted procedures in terms of units, terminology, data and information exchange, operational procedures, and telecommunication of cyclone information. Each member of a regional body is normally responsible for its land and coastal waters warnings. A complete list of WMO members and RSMCs is available on the WMO-TCP website. WMO then collects cyclone information and visualizes it on world maps. The University of Hawaii collects information from WMO and provides online information on cyclone categories, wind speed, and current and predicted courses.

Although comprehensive coverage of early warning systems for storms and tropical cyclones is available, recent disasters such as Hurricane Katrina of 2005 have highlighted inadequacies in early warning system technologies for enabling effective and timely emergency response. There is a pressing need to improve communication between the sectors involved by strengthening the links between scientific research, organizations responsible for issuing warnings, and authorities in charge of responding to these warnings. While the WWW is an efficient framework of existing RSMC, NMHSs and networks, national capacities in most developing countries need improvements in order to effectively issue and manage early warnings. Action plans must also be improved.

Epidemics

Epidemics pose a significant threat worldwide, particularly in those areas that are already affected by other serious hazards, poverty, or under-development. Epidemics spread easily across country borders. Globalization increases the potential of a catastrophic disease outbreak: there is the risk that millions of people worldwide could potentially be affected.

A global disease outbreak early warning system is urgently needed. WHO is already working in this field through the Epidemic and Pandemic Alert and Response, which provides real-time information on disease outbreaks, and GOARN. The 192 WHO member countries, disease experts, institutions, agencies, and laboratories, part of an Outbreak Verification List, are constantly informed of rumoured and confirmed outbreaks. The WHO constantly monitors anthrax, avian influenza, Crimean-Congo hemorrhagic fever (CCHF), dengue hemorrhagic fever, Ebola hemorrhagic fever, Hepatitis, Influenza, Lassa fever, Marburg Hemorrhagic Fever, Meningococcal disease, plague, Rift Valley fever, Severe Acute Respiratory Syndrome (SARS), Tularaemia, and Yellow fever.

A global early warning system for animal diseases transmissible to humans was formally launched in July 2006 by the FAO, the World Organization for Animal Health (OIE), and WHO. The Global Early Warning and Response System for Major Animal Diseases, including Zoonoses (GLEWS) monitors outbreaks of major animal diseases worldwide.

A malaria early warning system is not yet available and the need for system development is pressing, especially in Sub-Saharan Africa where malaria causes more than one million deaths every year. The IRI institute at Columbia University provides malaria risk maps based on rainfall anomaly, which is one of the factors influencing malaria outbreak and distribution, but no warning is disseminated to the potentially affected population.

In addition, the Malaria Atlas Project (MAP) supported by the Wellcome Trust, the Global Fund to Fight AIDS, Tuberculosis and Malaria, the University of Oxford-Li Ka Shing Foundation Global Health Programme and others, aims to disseminate free, accurate and up-to-date information on malaria. The MAP is a joint effort of researchers from around the globe working in different fields (from public health to mathematics, geography and epidemiology). MAP produces and makes available a range of maps and estimates to support effective planning of malaria control at national and international scales.

3.2 Slow-onset (or "creeping") environmental threats

Air quality

Air pollution affects developing and developed countries without exception. For this reason, air quality monitoring and early warning systems are in place in most countries worldwide. Nevertheless, there is still a technological divide between developed and developing countries; in fact, these systems are most developed in the United States, Canada, and Europe. There are several successful cases to mention in Asia (Taiwan, China, Hong Kong, Korea, Japan, and

Thailand), a few in Latin America (Argentina, Brazil, and Mexico City) and only one in Africa (Cape Town, South Africa).

Most of the existing systems focus on real-time air quality monitoring by collecting and analyzing pollutant concentration measurements from ground stations. Satellite observation is extremely useful for aviation and tropospheric ozone monitoring, which is done by NASA and ESA. Air quality information is communicated mainly through web services. The U.S. Environmental Protection Agency (EPA) provides an email alert service (EPA AIRNow) only available in the U.S. and the Ministry of Environment of Ontario, Canada, also provides email alerts. The EPA AIRNow notification service provides air quality information in real-time to subscribers via e-mail, cell phone or pager, allowing them to take steps to protect their health in critical situations.

While current air quality information is provided by each of the air quality monitoring systems listed in the Appendix, few sources provide forecasts. The following agencies provide forecasts, which are fundamental for early warning: U.S. EPA, ESA, Prev'Air, and the Environmental Agencies of Belgium, Germany, and Canada (See Appendix). Prediction capability is an essential component of the early warning process. Existing air quality monitoring systems need to be improved in order to provide predictions to users days in advance so they can act when unhealthy air quality conditions occur.

Droughts, desertification and food security

Drought

Drought early warning systems are the least developed systems due its complex processes and environmental and social impacts. The study of existing drought early warning systems shows that only a few such systems exist worldwide.

On a regional scale, the FEWS Net for Eastern Africa, Afghanistan, and Central America reports on current famine conditions, including droughts, by providing monthly bulletins that are accessible on the FEWS Net webpage. For the United States, the U.S. Drought Monitor (Svoboda and others 2002) provides current drought conditions at the national and state level through an interactive map available on the website accompanied by a narrative on current drought impacts and a brief description of forecasts for the following week. The U.S. Drought Monitor, a joint effort between the US Department of Agriculture (USDA), NOAA, the Climate Prediction Center, the University of Nebraska Lincoln and others, has become the best available product for droughts (Svoboda and others 2002). It has a unique approach that integrates multiple drought indicators with field information and expert input, and provides information through a single easy-to-read map of current drought conditions and short notes on drought forecast conditions. For China, the Beijing Climate Center (BCC) of the China Meteorological Administration (CMA) monitors drought development. Based on precipitation and soil moisture monitoring from an agricultural meteorological station network and remote-sensing-based monitoring from CMA's National Satellite Meteorological Center, a drought report and a map on current drought conditions are produced daily and made available on their website. The European Commission Joint Research Center (EC-JRC) provides publicly available drought-relevant information through the following real-time online maps: daily soil moisture maps of Europe; daily soil moisture anomaly maps of Europe; and daily maps of the forecasted top soil moisture development in Europe (seven-day trend).

At a global scale, two institutions (FAO's Global Information and Early Warning System on Food and Agriculture (GIEWS) and Benfield Hazard Research Center of the University College London) provide some information on major droughts occurring worldwide. The FAO-GIEWS provides information on countries facing food insecurity through monthly briefing reports on crop prospects and food situations, including drought information, together with an interactive map of countries in crisis, available through the FAO website. Benfield Hazard Research Center uses various data to produce a monthly map of current drought conditions accompanied by a short description for each country. In addition, the WMO provides useful global meteorological information, such as precipitation levels, cloudiness, and weather forecasts, which are visualized on a clickable map on the WMO website.

Existing approaches for drought early warning must be improved. Due to the complex nature of droughts, a comprehensive and integrated approach (such as the one adopted by the U.S. Drought Monitor) that would consider numerous drought indicators is required for drought monitoring and early warning. In addition, for large parts of the world suffering from severe droughts, early warning systems are not yet in place, such as in western and southern Africa, and in eastern Africa where FEWS Net is available but no drought forecast is provided. Parts of Europe (Spain, parts of France, southern Sweden, and northern Poland) are characterized by high drought risk but have no system in place. India, parts of Thailand, Turkey, Iran, Iraq, eastern China, areas of Ecuador, Colombia, and the south-eastern and western parts of Australia also require a drought warning system.

Desertification

The United Nations Convention to Combat Desertification (UNCCD), signed by 110 governments in 1994, aims to promote local action programs and international activities. National Action Programmes at the regional or sub-regional levels are key instruments for implementing the convention and are often supported by action programmes at sub-regional and regional levels. These programs lay out regional and local action plans and strategies to combat desertification. The UNCCD website provides a desertification map together with documentation, reports, and briefing notes on the implementation of action programs for each country worldwide.

Currently no desertification early warning system is fully implemented, despite their potential to mitigate desertification.

Food security

The FAO's GIEWS supports policy-makers by delivering periodic reports through the GIEWS webpage and an email service. GIEWS also promotes collaboration and data exchange with other organizations and governments. The frequency of briefs and reports—which are released monthly or bimonthly—may not be adequate for early warning purposes. The WFP is also involved in disseminating reports and news on famine crises through its web-service. No active dissemination is provided by WFP. Another service is FEWS net, a collaborative effort of the USGS, United States Agency for International Development (USAID), NASA, and NOAA, which reports on food insecurity conditions and issues watches and warnings to decision-makers. These bulletins are also available on their website. Food security prediction estimates and maps would be extremely useful for emergency response, resources allocation, and early warning. The Food Security and Nutrition Working Group (FSNWG) serves as a platform to promote the disaster risk reduction agenda in the region and provides monthly updates on food security through maps and reports available on its website. FEWSnet and FSNWG were instrumental in predicting the food crisis in 2010-2011 in the East African Region in a timely manner. Nevertheless these early warnings did not lead to early action to address the food crisis. If they had been used adequately, the impacts of the serious humanitarian crisis in the Horn of Africa could have been partially mitigated (Ververs 2011).

Impact of climate variability

Nearly all efforts to cope with climate change or variability focus on either mitigation to reduce emissions or on adaptation to adjust to changes in climate. Although it is imperative to continue with these efforts, the on-going pace of climate change and the slow international response suggests that a third option is becoming increasingly important: to protect the population against the immediate threat and consequences of climate-related extreme events, including heat waves, forest fires, floods and droughts, by providing it with *timely, reliable and actionable warnings.* Although great strides have been made in developing climate-related warning systems over the past few years, current systems only deal with some aspects of climate-related risks or hazards, and have large gaps in geographic coverage. Information exists for melting glaciers, lake water level, sea height and sea surface temperature anomalies, El Niño and La Niña. The National Snow and Ice Data Center (NSIDC)-Ice Concentration and Snow Extent provides near real-time data on daily global ice concentration and snow coverage. The USDA, in cooperation with the NASA and the University of Maryland, routinely monitors lake and reservoir height variations for approximately 100 lakes worldwide and provides online public access to lake water level data. Information on Sea Height Anomaly (SHA) and Significant Wave Height data are available from altimeter JASON-1, TOPEX, ERS-2, ENVISAT and GFO on a near-real time basis with an average 2-day delay. This information is provided by NOAA. Additionally, near real-time Sea Surface Temperature (SST) products are available from NOAA's GOES and POES, as well as NASA's EOS, Aqua and Terra. The International Research Institute (IRI) for Climate and Society provides a monthly summary of the El Niño and La Niña Southern Oscillation, providing forecast summary, probabilistic forecasts, and a sea surface temperature index. However, these systems are still far from providing the coverage and scope that is needed and technically feasible. Large parts of the world's most vulnerable regions are still not covered by a comprehensive early warning system. Most systems only deal with one aspect of climate-related risks or hazards, e.g., heat waves or drought. Finally, most systems do not cover the entire early warning landscape from collection of meteorological data to delivery and response of users. Recently, the World Meteorological Organization proposed a Global Framework for Climate Services, which aims to strengthen the global cooperative system for collecting, processing and exchanging observations and for using climate-related information (WMO 2011).

Chapter 4: Conclusions and Future Perspectives

4.1 Early warning systems: current gaps and needs

Early warning technologies appear to be mature in certain fields but not yet in others. Considerable progress has been made, thanks to advances in scientific research and in communication and information technologies. Nevertheless, a significant amount of work remains to fill existing technological, communication, and geographical coverage gaps. Early warning technologies are now available for almost all types of hazards, although for some hazards (such as droughts and landslides) these technologies are still less developed. Most countries appear to have early warning systems for disaster risk reduction. However, there is still a technological and national capacity divide between developed and developing countries. From an operational point of view, some elements of the early warning process are not yet mature. In particular, it is essential to strengthen the links between sectors involved in early warning, including organizations responsible for issuing warnings and the authorities in charge of responding to these warnings, as well as promoting good governance and appropriate action plans.

4.2 Early warning systems: future perspectives

It is generally recognized that it is fundamental to establish effective early warning systems to better identify the risk and occurrence of hazards and to better monitor the population's level of vulnerability. Although several early warning systems are in place at the global scale in most countries for most hazard types, there is the need "To work expeditiously towards the establishment of a worldwide early warning system for all natural hazards with regional nodes, building on existing national and regional capacity such as the newly established Indian Ocean Tsunami Warning and Mitigation System" (2005 UN World Summit Outcome). By building upon ongoing efforts to promote early warning, a multi-hazard early warning system will have a critical role in preventing hazardous events from turning into disasters. A globally comprehensive early warning system can be built, based on the many existing systems and capacities. This will not be a single, centrally planned and commanded system, but a networked and coordinated assemblage of nationally owned and operated systems. It will make use of existing observation networks, warning centres, modeling and forecasting capacities, telecommunication networks, and preparedness and response capacities (UN 2006). A global approach to early warning will also guarantee consistency of warning messages and mitigation approaches globally thus improving coordination at a multi-level and multi-sector scale among the different national actors such as the technical agencies, the academic community, disaster managers, civil society, and the international community.

The next section provides an analysis of existing global early warning/monitoring systems that aggregate multi-hazard information.

4.3 State of existing multi-hazard global monitoring/early warning systems

This section presents the results of a comparative analysis of multi-hazard global monitoring/early warning systems. The aim of this analysis is to assess the effectiveness of existing global scale multi-hazard systems and define the set of needs suggested by comparing existing services. It assesses existing monitoring/early warning systems (Grasso and Singh 2007), chosen to be multi-hazard with global coverage, such as WFP's (the UN food aid agency's) HEWS; AlertNet, the humanitarian information alert service by Reuters; ReliefWeb, the humanitarian information alert service by UN-OCHA; GDACS (Global Disaster Alert and Coordination System), a joint initiative of the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) and the EC-JRC; and USGS ENS. These systems have been analysed for the type of events covered, variety of output/communication forms and range of users served.

These systems cover a range of hazards and communicate results using a variety of methods. USGS ENS only provides information on earthquakes and volcanic eruptions through the Volcano Hazards Program (VHP) in collaboration with Smithsonian Institution. ReliefWeb focuses on natural hazards (earthquakes, tsunamis, severe weather, volcanic eruptions, storms, floods, droughts, cyclones, insect infestation, fires, and technological hazards) and health; AlertNet additionally provides information on food insecurity and conflicts. GDACS provides timely information on natural hazards (earthquakes, tsunamis, volcanic eruptions, floods, and cyclones). HEWS informs users on earthquakes, severe weather, volcanic eruptions, floods, and locusts.

Existing systems, such as HEWS, post the information on a web site, provide mobile phone and RSS services, and GDACS sends emails, SMS and faxes to users. The GDACS notification service mostly addresses humanitarian organizations, rescue teams or aid agencies. AlertNet provides information to users through a web service, email, SMS and reports. ReliefWeb uses web services, email and reports to disseminate information to users. ReliefWeb and AlertNet also use new communications tools (Facebook and Twitter). OCHA's Virtual On-site Operations Coordination Centre (Virtual-OSOCC) enables real-time information exchange by all actors of the international disaster response

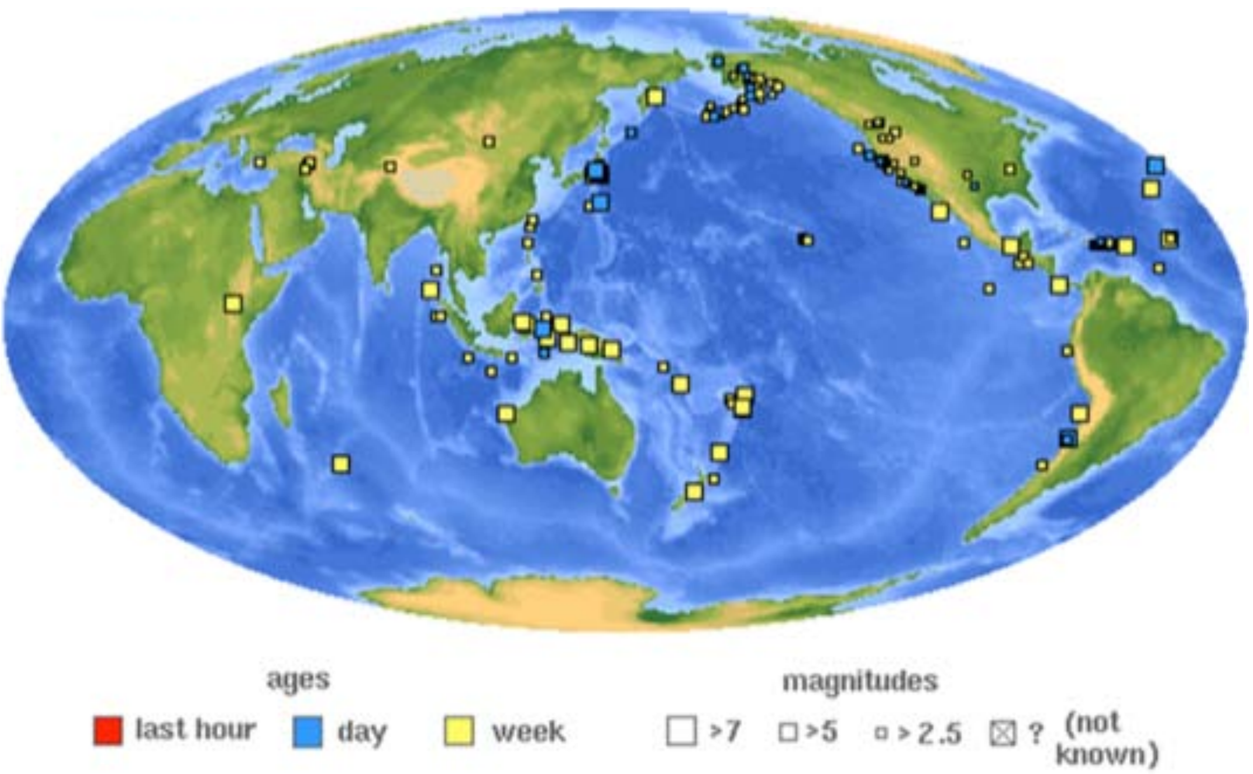


Figure 4: USGS map of recent earthquakes. The symbols showing recent earthquakes are colour coded; the most recent earthquakes are red and past-day events are orange, while last week's events are yellow. Note that the size of symbol decreases with decreasing magnitude. From: http://earthquake.usgs.gov/eqcenter/recenteqsww/ (accessed 12 August 2011).

community during the early phases following disasters. This service has been integrated within GDACS but is restricted to disaster managers.

The only natural event notification provided by USGS email service is earthquakes. HEWS offers no email notifications for natural events. AlertNet and ReliefWeb inform users on natural hazards and on health, food and security issues. USGS, ReliefWeb, AlertNet and GDACS serve a wide a variety of users such as international organizations, humanitarian aid, policy/decision makers, and civil society.

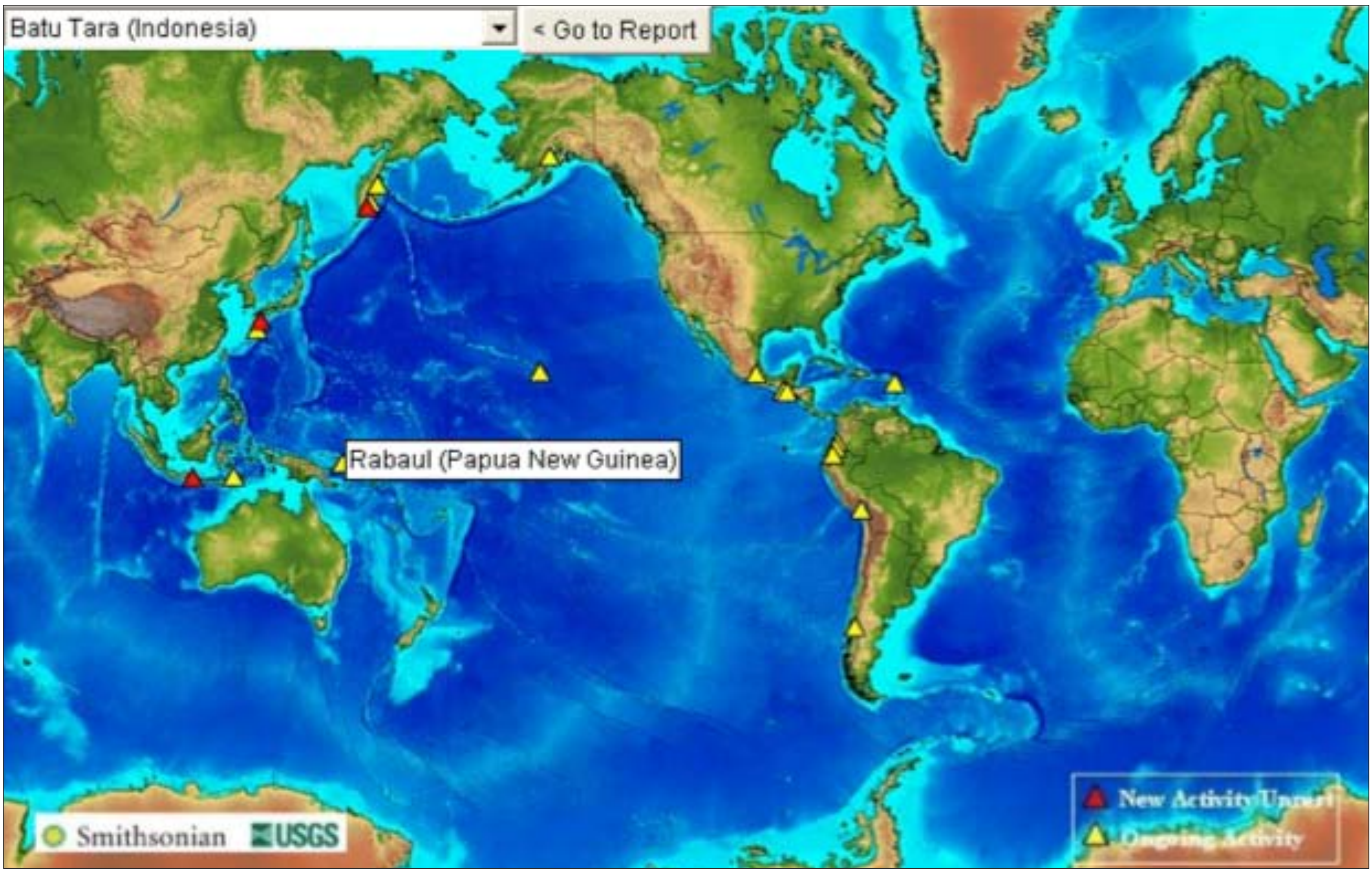


Figure 5: The USGS and Smithsonian Institution's Volcanic Activity Map showing past-week volcanic eruptions; red triangles show new volcanic activity and yellow is for ongoing activity. From: http://www.volcano.si.edu/reports/usgs/ (accessed 13 March 2009).

Figure 6: WFP–HEWS Early Warning Natural Hazards Map. The above global map provides the latest natural hazard information. From: http://www.hewsweb.org/hp/ (accessed 12 July 2011).

The optimal global coverage multi-hazard system has to be as comprehensive as possible in terms of content, output and range of users. It will enhance existing systems by streaming data and information from existing sources and it will deliver this information in a variety of user-friendly formats to reach the widest range of users. By building on existing systems the multi-hazard system will inherit both the technological and geographical coverage gaps and limitations of existing early warning systems. The review analysis performed in Chapter 3 has shown that for some hazards (such as droughts and landslides) these technologies are still less developed and for tsunamis these systems are still under development for areas at risk. The analysis has shown that there is still a technological and national capacity divide between developed and developing countries. From an operational point of view, the links and communication networks between all sectors involved (organizations responsible for issuing warnings

Volcano on the Canary Islands.

Figure 7: AlertNet Map for country updates; circles with increasing diameter indicate higher number of events. From: http://www.alertnet.org/ (accessed 12 August 2011).

and the authorities in charge of responding to these warnings) need improvement. Likewise, good governance and appropriate action plans need to be promoted. Overcoming these gaps and enhancing, integrating, and coordinating existing systems is the first priority for the development of a global scale multi-hazard early warning system.

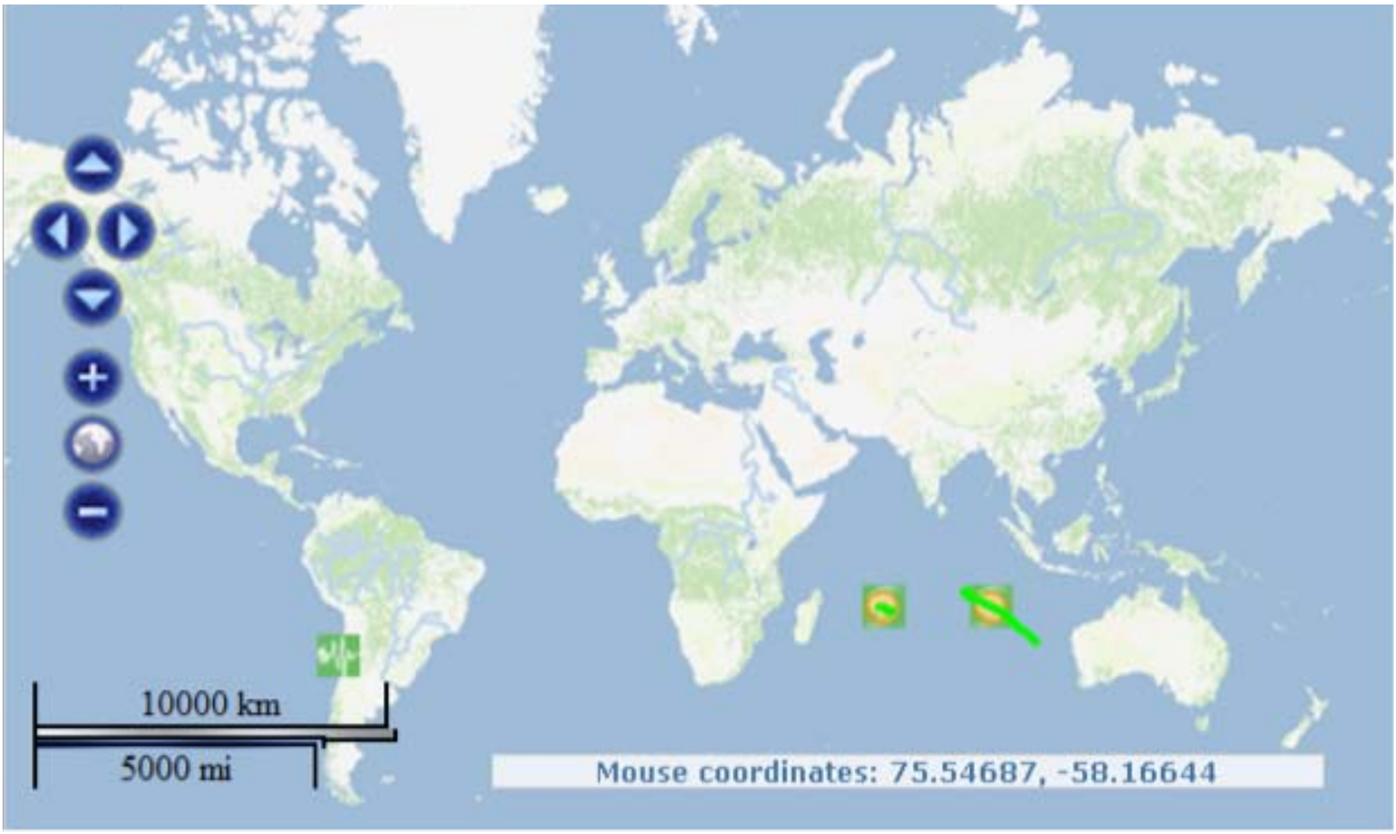


Figure 5 GDACS Map for hazards: earthquakes, tsunamis, cyclones, volcanic eruptions, floods. Symbols for events are color coded according to intensity and potential impact. From: www.gdacs.org (accessed 08/12/2011).

4.4 Conclusions and recommendations

Early warning technologies have greatly benefited from recent advances in communication and information technologies and an improved knowledge on natural hazards and the underlying science. Nevertheless many gaps still exist in early warning technologies and capacities, especially in the developing world, and a lot more has to be done to develop a global scale multi-hazard system. Operational gaps need to be filled for slow-onset hazards both in monitoring, communication and response phases. Effective and timely decision-making is needed for slow-onset hazards.

Below are some recommendations:

1) Fill existing gaps

Chapter 3 identified the weaknesses and gaps in existing early warning systems. Technological, geographical coverage, and capacity gaps exist, in addition to operational gaps for slow-onset hazards. In particular, actions need to be taken to improve prediction capabilities for landslides hazard aimed at developing a landslides early warning system. Likewise, there is a pressing need to improve existing prediction capabilities for droughts. A global early fire warning system is not yet in place, the tsunami early warning systems for the Indian Ocean and the Caribbean are not yet fully operational and a desertification early warning system has not been developed yet. There are ongoing efforts to develop these systems, such as the GFMC effort for the global fire EWS, the Indian Ocean Tsunami Warning System operated by Indonesia and a NOAA led effort in the Caribbean. A malaria early warning system is mandatory for Africa, where one million deaths occur every year due to malaria. Climate variability impacts need to be monitored within a global and coordinated effort, and the Global Framework for Climate Services needs to be further elaborated and operationalized. Local earthquake early warning systems applications are needed in high seismic risk areas, where early warning systems are not yet in place. Air quality and flood systems require improvements in prediction capabilities. Dust storms and transboundary early warning systems do not yet exist. A coordinated volcanic early warning system that would integrate existing resources is also needed as well as an increase in coverage of volcanic observatories. Particular attention should be paid to fill gaps in decision making processes for slow-onset hazards. Their extent and impact are challenging to quantify. For this reason, actions and response are far more difficult tasks for slow-onset hazards than they are for other natural hazards. An institutional mechanism to regularly monitor and communicate slow-onset changes is needed to keep changes under review and to enable rational and timely decisions to be taken based on improved information.

2) Build capacity

The evaluation study of existing early warning systems (Chapter 3) highlighted that a technological divide between developed and developing countries still exists. It is critical to develop basic early warning infrastructures and capacities in parts of the developing world most affected by disasters; it is also important to promote education programs on disaster mitigation and preparedness and integrate disaster mitigation plans into the broader development context. Poor countries suffer greater economic losses from disasters than rich countries. Development plays a key role and has a significant impact on disaster risk. Almost 85 per cent of the people exposed to the deadliest hazards, earthquakes, floods, cyclones and droughts live in the developing world. The impact of disasters is mostly influenced by previous development choices. By integrating disaster mitigation strategies into planning and policies, the effects of disasters can be sensibly reduced and managed. "Disaster risk is not inevitable, but on the contrary can be managed and reduced through appropriate development actions" (United Nations Development Programme-UNDP 2004). It is through "risk-sensitive development planning that countries can help reduce disaster risks".

Key targets for capacity building include:

1. Developing national research, monitoring and assessment capacity, including training in assessment and early warning;
2. Supporting national and regional institutions in data collection, analysis and monitoring of natural and man-made hazards;
3. Providing access to scientific and technological information, including information on state-of-the-art technologies;
4. Education and awareness-raising, including networking among universities with programmes of excellence in the field of the emergency management;
5. Organizing of training courses for local decision makers and communities;
6. Bridging the gap between emergency relief and long-term development.

3) Bridge the gaps between science and decision making, and strengthen coordination and communication links

Scientific and technological advances in modeling, monitoring and predicting capabilities could bring immense benefits to early warning if science were effectively translated into disaster management actions. Bridging the gap between scientific research and decision making will make it possible to fully exploit capacities of early warning technologies for societal benefit. The major challenge is to ensure that early warnings result in prompt responses by governments and potentially the international community. This requires that information be effectively disseminated in an accessible form down to the end user. This is achievable by adopting standard formats and easy-to-use tools for information dissemination, such as interactive maps, emails, SMS, etc. The adoption of standard formats (such as the Common Alerting Protocol CAP) for disseminating and exchanging information has to be promoted. The advantage of standard format alerts is their compatibility with all information systems, warning systems, media, and most importantly, with new technologies such as web services. The adoption of standard formats guarantees consistency of warning messages and is compatible with all types of information systems and public alerting systems, including broadcast radio and television as well as public and private data networks, with multi-lingual warning systems and emerging technologies. This would easily replace specific application oriented messages and will allow the merging of warning messages from several early warning systems into a single multi-hazard message format. Finally, it is critical to strengthen coordination and communication links by defining responsibility mechanisms and appropriate action plans. More often, time-sequenced warning messages are released in early warning processes, implying a decrease in warning times available for action and in reliability of the information. This trade-off needs to be addressed.

A volunteer group training in handling flash flood casualities, Pakistan.

ground reporter/Flickr.com

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Acronyms

AMSR-E	Advanced Scanning Microradiometer
AMSU	NOAA/Advanced Microwave Sounding Unit
ATWC	Alaska Tsunami Warning Center
AVHRR	Advanced Very High Resolution Radiometer
BCC	Beijing Climate Center
CAP	Common Alerting Protocol
CEOS	Committee on Earth Observation Satellites
CMA	China Meteorological Administration
CNES	Centre National d'Etudes Spatiales
DEM	Digital elevation maps
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
EC	European Commission
EC-JRC	European Commission Joint Research Center
ECPC	Experimental Climate Prediction Center
EDM	Electronic Distance Measurement
EFAS	European Flood Alert System
ENAC	Emergency Notification and Assistance Convention
EO	Earth observation
ESA	European Space Agency
EOS	Earth Observing Satellites
EPA	U.S. Environmental Protection Agency
EWS	Early Warning System
EW	Early Warning
FAO	Food and Agriculture Organization of the United Nations
FEWS Net	Famine Early Warning System
FSNWG	Food Security and Nutrition Working Group
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GDACS	Global Disaster Alert and Coordination System
GDPS	Global Data Processing System
GEOSS	Global Earth Observation System of Systems
GFAS	Global Flood Alert System
GFIMS	Global Fire Information Management System
GFMC	Global Fire Monitoring Center
GIEWS	Global Information and Early Warning System on Food and Agriculture
GIS	Geographical Information Systems
GOARN	Global Outbreak Alert and Response Network
GOES	Geostationary operational environmental satellites
GOOS	Global Ocean Observing System
GOS	Global Observing System
GPHIN	Global Public Health Intelligence Network
GPS	Global Positioning System
GSN	Global Seismic Networks

GTOS	Global Terrestrial Observing System
GTS	Global Telecommunications System
HEWS	Humanitarian Early Warning Early Warning Service
IAEA	International Atomic Energy Agency
ICT	Information and Communication Technology
ICL	International Consortium on Landslides
IEC	Incident and Emergency Centre
IGOS	Integrated global observing strategy
INPE	Brazilian Space Research Institute
IOC	ntergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel for Climate Change
IR	Infra-red
IRI	International Research Institute
IRIS	Incorporated Research Institutions for Seismology
ISDR	International Strategy for Disaster Reduction
ITIC	International Tsunami Information Center
JMA	Japan Meteorological Agency
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
NASA	National Aeronautics and Space Administration
NEWS	Nuclear Event Web-based System
NMHS	National Meteorological and Hydrological Services
NOAA	National Oceanic and Atmospheric Organization
NOAA-NESDIS	NOAA's National Environmental Satellite, Data, & Information Service
NSIDC	National Snow and Ice Data Center
NWS	National Weather Service
OMI	Ozone Monitoring Instrument
OIE	World Organization for Animal Health
OLS	Optical Linescan System
POES	Polar Orbiting Environmental Satellites
PPEW	Platform for the Promotion of Early Warning (ISDR)
PTWC	Pacific Tsunami Warning Center
PTWS	Pacific Tsunami Warning System
RSMC	Regional Specialized Meteorological Centres
RSS	Really Simple Syndication
SAR	Synthetic Aperture Radar
SCHIAMACH	Scanning Imaging Absorption Spectro-Meter for Atmospheric Chartography
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SHA	Sea Height Anomaly
SMS	Short Message Service
SSM/I-Special Sensor Microwave/Imager	
SST	Sea surface temperature
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP-DEWA	United Nations Environment Programme-Division of Early Warning and Assessment
UNESCO	United Nations Educational, Scientific and Cultural Organization
UN-OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNOOSA	United Nations Office for Outer Space Affairs
USAID	United States Agency for International Development
USGS	U.S. Geological Survey
USGS-ENS	U.S. Geological Survey-Earthquake Notification Service
VHP	Volcano Hazards Program
WCP	World Climate Programme
WCRP	World Climate Research Programme
WFP	World Food Programme
WHO	World Health Organization
WMO	World Meteorological Organization
WMO-TCP	World Meteorological Organization-Tropical Cyclone Programme
WOVO	World Organization of Volcanic Observatories
WWW	World Weather Watch
XML	Extensible Markup Language

Appendix

Type of event	Source	Geographic Coverage	Output	Website	Description
Air Pollution					
	European Space Agency (ESA)	Global	Daily Maps of total ozone column, global ozone field, erythemal UV index, NO_2 column, absorbing aerosol index and 8-days forecsats	http://www.temis.nl/index.html	ESA provides daily maps of air quality: Ozone column from SCIAMACHY, GOME or OMI; UV information is from SCIAMACHY and other sources, NO_2 from OMI and GOME-2 and SCIAMACHY. Is also available a 8-day forecast of total ozone column and UV index at a global scale. *Comments:* Information on ground-level ozone is not provided thus the use of these products for local scale air pollution assessment is limited.
	NASA	Global	Daily maps of total ozone column and Aerosol index	Maps of total ozone column from OMI: http://toms.gsfc.nasa.gov/teacher/ozone_overhead_v8.html?96,56 Maps of total ozone from OMI: http://toms.gsfc.nasa.gov/ozone/ozone_v8.html Maps of aerosol index: http://toms.gsfc.nasa.gov/aerosols/aerosols_v8.html	NASA provides daily maps of total ozone column and aerosol index from OMI instrument that also provides information on aerosol type and cloud coverage. Using these data it is possible to monitor a wide range of phenomena such as desert dust storms, forest fires and biomass burning. *Comments:* Information on ground-level ozone is not provided thus the use of these products for local scale air assessment pollution is limited.
	Europe				
	European Environment Agency-EEA	Europe	Real-time Maps of ground-level ozone	http://www.eea.europa.eu/maps/ozone/welcome/	Data is collected by EEA from several European organizations which provide ground-level ozone measurements to EEA. Data is then made available on the EEA website through real-time interactive maps, which are updated an hourly basis. Air quality maps are color coded according to threshold values in EU legislation. *Comments*: The air quality data used on EEA website are preliminary. They are received immediately —within an hour of the measurement being made —from measurement stations. Particulate matter information will be provided in the future. Forecasts of ground-level ozone are not available.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Air Quality Network	U.K.	Real-time maps of air quality index	For London: http://www.londonair.org.uk/ london/asp/PublicBulletin.asp?bulletindate=03%2F05%2F2006&region=0&bulletin=daily&site=&la_id=&postcode=&Submit=Go For the whole U.K. http://www.airquality.co.uk/archive/index.php	The London Air Quality Network measures air quality parameters as NO_2, CO, SO_2, ozone, PM2.5 and PM10 in and around greater London. Measurements are collected either hourly or twice daily from continuous monitoring sites, processed and checked then placed on the web site with an hourly update. The air quality index displayed on the map is color coded. *Comments*: Air quality information is not complete for all the monitoring sites. Forecasts of air quality index are not available.
	Leeds City Council	Leeds, U.K.	Real-time maps of fPM10, SO_2, NO_2, CO_2, ozone.	http://www.airviro.smhi.se/leeds/	Leeds City Council Air Pollution Monitoring site operates a monitoring network to gather information used to review and assess air quality within the Leeds area. The maps gives access to the PM10, SO_2, NO_2, CO_2, ozone current values and results for the last 7 days are also available. It is also possible to download data in Excel format. *Comments:* Forecasts of PM10, SO_2, NO_2, CO_2, ozone are not available.
	National Environmental Research Institute of Denmark	Denmark	Real-time maps of air quality index	http://www2.dmu.dk/1_Viden/2_miljoe-tilstand/3_luft/4_maalinger/default_en.asp	Air quality in Denmark is monitored with a network of measuring stations. Data are usually updated every hour during daytime and updated in real-time. *Comment*: The webpage is only available in Danish.
	PREV'Air (Ministere de L'Ecologie et du development durable, INERIS, CNRS, Meteo France and Institute Pierre Simon Laplace)	Europe	Real-time maps of ozone, NO_2, and PM10 (only for France) and 3-day forecasts	http://prevair.ineris.fr/fr/index.php http://www.notre-planete.info/environnement/picsactus.php	Real-time maps of ozone, NO_2, and PM10 are available for France from Associations Agréées de Surveillance de la Qualité de l´Air (AASQA) updated every hour. PREV'Air uses a predictive model to produce 2-days prediction maps ozone, NO_2, and PM2.5, PM10 for Europe and for ozone the product is available also at a global scale. *Comments:* The website is available only in French.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Interregional Cell for the Environment	Belgium	Daily values and forecast maps of ozone, NO_2, CO, SO_2, PM10, PM2.5 and C_6H^6	Observations: http://www.irceline.be/~celinair/english/homeen_java.html Home page: http://www.irceline.be/	This effort is a collaborative effort Interregional Cell for the Environment and the European Agency for the Environment EEA.
	AirParif	Ile de France	Real-time and forecast maps of NO_2, PM10, ozone and SO_2	http://www.airparif.asso.fr/	AIRPARIF provides air quality information for the region and 1 day forecast. It also displays an interactive map on air quality for major European cities.*Comments*: The website is available only in French.
	Federal Environmental Agency	Germany	Real-time maps of NO_2, ozone, PM10, CO_2 and SO_2. Forecast maps of ozone	http://www.env-it.de/luftdaten/start.fwd?setLanguage=en	Federal Environmental Agency (FEA) and the German Laender collect air quality data from measuring stations in Germany on air quality. *Comments:* Some of the website's pages are available only in German.
	Environmental Protection Agency	Ireland	Daily values of NO_2, SO_2, PM, benzene	http://www.epa.ie/whatwedo/monitoring/air/data/	The Environmental Protection Agency (EPA) for Ireland provide an interactive map of air quality and daily values of NO_2, SO_2, PM, benzene. *Comments:* Daily values are not available for all monitoring sites. Forecasts are not available.
	Asia				
	Ministry of Environmental Protection Administration of China	China-84 major cities in China	Daily values of air quality index and prominent pollutant (PM or SO_2)	Main website in English: http://english.mep.gov.cn/ Air Quality Daily: http://datacenter.mep.gov.cn/report/air_daily/air_dairy_en.jsp Air Quality Forecast: http://datacenter.mep.gov.cn/report/air_forecast/dairy_forecast_en.jsp	Ministry of Environmental Protection Administration of China provides daily air quality index and prominent pollutant (PM or SO_2) associated with a level grade for 120 cities in China on their website. Forecasts are also available. *Comments:* Daily values are not available for all monitoring sites.
	Environmental Protection Department-Government of Hong Kong	Hong Kong	Daily values of air quality index and prominent pollutant (PM or NO_2).	http://www.epd-asg.gov.hk/	The Environmental Protection Department (EPD) provides daily air quality index and prominent pollutant (PM or NO_2) associated with a level grade. Graphs are also available to show data of the past days. *Comments:* Forecasts are not provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Environmental Protection Administration	Taiwan	Real-time air quality index map. For each monitoring site is provided a detailed table of SO_2, CO, ozone, PM10, O_2.	http://210.69.101.141/taqm/en/default.aspx	The EPA of Taiwan aims at preventing pollution, and supporting international environmental initiatives in order to achieve sustainable development. EPA provides a daily map of air quality level for Taiwan. *Comments:* Forecasts are also provided.
	AIRKOREA	Korea	Real-time map of air quality index and NO_2, CO, PM10, ozone, O_2, SO_2.	http://www.airkorea.or.kr/airkorea/eng/realtime/main.jsp	Since 2005, AIRKOREA provides a public access to air quality information collected hourly in more than 16 areas in South Korea. On the website, an interactive map shows air quality index and pollutant values for major cities. *Comments:* Forecasts are not provided.
	Pollution Control Department–Ministry of Natural Resources and Environment	Thailand	Daily map of air quality index and values of PM10, SO_2, NO_2, CO, ozone are provided in a table.	Daily air quality map: http://www.pcd.go.th/AirQuality/Regional/Graph/createaqi2.cfm Values of SO_2, NO_2, CO, ozone: http://www.pcd.go.th/AirQuality/Regional/Default.cfm	Pollution Control Department provides access to air quality information for 30 locations in Thailand. A color coded air quality map is available on the website. For each location is also provided a table with pollutants values. *Comments:* Forecasts are not provided.
	Australia				
	Environment Protection Authority–Department of Environment and Conservation	New South Wales	Values of ozone, NO_2, PM10, CO, SO_2.	http://www.environment.nsw.gov.au/AQMS/ aqi.htm.	The EPA is involved in programs on pollution, coastal management, and water quality. The EPA website provides daily values of pollutants for the Sydney area, Illawarra, Hunter, Tablelands and Slopes areas. *Comments:* Forecasts are not provided.
	Environment Protection Authority–Victoria	Victoria, Australia	Map of air quality index and forecasts of CO, NO_2, O_3 and hydrocarbons concentrations. (only for Victoria and Melbourne). Also wind condition and temperature are provided.	Map of air quality index: http://www.epa.vic.gov.au/Air/AQ4Kids/station_map.asp Forecasts: http://www.epa.vic.gov.au/Air/AAQFS/AAQFS_VIC_Forecast.asp http://www.epa.vic.gov.au/Air/AAQFS/AAQFS_Melb_Forecast.asp	EPA Victoria provides public access to values of several air pollutants selected CO, NO_2, O_3 and hydrocarbons concentrations. In addition to it, prevailing temperature and wind conditions, are also provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
	North and South America				
	Environment Canada	Canada	Real-time maps of air quality index and forecasts (only in summer)	http://www.ec.gc.ca/cas-aqhi/	Environment Canada website provides access to real-time maps of air quality index for British Columbia, Alberta, Ontario, Quebec, New Brunswick, Prince Edward Island, Nova Scotia, Labrador and Newfoundland. From May to September forecasts are also available. Air Quality advisories are issued when the air pollution levels exceed national standards. They are issued in partnership with provincial and municipal environment and health authorities and contain advice on action that can be taken to protect the health of Canadians and the environment. *Comments:* Forecasts are available only in summer.
	Alberta Government	Alberta, Canada	Maps of air quality index	http://environment.alberta.ca/0977.html http://www.environment. alberta.ca/apps/aqhi/aqhi.aspx	Alberta Government website provides access to air quality information through interactive Google maps, which also provides forecasts.
	Ministry of Environment, Government of British Columbia	British Columbia, Canada	Real-time values air quality	http://www.bcairquality.ca/	The Water, Air and Climate Change Branch Ministry of Environment provides information on air quality for various locations in British Columbia, together with forecasts.
	Ministry of Environment, Ontario	Ontario	Real-time and forecast maps of air quality index and information on O_3, PM, NO_2, SO. E-mail alerts	http://www.airqualityontario.com/	Ministry of Environment provides a detailed and comprehensive service to air quality information with daily updated air quality index maps and 3-day forecast; email alerts for several locations in Ontario are also available.
	Ministry of Environment, Quebec	Quebec	Daily map of air quality index	http://www.iqa.mddep.gouv.qc.ca/contenu/index_en.asp#carte	Ministry of Environment, Quebec provides daily air quality and past days values. This information is accessible on the website through an interactive map. *Comments:* Forecasts are not available

Type of event	Source	Geographic Coverage	Output	Website	Description
	Ville de Montreal	Montreal	Maps of air quality index and values of PM, CO, NO_2, O_3 (shown on a graph). Forecast report	http://ville.montreal.ca/portal/page?pageid=7237,74495616&&_dad=portal&schema=PORTAL	The City of Montréal operates its own Air Quality Monitoring Network. For each station, air quality levels are provided *Comments:* Website is only in French.
	Bay area air quality management district	Bay Area, U.S.	Daily and forecast maps of air quality index and value of PM2.5. Bulletins on air quality incidents	Air quality forecast: http://www.sparetheair.org/Stay-Informed/Todays-Air-Quality/Five-Day-Forecast.aspx Bulletins: http://www.baaqmd.gov PM2.5: http://gate1.baaqmd.gov/aqmet/aq.aspx	The Bay Area Air Quality Management provides daily information on air quality and 5-days forecasts.
	U.S. Environmental Protection Agency	U.S. and Canada	Real-time and forecast maps of air quality index and values of O_3 and PM2.5	U.S.: http://airnow.gov/ Canada: http://airnow.gov/index.cfm?action=airnow.canada	EPA AirNow provides real-time air quality index for the major cities of U.S. and parts of Canada. Maps are provided via AirNow website and the website offers daily forecasts as well as real-time air quality conditions for over 300 cities across the US, and provides links to more detailed State and local air quality web sites. The Enviroflash notification service provides air quality information in real-time to subscribers by e-mail, cellphone, pager, allowing them to take steps to protect their health in critical situations.
	CAMNET Real-time pollution and visibility camera network	North East Coast, U.S.	Live pictures from webcams, 0_3 and PM levels, wind speed	http://www.hazecam.net/	CAMNET provides webcam live pictures and corresponding air quality conditions from scenic urban and rural vistas in the Northeast. CAMNET, brings to the attention the effects of air pollution on visibility. *Comments:* Values of pollutants are not available.
	Virginia Department of Air Quality	Virginia, U.S.	Current and forecasts of air quality index	http://www.deq.state.va.us/airquality/	Virginia Department of Air Quality monitors levels of ozone and particle pollution from stations around Virginia and provides air quality index for each town. *Comments:* Values of pollutants are not available.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Georgia Department of Natural Resources	Georgia, U.S.	Daily Values of O_3, SO_2, CO, NO_2, PM10, PM2.5 and air quality index (also forecasts).	http://www.air.dnr.state.ga.us/amp/	The Ambient Monitoring Program measures levels of air pollutants throughout the State. The data are used to calculate the Air Quality Index and to compare it with air standards established. *Comments:* Forecasts are available only for air quality index.
	Delaware Air Quality Monitoring Network	Delaware, U.S.	Daily maps of air quality index and values of O_3, PM, wind speed and direction.	http://www.dnrec.state.de.us/air/aqm_page/airmont/Air.asp	Data are collected by air quality monitoring stations distributed in the region. A map shows the air quality index and for each station location are provided values of O_3, PM, wind speed and direction.*Comments:* Forecasts are not provided.
	Department of Conservation and Natural Resources	Nevada, U.S.	Air quality information and values of O_3, PM10 and PM2.5 and others	Website: http://ndep.nv.gov/admin/monitoring.htm	The department provides air quality status and trends for the State's monitoring jurisdiction. Graphs of the monitoring data for each station can be found by navigating through the Monitoring Data menu item. *Comments:* Forecasts are not provided.
	Arizona Department of Environmental Quality	Arizona, U.S.	Daily and forecast values of O_3, CO, PM10, PM2.5 and air quality index. Live images from webcams in the Phoenix area.	Live webcam pictures: http://www.phoenixvis.net/ http://www.azdeq.gov/environ/air/monitoring/links.html http://www.azdeq.gov/environ/air/index.html	Arizona Department of Environmental Quality informs on air quality by providing daily values of pollutants and live webcam images. Forecasts are provided through a report. *Comments:* Daily values are provided by US EPA.
	Department of Environmental Quality, Montana	Montana, U.S.	Maps of air quality index	http://todaysair.mt.gov/	Air quality of Montana is provided through an interactive color coded maps. For each station a graph of hourly air quality variations is shown on the website. Thresholds are also set for unhealthy, very unhealthy, and hazardous conditions. *Comments:* Values of pollutants are not provided.
	Idaho Department of Environmental Quality	Idaho, U.S.	Daily maps and values of air quality index, O_3 CO, SO_2, NO_2, PM	http://airquality.deq.idaho.gov/	For each monitored site, the Idaho Department of Environmental Quality provides air quality index maps and the values of pollutant of concern. *Comments:* Information is not complete for all monitoring sites

Type of event	Source	Geographic Coverage	Output	Website	Description
	Florida Department of Environmental Protection	Florida, U.S.	Real-time and forecast maps of air quality index, O_3 and PM.	http://www.dep.state.fl.us/air/air_quality/airdata.htm	Through a Java/GIS application map air quality information is provided, in particular hourly ozone, particulate matter and air quality index. *Comments:* Values of pollutants are not available.
	Wisconsin Department of Natural Resources	Wisconsin, U.S.	Real-time map of air quality index and values of SO, NO_2, CO, PM10 and PM2.5.	http://dnr.wi.gov/air/aq/health/status.asp http://prodoasjava.dnr.wi.gov/wisards/webreports/previousDaysData.do	The map provided by the Wisconsin Department of Natural Resources shows air quality index derived from ozone and PM2.5 values. The Air Quality Index is calculated from real time data. Additional pollutants are available as SO, NO_2, CO, PM10, provided for each monitoring site in a table. *Comments:* Forecasts are not provided.
	Pima County Department of Environmental Quality	Tucson, Arizona, U.S.	Values of O_3, wind speed, wind direction.	http://www.airinfonow.org/monsites/map_site.asp	The Pima County Department of Environmental Quality Air Info Now web site, provides current air quality information for the metropolitan Tucson area. The information can be accessed from an interactive map, clicking on each monitoring site a table opens providing ozone concentration and wind and temperature recordings. *Comments:* Air quality index and other relevant pollutants are not provided, neither forecasts.
	Greater Vancouver Regional District-GVRD	Canada	Air quality index and forecasts	http://www.metrovancouver.org/services/air/providedmonitoring/Pages/airqualityindex.aspx	Real-time information on air quality for several locations is by GVRD. An interactive map shows the monitoring stations aroundthe Vancouver area. For each site are provided graphs of air quality index and forecasts. *Comments:* Values of relevant pollutants are not provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Inter Agency Real-Time Smoke Particulate Monitoring	U.S.	Graphs of air quality index, Real-time smoke monitoring.	http://www.satguard.com/USFS/realtime/fleet.asp	This web site provides real-time smoke concentration data (along with some other meteorological information) from portable smoke monitors. Historical data from past monitoring efforts are also available. The data is updated hourly with 5-minute averages from the operating site. An interactive map is available on the website from which users can access detailed tables of air quality index. *Comments:* Note only 9 sites are monitored throughout the US.
	Washington Department of Ecology	Washington area, U.S.	Daily maps of air quality index and values of pollutant of concern.	https://fortress.wa.gov/ecy/enviwa/Default.htm	An interactive map is available on the website of the Washington Department of Ecology. For each site is provided a graph of the recording of the pollutant of concern (O_3, PM, CO). *Comments:* Not all pollutants are available for all monitoring stations. In addition, forecasts are not available.
	USDA, Forest Service Real-time air quality	U.S.	Live webcam images and values of air quality index, O_3 and PM10 and PM2.5.	http://www.fsvisimages.com/descriptions.aspx	Forest Service Real-time air quality provides live pictures from webcams and corresponding air quality conditions in the Northeast. Real-time display panel for visibility data show the air pollution and meteorological conditions associated with each image. These data are collected at the site of the camera or at another location within the scene of the photograph. *Comments:* Forecasts are not available.
	Ministry of Defense, National Meteorological Service	Argentina	Daily values of O_3	http://www.meteofa.mil.ar/?mod=ozono&id=1	Ministry of Defense, National Meteorological Service website provides a table with daily values of ozone for Base Vicecomodoro Marambio, Ushuaia, Comodoro Rivadavia, Buenos Aires. *Comments:* Forecasts are not available.

Type of event	Source	Geographic Coverage	Output	Website	Description
	INPE, Brazil	Brazil	Maps of CO, O_3, NOx, PM, and Volatil Organic Compounds	http://meioambiente.cptec.inpe.br/	INPE produces real-time maps of air quality for Brazil, from satellite observations. Maps are produced for fine particles from fires, carbon monoxide and industrial and urban emissions and are updated every 2 hours. *Comments:* The website is available only in Portuguese.
	Secretaria del Medio Ambiente	Mexico City	Hourly maps of air quality index	http://www.sma.df.gob.mx/simat/	Secretaria del Medio Ambiente monitors hourly the air quality of Mexico City. For each monitoring location is provided a table of major pollutants and the related air quality index. *Comments:* Website is available only in Spanish.
	Direccion de Ecologia	Baja California	Daily maps of air quality index	http://aire.bajacalifornia.gob.mx/eng/aqmaps.cfm	Direccion de Ecologia provides daily information on air quality for different locations in Baja California. Information on air quality and related health effects is provided for each location. *Comments:* Values of pollutants are not provided, neither forecasts.
	Africa				
	City of Cape Town air quality network	Cape Town, South Africa	Data provided by request	http://www.capetown.gov.za/airqual/	Reports are available and data can be requested by email.

Type of event	Source	Geographic Coverage	Output	Website	Description
Wild-Fires					
	ECPC, Experimental Climate Prediction Centre	Global	Fire Weather Index (FWI) maps forecast for tomorrow, weekly and monthly forecast.	http://ecpc.ucsd.edu/d2s/index.html	The Experimental Climate Prediction Center (ECPC) at the Climate Research Division, Scripps Institution of Oceanography, University of California, San Diego, in collaboration with a number of national and international researchers, undertakes research on climate analysis and predictions, regional seasonal predictions of fire danger indices for the US Forest Service (and global predictions for the Global Fire Monitoring Centre, which is an Activity of the UN International Strategy for Disaster Reduction). ECPC produces forecast maps of fire weather index for fire early warning. *Comments:* ECPC does not report on active fires.
	University of Maryland, Webfire Mapper	Global	Map of active fires and information on temperature and certainty. E-mail notification service	http://firefly.geog.umd.edu/firms/	Web Fire Mapper displays active fires detected by the MODIS Rapid Response System. FIRMS is funded by NASA and builds on Web Fire Mapper, a web mapping interface that displays hotspots/fires detected by the MODIS Rapid Response System and delivers near real-time hotspot/fire information and monthly burned area information to international users and support fire managers around the World. *Comments:* Webfire Mapper reports on active fires worldwide but does not provide forecast products.

Type of event	Source	Geographic Coverage	Output	Website	Description
	GFMC, Global Fire Monitoring Centre (activity by ISDR)	Global	Daily/Weekly information on fires, satellite images, fire danger map	http://www.fire.uni-freiburg.de/	The GFMC provides a global portal for wildland fire documentation, information and monitoring and is publicly accessible through the Internet. The regularly updated national to global wildland fire products of the GFMC are generated by a worldwide network of cooperating institutions. The online and offline products collected from several sources include: Early warning of fire danger and near-real time monitoring of fire events; Interpretation, synthesis and archive of global fire information. *Comments:* The GFMC provides a comprehensive overview and amount of material for fire monitoring and early warning. Users may find difficult to browse material in the website.
	North and South America				
	NOAA SPC, NOAA Storm Prediction Centre	U.S.	Fire weather forecast maps and satellite images	http://www.spc.noaa.gov/products/fire_wx/ http://www.spc.noaa.gov/products/fire_wx/#Day2	NOAA SPC provides forest weather forecast maps for US identifying areas under threat and fire weather outlooks for a 3-8 days' time frame. The maps can be also overlaid on satellite images depicting active fires.
	USDA, Forest Service, Wildland Fire Assessment System	U.S.	Fire Danger maps and forecasts	http://www.wfas.net/	The Wildland Fire Assessment System, is an internet-based information system. The current implementation provides a national view of weather and fire potential, including national fire danger and weather maps and satellite-derived products, as daily forest fire danger maps and 48h forecasts. *Comments:* Maps are available in low resolution and only for U.S.
	CFS, Canadian Forest Service	Canada	Fire danger maps and satellite images	http://cwfis.cfs.nrcan.gc.ca/en_CA/index	The Canadian Wildland Fire Information System creates behaviour maps year-round and hot spot maps throughout the forest fire season, generally between May and September.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Ministry of Defense, National Meteorological Service	Argentina	Daily fire risk maps	Haines index maps: http://www.meteofa.mil.ar/?mod=dpd&id=3 Fire risk maps: http://www.meteofa.mil.ar/?mod=dpd&id=4	Ministry of Defense, National Meteorological Service produces daily maps of convective fire risk using the Haines Index that is an indicator for the potential development of convective fire activity in dependence of vertical temperature and humidity profiles calculated in the lower, middle and high atmosphere. Fire risk maps are produced based on meteorological data (temperature, relative humidity, wind and precipitation at 18:00 UTC). *Comments:* Website is available only in Spanish.
	CPTEC-INPE, Centro de Previsao de Tempo e Estudios Climaticos, Brazil	South America	Map of active fires and forecast maps.	http://sigma.cptec.inpe.br/queimadas/index_in.php	INPE produces real-time maps of wild fires for South America and also Africa. The information is provided by interactive maps available on the website. Forecast maps are also available.
	Europe				
	German Weather Service	Germany	Fire danger maps	http://www.dwd.de/bvbw/appmanager/bvbw/dwdwwwDesktop?_nfpb=true&_pageLabel=_dwdwww_spezielle_nutzer_landwirtschaft_agrarwetter&T3420104081166522216849gsbDocumentPath=Content%2FLandwirtschaft%2FWarndienste%2FWaldbrand%2Fwbx__teaser.html&_state=maximized&_windowLabel=T3420104081166522216849&lastPageLabel=_dwdwww_spezielle_nutzer_landwirtschaft_agrarwetter	German Weather Service (Deutscher Wetterdienst - DWD) provides daily prediction of forest fire danger maps.
	Finnish Meteorological Institute	Finland	Fire danger maps	http://virpo.fmi.fi/metsapalo_public/	The Finnish Meteorological Institute publishes a daily fire danger map of Finland. The map is based on the Forest Fire Index Calculation System. *Comments:* The website is in Finnish

Type of event	Source	Geographic Coverage	Output	Website	Description
	Australia				
	National Rural Fire Authority	New Zealand	Map of active fires and forecast maps.	http://nrfa.fire.org.nz/	Forecasted fire danger is provided daily by the NRFA. Monthly severity comparisons is also provided.
	Africa				
	University of Maryland, NASA, EUMETSAT, CSIR, ESKOM	South Africa	Map of active fires	http://www.wamis.co.za/	Web Fire Mapper displays active fires detected by the MODIS Rapid Response System, from a collaboration between the NASA Goddard Space Flight Centre (GSFC) and the University of Maryland (UMD). *Comments*: Forecast products are not available.
	Zululand Fire	Kwazulu Natal	Fire danger information	http://www.zfps.co.za/weather-links.html Fire danger index calculator: http://www.zfps.co.za/fdi-calculator.html	Zululand Fire service provides links to fire weather information and an interactive fire danger index calculator. *Comment:* Fire danger maps are not provided.
	Asia				
	Korea Research Institute	Korea	Fire danger maps	http://forestfire.kfri.go.kr	Korea Forest Service provides an information service which includes the prediction of forest fire danger. On this web a daily forest fire danger map of South Korea is published. *Comments:* The website is available only in Korean.
	Malaysian Meteorological Department	South East Asia	Fire danger maps	http://www.met.gov.my/index.php?option=com_content&task=view&id=1556&Itemid=1121&lang=english	Malaysia Meteorological Department provides a fire danger maps. Temperature, humidity and rainfall maps are also provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
Earthquakes					
	USGS, U.S. Geological Survey	Global	Seismic parameters (in CAP, RSS) and near-real time 2D maps and 3D in Google Earth	Alerts in the Common Alerting Protocol (CAP): http://earthquake.usgs.gov/eqcenter/recenteqsww/catalogs/caprss1days2.5.xml List of Alerts in several formats (CAP, RSS, Google Earth): http://earthquake.usgs.gov/eqcenter/recenteqsww/catalogs/ 2D Maps: http://earthquake.usgs.gov/eqcenter/recenteqsww/	USGS provides near-real-time information on location, magnitude, depth, of earthquakes worldwide. The U.S. Geological Survey (USGS) Earthquake Notification Service (ENS) alerts subscribed users via email. *Comments:* USGS reports on earthquakes within minutes.
	Geofon	Global	Seismic parameters	http://www.gfz-potsdam. de/geofon/new/rt.html http://geofon.gfz-potsdam.de/db/eqinfo.php	The GEOFON/GEVN real-time data servers acquires data from a virtual broadband seismic network which is composed of GEOFON stations and many stations from international partner networks. The data is also re-distributed in real-time to the public. It is also archived in the GEOFON Data Archive for backup purposes and made available from there to the users by the normal archive data request tools. *Comments:* Geofon reports on earthquakes within minutes. Early warning for this reason is not possible.
	Europe				
	CRdC AMRA, Competence Center of Campania Region, Environmental Risk Analysis and Monitoring	Naples, Italy	Alerts to users	Gasparini P., Barberi F., Belli A.: Early Warning of Volcanic eruptions and Earthquakes in the neapolitan area, Campania Region, South Italy, Proceedings of the second international warning, Bonn, 16-18 October 2003.	A seismic early warning system for the protection of the Neapolitan area is under development. The early warning system would provide tens of seconds of warning time available for seismic risk mitigation before ground shaking initiates in Naples. *Comments:* The system is still under development. Information is not publicly available, but only to users.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Ignalina Power Plant	Lithuania	Shut down the reactor	Wieland, M., Griesser, L., and Kuendig, C., Sesmic Early Warning System For a Nuclear Power Plant. Proceedings of the "12th World Conference on Earthquake Engineering–12WCEE" Auckland, New Zealand, 2000.	An EWS has been installed at the Ignalina Nuclear Power Plant in Lithuania (Wieland, 2000). The system consists of six seismic stations encircling the Nuclear Power Plant at a distance of 30 km and a seventh station at the power plant. The system will shut down the reactor before a hazardous earthquake might occur in the vicinity of the Nuclear Power Plant. *Comments:* Information is not publicly available, but only to users.
	University of Bucharest	Romania, Bucharest	Alerts to users	Wenzel F., Oncescu M.C., Baur M., Fiedrich F., Ioncescu C., An early warning system for Bucharest, Seismological Research Letters 70:2:161-169, 1999.	The EWS for the protection of Bucharest, Romania. provides a warning time of about 25-30 seconds for the urban area of Bucharest located at 130 Km from the epicentral area (Wenzel et al., 1999). *Comments:* Information is not publicly available, but only to users.
	Bogazici University, Department of Earthquake Engineering, Istanbul	Istanbul	Alerts sent to users (such as power and gas companies, nuclear research facilities, critical chemical factories, subway system and several high-rise buildings)	Erdik M., Istanbul Earthquake Early warning and Rapid response system, Proc. Of Workshop on earthquake early warning, CalTech, Pasadena, 13-15 July 2005.	Rapid Response and Early Warning system is in operation in the metropolitan area of Istanbul. Ten strong motion stations were installed as close as possible to the fault zone. Data is continuously ollected from these stations via digital radio modem to provide early warning for potentially disastrous earthquakes. Whenever 2 stations detect a shaking intensity value that exceeds the threshold, the first alarm is issued. Early warning signals will be communicated to the users by UHF systems. *Comments:* Information is not publicly available, but only to users.
	Asia				
	SDR, System and Data Research Co., Ltd.	Asia, Japan	Stopping of the high velocity Shinkansen railway line.	http://www.sdr.co.jp/eng_page/index2_e.html	The system is operated by SDR which is the producer of UrEDAS (Urgent Earthquake Detection and Alarm System) instruments able to detect a seismic event and issue an alarm. The system issues an alarm if the acceleration of the ground motion exceeds a pre-defined threshold level and immediately, the high velocity Shinkansen railway is stopped. *Comments:* Information is not publicly available.

Type of event	Source	Geographic Coverage	Output	Website	Description
	TGC, Tokyo Gas Co., Ltd	Asia, Japan, Tokyo	Interruption of gas supply	Tokyo Gas annual report 1999, Safety.	Tokyo Gas has developed a safety system to ensure stable supply in the event of an earthquake or other disaster. The goal is to prevent secondary damage such as fires and explosions consequences of earthquakes. *Comments:* Information is not publicly available.
	Central Weather Bureau	Taiwan	Alerts sent to users	Wu, Y. M., T. C. Shin and Y. B. Tsai, Quick and reliable determination of magnitude for seismic early warning, Bull. Seismol. Soc. Am. 88, 1254- 1259. 1998.	An EWS for Taiwan has been implemented as part the "Taiwan Rapid Earthquake Information Release System -TREIRS" which has been developed by Central Weather Bureau in 1995. *Comments:* Information is not publicly available.
	JMA, Japan Meteorological Agency	Japan	Alerts to universities, private organizations and the public	Horiuchi, S., H. Negishi, K. Abe, A. Kimimura, and Y. Fujinawa. An automatic processing system for broadcasting earthquake alarms. Bulletin of Seismological Society of America, BSSA, Submitted, 2004. http://www.jma.go.jp/en/quake/	Within a few seconds from the first trigger based on the first seconds of observation, location and magnitude are calculated. The central processing stations are located at JMA Tokyo and Tsukuba Information Center. Through a dedicated line and wireless communication system the information is transmitted to users. Since October 2007, the warnings are transmitted through media like TV and radio and are used for other applications such as promptly slowing down trains, controlling elevators to avoid danger and enabling people to quickly protect themselves. More information at: www.bousai.go.jp/kyoryoku/soukikeikai.pdf
	North and South America				
	CIRES, Centro de Instrumentacion y Registro Sismico	Mexico, Mexico City	Alerts to residents and authorities	Espinosa-Aranda JM, Jimenez A, Ibarrola G, Alcantar F, Aguilar A, Mexico City Seismic Alert System. Seismogical Research Letters 66: 42-53, 1995.	The system has been installed in 1991 for the protection of Mexico City. The system issues alerts to residents and authorities. Evacuation alerts are issued in case of damaging earthquakes with magnitude exceeding a critical threshold. The system started in 1991 in experimental mode for schools' alert and stopping the metropolitan subway system. Only several years later it became a public service.

Type of event	Source	Geographic Coverage	Output	Website	Description
	CalTech, UC Berkeley	California	Magnitude and location estimates	http://www.elarms.org Allen, R.M. and Kanamori, H., The Potential for Earthquake Early Warning in Southern California, Science, 300, 786-789, 2003.	Allen and Kanamori (2003) developed ElarmS an early warning methodology for Southern California. Within seconds after the earthquake origin Elarms is able to estimate the earthquake magnitude and location, to provide early warning of few to tens of seconds in case of damaging seismic event. *Comments:* The system has not been implemented yet. Seismologists across California are testing Elarms.
Tsunamis					
	UNESCO-IOC, United Nations Educational Scientific and Cultural Organization-Intergovern-mental Oceanographic Commission	Global	Tsunami warnings and advisories	http://www.unesco.org/new/en/natural-sciences/ioc-oceans/sections-and-programmes/tsunami/ http://itic.ioc-unesco.org/	After forty years of experience coordinating the Pacific Tsunami Warning System (PTWS), UNESCO-IOC is leading a global effort to establish ocean-based tsunami warning systems. The website integrates information from different sources and provides tsunami warnings and other technical information.
	PTWS, Pacific Tsunami Warning System	Pacific	Tsunami Bulletins. Email and SMS alert service	http://ptwc.weather.gov/	The Pacific Tsunami Warning Center (PTWC) serves as the operational headquarters for the Pacific Tsunami Warning System in the Pacific (PTWS). The Pacific basin is monitored by the Pacific Tsunami Warning System (PTWS) which was established by 26 Member States and is operated by the PTWC, located near Honolulu, Hawaii. PTWC monitors stations throughout the Pacific basin to issue tsunami warnings to Member States, serving as the regional center for Hawaii and as a national and international tsunami information center. The system disseminates tsunami information and warning messages to over 100 points across the Pacific. *Comments:* PTWS website provides also tsunami bulletins for Hawaii, and ad interim for: Indian Ocean, and Caribbean. Note SMS service is available for some Pacific, Asian, and African countries.

Type of event	Source	Geographic Coverage	Output	Website	Description
	HKO, Hong Kong Observatory	Hong Kong	Tsunami information (recorded sea level change, seismic parameters)	http://www.hko.gov.hk/gts/equake/tsunami_mon_e.htm	HKO tsunami warning system consists in monitoring the warning messages issued by the Pacific Tsunami Warning Centre (PTWC). In addition to it the sea water levels recorded by tide gauges in Hong Kong are observed and monitored. In the event of a tsunamigenic earthquake affecting Hong Kong, the HKO will issue a tsunami warning to the public. The maximum sea level change recorded in the past years has been 0.3 m.
	JMA, Japan Meteorological Agency	Japan	Tsunami warnings and advisories	http://www.jma.go.jp/en/tsunami/	When an earthquake occurs with potential of generating tsunamis, JMA issues tsunami forecasts within 3 minutes after the occurrence of the earthquake. In case tsunamis are originated by seismic events far from Japan, JMA takes a coordinated action with the Pacific Tsunami Warning Center (PTWC) in Hawaii and issues forecasts for the long-propagating tsunamis.
Volcanic Eruptions					
	Global Volcanism Program (USGS, U.S. Geological Survey and Smithsonian Institution)	Global	Reports and warnings	http://www.volcano.si.edu/reports/usgs/	The Global Volcanism Program is a joint collaborative effort between Smithsonian and USGS. Weekly and monthly bulletins are released on the website. Volcanic activity information is collected from worldwide volcanic observatories participating to the Global Volcanism Program. *Comments:* Not all volcanic activities are reported on the website, only when changes in volcanic activity occur.

Type of event	Source	Geographic Coverage	Output	Website	Description
	North and South America				
	MVO, Monserrat Volcano Observatory	Carribean, Monserrat	Reports and warnings	http://www.mvo.ms/	MVO monitors volcanic activity through by continuously monitoring the seismic activity associated with the volcano. The seismic network has been upgraded to include 10 broadband, high dynamic range instruments with fully digital telemetry. The signals are received at the MVO and daily or monthly reports on volcano activity, and hazard assessment are released. *Comments:* Frequency of these reports depends on the level of activity of the volcano.
	University of West Indies Seismic Research Unit	America, West Indies	Reports and warnings	http://www.uwiseismic.com/General.aspx?id=46	The Seismic Research Unit has established a monitoring network and warning system specifically for Kick 'em Jenny, a submarine volcano located near Grenada island. The main purpose of this is to provide warning to shipping in the vicinity.
	Observatorio Vulcanologico Universidad de Colima	Mexico	Reports and warnings	http://www.colima-estado.gob.mx/seguridad/indvolcan.php	Reports are released on a daily basis together with pictures from the volcano de fuego in Colima. *Comments:* The webpage is available only in Spanish.
	Instituto Nacional de Sismologia, Vulcanologia, Meteorologia y Hidrologia INSIVUMEH	Guatemala	Reports and warnings	http://www.insivumeh.gob.gt/principal/alertas.htm http://www.insivumeh.gob.gt/geofisica/especial.htm http://www.insivumeh.gob.gt/geofisica/boletin%20formato.htm	Instituto Nacional de Sismologia, Vulcanologia, Meteorologia y Hidrologia releases daily bulletins of volcanic activity and special bulletins are available in case of an emergency. *Comments:* The webpage is available only in Spanish
	Servicio Nacional de Estudios Territoriales (SNET) Ministerio De Medio Ambiente y Recursos Naturales	El Salvador	Reports and warnings	http://www.snet.gob.sv/ver/vulcanologia/informes+especiales/	Servicio Nacional de Estudios Territoriales (SNET) provides special bulletins on volcanic activity, available on the website. *Comments:* The webpage is available only in Spanish

Type of event	Source	Geographic Coverage	Output	Website	Description
	Instituto Nicaraguense de Estudios Territoriales (INETER) Volcanology Department	Nicaragua	Reports and warnings	http://www.ineter .gob.ni/	Instituto Nicaraguense de Estudios Territoriales (INETER) website provides access to volcanic activity information, condensed into short reports. Live webcam images are also available. *Comments:* The webpage is available only in Spanish
	Observatorio Vulcanológico y Sismológico de Costa Rica Universidad Nacional (OVSICORI-UNA)	Costa Rica	Reports and Warnings	http://www.ovsicori. una.ac.cr/	Observatorio Vulcanológico y Sismológico de Costa Rica provides online access to news reports on volcanic activity of volcanoes in Costa Rica. *Comments:* The webpage is available only in Spanish
	Instituto de Investigaciones en Geociencias, Mineria y Quimica (INGEOMINAS)	Colombia	Reports and Warnings	http://www.ingeominas .gov.co/Observatorios-Vulcanologicos.aspx	Instituto de Investigaciones en Geociencias provides daily bulletins of volcanic activity for Colombia, available on the website. *Comments*: The webpage is available only in Spanish
	Mount Erebus Volcano Observatory Department of Earth & Environmental Science New Mexico Institute of Mining and Technology	Mount Erebus, Antarctica	Temperature, wind Speed, deformation, humidity	http://erebus.nmt.edu/	Mount Erebus Volcano Observatory provides information on temperature, wind speed, deformation, and humidity and other information of Mount Erebus volcano. Last 2 days and 30 days graphs are also available.
	Japan Meteorological Agency	Japan	Reports and Warnings	http://www.jma.go. jp/en/volcano/	The Japan Meteorological Agency provides online access to volcanic activity reports and color coded advisories, as well as forecasts. Ash monitoring and alerts for aviation is also available on the website. *Comments:* Reports are updated weekly.
	Institute of Geological & Nuclear Sciences Ltd GeoNet Project	New Zealand	Reports and Warnings	http://geonet.org.nz/ volcano/	In New Zealand volcano surveillance is undertaken by the GeoNet project in collaboration with two Regional Councils who operate volcano-seismic networks. GeoNet project of the Institute of Geological & Nuclear Sciences (GNS) issues alert bulletins for public, media and research.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Philippine Institute of Volcanology and Seismology	Philippines	Reports and Warnings	http://www.phivolcs.dost.gov.ph/index.php?option=com_content&view=category&id=70&Itemid=500008	Philippine Institute of Volcanology and Seismology maintains and operates volcano systems for monitoring and forecasting purposes. The institute assesses volcanic activity and then provides volcanic activities alerts to the public, and to local and international scientific communities. For each volcano is also available an archive of past advisories.
Landslides					
	International Consortium on Landslides	Global	Map and reports of landslides	http://icl.iplhq.org/ Recent landslides: http://landslides.usgs.gov/recent/	The International Consortium on Landslides (ICL) created at the Kyoto Symposium in January 2002 is an International non-governmental and non-profit scientific organization, which is supported by several international organizations as UNESCO, WMO, FAO, UN/ISDR etc. ICL website provides a link to worldwide landslides information, thorugh USGS website. Comments: ICL does not provide forecasts on landslides.
Droughts					
	BENFIELD HAZARD RESEARCH CENTRE	Global	Monthly maps on drought current conditions	http://drought.mssl.ucl.ac.uk/drought.html?map=%2Fwww%2Fdrought%2Fweb_pages%2Fdrought.map&program=%2Fcgi-bin%2Fmapserv&root=%2Fwww%2Fdrought2%2F&map_web_imagepath=%2Ftmp%2F&map_web_imageurl=%2Ftmp%2F&map_web_template=%2Fdrought.html	The Global Drought Monitor provides maps and short reports on countries facing exceptional drought conditions. The information is updated on a monthly basis. Hydrological drought conditions are displayed based on two drought indices called the Standardised Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI). *Comments:* The Global Drought Monitor provides an overall drought picture with ~100 Km spatial scale, local conditions may erroneously represented. Drought forecasts are not provided. For this reason droughts early warning is not possible.

Type of event	Source	Geographic Coverage	Output	Website	Description
	FAO, Food and Agriculture Organization, Global Information and Early Warning System on Food and Agriculture (GIEWS)	Global	Reports, e-mails and map of countries facing food insecurity.	http://www.fao.org/giews/english/index.htm http://www.fao.org/giews/english/giews_en.pdf	GIEWS monitors the food supply and demand, provides emergency response in case of human or natural induced disasters, informing policy makers with periodical reports, available through GIEWS webpage and an e-mail service. *Comments:* Reports are not specifically focused on drought conditions and are released monthly or less frequently.
	U.S. Drought Monitor (a collaboration between USDA, NOAA, Climate Prediction Center and National Drought Mitigation Center at University of Nebraska)	U.S.	Maps on drought, current condition maps and forecast drought products	http://drought.unl.edu/MonitoringTools/USDroughtMonitor.aspx http://droughtmonitor.unl.edu/ http://www.cpc.ncep.noaa.gov/products/expert_assessment/seasonal_drought.html	North America Drought Monitor provides weekly drought maps which integrate multiple indices, satellite data products and experts' opinions. Several forecast products are also provided, such as: climate outlooks, seasonal drought outlook, streamflow forecast maps, forecast Palmer drought severity index, soil moisture forecast maps. *Comments:* Advantages are represented by the availability of both drought current conditions and forecast maps. The disadvantage is represented by a reduced geographical coverage, maps are limited only to U.S.
	FEWS, Famine Early Warning System	South, East and West Africa, Central America, Caribbean, Central Asia and Middle East	Reports on food insecurity	http://www.fews.net/	FEWS NET is a collaborative effort of USGS, USAID, NASA, and NOAA. FEWS net reports on food insecurity conditions and issues watches and warnings to decision makers, which are also available on the website. *Comments:* FEWS informs on current situation of countries facing food insecurity and is not specifically focused on droughts.
	EC-JRC, European Commission Joint Research Center Institute for Environment and Sustainability	Europe	Maps of soil moisture	http://desert.jrc.ec.europa.eu/action/php/index.php?action=view&id=201	JRC's Action DESERT is developing a European Drought Observatory (EDO) for drought forecasting, assessment and monitoring. Currently, EC-JRC provides publicly available daily soil moisture maps of Europe; precipitation, vegetation response and others, through a portal. *Comment*: The Drought Observatory is still under development.

Type of event	Source	Geographic Coverage	Output	Website	Description
	BCC, Beijing Climate Center of the China Meteorological Administration	China	Daily maps on droughts current conditions	http://bcc.cma.gov.cn/en/	Beijing Climate Center (BCC) monitors drought conditions for China. Drought report and a map on current drought conditions are produced daily and made available on their website, based on precipitation and soil moisture monitoring from an agricultural meteorological station network and remote-sensing-based monitoring from CMA's National Satellite Meteorological Center. *Comment:* Forecasts are not provided.
Floods					
	Dartmouth Flood Observatory	Global	Map of current floods	http://floodobservatory.colorado.edu/ http://floodobservatory.colorado.edu/Archives/index.html	The Dartmouth Flood Observatory detects, maps, and measures major flood events world-wide using satellite remote sensing. Maps, predictions, estimated discharge and severity of the flood are provided for each event. *Comments:* Flood information is provided for current floods, but forecasts are not available.
	IFnet	Global	Precipitation amount maps and flood reports	http://www.internationalfloodnetwork.org/03_f_info.html http://gfas.internationalfloodnetwork.org/gfas-web/	IFnet, through the Global Flood Alert System (GFAS) uses global satellite precipitation estimates for flood forecasting and warning. GFAS converts the satellite precipitation estimates from NASA into global rainfall maps, and precipitation probability estimates. *Comments:* IFnet is running on a trial basis.
	Europe				
	EFAS, European Flood Alert System	Europe	Information on ongoing floods and forecasts	http://efas-is.jrc.ec.europa.eu/	Launched in 2003, EFAS has been working on an experimental basis since 2005, with the plan to be fully operational in 2012. The EFAS provides early flood warnings to national members and the European Commissionin order to mitigate flood impact on population. *Comments:* EFAS is working on experimental basis.

Type of event	Source	Geographic Coverage	Output	Website	Description
	North and South America				
	NOAA	U.S.	River observations and forecasts	River gauges: http://water.weather.gov/ahps/	NOAA provides river's level measurements from river gauges, it provides also other information on current river conditions, and forecasts.
Severe Weather, Storms Cyclones, Hurricanes					
	WMO, World Meteorological Organization	Global	Maps of tropical cyclones, heavy rain/snow, thunderstorms, cloudiness and rain	http://severe.worldweather.org/ World Weather Watch (WWW): http://www.wmo.ch/pages/prog/www/ ; http://www.worldweather.org/ World Meteorological Organization Tropical Cyclone Programme: http://www.wmo.ch/pages/prog/www/tcp/index_en.html	World Weather Watch, operated by WMO, provide global collection, analysis and distribution of weather observations, forecasts and warnings. WWW is an operational framework of coordinated national systems, operated by national governments. website. The WMO Tropical Cyclone Program, part of WWW, has established tropical cyclone committees that extend across the regional bodies (Regional Specialized Meteorological Centres (RSMC) which, together with National Meteorological and Hydrological Services (NMHSs), monitor tropical cyclones globally and issue official warnings to the Regional Meteorological Services of countries at risk. This information is publicly available on WMO website through warnings and maps.
	National Hurricane Center-NOAA	Eastern Pacific and Atlantic	Maps actual and predicted tracks. Values of time, location, speed, wind. Wind speed probabilities. Email service.	http://www.nhc.noaa.gov/	National Hurricane Center-NOAA provides and online access to maps of hurricanes (location and tracks) and advisories are issued. A new product released by National Hurricane Center-NOAA is the wind speed probability information. NHC's tropical cyclone text products are available by email.
	University of Hawaii	Global	Maps actual and predicted tracks. Values of time, location, speed, wind.	http://www.solar.ifa.hawaii.edu/Tropical/tropical.html	University of Hawaii provides online access to maps of tropical storms together with values of time, location, speed and wind together with strike probabilities. This information is collected from several sources.

Type of event	Source	Geographic Coverage	Output	Website	Description
	Asia				
	Hong Kong Observatory	Hong Kong, Asia	Maps of tropical cyclones and Warnings	http://www.hko.gov.hk/informtc/informtc.htm	Whenever a tropical cyclone warning signal is issued, bulletins are issued on the website for distribution to the mass media and for immediate broadcast by radio and television stations. The Hong Kong Observatory also operates an automatic telephone answering service "Dial-a-weather" to provide similar information.
Epidemics					
	WHO, World Health Organization	Global	Alerts to international community on threat of outbreaks and online disease outbreak news.	http://www.who.int/csr/outbreaknetwork/en/ Disease outbreak news: http://www.who.int/csr/don/en/	WHO through The Global Outbreak Alert and Response Network provides real-time information and dissemination on disease outbreaks, that are of international importance. The Network provides an operational framework to link this expertise and skill to keep the international community constantly alert to the threat of outbreaks and ready to respond.
	European Centre for Disease Prevention and Control, ECDC	Europe	Online disease outbreak news.	http://www.ecdc.europa.eu/en/Pages/home.aspx	The ECDC works in partnership with national health protection bodies across Europe to strengthen and develop continent-wide disease surveillance and early warning systems. Currently, ECDC provides online access to authoritative scientific reports about the risks posed by new and emerging infectious diseases. *Comments*: News information is restricted to Europe.
	U.S. Centre for Disease Control, CDC	U.S.	Online disease outbreak news and e-mail alerts	http://www.cdc.gov/outbreaks/index.html	Department of Helath and Human Services, Centre for Disease Control provides information on disease, agents and other threats reporting online the key facts, prevention measures and current situation. *Comments:* News information is mainly focused on U.S.

Type of event	Source	Geographic Coverage	Output	Website	Description
Avian Flu					
	WHO	Global	Online disease outbreak news	http://www.who.int/csr/disease/avian_influenza/en/	The system supports disease tracking, sharing information and aid operations. Avian influenza news are published online into short reports.
Animal Diseases					
	FAO, OIE and WHO	Global	maps and short outbreak reports online	http://www.glews.net/	Since July 2006, the Global Early Warning and Response System for Major Animal Diseases, including Zoonoses (GLEWS) monitors outbreaks of major animal diseases, including zoonoses, worldwide.
Malaria					
	IRI	Africa	Map of malaria risk	http://iridl.ldeo.columbia.edu/maproom/.Health/.Regional/.Africa/.Malaria/.MEWS/	IRI provides rainfall anomalies which it may provide insights on malaria risk. The map is produced on a biweekly basis. *Comments:* The malaria risk map is based purely on climatic constraints to malaria transmission, and does not account for areas in the northern and southern margins of the African continent where control has eliminated malaria risk. Alerts service is not provided.
	Wellcome Trust, the Global Fund to Fight AIDS, Tuberculosis and Malaria, the University of Oxford-Li Ka Shing Foundation Global Health Programme and others	Global	Maps	http://www.map.ox.ac.uk/	Malaria Atlas Project (MAP) provides malaria map products to all users under the Creative Commons Attribution 3.0 Unported License and can be downloaded from the MAP site.

Type of event	Source	Geographic Coverage	Output	Website	Description
Famine					
	FEWS, Famine Early Warning System	South, East and West Africa, Central America, Caribbean, Central Asia and Middle East	Reports on food insecurity	http://www.fews.net/	FEWS NET is a collaborative effort of USGS, USAID, NASA, and NOAA. FEWS NET reports on food insecurity conditions and issues watches and warnings to decision makers, which are also available on the website. *Comments:* FEWS informs on current situation of countries facing food insecurity but it does not report forecasts. For this reason early warning is not possible.
	FAO, Food and Agriculture Organization, Global Information and Early Warning System on Food and Agriculture (GIEWS)	Global	Reports, e-mails and map of countries facing food insecurity.	http://www.fao.org/giews/english/index.htm http://www.fao.org/giews/english/giews_en.pdf	GIEWS monitors the food supply and demand, provides emergency response in case of human or natural induced disasters, informing policy makers with periodical reports, available through GIEWS webpage and an e-mail service. *Comments:* Reports are released monthly or less frequently.
	WFP, World Food Program	Global	Emergency reports, briefing notes, photo galleries.	http://www.wfp.org/food-security http://www.wfp.org/food-security/assessment-bank	On WFP website information on current situation of food crisis worldwide is available through briefing notes, reports and photo galleries. The Vulnerability Analysis and Mapping Branch (VAM) provides WFP decision makers with the information necessary to design and implement its operations. The role of VAM is, therefore, to identify populations that not only require food assistance, but also how WFP support can be tailored to make a difference in peoples lives and their livelihoods. *Comments:* Reports on countries facing food insecurity. In the VAM website information is not updated frequently, some reports are 2 years old.
	Food Security and Nutrition Working Group (FSNWG)	East Africa	Maps and monthly updates	http://www.disasterriskreduction.net/	FSNWG supported by the EC provides a platform for DRR in the Region. It provides on its website maps and updates on food insecurity in the Region.

Glossary

This glossary is compiled from citations in different chapters, and draws from glossaries and other resources available: United Nations Environment Programme (UNEP) Global Environment Outlook, UNEP list of acronyms and glossary terms, UN ISDR Terminology on Disaster Risk Reduction, University of Princeton, University of Naples "Federico II", OASIS Standards, National Oceanic and Atmospheric Organization (NOAA), U.S. Environmental Protection Agency (EPA), United Nations Framework Convention for Climate Change (UNFCCC), United Nations Convention to Combat Desertification (UNCCD), Convention on Biological Diversity (CBD), UN-Habitat.

Adaptation

(1) Actions taken to help communities and ecosystems cope with changing climate conditions (UNFCCC). (2) Genetically determined characteristic that enhances the ability of an organism to cope with its environment (CBD).

Aerosols

A collection of airborne solid or liquid particles, with a typical size between 0.01 and 10 μm, that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin.

Air quality

Smog is the product of human and natural activities such as industry, transportation, wild-fires, volcanic eruptions, etc. and can have serious effects on human health and the environment.

U.S. EPA uses and Air Quality Index (AQI) which is calculated on five major air pollutants regulated by the Clean Air Act: ground-level ozone, particle pollution (also known as particulate matter), carbon monoxide, sulfur dioxide, and nitrogen dioxide. For each of these pollutants, EPA has established national air quality standards to protect public health .Ground-level ozone and airborne particles are the two pollutants that pose the greatest threat to human health in this country.

Biodiversity

The variety of life on Earth, including diversity at the genetic level, among species and among ecosystems and habitats. It includes diversity in abundance, distribution and in behaviour. Biodiversity also incorporates human cultural diversity, which can both be affected by the same drivers as biodiversity, and itself has impacts on the diversity of genes, other species and ecosystems.

Biofuels

Fuel produced from dry organic matter or combustible oils from plants, such as alcohol from fermented sugar, black liquor from the paper manufacturing process, wood and soybean oil.

Biomass

Organic material, both above ground and below ground, and both living and dead, such as trees, crops, grasses, tree litter and roots.

Capacity

The combination of all the strengths, attributes and resources available within a community, society or organization that can be used to achieve agreed goals.

Comment: Capacity may include infrastructure and physical means, institutions, societal coping abilities, as well as human knowledge, skills and collective attributes such as social relationships, leadership and management. Capacity also may be described as capability. Capacity assessment is a term for the process by which the capacity of a group is reviewed against desired goals, and the capacity gaps are identified for further action.

Capacity building

Process of developing the technical skills, institutional capability, and personnel.

Climate change

Change of climate, which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

Climate Variability

Variations in the mean state and other statistics (such as standard deviations and the occurrence of extremes) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes in the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Common Alerting Protocol

The Common Alerting Protocol (CAP) provides an open, non-proprietary digital message format for all types of alerts and notifications. It does not address any particular application or telecommunications method. The CAP format is compatible with emerging techniques, such as Web services, as well as existing formats including the Specific Area Message Encoding (SAME) used for the United States' National Oceanic and Atmospheric Administration (NOAA) Weather Radio and the Emergency Alert System (EAS).

Cost-Benefit Analysis

A technique designed to determine the feasibility of a project or plan by quantifying its costs and benefits.

Cyclone

An atmospheric closed circulation rotating counter-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

Deforestation

The direct human-induced conversion of forested land to non-forested land.

Desertification

Degradation of land in arid, semi-arid and dry sub-humid areas, resulting from various factors, including climatic variations and human activities.

Disaster

A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources.

Comment: Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation.

Disaster risk

The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period.

Comment: The definition of disaster risk reflects the concept of disasters as the outcome of continuously present conditions of risk. Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socio-economic development, disaster risks can be assessed and mapped, in broad terms at least.

Disaster risk reduction

The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events.

Comment: A comprehensive approach to reduce disaster risks is set out in the United Nations-endorsed Hyogo Framework for Action, adopted in 2005, whose expected outcome is "The substantial reduction of disaster losses, in lives and the social, economic and environmental assets of communities and countries." The International Strategy for Disaster Reduction (ISDR) system provides a vehicle for cooperation among Governments, organisations and civil society actors to assist in the implementation of the Framework. Note that while the term "disaster reduction" is sometimes used, the term "disaster risk reduction" provides a better recognition of the ongoing nature of disaster risks and the ongoing potential to reduce these risks.

Droughts

A period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area.

Early warning system

The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss.

Comment: This definition encompasses the range of factors necessary to achieve effective responses to warnings. A people-centred early warning system necessarily comprises four key elements: knowledge of the risks; monitoring, analysis and forecasting of the hazards; communication or dissemination of alerts and warnings; and local capabilities to respond to the warnings received. The expression "end-to-end warning system" is also used to emphasize that warning systems need to span all steps from hazard detection through to community response.

Earth observation

Earth Observation, through measuring and monitoring, provides an insight and understanding into Earth's complex processes and changes. EO include measurements that can be made directly or by sensors in-situ or remotely (i.e. satellite remote sensing, aerial surveys, land or ocean-based monitoring systems, Figure 3), to provide key information to models or other tools to support decision making processes.

Earthquakes

Earthquakes are due to a sudden release of stresses accumulated around the faults in the Earth's crust. This energy is released through seismic waves that travel from the origin zone, which cause the ground to shake. Severe earthquakes can affect buildings and populations. The level of damage depends on many factors such as intensity of the earthquake, depth, vulnerability of the structures, and distance from the earthquake origin.

Ecosystem

Dynamic complex of plant, animal, microorganism communities and their non-living environment, interacting as a functional unit. Ecosystems are irrespective of political boundaries.

El Niño-southern oscillation

A complex interaction of the tropical Pacific Ocean and the global atmosphere that results in irregularly occurring episodes of changed ocean and weather patterns in many parts of the world, often with significant impacts over many months, such as altered marine habitats, rainfall changes, floods, droughts, and changes in storm patterns.

Comment: The El Niño part of the El Niño-Southern Oscillation (ENSO) phenomenon refers to the well-above-average ocean temperatures that occur along the coasts of Ecuador, Peru and northern Chile and across the eastern equatorial Pacific Ocean, while La Niña part refers to the opposite circumstances when well-below-average ocean temperatures occur. The Southern Oscillation refers to the accompanying changes in the global air pressure patterns that are associated with the changed weather patterns experienced in different parts of the world.

Emergency management

The organization and management of resources and responsibilities for addressing all aspects of emergencies, in particular preparedness, response and initial recovery steps.

Comment: A crisis or emergency is a threatening condition that requires urgent action. Effective emergency action can avoid the escalation of an event into a disaster. Emergency management involves plans and institutional arrangements to engage and guide the efforts of government, non-government, voluntary and private agencies in comprehensive and coordinated ways to respond to the entire spectrum of emergency needs. The expression "disaster management" is sometimes used instead of emergency management.

Extensible Markup Language

A markup language that defines a set of rules for encoding documents in a format that is both human-readable and machine-readable.

E-waste

A generic term encompassing various forms of electrical and electronic equipment that has ceased to be of value and is disposed of. A practical definition of e-waste is "any electrically powered appliance that fails to satisfy the current owner for its originally intended purpose."

False Alarm

In the context of Early Warning Systems, a false alarm is defined as the situation in which an alarm is activated when it should not have been.

Fine Particle

Particulate matter suspended in the atmosphere less than 2.5 μm in size (PM2.5).

Floods

An overflow of water onto normally dry land. The inundation of a normally dry area caused by rising water in an existing waterway, such as a river, stream, or drainage ditch. Ponding of water at or near the point where the rain fell. Flooding is a longer term event than flash flooding: it may last days or weeks. Floods are often triggered by severe storms, tropical cyclones, and tornadoes.

Food security

When all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life.

Forecast

Definite statement or statistical estimate of the likely occurrence of a future event or conditions for a specific area.

Comment: In meteorology a forecast refers to a future condition, whereas a warning refers to a potentially dangerous future condition.

Forest

Land spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10 per cent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.

Gaussian distribution

The Gaussian (normal) distribution was historically called the law of errors. It was used by Gauss to model errors in astronomical observations, which is why it is usually referred to as the Gaussian distribution.

Geological hazard

Geological process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: Geological hazards include internal earth processes, such as earthquakes, volcanic activity and emissions, and related geophysical processes such as mass movements, landslides, rockslides, surface collapses, and debris or mud flows. Hydrometeorological factors are important contributors to some of these processes. Tsunamis are difficult to categorize; although they are triggered by undersea earthquakes and other geological events, they are essentially an oceanic process that is manifested as a coastal water-related hazard. Within this report, tsunamis are included in the geological hazards group.

Geographic Information System

A computerized system organizing data sets through a geographical referencing of all data included in its collections.

Greenhouse gases

Atmospheric gases that trap the heat and are responsible for warming the earth and climate change. The major greenhouse gases are: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_20). Less prevalent but very powerful greenhouse gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6). Those gases are regulated under the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. Some greenhouse gases are also regulated under the Montreal Protocol for their effects on the ozone layer.

Habitat

(1) Place or type of site where an organism or population naturally occurs (CBD). (2) Shorthand for UN-Habitat.

Hazard

A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: The hazards of concern to disaster risk reduction as stated in footnote 3 of the Hyogo Framework are "… hazards of natural origin and related environmental and technological hazards and risks." Such hazards arise from a variety of geological, meteorological, hydrological, oceanic, biological, and technological sources, sometimes acting in combination. In technical settings, hazards are described quantitatively by the likely frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis.

Hotspot

(1) Area particularly rich in total numbers of species (biodiversity hotspot). (2) Area of especially high concentrations of pollutants.

Human Health

A state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity.

Hurricane/Typhoon

A tropical cyclone in which the maximum sustained surface wind (using the U.S. 1-minute average) is 64 kt (74 mph or 119 km/hr) or more. The term hurricane is used for Northern Hemisphere tropical cyclones east of the International Dateline to the Greenwich Meridian. The term typhoon is used for Pacific tropical cyclones north of the Equator west of the International Dateline.

Hydrometeorological hazard

Process or phenomenon of atmospheric, hydrological or oceanographic nature that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: Hydrometeorological hazards include tropical cyclones (also known as typhoons and hurricanes), thunderstorms, hailstorms, tornados, blizzards, heavy snowfall, avalanches, coastal storm surges, floods including flash floods, drought, heatwaves and cold spells. Hydrometeorological conditions also can be a factor in other hazards such as landslides, wildland fires, locust plagues, epidemics, and in the transport and dispersal of toxic substances and volcanic eruption material. Within this report, droughts have been addressed separately.

Land Cover

The physical coverage of land, usually expressed in terms of vegetation cover or lack of it. Influenced by but not synonymous with land use.

Land Degradation

The loss of biological or economic productivity and complexity in croplands, pastures and woodlands. It is due mainly to climate variability and unsustainable human activity.

Landslides

Landslides are displacements of earth, rock, and debris caused by heavy rains, floods, earthquakes, volcanoes, and wildfires.

Land Use

The human use of land for a certain purpose. Influenced by, but not synonymous with, land cover.

Missed Alarm

In the context of Early Warning Systems, a missed alarm is defined as the situation in which an alarm is not activated when it should have been.

Mitigation

The lessening or limitation of the adverse impacts of hazards and related disasters.

Comment: The adverse impacts of hazards often cannot be prevented fully, but their scale or severity can be substantially lessened by various strategies and actions. Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness. It should be noted that in climate change policy, "mitigation" is defined differently, being the term used for the reduction of greenhouse gas emissions that are the source of climate change.

Natural hazard

Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: Natural hazards are a sub-set of all hazards. The term is used to describe actual hazard events as well as the latent hazard conditions that may give rise to future events. Natural hazard events can be characterized by their magnitude or intensity, speed of onset, duration, and area of extent. For example, earthquakes have short durations and usually affect a relatively small region, whereas droughts are slow to develop and fade away and often affect large regions. In some cases hazards may be coupled, as in the flood caused by a hurricane or the tsunami that is created by an earthquake.

Pollutant

Any substance that causes harm to the environment when it mixes with soil, water or air.

Pollution

The presence of minerals, chemicals or physical properties at levels that exceed the values deemed to define a boundary between "good or acceptable" and "poor or unacceptable" quality, which is a function of the specific pollutant.

Prediction

The act of attempting to produce a description of the expected future, or the description itself, such as "it will be 30 degrees tomorrow, so we will go to the beach."

Preparedness

The knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from, the impacts of likely, imminent or current hazard events or conditions.

Comment: Preparedness action is carried out within the context of disaster risk management and aims to build the capacities needed to efficiently manage all types of emergencies and achieve orderly transitions from response through to sustained recovery. Preparedness is based on a sound analysis of disaster risks and good linkages with early warning systems, and includes such activities as contingency planning, stockpiling of equipment and supplies, the development of arrangements for coordination, evacuation and public information, and associated training and field exercises. These must be supported by formal institutional, legal and budgetary capacities. The related term "readiness" describes the ability to quickly and appropriately respond when required.

Prevention

The outright avoidance of adverse impacts of hazards and related disasters.

Comment: Prevention (i.e. disaster prevention) expresses the concept and intention to completely avoid potential adverse impacts through action taken in advance. Examples include dams or embankments that eliminate flood risks, land-use regulations that do not permit any settlement in high risk zones, and seismic engineering designs that ensure the survival and function of a critical building in any likely earthquake. Very often the complete avoidance of losses is not feasible and the task transforms to that of mitigation. Partly for this reason, the terms prevention and mitigation are sometimes used interchangeably in casual use.

Probability of missed alarm

In the context of Early Warning systems, the probability of missed alarm is the probability of having threshold exceedance but no alarm activation.

Probability of false alarm

In the context of Early Warning systems, the probability of false alarm is the probability of having no threshold exceedance but alarm activation.

Really Simple Syndication

Really Simple Syndication is a family of web feed formats used to publish frequently updated works—such as blog entries, news headlines, audio, and video—in a standardized format.

Recovery

The restoration, and improvement where appropriate, of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors.

Comment: The recovery task of rehabilitation and reconstruction begins soon after the emergency phase has ended, and should be based on pre-existing strategies and policies that facilitate clear institutional responsibilities for recovery action and enable public participation. Recovery programmes, coupled with the heightened public awareness and engagement after a disaster, afford a valuable opportunity to develop and implement disaster risk reduction measures and to apply the "build back better" principle.

Response

The provision of emergency services and public assistance during or immediately after a disaster in order to save lives, reduce health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Comment: Disaster response is predominantly focused on immediate and short-term needs and is sometimes called "disaster relief". The division between this response stage and the subsequent recovery stage is not clear-cut. Some response actions, such as the supply of temporary housing and water supplies, may extend well into the recovery stage.

Risk

The combination of the probability of an event and its negative consequences.

Comment: This definition closely follows the definition of the ISO/IEC Guide 73. The word "risk" has two distinctive connotations: in popular usage the emphasis is usually placed on the concept of chance or possibility, such as in "the risk of an accident"; whereas in technical settings the emphasis is usually placed on the consequences, in terms of "potential losses" for some particular cause, place and period. It can be noted that people do not necessarily share the same perceptions of the significance and underlying causes of different risks.

Risk assessment

A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend.

Comment: Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process.

Sustainable development

Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Comment: This definition coined by the 1987 Brundtland Commission is very succinct but it leaves unanswered many questions regarding the meaning of the word development and the social, economic and environmental processes involved. Disaster risk is associated with unsustainable elements of development such as environmental degradation, while conversely disaster risk reduction can contribute to the achievement of sustainable development, through reduced losses and improved development practices.

Technological hazards

A hazard originating from technological or industrial conditions, including accidents, dangerous procedures, infrastructure failures or specific human activities, that may cause loss of life, injury, illness or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage.

Comment: Examples of technological hazards include industrial pollution, nuclear radiation, toxic wastes, dam failures, transport accidents, factory explosions, fires, and chemical spills. Technological hazards also may arise directly as a result of the impacts of a natural hazard event.

Tsunami

A tsunami is a series of ocean waves generated by sudden displacements in the sea floor, landslides, or volcanic activity.

Volcanic eruptions

Volcanic eruptions may be mild, releasing steam and gases or lava flows, or they can be violent explosions that release ashes and gases into the atmosphere.

Vulnerability

The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Comment: There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for wise environmental management. Vulnerability varies significantly within a community and over time. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure. However, in common use the word is often used more broadly to include the element's exposure.

Water Quality

The chemical, physical and biological characteristics of water, usually in respect to its suitability for a particular purpose.

Wild-fires

Wild-fires may be natural processes, human induced for agriculture purposes, or just the result of human negligence. Wild-fires pose a threat to lives and properties and are often connected to secondary effects such as landslides, erosion, and changes in water quality.

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