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Early Warning Systems:

State-of-Art Analysis and Future Directions

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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 natural 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 state-of-art assessment of existing monitoring/early warning systems (EWS) organized according to type of environmental threats is presented below. This report will focus on: air quality, wildland fires, nuclear and chemical accidents, geological hazards (earthquakes, tsunamis, volcanic eruptions, landslides), hydro-meteorological hazards (desertification, droughts, floods, impact of climate variability, severe weather, storms, and tropical cyclones), epidemics and food insecurity. Current gaps and needs are identified 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 for disasters and environment; Chapter 3 focuses on the existing early warning/monitoring systems; and Chapter 4 presents a global multi-hazard approach to early warning.

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, (from International Strategy for Disaster Reduction (ISDR), United Nations (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 public.

4. *Response*: Coordination, good governance and appropriate action plans are a key point 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 disasters' impact on society, economies, and environment.

Types of Hazards

Hazards can be associated with two types of events: ongoing and rapid/sudden-onset threats and slow-onset (or "creeping") threats.

1. Ongoing and Rapid/sudden-onset: These would 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 would include such issues as: air and water quality, soil pollution, acid rain, climate change, desertification processes (including soil erosion and land degradation), droughts, 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 (emerging and re-emerging infectious diseases and links to environmental change), land cover/land changes, environment and conflict, among others. Such creeping changes are often left unaddressed as policymakers choose or need to cope 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 refer to them as quick onset. Most of the hydro-meteorological hazards (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).

Rapid/sudden-onset and slow-onset events will provide different amounts of available warning time.
Early Warning systems may provide seconds to months of available warning time for earthquakes to droughts, respectively, which are the quickest and slowest onset hazards. Fig. 1 shows warning times for climatic hazards.

In particular, 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.

Warning time, provided by warning systems, increases to years or even decades of lead-time available for slow-onset threats (as El Nino, global warming etc. in Fig. 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 environment.

Table 1. Types of Environmental Threats

Types of Environmental Threats	
1. Ongoing and Rapid/sudden-onset threats	**i.e. oil spills, nuclear plant failures, and chemical plant accidents, geological hazards and hydro-meteorological hazards-except droughts.**
2. Slow-onset (or "creeping") threats	**i.e. 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	***i.e. ecosystems changes, urban growth, transboundary pollutants, loss of wetlands etc.***
2.2 New emerging science	***i.e. associated with biofuels, nanotechnology, carbon cycle, climate change, etc***
2.3 Contemporary environmental threats	***i.e. E-waste, bottled water, etc***

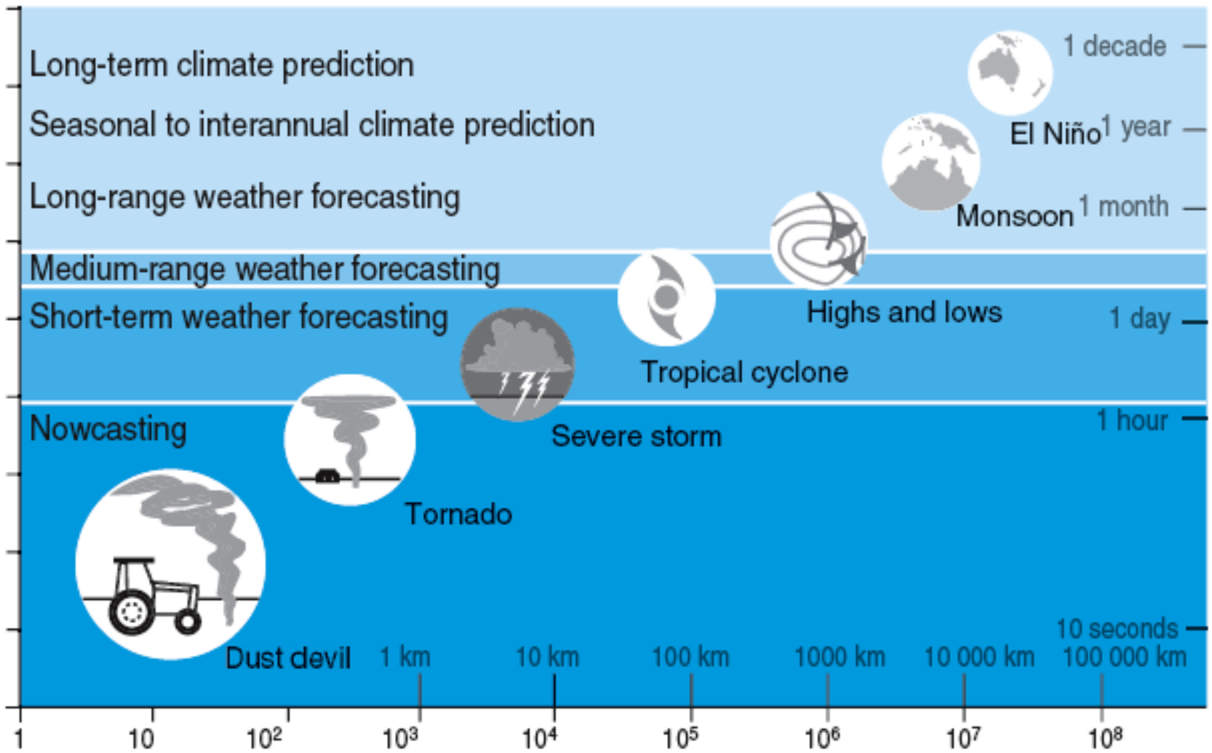

Figure 1 How early is early warning. (Golnaraghi M., 2005). The graph shows timeliness of early warning systems for hydro-meteorological hazards and area of impact (by specifying the diameter of the spherical area) for climatic hazards.

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 when a disaster close to happening. If well integrated with risk assessment studies and communication and action plans, early warning systems can lead to substantive benefits.

Is essential to note that "predictions are not useful, however, unless they are translated into a warning and action plan the public can understand and unless the information reaches the public in a timely manner" (Glantz, 2003). Effective early warning systems embrace all aspects of emergency management, such as: risk assessment analysis, which is one of early warning system's design requirements; monitoring and predicting location and intensity of the natural disaster waiting to happen; communicating alerts to authorities and to potentially affected; and responding to the disaster. All aspects have to be addressed by the early warning system. Commonly, early warning systems lack of one or more elements. In fact, the review of existing early warning systems shows that in most cases communication systems and adequate response plans are lacking.

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). Monitoring and predicting systems, if associated with communication system and response plans, can then be considered early warning systems (Glantz, 2003).

Early warnings may be disseminated to targeted users (local early warning applications) or broadly to communities, 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. The main goal of early warning systems is to take action to protect or reduce loss of life or to mitigate damage and economic loss, before the disaster occurs.

Nevertheless, to be effective this warning 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 taking action, and *simple* so as to be understood.

Timeliness is often in conflict with the desire to have reliable predictions, which become more accurate as more observations are collected from the monitoring system (Grasso V. F., 2007). There is therefore 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 is collected by the monitoring system part of the EWS network. It must be understood that every prediction, being a prediction, 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. In making this decision, two kinds of wrong decisions may occur (Grasso V. F., 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 at the same time communicate the level of uncertainty and expected cost of taking action but also be simple 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.

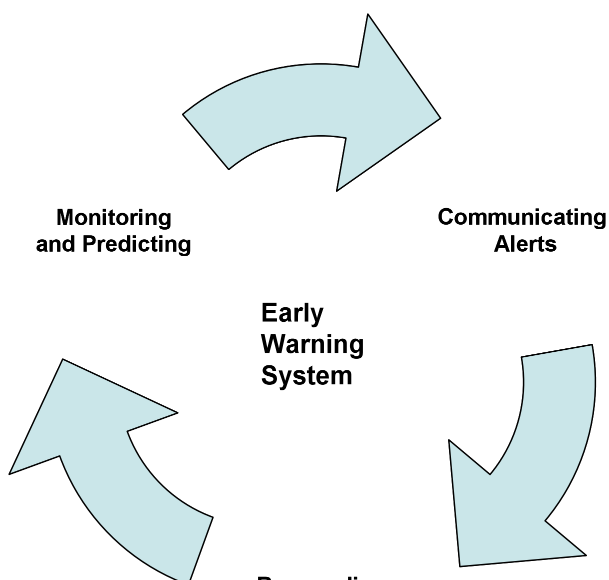

Figure 2 Early Warning System operational aspects

EWS: decision making procedure based on cost-benefit analysis

For an improved performance of EWS, a performance-based decision making procedure needs to be based on expected consequences of taking action, in terms of probability of 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 V. F., 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 false and missed alerts incidence. The proposed decision making procedure intends to fill this gap. The EWS will provide to the user 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 of data available will produce an improvement of the prediction accuracy. The prediction and its uncertainty are updated as more data come in. The actual severity of the event, S, is unknown and may be defined by adding the prediction error, ε_{tot} to the predicted value, $\hat{S}$.
The potential probability of false (missed) alarm is given by the probability of S being less (greater) than the critical threshold, it becomes an actual probability of false (missed) alarm if the alarm is (not) raised:

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

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

Referring to the principle of maximum entropy (Jaynes E.T., 2003), the prediction error is being 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 mean equal to the prediction $\hat{S}(t)$ and uncertainty equal to $\sigma_{tot}(t)$, that is the standard deviation of the prediction error $\varepsilon_{tot}(t)$. Eq. (1) and (2) may be written as (Grasso V.F. et al., 2007):

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

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

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:

$$P_{fa} \leq \beta = \frac{C_{save}}{C_{fa} + C_{save}}; \quad P_{ma} < \alpha = \frac{C_{fa}}{C_{fa} + C_{save}} \tag{5}$$

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 threshold probabilities that are tolerable 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.

Communication of early warning information

An effective early warning system needs an effective communication system.
Early warning communication systems are made of two main components (EWCII, 2003):

- communication infrastructure hardware that must be reliable and robust, especially during the natural disasters; 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.

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. ICT plays an important role in disaster communication and dissemination of information to organizations in charge of responding to warnings and to the public during and after a disaster (Tubtiang, 2005).

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, in order to ensure reliable and effective operation of the communication systems during and after disaster occurrence, and to avoid network congestion, frequencies and channels must be reserved and dedicated to disaster relief operations.

Nowadays, an extreme 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 communications and data exchanges worldwide. According to the Internet World Stats database, as of November 2007, global documented Internet usage was 1.3 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 rapid and effective detection of 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 visualization 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 coming years, the multi-scaled global information network will greatly improve thanks to new technological advances facilitating 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 general public with high-quality, scientifically credible information in a timely fashion.

Dissemination of warnings often follows a cascade process, which starts at international or national level and then moves outwards or downwards in the scale, reaching regional and community levels (Twigg J., 2003). Early warnings may activate other early warnings at different authoritative levels, flowing down in responsibility roles, but 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 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 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) language. It contains information about the alert message, the specific hazard event, and appropriate responses, including urgency of action to be taken, severity of the event, and certainty of the information.

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.
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 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 D. et al., 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 the 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 uncertainty level of the information must be communicated to users together with early warning (Grasso V. F. et al., 2007).

Establish proper priorities. Resources must be allocated wisely and priorities should be set, based on risk assessment analysis, for long- and short-term decision-making, such as investing in local early warning systems, education, or enhanced monitoring and observational systems. On the other hand, 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, labor, and social security as well as 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 lead to the disaster we all have witnessed. Such ineffective decision-making must be dealt with to avoid future disaster such as the one in New Orleans.

Chapter 2: Role of Earth Observation

At a time when the world community is striving to identify the impacts of humans 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 harmful as well as constructive changes to the Earth's environment and natural resource base (i.e. ecosystems changes, urban growth, transboundary pollutants, loss of wetlands, etc).
Earth observation (EO) through measuring and monitoring provides an insight and understanding into Earth's complex processes and changes. 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. By enhancing the visualization of scientific information on environmental change, satellite imagery will enable environmental management and raise the awareness on 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.

EO role is here discussed for each type of environmental threat.

- 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 fluourosensors, airborne and satellite optical sensors, as well as airborne and satellite Synthetic Aperture Radar (SAR) are used for this purpose.
SAR has the advantage of providing data also during cloud cover conditions and darkeness, unlike optical sensors. In addition, optical sensors 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 to 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 of sea surface roughness patterns and modified by oil spills.
To date, no operational application for the use of satellite imagery for oil spills detection exists, due to limited spatial and temporal resolution, and often processing times are too long for operational purposes. Another gap yet exists in the measurement of the thickness of the oil spill (Mansor S.B., et.al., 2007; U.S. Department of the Interior, Minerals Management Service, 2007)

- Chemical and Nuclear Accidents

Chemical or nuclear accidents may have disastrous consequences as the 1984accidents 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, that has been the worst such accident to date affecting part of the Soviet Union, eastern Europe, Scandinavia, and later western Europe.
EO provides key data for monitoring and forecasting dispersion, spread of the substance.
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 into decision models. Meteorological conditions influence the spread, dispersion and dilution of the substance, as well as, in some cases, the transformation and interaction of the substance with other constituents of the environment.
In some cases emergencies are localized while in other situations transport processes are most important. Meteorological data, weather forecasts and atmospheric transport and dispersion model products are key for disaster management.
The World Meteorological Organization (WMO) has in place operational international arrangements with the International Atomic Energy Agency (IAEA) to provide meteorological support to environmental emergency response related to nuclear accidents and radiological emergencies, when needed and future plans will include support also for chemical accidents.

- Geological Hazards

Geohazards associated with geological processes such as earthquakes, landslides, volcanic eruptions are mainly controlled by ground deformation which then becomes the key parameter to monitor. EO data allows monitoring of physical parameters associated with geohazards, such as deformation, plate movements, seismic monitoring, baseline topographic and geoscience mapping. EO products serve their purpose for early detection and mitigation, before the event, and for damage assessment for disaster recovery, during the event 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 observation cover wide areas but not continuous in time. These data need to be integrated for an improved more comprehensive approach (Committee on Earth Observation Satellites (CEOS), 2002; Integrated global observing strategy (IGOS-P), 2003).

For **volcanic eruptions** monitoring, data needed are: 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) and models to help predict the extent of the lava flow. As soon as the volcanic unrest initiates, the information needs to be timely and relatively high-resolution, and once the eruption starts, the flow has to speed up. Seismic behavior 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; regional network).

For **earthquakes**, information on location and magnitude of the event is the first information that 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 origin and before the strong shaking occurs at the site. Shakemap generated within 5 minutes provides 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 response 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 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; SAR interferometry needs to continuously monitored.

Useful information for **landslides** and ground instability is: hazard zonation maps (landslides, debris flows, rockfalls, subsidence and ground instability scenarios) during the mitigation phase, associated with landlside inventory, DEM, deformation (GPS network; SAR interferometry; other surveys as leveling, laser scanning, aerial etc), hydrology, geology, soil, geophysical, geotechnical, climatic, seismic zonation maps, land cover, land use, historical archives. Forecasting location and extent of ground instability or landslide is quite challenging. While mechanism of subsidence are well understood, for landslides this still remains a challenge for scientists. Landslides can be preceded by cracks, accelerating movement, rock fall activity. Real-time monitoring of key parameters then 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.

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.

- Hydro-meteorological hazards

Hydro-meteorological hazards include the wide variety of meteorological, hydrological and climate phenomena which 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 et al., 2002).

In particular, for **floods** observation, polar orbital and geostationary satellite data are used. In particular, Two types of polar orbital satellites: 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 satellite as GOES 8 and 10, METEOSAT, GMS, the Indian INSAT and the Russian GOMS; and polar orbitals as NOAA (NOAA 15) and SSMI.
GOES and POES weather satellites provide useful information on precipitation, moisture, temperature, winds and soil wetness, which is combined with ground observation.

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.

- Wild-Fires

Fire detection using satellite technologies is possible thanks to significant temperature difference between the Earth surface (usually not exceeding 10-250C) and the seat of fire (300-9000C), which results in thousand times difference in heat radiation generated by these objects. NOAA (AVHRR radiometer with 1,100m spatial resolution and 3,000km swath width) and Earth Observing Satellites (EOS) (Terra and Aqua satellites with MODIS radiometer installed on them having 250, 500 and 1,000m spatial resolution and 2,330 km swath width) are most widely used modern satellites for operative fire monitoring. Klaver et al. (1998) High-resolution sensor, such as the Landsat Thematic Mapper or SPOT multispectral scanner, or from National Oceanic and Atmospheric Administration's AVHRR or MODIS are used for fire potential definition. For fire detection and monitoring, 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 are used. AVHRR and higher resolution images (SPOT, Landsat, and radar) can be used to assess the extent and impact of the fire.

- Slow-onset (or “creeping”) environmental threats:

➢ Air quality

National Aeronautics and Space Administration (NASA) and 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, TOMS also 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 sulfates, 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 2380 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.

➢ 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 color data used to determine factors affecting global change, particularly ocean ecology and chemistry. MODIS data, 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 K., 2007).

Overall, air, soil and water quality monitoring coverage still appears to be irregular and appears to be adequate and available in real-time only for some contaminants. (GEO, 2005).

- Droughts

For droughts monitoring, a comprehensive and integrated approach is required due to the complex nature of droughts. Numerous drought indicators should be monitored routinely to determine the drought extent and impacts. Becomes clear that, 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 M. et al., 2002).

In particular there are 6 key parameters:

1) the 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 hydrological model which takes observed precipitation and temperature and calculates soil moisture, evaporation and runoff. The potential evaporation is estimated from observed temperature)
3) Daily streamflow percentiles,
4) percent of normal precipitation,
5) standardized precipitation index, and
6) remotely sensed vegetation health index,

which are used into a composite product developed from a rich information stream, including climate indices, numerical models, and the input of regional and local experts.

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, 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 M. et al., 2002). A complete list of drought products can be found on NOAA's National Environmental Satellite, Data, & Information Service (NOAA-NESDIS) web page.

- Location specific environmental changes (i.e. ecosystems changes, loss of biodiversity and habitats, land cover/land changes, coastal erosion, urban growth etc)

Sustained and comprehensive observations clearly provide unique, visible evidence that human actions are causing substantial harmful as well as constructive changes to the Earth's environment and natural resource base.
Since 1972, Landsat satellites (series 1 to 7) is extensively used for environmental changes having the great advantage of providing repetitive, synoptic, global coverage of high-resolution multi-spectral imagery (Fadhil A.M., 2007). This allows the use of Landsat 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 for land-atmosphere interactions affecting climate and as an indicator of climate change, especially regional climate change (IGOS-P, 2004). Therefore characterization, monitoring and understanding of land cover and its socio-economic and biophysical drivers becomes central. High capability demonstrated by Landsat SPOT and IRS, but no long term operational commitment. (IGOS-P, 2004).

The proof of the importance and impact of visual evidence of environmental change in hotspots is demonstrated by United Nations Environment Programme (UNEP) best selling publication *One Planet, Many People: Atlas of Our Changing Environment*, which shows before and after satellite photos to document changes to the Earth's surface over the past 30 years. The Atlas contains some astounding 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 the report is to identify current gaps and future needs of early warning systems through the analysis of the state-of-art of existing early warning and monitoring systems for environmental hazards. In particular among existing early warning/monitoring systems, only the systems which provide publicly accessible information and products have been included in the analysis.
For the present study, several sources have been used, such as: "Global Survey of Early Warning Systems" report by UN (2005) 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.

In particular, for each hazard type a gap analysis has been carried out to identify critical aspects and future needs. Below is the outcome of the review of existing early warning/monitoring systems for each hazard type, and in Appendix are the details of all systems organized in tables by hazard type. The current gaps identified for each hazard type could be related to either 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 to assess if all the areas under risk have an early warning or monitoring system in place in order to identify which are the areas that require the development of an early warning system. For this analysis the maps of risks of mortality- and economic loss-related from Natural Disaster Hotspots: A Global Risk Analysis, a report from the World Bank (Dilley M. et al., 2005), have been used.

Ongoing and Rapid/sudden-onset threats

Chemical and Nuclear Accidents

Releases of a hazardous substance from industrial accidents can have immediate adverse affect 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. WMO network of eight specialized numerical modelling centres called Regional Specialized Meteorological Centres (RSMCs) provide predictions of movement of contaminants on 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, International Civil Aviation Organization (ICAO), the International Criminal Police Organization (INTERPOL), the Nuclear Energy Agency of the Organisation 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 goal is to provide support during incidents or emergencies by providing near real-time reporting of information through: the Incident and Emergency Centre (IEC) maintains a 24 hour on-call system for rapid initial assessment and, if needed, triggering response operations, Emergency Notification and Assistance Convention Website (ENAC) is a website to exchange information on nuclear accidents or radiological emergencies, Nuclear Event Web-based System (NEWS) 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, 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.

Wildland Fires

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

Early warning methodologies for wildland fires are based on the prediction of precursors, such as fuel loads and lightning danger. These parameters are relevant for fire triggering prediction, but once the fire has begun, fire behavior 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 et al., 2003).
Wildland fire information is available worldwide through the Global Fire Monitoring Center (GFMC), a global portal for wildland 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 wildland fire products through a worldwide network of cooperating institutions. GFMC fire products include: fire danger maps, 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 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, collaboration between the University of Maryland and NASA, provides near real-time information on active fires worldwide, detected by 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. 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, is 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, and obtaining real impact through follow up legal initiatives and Parliamentary enquiries.

Although global scale fire monitoring systems exist, an internationally standardized approach is required to create a globally comprehensive fire early 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 wildland 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 Wildland Fire, which is under development as part of the Global Earth Observation System of Systems (GEOSS) effort, will address these issues.

Geological Hazards

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.

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 epicenter. 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 et al., 1995; Wu et al., 1998; Wu and

Teng, 2002; Odaka et al., 2003; Kamigaichi, 2004; Nakamura, 2004; Horiuchi et al., 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 population by TV, among others.
On the global scale, multi-national initiatives, such as U.S. Geological Survey (USGS) and GEOFON, operate global seismic networks for seismic monitoring but do not provide seismic early warning information. Today, 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 (network of the GeoForschungsZentrum Potsdam) 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 of early warning applications, such as Peru, Chile, Iran, Pakistan, India.

Tsunamis

A tsunami is a series of waves triggered by submarine earthquakes, landslides, volcanic eruptions or underwater explosions. Tsunamis can have devastating effects on coastal areas.

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 the Indian Ocean 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 are ongoing for the development of these systems. The German-Indonesian Tsunami Early Warning System for the Indian Ocean is being implemented. Main milestones like the development of the automatic data processing software as well as the underwater communication for the transmission of the pressure data from the ocean floor to a warning centre are being finalised. 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 Japan Meteorological Agency (JMA). Regional and national tsunami information centers exist worldwide; the complete list is available from IOC.
Currently, no global tsunami warning system is in place. In addition, although, interim advisories are provided by PTWC and JMA for the Indian Ocean and the Caribbean, fully operational tsunami early warning systems are needed for these areas. Since 2005, steps have been taken to develop an Indian Ocean tsunami system such as establishing 26 tsunami information centers and deploying 23 real-time sea level stations and 3 deep ocean buoys in countries bordering Indian Ocean. Nevertheless, on July 17, 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 has shown that there are still operational gaps to be solved in the Indian Ocean tsunami early warning system, notably in warning coastal communities in time.

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 lands and communities living in their path, affect air quality, and even influence the Earth’s climate for a short time. Volcanic ash can impact aviation and communications.

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. Globally, volcanic activity information is provided by the Smithsonian institution, which partners with 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 daily basis. Weekly and monthly summary reports are also available, but these report only 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 of ash-producing eruptions. There are several ash advisory centers distributed worldwide in London, Toulouse, Anchorage, Washington, Montreal, Darwin, Wellington, Tokyo, and Buenos Aires.
Volcano observatories are well distributed worldwide. A complete list of volcano observatories is available at the World Organization of Volcanic Observatories (WOVO) web site, which contains good worldwide geographical coverage; however, there is still a divide between developed and developing countries. In particular, Japan and United States volcanoes are well monitored by a large number of observatories and research centers. Most Central and South American countries (Mexico, Guatemala, El Salvador, Nicaragua, Costa Rica, Colombia, Ecuador, Peru, Chile, Trinidad, 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. There is 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.

Landslides

Landslides are displacements of earth, rock, and debris caused by heavy rains, floods, earthquakes, volcanoes, and wildfires. 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 media and news sources. 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 landslides prediction capability would allow ICL to provide early warning to authorities and population. 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.

Hydro-Meteorological Hazards (except droughts)

Floods

Floods are often triggered by severe storms, tropical cyclones, and tornadoes. The number of floods has continued to rise steadily, becoming together with droughts the most deadly natural 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.

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 US major 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 6 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.

On a 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 under development by EC- JRC, will provide early flood warnings to National Hydrological Services in order to mitigate flood impact on population. The EFAS testing is being performed for the Danube river basin, focusing on the system's calibration and validation. EFAS proposes to monitor floods in Europe and to issue early warnings for floods up to 10 days in advance. This information will be sent to civil and water management agencies to efficiently implement their plans in downstream areas. It could also help the European Commission and international aid organizations to better prepare and coordinate their actions.

Although floods are the deadliest natural hazards that are currently increasing in frequency, the study shows 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. In addition, at a global scale flood monitoring systems are more developed than flood early warning systems that have received less attention. For this reason, existing technologies for flood monitoring must be improved aiming at increasing 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 by: 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, in reality, an operational framework of coordinated national systems, operated by national governments.

Part of the WWW are also: the World Climate Programme (WCP) giving access to climate data and applications, the Tropical Cyclone Programme (TCP) in charge of issuing tropical cyclones and hurricanes forecasts, warnings and advisories.

At the global level, WMO-TCP seeks to promote and coordinate efforts to mitigate risks associated with tropical cyclones.

TCP 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. 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 cyclones' category, 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. Action plans must also be improved.
For meteorological early warning the WWW is an efficient framework of existing RSMC, NMHSs and networks. Nevertheless, within this framework, national capacities in most of developing countries need improvements for effectively issuing and managing early warnings. Upgrading national capacities will result in improving the global meteorological early warning capacity at regional and global scales. Coordination at all levels also needs improvement (O'Neill D., 1997).

Epidemics

Epidemics pose a significant threat worldwide, particularly in those areas that are already affected by other serious hazards, poverty, or underdevelopment.
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 rumored and confirmed outbreaks. The diseases that that the WHO monitors constantly are:

- Anthrax
- Avian influenza
- Crimean-Congo hemorrhagic fever (CCHF)
- Dengue/dengue hemorrhagic fever
- Ebola hemorrhagic fever
- Hepatitis
- Influenza
- Lassa fever
- Marburg hemorrhagic fever
- Meningococcal disease
- Plague
- Rift Valley fever
- Severe Acute Respiratory Syndrome (SARS)
- Smallpox
- Tularaemia
- 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 system is under development and it will focus on disease tracking, sharing information, and aid operations.
A malaria early warning system is not yet available and the need for the system development is pressing, especially in Sub-Saharan Africa where malaria causes more than one million deaths every year. The IRI institute of the 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.

Slow-onset (or "creeping") threats

Air Quality

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

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 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 also provides email alert service, for Canada. 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 system 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, to enable users to take action in case of unhealthy air quality conditions.

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.

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 Programs at the regional or sub-regional levels are key instruments for implementing the convention. 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 for desertification mitigation.

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).

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 global scale, three institutions (FAO's Global Information and Early Warning System on Food and Agriculture (GIEWS), Humanitarian Early Warning Service (HEWS) by the World Food Programme (WFP) 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 situation, including drought information, together with an interactive map of countries in crisis, available through the FAO website. The HEWS collects drought status information from several sources including FAO-GIEWS, WFP, and Famine Early Warning System (FEWS Net), and packages this information into short notes and a map (from FAO-GIEWS) which is then provided, on a monthly basis, through the HEWS website. Benfield Hazard Research Center uses various data to produce a monthly map of current drought condition accompanied by a short description for each country.
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 et al., 2002) provides drought current conditions at the national and state level through an interactive map available on the website accompanied with a narrative on current drought impacts and a brief description of

forecasts for the following week. The U.S. Drought Monitor, which is a joint effort between US Department of Agriculture (USDA), NOAA, Climate Prediction Center, University of Nebraska Lincoln and others, 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. It has become the best available product for droughts (Svoboda et al., 2002). 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). 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 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. Although all types of droughts originate from a precipitation deficiency, monitoring only this parameter is insufficient to assess a drought's severity and resultant impacts (World Meteorological Organization, 2006). Precipitation must be integrated with other climatic parameters and with water information such as streamflow, snow pack (wherever applicable), groundwater levels, reservoir and lake levels, and soil moisture into a comprehensive assessment of current and future drought and water supply conditions. 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.

Impact of Climate Variability

According to the recent Intergovernmental Panel for Climate Change (IPCC) report, from the poles to the tropics, the earth's climate and ecosystems are already being shaped by the atmospheric buildup of greenhouse gases and 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 were among the world's poorest. Climate variability impact information 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.

Currently no global comprehensive early warning system for climate variability exists, but several single sources exist for:

Melting Glaciers:
The National Snow and Ice Data Center (NSIDC)-Ice Concentration and Snow Extent provides near real-time daily global ice concentration and snow coverage.
http://nsidc.org/data/google_earth/

Lake Water Level:
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 provide online public access to lake water level information.
http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir/

Sea Height Anomalies:
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 a 2-day average delay. This information is provided by NOAA.
http://www.aoml.noaa.gov/phod/dataphod/work/trinanes/INTERFACE/index.html

El Niño, La Niña:
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.
http://iri.columbia.edu/climate/ENSO/currentinfo/QuickLook.html

Sea Surface Temperature Anomalies:
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.
http://www.osdpd.noaa.gov/PSB/EPS/SST/climo.html
http://poet.jpl.nasa.gov/

Food Insecurity

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 USGS, United States Agency for International Development (USAID), NASA, and NOAA, that 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 are mandatory and would be extremely useful for emergency response, resources allocation, and early warning.

Chapter 4: Conclusions and Future Perspectives

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 natural disaster mitigation; 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, is essential to strengthen the links between all sectors involved (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.

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 level of vulnerability of a population. Although several early warning systems are in place at 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 centers, 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, improving, as a result, coordination at a multi-level and multi-sector scale.

Below is presented an analysis of existing global early warning/monitoring systems which aggregate multi-hazard information.

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

The analysis assesses existing monitoring/early warning systems (Grasso V. and Singh A., 2007), chosen to be multi-hazard with global coverage, such as: WFP (which is the UN food aid agency), HEWS, AlertNet (humanitarian information alert service by Reuters), ReliefWeb (humanitarian information alert service by UN-OCHA), GDACS (Global Disaster Alert and Coordination System, which is a joint initiative of the United Nations Office for the Coordination of Humanitarian Affairs (UN-OCHA) and the EC-JRC, and USGS ENS. NASA and CISCO have announced on March 2009 a collaborative effort aimed at developing a platform called "Planetary Skin", that will gather data for monitoring environmental conditions around the world.

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 this comparative analysis of existing services. The systems have been analyzed for type of events covered, variety of output/communication forms and range of users served.

USGS ENS provides information only on earthquakes and volcanic eruptions through the Volcano Hazards Program (VHP) in collaboration with Smithsonian Institution. AlertNet and ReliefWeb focus on natural hazards (earthquakes, tsunamis, severe weather, volcanic eruptions, El Nino, floods, droughts, cyclones, locusts) and health, food insecurity and conflicts; GDACS provides timely information on natural hazards (earthquakes, tsunamis, volcanic eruptions, floods, droughts, cyclones); WFP informs users on earthquakes, severe weather, volcanic eruptions, floods, droughts, locusts.

Existing systems, such as WFP and HEWS, post the information on a web site and GDACS sends emails, SMS and faxes to users. The GDACS notification service is mostly addressed to international organizations, rescue teams or aid agencies. AlertNet provides information to users through web service, Email, SMS and reports. ReliefWeb uses web service, Email and report to disseminate information to users.

The only natural event notification provided by USGS email service is earthquakes. HEWS and WFP offer 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. EC JRC also operates a disaster coordination program together with several partners as UN-OCHA, UNOSAT and HEWS with the main aim at favoring real-time information exchange by all actors of the international disaster response community. As part of the coordination program, UN-OCHA provides an e-mail and SMS service to inform users about critical situation updates during disaster response operations.

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 limitations and gaps of existing early warning systems, both technological and geographical coverage gaps.
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 still under 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 and the authorities in charge of responding to these warnings) need improvement. Likewise, promotion of good governance and appropriate action plans are needed. Overcoming these gaps, enhancing, integrating and coordinating existing systems, is the first priority for the development of a global scale multi-hazard early warning system.

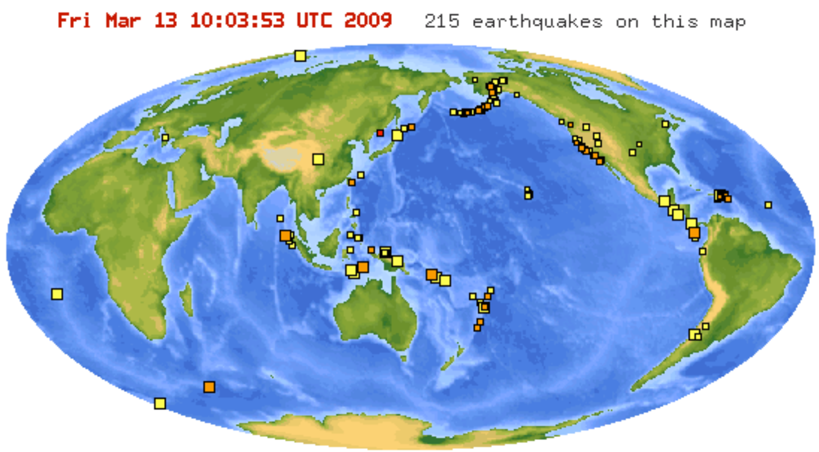

Figure 3 USGS Map of recent earthquakes. The symbols showing recent earthquakes are color coded, most recent earthquakes are red and past-day events are orange, last week events are yellow. Note that the size of symbol decreases with decreasing magnitude. From: http://earthquake.usgs.gov/eqcenter/recenteqsww/ (accessed 03/13/2009)

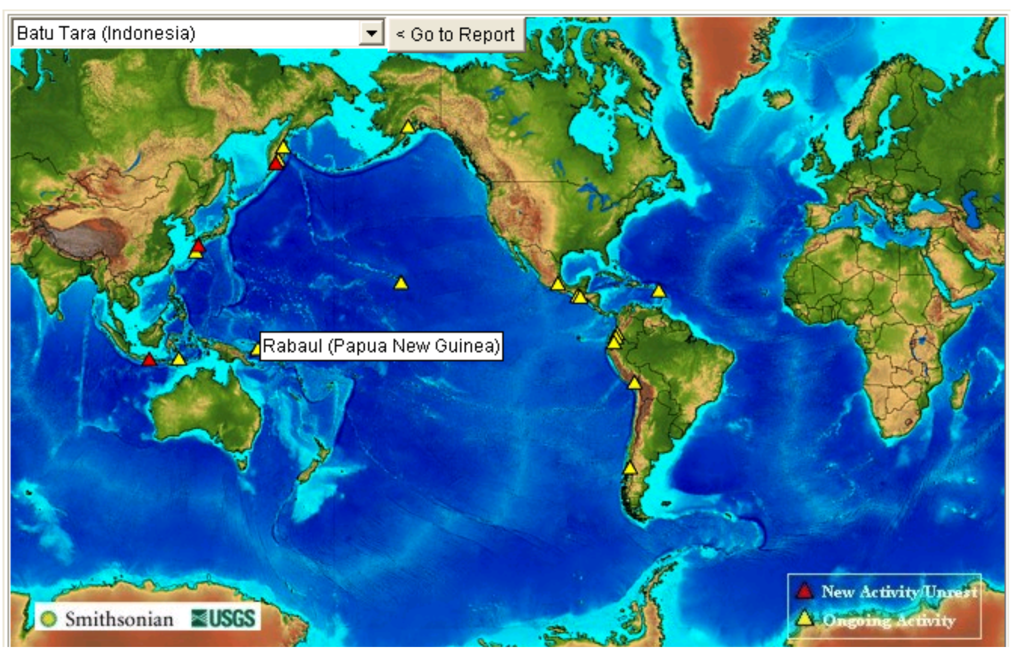

Figure 4 USGS and Smithsonian Institution: Volcanic Activity Map showing past week volcanic eruptions, red triangles show new volcanic activity and yellow is for ongoing activity. From: http://www.volcano.si.edu/reports/usgs/ (accessed 03/13/2009)

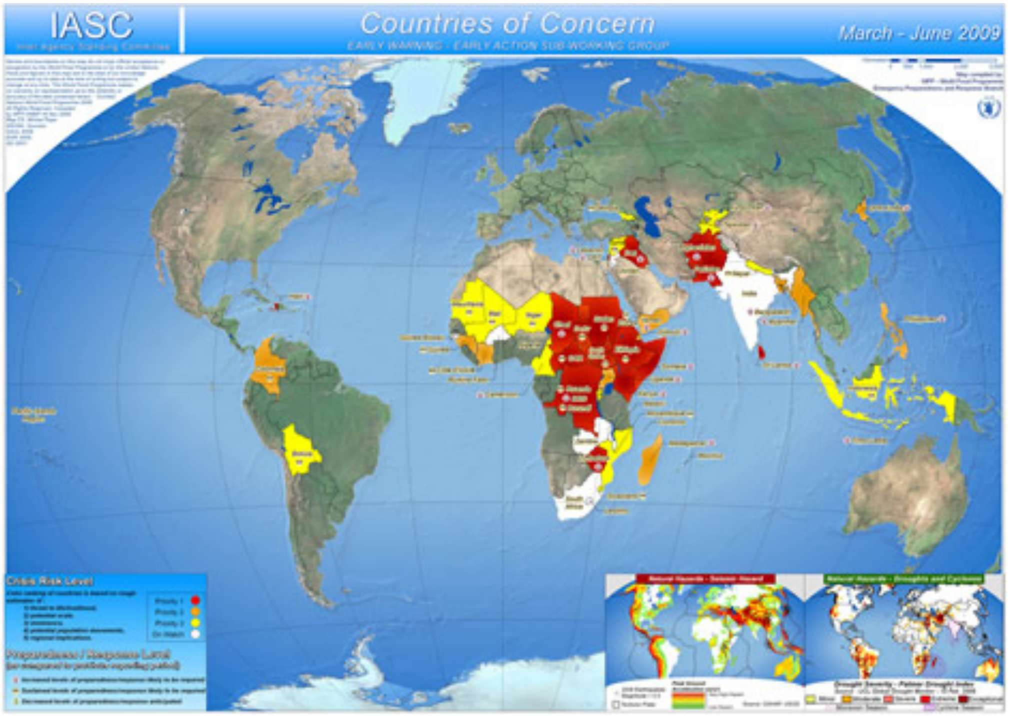

Figure 5 WFP Early Warning Natural Hazards Map. The above global map of Countries of Concern: Natural Hazards, is updated quarterly by the Emergency Preparedness and Response Branch of the WFP. From: http://www.wfp.org/newsroom/in_depth/early_warning (accessed 03/13/2009)

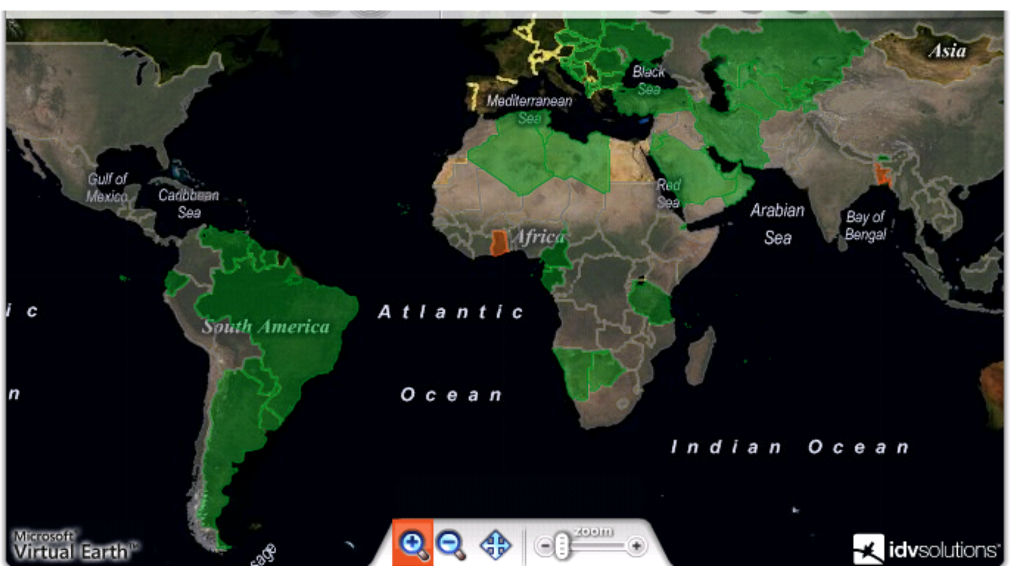

Figure 6 AlertNet Map for hazards, such as: conflicts (blue), food insecurity (purple), storms (red), sudden disasters (brown), health (forest green), and earthquakes (light green). From: http://www.alertnet.org/map/index.htm (accessed 03/13/2009)

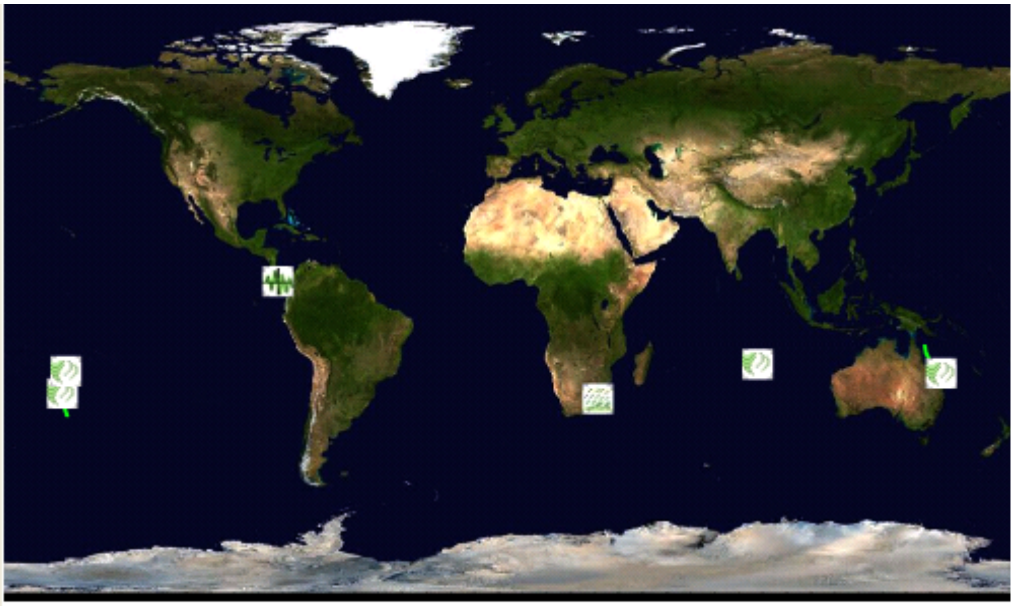

Figure 7 GDACS Map for hazards: earthquakes, cyclones, volcanic eruptions, floods. Symbols for events are color coded according to intensity and potential impact. (accessed 03/13/2009)

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 yet a lot has to be done for the development of 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:

- **Filling existing gaps**: technological, geographical coverage, capacity gaps; and operational gaps for slow-onset hazards.

The weaknesses and gaps of existing early warning systems have been identified in Chapter 3.

In particular the actions need to be taken to improve prediction capabilities for landslides hazard aiming at the development of landslides early warning system which is currently not yet in place. Likewise, for droughts there is a pressing need to improve existing prediction capabilities and develop systems where needed but not yet in place. A fire global early warning system is not yet in place, as well as tsunami early warning systems for Indian Ocean and the Caribbean and desertification early warning system. There are ongoing efforts for the development of these systems. These gaps need to be filled. Malaria early warning system is mandatory for Africa, where one million of deaths occur every year due to malaria. Climate variability impacts need to be monitored within a global and coordinated effort. Local earthquake early warning systems applications are needed in high seismic risk areas, where early warning systems are not yet in place. Air quality systems require improvements in prediction capabilities as well as floods systems. Dust storms and trans-boundary 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 of the coverage of volcanic observatories. A particular attention should be paid to fill gaps in decision making processes for slow-onset hazards. Its extent and impact are challenging to quantify which makes assessment and monitoring more challenging than for other hazards. 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 rationale and timely decisions to be taken based on improved information.

UNEP's best selling publication *One Planet, Many People: Atlas of Our Changing Environment* was developed to keep under review the world environmental situation and to ensure that emerging environmental problems of wide international significance receive appropriate and adequate consideration by governments. The Atlas contains some astounding satellite imagery and illustrates the alarming rate of environmental destruction. In particular, the study on the restoration of Mesopotamia marshlands, documented through satellite images of 1973, 2000 and 2004, shows that action can be effective also when it seems too late

- **Capacity building**: develop basic early warning infrastructures and capacities in parts of the developing world most affected by natural disasters; promote education programs on disasters mitigation and preparedness and integrate disaster mitigation plans into broader development context;

The evaluation study of existing early warning systems (Chapter 3) highlighted that a technological divide between developed and developing countries still exists. Indeed poorer countries suffer greater economic losses from natural disasters than richer countries. Development plays a key role and has a significant impact on disaster risk. Almost 85% of the people exposed to the deadliest hazards, earthquakes, floods, cyclones and droughts live in the developing world. Impact of disasters is mostly influenced by development choices made previously. By integrating disaster mitigation strategies into planning and policies, 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 are:

1. Development of national research, monitoring and assessment capacity, including training in assessment and early warning;
2. Support to national and regional institutions in data collection, analysis and monitoring of natural and man-made hazards;
3. 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. Organization of training courses for local decision makers and communities
6. Bridge the gap between emergency relief and long-term development.

- **Bridge the gaps between science and decision making and Strengthen coordination and communication links**: Provide simple, effective and timely warnings and promote the use of standard protocols for warning dissemination and information exchange

Scientific and technological advances in modeling, monitoring and predicting capabilities would bring incredible benefits to early warning if science would be translated into effective 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 yet to ensure that early warnings result in prompt responses by governments and potentially the international community. First of all, it requires that information be effectively disseminated in an accessible form down to the end user, achievable by adopting standard formats and easy-to-use tools for information dissemination, such as interactive maps, emails, SMS, etc.

A common area of further development for early warning systems for every type of hazards is strengthening coordination and communication links by defining responsibility mechanisms and appropriate action plans. More often cascade mechanisms of warning are used in early warning processes but this implies a decrease in warning times available for action and in reliability of the information. This trade-off requires to be addressed

To bridge communications gaps and to guarantee that warnings are well received and understood, warning messages need to be timely, reliable and simple. The adoption of standard formats (such as the Common Alerting Protocol CAP) for disseminating and exchange 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.

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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
GDACS- Global Disaster Alert and Coordination System
GDPS-Global Data Processing System
GEOSS- Global Earth Observation System of Systems
GFAS-Global Flood Alert 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
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-Intergovernmental 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
SCHIAMACHY-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
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 GOME (Global Ozone Monitoring Experiment); UV information is from GOME and SCIAMACHY, NO_2 from OMI and GOME 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 pressure and 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 pollution assessment 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 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.

	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_2, ozone 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 is displayed on the map is color coded. Comments: NO_2, CO_2, ozone and PM10 are not available for all the monitoring sites. Forecasts of air quality index are not available.
	Leeds City Council	Leeds, U.K.	Real-time maps of PM10, 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). PREV'Air uses a predictive model to produce 3-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.
	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/pages/indices/resultats?ancre=carte&jour=jour	AIRPARIF's task is to constantly measure air quality to evaluate the associated health risks and effects on the environment and buildings and to inform the public authorities and general public. Comments: The website is available only in French.
	Federal Environmental Agency	Germany	Real-time maps of NO2, ozone, PM10, CO2 and SO2. 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/OurEnvironment/Air/AccessMaps/	The Environmental Protection Agency (EPA) for Ireland provide an interactive map of daily values of NO_2, SO_2, PM, benzene. Comments: Daily values are not available for all monitoring sites. Forecasts are not available.
	Asia				
	State Environmental Protection Administration of China	China-84 major cities in China	Daily values of air quality index and prominent pollutant (PM or SO2).	http://www.zhb.gov.cn/english/air-list.php3	State Environmental Protection Administration of China provides daily air quality index and prominent pollutant (PM or SO2) associated with a level grade for 84 major cities in China on their website. Comments: Daily values are not available for all monitoring sites. Forecasts are not available.
	Environmental Protection Department-Government of Hong Kong	Hong Kong	Daily values of air quality index and prominent pollutant (PM or NO2).	http://www.epd-asg.gov.hk/eindex.php	The Environmental Protection Department (EPD) provides daily air quality index and prominent pollutant (PM or NO2) associated with a level grade. Graphs are also available to show data of the past days. Comments: Forecasts are not provided.
	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/emce/index.aspx?mod=PsiAreaHourly	The EPA 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 not provided.
	Japan real-time data	Japan	Real-time map of air quality index	http://www2.kankyo.metro.tokyo.jp/bunpu1/air/mapmenu.asp?mapno=5&date=20	Comments: The website is available only in Japanese.

	AIRKOREA	Korea	Real-time map of air quality index and NO2, CO, PM10, ozone, O2, SO2.	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 SO2, NO2, CO, ozone are provided in a table.	Daily air quality map: http://www.pcd.go.th/AirQuality/Regional/Graph/createaqi2.cfm Values of SO2, NO2, CO, ozone: http://www.pcd.go.th/AirQuality/Regional/Default.cfm	Pollution Control Department provides access to air quality information for 18 locations in Thailand. A color coded air quality map is avaialbel 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.epa.nsw.gov.au/airqual/web24hsum.asp	The EPA is involved in programs on pollution, coastal management, 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.
	North and South America				
	Environment Canada	Canada	Real-time maps of air quality index and forecasts (only in summer)	http://www.msc-smc.ec.gc.ca/aq_smog/aqcurrent_e.cfm	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://www.telusgeomatics.com/tgpub/ag_air/default.asp	Alberta Government website provides access to air quality information through interactive maps. Comments: To visualize maps of air quality is necessary to download and install a specific software available on the website
	Ministry of Environment, Government of British Columbia	British Columbia, Canada	Real-time values of CO, NO_2, O_3, PM10, SO_2, H_2S	http://www.env.gov.bc.ca:8000/pls/aqiis/air.summary	The Water, Air and Climate Change Branch Ministry of Environment provides values of several pollutants for various locations in British Columbia, presented in a text table on the website. Comments: Forecasts are not available.
	Ministry of Environment Ontario	Ontario	Real-time and forecast maps of air quality index. 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. Comments: Values of pollutants are not available, only air quality index is provided.
	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
	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://www.rsqa.qc.ca/framville.asp?url=framrsqf.asp	The City of Montréal operates its own Air Quality Monitoring Network. For each station a graph shows the pollutant values plotted versus time. Forecast reports are published on the website. 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 and O3. Bulletins on air quality incidents	Air quality forecast: http://www.sparetheair.org/data/five_day.htm Bulletins: http://www.baaqmd.gov/enf/incidents/index.htm O3: http://gate1.baaqmd.gov/aqmet/aq.aspx	The Bay Area Air Quality Management provides daily information on air quality and forecast maps, together with reports on air quality incidents (i.e. release of air contaminates). Comments: Forecasts are available only for PM2.5.

	U.S. Environmental Protection Agency	U.S. and Canada	Real-time and forecast maps of air quality index and values of O3 and PM2.5	U.S.: http://airnow.gov/ Canada: http://airnow.gov/index.cfm?action=airnow.canadamaps	EPA AirNow provides real-time air quality index for the major cities of USA. Maps are provided via airnow website and The Web site 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.
	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 Net work	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 AIR QUALITY and ENVIRONMENTAL MANAGMENT	Nevada, U.S.	Daily maps of air quality index and values of O_3, PM10 and PM2.5	Website: http://www.ccairquality.org/ Air quality information: http://www.ccairquality.org/daily.html	The Department of Air Quality and Environmental Management (DAQEM) provides hourly air quality data and daily maps. 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 Phoenix area.	Live webcam pictures: http://www.phoenixvis.net/ http://www.azdeq.gov/environ/air/monitoring/links.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://www.deq.mt.gov/Airmonitoring/AirDataMap3.asp?imageName=MSLHLNSSIMS218322232174.jpg	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 and PM	http://www.deq.state.id.us/air/aqindex.cfm http://www.tcsn.net/family/Idaho/index.html	For each monitored site, the Idaho Department of Environmental quality provides air quality index maps and the values of pollutant of concern. Comments: O_3 and PM are not available for all monitoring sites
	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/airquality.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://maps.dnr.state.wi.us/imf/dnrimf.jsp?site=wisards	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 O3, 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	Graphs of air quality index and CO, NO_2, SO_2, PM10 and O_3.	http://www.gvrd.bc.ca/aqi/	Real-time information on air quality for several locations is provided by GVRD. An interactive map shows the monitoring stations around the Vancouver area. For each site are provided graphs of air quality index and pollutants variations over time. Comments: Values of air quality index and other relevant pollutants are not provided, neither forecasts.
	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 5 sites are monitored and air quality index is the only parameter to be provided.
	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/aqp/Public/databyarea.shtml	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/all.html	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
	INPE, Brazil	Brazil	Maps of CO, PM, and UV radiation.	http://www.cptec.inpe.br/meio_ambiente/index.shtml http://satelite.cptec.inpe.br/saude.htm	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/sma/index.php 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	Air quality index values	http://www.capetown.gov.za/airqual/	For each monitored station is provided color coded information on air quality based on the U.K. color scale for air quality acceptable levels. Comments: Values of pollutants are not provided, neither forecasts.

Type of event	Source	Geographic Coverage	Output	Website	Description
Wildland Fires	ECPC, Experimental Climate Prediction Centre	Global	Fire Weather Index (FWI) maps forecast for tomorrow, weekly and monthly forecast.	http://www.fire.uni-freiburg.de/fwf/ecpc1.htm http://www.fire.uni-freiburg.de/	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://maps.geog.umd.edu/default.asp	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). Interactive maps are available on the website to view active fires for the world or for selected regions. A new email fire alert system is also available for email alerts to subscribed users. Comments: Webfire Mapper reports on active fires worldwide but does not provide forecast products.
	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 potential threat for 3-day 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/content/view/17/32/	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/index_e.php	The Canadian Wildland Fire Information System creates daily fire weather and fire behavior maps year-round and hot spot maps throughout the forest fire season, generally between May and September.
	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://paraguay.cptec.inpe.br/produto/queimadas/#	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.
	CFS, Canadian Forest Service	Mexico	Maps of temperature, wind speed, fire weather index, fire intensity, and precipitation.	http://cwfis.cfs.nrcan.gc.ca/mexico/	The México Wildland Fire Information System (El Programa de Sistemas de Manejo de Incendios) is a comprehensive fire information system which has been set up in collaboration with Natural Resources Canada, Canadian Forest Service. Comments: The website is available only in Spanish.

	Europe				
	German Weather Service	Germany	Fire danger maps	http://www.agrowetter.de/Agrarwetter/waldix.htm	German Weather Service (Deutscher Wetterdienst - DWD) provides an daily prediction of forest fire danger maps. Comments: Website is available only in German
	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
	Swedish Rescue Services Agency (SRSA)	Sweden	Fire risk and soil moisture maps	http://www.raddningsverket.se/templates/SRV_Page____830.aspx	Comments: The website is available in Swedish.
	Australia				
	National Rural Fire Authority	New Zealand	Map of active fires and forecast maps.	http://nrfa.fire.org.nz/	Forecasted fire danger is periodically provided by the NRFA. Maps of the likely fire danger for several weeks are based on projected seasonal climate forecasts.
	Africa				
	University Of Maryland, NASA, EUMETSAT, CSIR, ESKOM	South Africa	Map of active fires	http://www.wamis.co.za/eskom/checkboxes/eskom.htm	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 maps	http://www.zfps.co.za/Fire%20Weather.htm	Zululand Fire service provides daily and forecast maps of fire danger index for Kwazulu Natal, collected from the South African Weather Service.
	Asia				
	Korea Research Institute	Korea	Fire danger maps	http://forestfire.kfri.go.kr/default.asp	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.kjc.gov.my/english/service/climate/fdrs1_x.html	Malaysia Meteorological Department provides a Fine Fuel Moisture Code Distribution Map that indicates the relative ease of ignition and flammability of fine fuels. Thus, the FFMC is used as an indicator of ignition potential or the potential for fires to start and spread in the area.

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. Early warning for this reason is not possible.
	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 conference on early 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 provides 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.

	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 continuous collected 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.
	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 natural 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 and private organizations	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.jaee.gr.jp/old/submit-j/v04n03/data/frame/2-5.html www.bousai.go.jp/kyoryoku/soukikeikai.pdf	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.
	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. Seismoogical 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.
	CalTech, UC Berkeley	California	Alerts sent to users (Not existing yet)	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 planning of testing applications of early warning.

Type of event	Source	Geographic Coverage	Output	Website	Description
Tsunamis	UNESCO-IOC, United Nations Educational Scientific and Cultural Organization-Intergovernmental Oceanographic Commission	Indian Ocean	Tsunami warnings and advisories	http://ioc3.unesco.org/indotsunami/	Currently, there is no Indian Ocean tsunami early warning system, in June 2005 the IOC secretariat was mandated by its member states to coordinate the establishment of tsunami warning systems for the Indian Ocean, the northeast Atlantic and Mediterranean, as well as for the Caribbean Sea. Intergovernmental Coordination Groups (ICG's) for each of these regional systems were established in 2005. Comments: The system is under development.
	PTWS, Pacific Tsunami Warning System	Pacific	Tsunami Bulletins. Email and SMS alert service	http://www.prh.noaa.gov/ptwc/	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 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. The system disseminates tsunami information and warning messages to over 100 points across the Pacific. Comments: PTWS website provides also tsunami bulletins for Indian Ocean and Puerto Rico and Virgin Islands. Note SMS service is available for some Pacific, Asian, and African countries.
	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. JMA provides also interim advisories for the Indian Ocean.

Type of event	Source	Geographic Coverage	Output	Website	Description
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 relaesed 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 occurr.
	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/KeJ/kejalert.html	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/2006/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
	Instituto Nicaraguense de Estudios Territoriales (INETER) Volcanology Department	Nicaragua	Reports and warnings	http://www.ineter.gob.ni/geofisica/vol/dep-vol.html	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/bseccion/eventos_volcanicos.htm	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://www.ees.nmt.edu/Geop/mevo/mevo.html	Mount Erebus Volcano Observatory provides information on temperature, wind speed, deformation, and humidity 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. 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://data.geonet.org.nz/geonews/sab/	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.
	Philippine Institute of Volcanology and Seismology	Philippines	Reports and Warnings	http://www.phivolcs.dost.gov.ph/VolLatest.htm	Philippine Institute of Volcanology and Seismology maintains and operates volcano systems for monitoring and forecasting purposes. The institute assesses volcanic activity and then provide 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.dpri.kyoto-u.ac.jp/Landslides%20Alert.htm	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 an interactive interface to worldwide landslides information. This information is shown through a map visualization and short reports are provided for each landslide event. Comments: ICL does not provide forecasts on landslides. ICL collects news information for its landslides reports.

Type of event	Source	Geographic Coverage	Output	Website	Description
Droughts	HEWS, Humanitarian Early Warning Service	Global	Monthly maps and reports on drought current conditions	http://www.hewsweb.org/drought/	HEWS provides the map of countries facing food insecurity (source: FAO) and descriptive reports on each of these countries. HEWS collects this information various sources such as: FAO, FEWS NET, and USAID. Comments: HEWS informs on current situation of countries facing food insecurity but it does not provide forecasts. For this reason droughts early warning is not possible.
	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. The droughts map is based on various data collected from various sources such as: precipitation by Global Precipitation Climatology Center at Deutscher Watterdienst, temperature by ECMWF, soil water holding capacity by UNEP, World map by ESRI, rivers by USGS and population by SEDAC at Columbia University. 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.
	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://www.drought.unl.edu/dm/index.html 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	East Africa, Afghanistan, Central America	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	Europe	Maps of soil moisture	http://natural-hazards.jrc.it/activities_droughts_realtime.html	EC-JRC provides publicly available 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). Comment: An integrated approach which would include several indexes and products is needed for drought monitoring and early warning.
	BCC, Beijing Climate Center of the China Meteorological Administration	China	Daily maps on droughts current conditions	http://bcc.cma.gov.cn/influ/hljc.php?WCHID=76&ChannelID=77	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.

Type of event	Source	Geographic Coverage	Output	Website	Description
Floods	Dartmouth Flood Observatory	Global	Map of current floods	http://www.dartmouth.edu/~floods http://www.dartmouth.edu/~floods/Archives/2006sum.htm	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	Daily soil moisture and forecast soil moisture maps for Europe	http://efas.jrc.it/	Since 2002, a European Flood Alert System (EFAS) is under development and JRC together with weather forecasts centers, such as ECMWF and DWD, is testing the system. The EFAS will provide early flood warnings to National Hydrological Services in order to mitigate flood impact on population. Comments: EFAS is still under Development.
	North and South America				
	NOAA	U.S.	Maps of current floods	River gauges: http://www.weather.gov/ahps/ Local maps: http://www.nws.noaa.gov/oh/hic/WFOs/WFOs.html Current conditions: http://www.nws.noaa.gov/oh/hic/current/river_flooding/floodtable.shtml	NOAA provides river's level measurements from river gauges, it provides also maps with current river conditions, and tables synthesizing current conditions in U.S.

Type of event	Source	Geographic Coverage	Output	Website	Description
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 Western 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 WMO.
	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.

Type of event	Source	Geographic Coverage	Output	Website	Description
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 Epidemic and Pandemic Alert and Response effort provides real-time information and dissemination on disease outbreaks. WHO maintains and regularly updates a network of electronically-interconnected WHO member countries (192), disease experts, institutions, agencies, and laboratories through an Outbreak Verification List. The members are kept constantly informed of rumoured and confirmed outbreaks. WHO also posts reports on verified outbreaks on its web site, Disease Outbreak News. Part of this effort is the Global Outbreak Alert and Response Network (GOARN). Comments: Disease outbreak news are available online but alert service is restricted to WHO member countries (192), disease experts, institutions, agencies, and laboratories.
	European Centre for Disease Prevention and Control, ECDC	Europe	Online disease outbreak news.	http://www.ecdc.eu.int/	The ECDC will work 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/	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.
Avian Flu	WHO, FAO and OIE	Global	Online disease outbreak news	http://www.fao.org/ag/againfo/subjects/documents/ai/HPAIGlobalStrategy31Oct05.pdf Avian flu news: http://www.who.int/csr/disease/avian_influenza/en/	A Global Early Warning and Response System for avian influenza is under development by WHO, FAO and OIE based on previously existing alert outbreak systems of each of the agencies for transboundary animal disease. A global early warning system for animal diseases transmissible to humans was formally launched in July 2006 by the UN Food and Agriculture Organization (FAO), the World Organization for Animal Health (OIE) and the World Health Organization (WHO). The system helps for disease traking, sharing information and aid operations. Avian influenza news are published online into short reports. Comments: Project is under development.

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 continent where control has eliminated malaria risk. Alerts service is not provided.

Type of event	Source	Geographic Coverage	Output	Website	Description
Famine	FEWS, Famine Early Warning System	East Africa, Afghanistan, Central America	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/english/?n=31	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.