Forecasts and Warnings of Natural Disasters and the Roles of National and International Agencies

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Abstract

Natural disasters are caused by natural events, which can be grouped as (i) extreme unstable events associated with rapidly growing instabilities of geophysical 'systems' - in the earth, atmosphere and ocean, such as volcanic eruptions and tropical cyclones, (ii) large 'variability' events associated with extremes of the inherent variability and chaotic behaviour of geophysical systems, such as precipitation over long periods, El-Nino oscillations and extreme hydrothermal activity, (iii) global change events on decadal or secular timescales, which may have anthropogenic causes, leading to disasters such as desertification, or severe loss of ocean plankton.

Following any of these primary events there may be equally harmful secondary events such as mud slides or tsunamis following volcanic eruptions. Whether these events lead to disasters depends to a large extent on the preparedness and resistance of the afflicted community - i.e. its vulnerability. Forecasts for these different categories of events are of two types· firstly 'risk' forecasts based on data of previous events, and secondly real-time forecasts for specific primary events which are derived by observations and by calculations, and may be deterministic or may be based on a combination of deterministic and statistical methods. For group (i) events, these forecasts only begin following some initial detection, whereas for groups (ii) and (iii) forecasts are made before any indication of the event, for different events in the ocean-atmosphere system these may range from days to years. Once the location, nature and scale of the primary event is forecast or known, many (but not all) types of secondary events may be also forecast with increasing accuracy using local geophysical data (eg which may be derived from satellites) and computational models of relevant processes (eg lava flow, flood waves etc).

This paper describes the organisation of forecasts and warnings and how it involves geophysical and disaster or emergency centres at the national, regional and international level. It is pointed out that a satisfactory system for issuing, receiving and acting on forecasts and warnings between countries by these centres (including the use of broadcasting media) require carefully negotiated procedures at the intergovernmental level, and that, for some kinds of weather and water disaster, these have been agreed through the World Meteorological Organisation. It is pointed out that no such international procedures have been agreed for other geophysical events and disasters, and that since this may lead to a confused response by disaster/emergency services, it would be appropriate to investigate whether WMO-like procedures might be developed for these situations. The final section of the paper reviews the need for defining targets for improvement in forecasting during the IDNDR, and that this should be preceded by establishing the accuracy of current methods, ie the baseline. Clarification of our objectives and targets may well lead to greater financial support from governments and other donors.

1. Introduction

We are concerned here with disasters to human communities and ecological systems which are seriously damaged by natural events, to the extent that the communities cannot themselves adequately handle all the consequences. These events occur when the dynamic balance in the geophysical (and sometimes biological) processes at the earth's surface are significantly disturbed.

From the point of view of the earth's equilibrium, these natural events are not associated with any significant long term departure from the usual physical, chemical and biological state of the atmosphere, ocean and land surface. Indeed these events are an integral part of the geophysical systems and help maintain them in equilibrium; for example the sliding movement of the tectonic plates, that cause continual earthquakes over a wide spectrum of magnitudes, is a necessary consequence of the continuous formation of the plates and their subduction back into the interior of the earth (eg **Main, 1993**).

These severe geophysical events may or may not lead to disasters, because this depends on their nature and special features of the events and of the affected communities, in particular the conjunction of different geophysical processes during the event and the 'vulnerability' of the community in question (for example whether or not it is situated on a low lying island in the path of a tsunami, or whether the houses are built well enough to withstand a certain level of earthquakes).

It is important to note that some geophysical events that give rise to 'natural' disasters, may be directly or indirectly caused by human influence, such as the collapse of a dam following an earthquake. Human activity may also be damaging on a global scale, since it appears to be the cause of the only 'natural' disturbances that develop within a period much less than a geological timescale and that may be severe enough to cause substantial, possibly irreversible, changes in the earth's equilibrium state These events are usually excluded from the discussion of natural disasters, (for example depletion of stratospheric ozone).

In order to reach the goal in this decade of reducing the impact on communities of natural disasters, it is necessary to attain the following objectives:

(i) to forecast when and where they occur, how they travel and evolve, and what secondary effects they cause;

(ii) to provide appropriate warnings, so that these communities are not only informed, but sufficiently impressed that they take remedial action before and during the disaster;

(iii) to establish from past data and from forecast calculations when, where and with what severity they affect communities;

(iv) to study, organise and fund the most economically and socially appropriate arrangements for actions in the precautionary, pre- and post-disaster, and remedial phases of disasters.

It might appear that the tasks in this list may not seem novel because they have all been undertaken for many years, particularly by meteorological and hydrological organisations which provide operational forecasting and regular warnings including forecasts and warnings for events leading to natural disasters.

In fact, these tasks are demanding because national and international organisations are still some way from meeting these objectives, even in meteorology and hydrology. In the case of these particular disasters, although there has been international collaboration in the operational exchange of data for 140 years since the Brussels convention in 1854, it is only recently that there have been protocols for the international exchange of forecasts and warnings. Even these are restricted to certain types of event (notably tropical cyclones, including hurricanes and typhoons). For other types of geophysical events and natural disasters, while there are scientific exchanges, for example through the International Council of Scientific Unions (I.C.S U.), there are no procedures agreed at a world wide intergovernmental level for operational exchange on an international basis of data, forecasts and warnings between the governmental agencies that have the authority to issue local warnings and organize emergency measures and disaster relief.

For all types of natural disaster, the communication of effective warnings of natural disasters to communities needs better co-ordination and improvement. The main defects in present arrangements concern firstly deficiencies in the provision of warnings, which may be totally absent, may either be misleading, and/or duplicated by local, regional and even international media. The second main defect is the highly variable response of communities; even when they receive unambiguous warnings and advice before or during an event, there is often some reluctance to take the appropriate action, for a variety of technical, social and economic factors that are now quite well understood, but the problem remains (even in quite advanced communities).

During this IDNDR, although all these goals will not be reached, it should be possible to make progress towards them, provided they are clear and the methods for attaining them are agreed. This requires joint discussion between the research, operational and governmental disaster agencies leading to the defining of measurable 'targets' to be reached at specified dates (or 'milestones') to ensure that progress is being made. These targets need to be worked out from a 'baseline' defined by the current levels of practice.

This paper, which is focused on the objectives (i), (ii) and (iii), consists firstly of a brief review of the scientific and technological basis of forecasting these geophysical events by classifying them into groups according to where they fit into the spectrum of fluctuations within the relevant geophysical system. This classification and analysis largely determines the most appropriate methods for forecasts and warnings; secondly the paper reviews how different international and national organisations and UN agencies are working to improve these forecasts, and their communication via various media and official channels to communities and individuals.

In conclusion, a number of major issues are identified where new agreements and institutional intergovernmental arrangements are becoming necessary if the developments in technology are to have their maximum benefit in improving forecasts and warnings. The paper makes use of previous expert reviews on the human and social aspects of disasters, for example in determining what are 'disasters', 'vulnerable' communities, the acceptable and informative types of warnings, and how communities respond to short or long-term warnings (eg **Aysan, 1993; Plate et al 1993**)

2. Natural disaster forecasts and their improvement

2.1 Classification according to geophysical process

Forecasts and warnings of events associated with strong geophysical disturbances and consequent natural disasters are based firstly on observations of the relevant geophysical phenomena, and secondly on the use of models appropriate to the type of process. Rather than listing all the processes and observational requirements for all the different types of events and disasters, it is more instructive to group them according to the relevant geophysical causes as follows:

Group (i) Extreme unstable events are phenomena that change rapidly over relatively small length scales, because they are essentially manifestations of rapidly growing instabilities of geophysical 'systems' at the earth's surface, and distinct from those of the dominant dynamical processes that take place on the longer period and longer length sales in these 'systems'. For example the geological events, volcanoes and earthquakes eg **Main 1993**, are drastic instabilities of the crust (for example with, respectively, the ejection of 1km^3 and displacements of 10m occurring in minutes within regions of about 1km - compared to the usual very small displacements (of the order of cms) that take many years). The meteorological events of tornadoes and hurricanes/cyclones are also instabilities of the atmosphere-ocean system, rapidly growing within 24 hrs over 10-100 km from quite small amplitude disturbances leading to windspeeds in excess of 200 km/hr, which are much greater than the usual windspeeds of 50 km/hr and smaller than the usual length scales, of synoptic disturbances of 1000km and growth time scales of 2-3 days.

These events usually interact with other geophysical or man-made 'systems' to cause 'secondary' events that lead to natural disasters to communities, and may also be significant as geophysical disturbances; for example, strong volcanic eruptions have many secondary events such as lava flows or clouds of hot dust-laden air descending rapidly down their slopes, or mud slides caused by volcanic eruptions breaching dams or volcanic dust mixed with rain or molten snow; earthquakes can produce vertical accelerations of the sea bed which cause longwaves on the sea surface, 'tsunamis', which propagate across oceans, at speeds of about 100ms^{-1}, grow in amplitude from about 1 m. to 20 m. when theyreach the shallower sea bed near other coastlines and wreak havoc on shore communities (eg **Dawson et al 1993**); there may be secondary events following hurricanes, typhoons and other severe cyclones, consisting of large wind induced waves, tidal surges and heavy rain at the nearby shore, which may lead to a 'disaster' as a result of inundation of communities, and damaging shipping and shoreline structures; when the events are strong enough urban areas can be damaged up to 200 km inland.

Whether these strong events lead to natural disasters depends very much on the 'vulnerability' of the community, to that particular set of events (eg **Aysan 1993**). Communities differ greatly in how well they are protected and prepared and in the degree to which they have suitable buildings, transport and communication systems to 'weather' an extreme event, and the organisation and infrastructure to respond.

Group (ii) Large 'variability' events are extremes of the inherent variability and chaotic behaviour of the main geophysical systems They occur on the dominant scale and period of these systems which are larger and longer than those of the extreme unstable events of group (i). On the human timescale these events are usually meteorological, hydrological or oceanographic, though certain geothermal phenomena also fall into this category; notable examples are the extended periods, ranging from 3 months to 2 years when large increases in rates of precipitation may occur, leading to flooding or decreases leading to drought, or when oscillations in the tropical ocean-atmosphere system lead to rises in ocean temperature (that can lead to disastrous loss in fish catch and starvation). These are natural fluctuations in the atmosphere-ocean-land surface system whose probabilities of recurrence at the same place with defined 'return periods' have been established by examining records. The extent to which these events can be forecast will be discussed in section 2.2.

These large scale and long period fluctuation events are usually most serious when they subsequently induce secondary events. These may or may not be on the same time scale as the primary event. In some cases long periods of rain may give rise to a similar period of flooding of farmland, as occurred in the USA in 1993. However in other situations, the primary events can lead to instabilities in the geophysical processes which cause secondary events with short length and timescales, and potentially damaging effects, as for example when large snowfalls are followed by sudden avalanches or heavy rain leads to a flood wave down a river system.

Group (iii) Global change events In the past over geological timescales the states of geophysical systems have undergone large changes as a result of external astronomical effects and changes within the earth. These have led to changes in magnitude and frequency in both types of natural disaster events already described

However it is anticipated that in the current geological era such natural changes will be small. The increasing world population and the associated agricultural, urban and industrial development (eg by atmospheric release of CO_2, and fluoro-carbons, and changes in the biomass) are producing significant changes in the physical, chemical and biological states of the atmosphere-ocean-land system that may induce directly, or by secondary causes, events that could lead to an increase in the number of natural disasters.

Some of the main primary events may be droughts and desertification, (caused by CO_2 emission), or excess ultra violet rays causing loss of ocean plankton (caused by reduction of stratospheric ozone). The secondary events may be increased as hurricanes and storms change their 'tracks' (eg **Collier et al 1994**), loss in food and fish production, and the possibility of greater severity of the impact of disasters on vulnerable communities because of the greater population with poorer health and housing (see for example **Houghton et al., 1990, 1992**).

2.2 Forecasting

Four main types of forecasts are required before, during and after natural disasters to provide warnings in order to mitigate their effects on communities. Their scheduling in relation to the different types of events is depicted schematically in Figs 1a and 1b.

2 2 1 Risk forecasts

Inevitably forecasts of specific 'disaster' events at specific places in a defined time period can only be provided for limited periods prior to the event. However from studies of past events of the underlying geophysical processes, of relevant geophysical data and of the vulnerability of relevant communities at risk it is now possible to derive by calculation useful estimates of the probability of such events occurring in particular areas and in different time intervals (eg over days or seasons), and

Fig. 1a DISASTER EVENTS FORECASTS AND WARNINGS

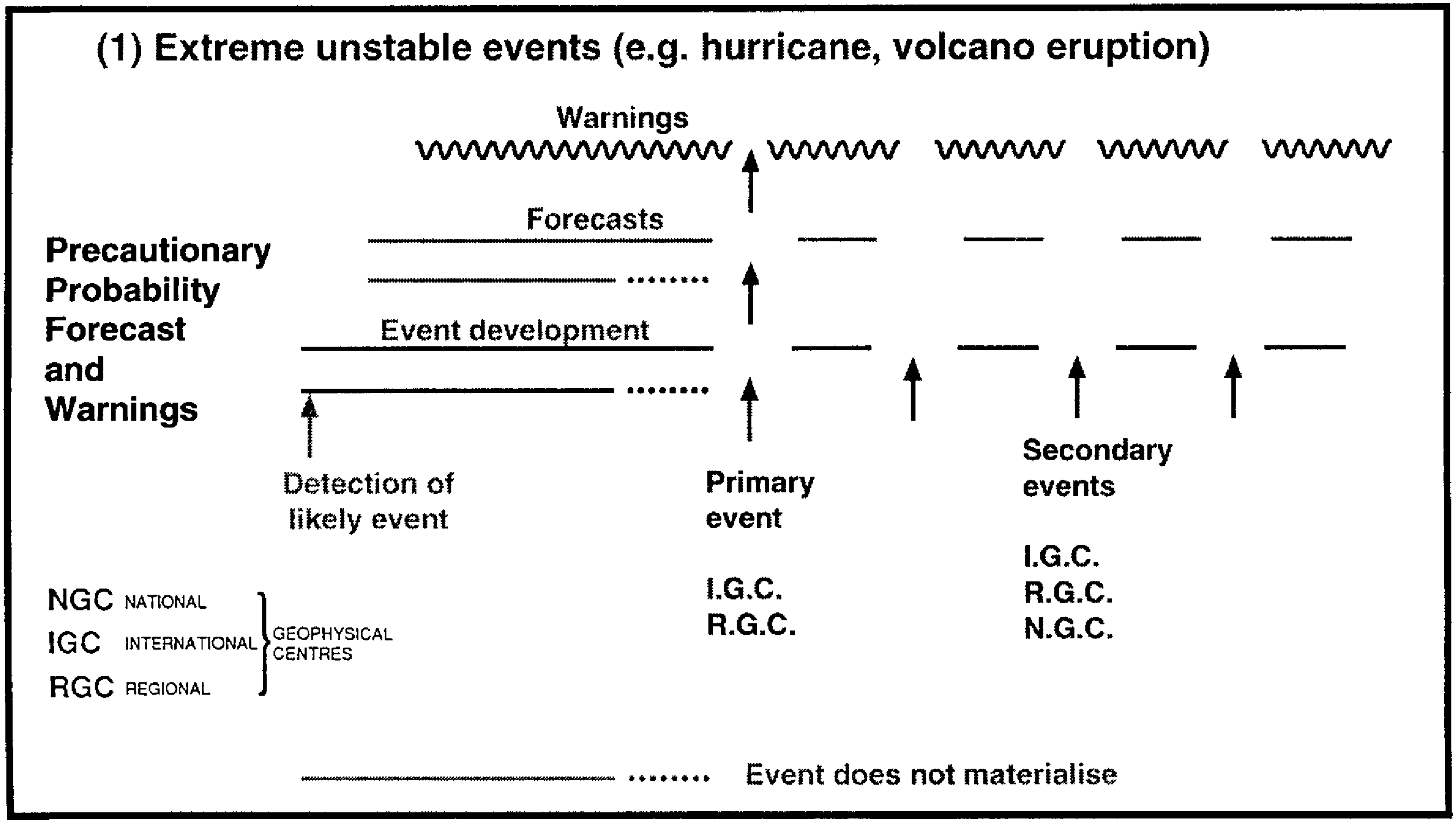
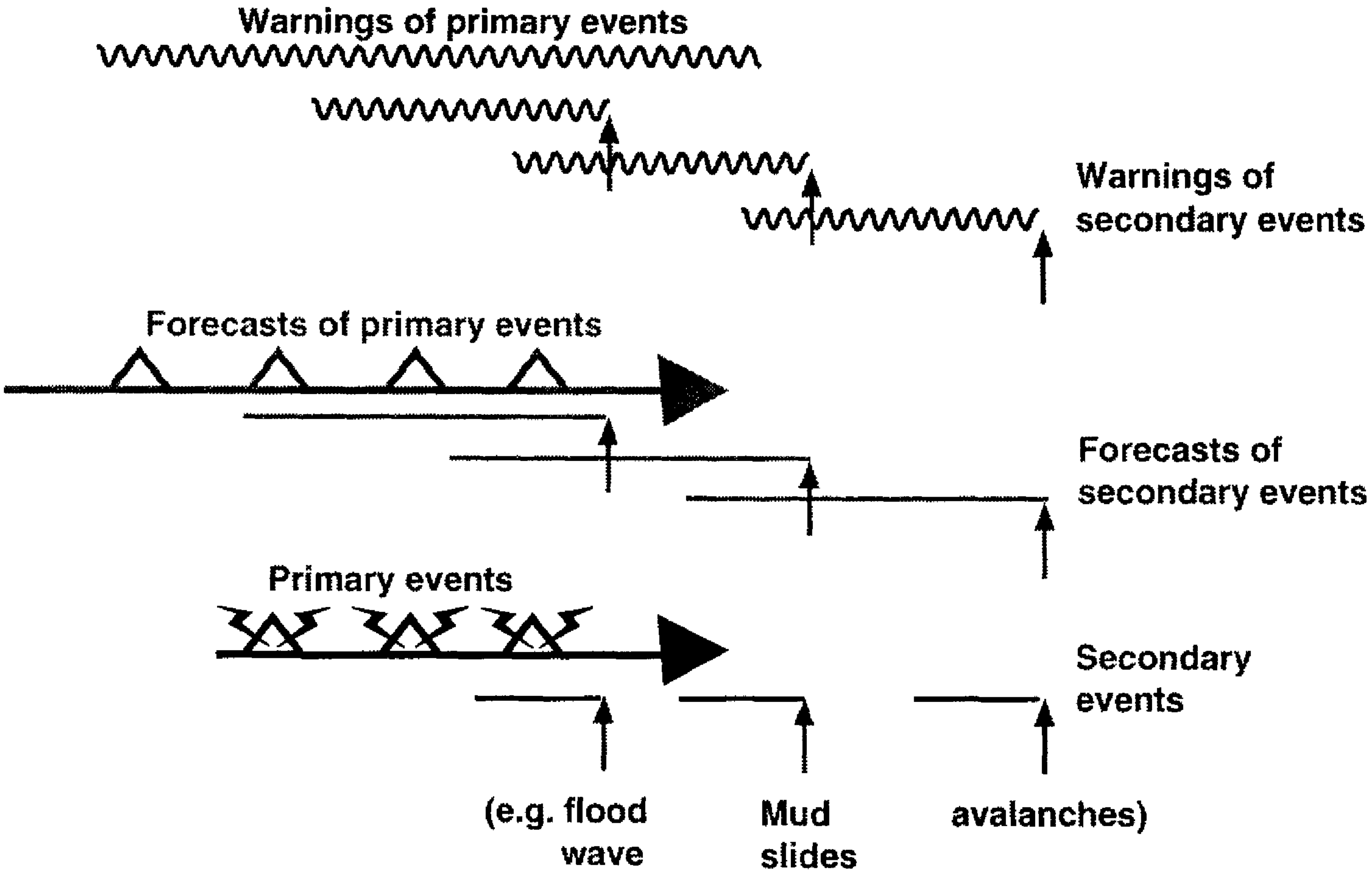


Fig. 1b DISASTER EVENTS FORECASTS AND WARNINGS

(2) Large variability events (e.g. exceptional precipitation)



recurring within given 'return' periods. One of the main difficulties of making such 'risk' forecasts, in a particular area, is that there may be no data of previous events in that area. However deeper scientific understanding, better quantitative models and new kinds of data (notably remote sensing) should enable 'risk forecasts' to be made on a routine basis assessment' for events in data sparse areas, just as it is now possible to do so in operational meteorology.

For some kinds of geophysical event, most risk forecasts only make use of past data, such as the calculation of return periods of floods, high winds and hurricanes. Whereas for earthquakes and volcanic eruptions, specific probabilistic forecasts are provided for events to occur in the future in specific areas and within defined periods of time (that may be no more precise than years or decades). This approach, which is still tentative, makes use of current data, for example of stresses, movements and temperature in the rocks (eg **Schmincke et al 1993**).

There are two main ways in which this statistical approach of precautionary forecasting has certainly proved its value in different fields of geophysics. Firstly there is much evidence that 'disaster' events have generally recurred within the 'return periods' evaluated for the related geophysical processes in that particular region of the world. In other words the return period concept has been validated (which confirms that these events are members of a defined statistical ensemble) (eg **Main 1993, Simiu & Scanlon 1978**).

Secondly these 'risk' forecasts have enabled precautionary warnings to be given of specific kinds of danger to particular communities. In an increasing number of countries these 'precautionary warnings' have been followed by preventative action, such as strengthening buildings, flood protection schemes, cyclone shelters etc. By making quantitative use of the appropriate estimates of the probability of disasters, there is the basis for a stronger justification for expenditure of appropriate resources on these actions.

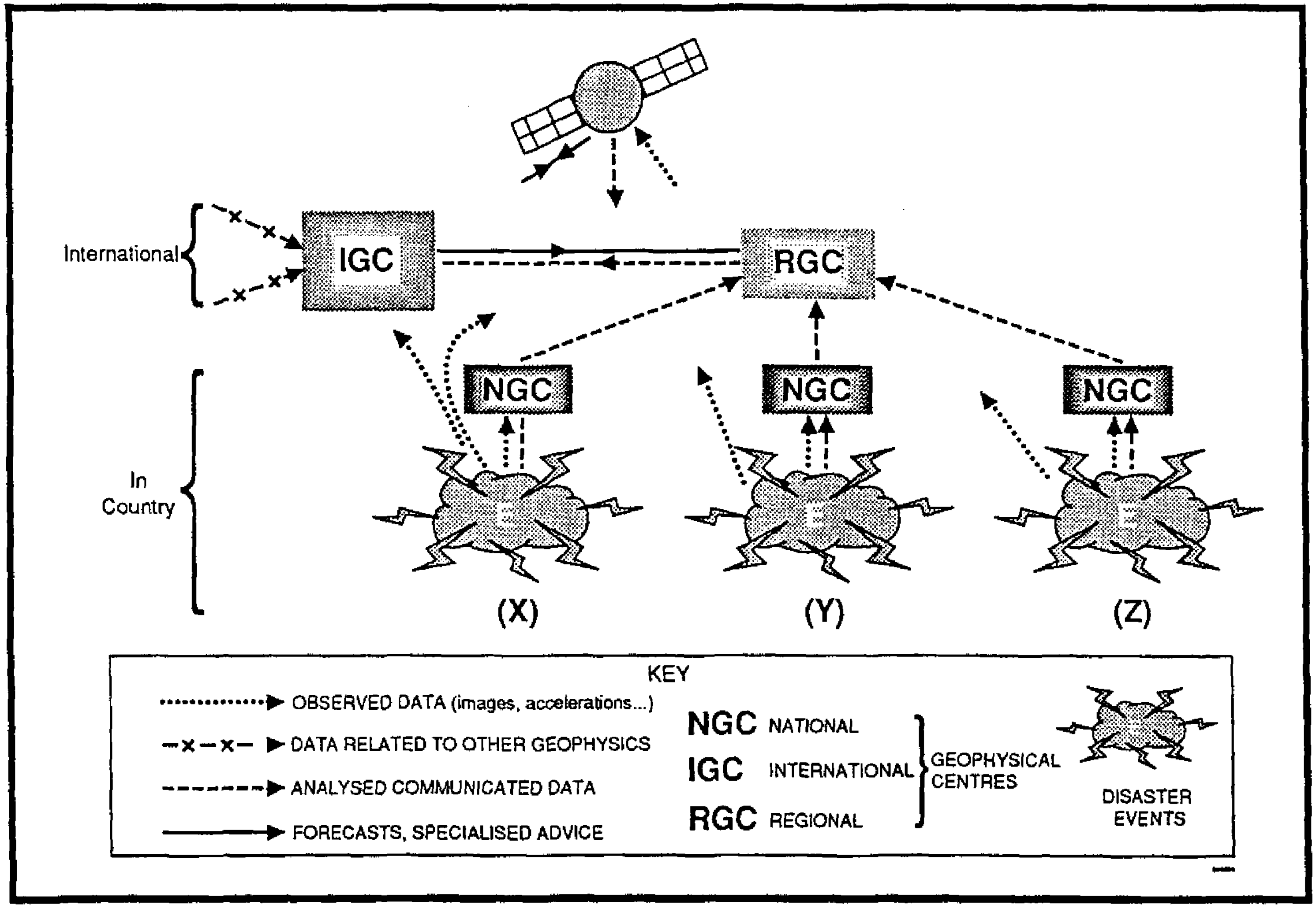
2.2.2 Real time forecasts for specific primary events

(i) *Extreme unstable events*. The satellite images of ocean cloud beginning to show the disc shape characteristic of a tropical cyclone, or the observed temperature and lava level of a volcano beginning to rise, are examples of the initial detection of a geophysical phenomenon that may develop into a primary event and a 'natural disaster'. For some very rapidly developing unstable events (on periods of minutes) such as tornadoes there is a 'pre-initial detection' phase when the general conditions are suitable for such an event. Following this moment of 'initial detection', local, regional or international geophysical centres may begin to make specific forecasts (see Fig 2), using observations made locally (eg ship measurements of hurricane winds, or vulcanologists' measurements of earth vibrations) or remotely (eg by satellites, seismic records etc) and transmitted between these centres. Such forecasts are aimed at predicting the location, time, form and magnitude of the primary event; these predictions are either probabilistic or are deterministic with a finite error, (that should if possible be estimated); for example a forecast may state that a cyclone will arrive in 24 hours on the coast at a particular point X with a possible error in the landfall position of about 100 km either side of X.

The methods used range from the extrapolation using real time data, (as in the use of weather radar to forecast tornadoes and flash floods for periods of minutes to hours), the use of empirical correlations or rules based on past data to forecast from present data (eg cyclones in the northern hemisphere tend to track on straight lines and then turn north, or the behaviour of volcanoes based on

Fig. 2 NATURAL DISASTERS

OBSERVATIONS DATA – FORECAST NETWORKS



the rate of change of its surface temperature etc), to the use of computational models incorporating data from world wide observations of all the relevant geophysical processes (of which the best current example is cyclone/hurricane forecasts by certain Regional Specialised Meteorological Centres (as designated by WMO)). In the case of hurricanes, the latter approach has only recently been found to be a reliable improvement over the former empirical methods for medium or longer periods of time (with typical errors in position for 48 and 72 hour periods lower by 10% from about 390 km and from 570 to 500 km respectively (**Chan & Kay 1993**)); in particular it is the only reasonably reliable method for forecasting the rapid changes in their direction.

(ii) *Large (variability) events.* It is possible to forecast for a limited period events that routinely occur within chaotic geophysical systems. **(Palmer 1993)**. The forecast period for particular variables may be longer or shorter depending on the availability of data from observations and the properties of the relevant processes and of the predictive models. For atmosphere-ocean systems there are three types of forecast model viz:

(a) firstly there are deterministic calculation based on models of the geophysical processes (such as deterministic numerical weather forecasts and seasonal climate forecasts which include many simplifications of processes taking place on length and time scales smaller than that of the 'mesh size' of the numerical calculation). Currently the weather forecasts give useful guidance on these kind of events out to 5 days, as for example temperature and snow forecasts in the 'storm of the century' in the USA in March 1993 and the cold weather disaster affecting refugees at the borders of Turkey, Iraq and Iran in January 1992.

(b) secondly there are statistical correlations, based on past data, between certain geophysical phenomena and particular events at later times which are used for forecasts over longer periods than about 10 days, because the purely deterministic forecast is inaccurate. Then a combined deterministic-statistical method is more effective: initially a large scale variable, such as atmospheric pressure is forecast deterministically (with an ensemble of calculations to indicate the reliability of this forecast); then the likelihood of local small scale events, such as temperature or rainfall, is derived by using the empirical correlation between these events (in the past) and the large scale variable. **(Harrison et al 1993)**.

(c) when numerical models are run for even longer periods to forecast seasonal and even climate changes (the forecasts being for average conditions over seasons or decades), it is necessary to include coupled calculations of the atmosphere and ocean, but because of limited computer capacity the spatial discrimination has to be reduced (typically up to about 300 km) These models are just beginning to give predictions of the variability of the average atmospheric and oceanographic behaviour for the next seasons (especially as regards drought or rain) in Equatorial Africa and north east Brazil.

At these low latitudes the atmosphere-ocean system develops a partly regular oscillation (the 'El-Nino') that is not strongly coupled to more chaotic and advected ocean-atmospheric 'eddies' in the temperate zones, where seasonal forecasts do not yet have any practical value (though they are beginning to be studied in detail)

2.2.3 Forecasts for specific secondary events

When river floods follow heavy-precipitation, or lava flows follow the eruption of a volcano, it is usually possible to forecast the form of the natural secondary events and the disaster consequences in relation to a specific primary event In many cases there is little need to make quantitative estimates of the 'event' or disaster magnitudes, it is enough to know that they will occur (eg a hurricane reaching the coast); but in other cases, for example estimations of the speed of a flood front of avalanche trajectories and strengths **Buisson & Charlier (1989)** or of lava 'fronts' on slopes of volcanoes are rather critical for planning emergency action **Wadge & McKendrick (1993)** show how remote sensing plus modelling of lava flows may enable forecasts of these secondary events to become significantly more reliable in future.

The essential ingredient for making these secondary forecasts are.

(i) Observations from the primary event (its location, type and the magnitude of its effects which may continue) and other relevant geophysical data (eg rain or snow level in estimating mud-slides from volcanoes, or soil type and topographic features when estimating the possibility of mud slides demolishing temporary housing on hill sides - such as occurred in Peru in 1970 (with 20,000 deaths eg **Mathess & Rump-Schenk 1993**). It is essential to have good surface observation and fast communication links to ensure that the data reaches the relevant geophysical centres for the timely production of forecasts. Remote sensing from satellites, radar etc is being used successfully to complement and in some cases make up for the lack of surface data, and it has the advantage of being regularly updated as the events develop.

(ii) Models to predict secondary events following the primary event. There may simply be empirical correlations or rules based on previous similar events; or they may be more advanced, and based on calculations of the relevant geophysical processes with input from detailed background data (eg the river system or local mountain topography) and data updated in real time. The models may also include calculations of the disaster consequences (eg destruction of structures), before and during the secondary event; in this case they may be connected to other models (for example in separate disaster centres) where these consequences are evaluated

(iii) Computational facilities for integrating the data and the models, and a procedure for applying them to those secondary events that are likely to lead to natural disasters. Computations are also necessary to estimate disaster consequences and plan for protective systems

Askew et al, 1993 describe how different flood models have been compared when the same data has been introduced, with errors for 3 days ahead of simple models being on occasions a factor of three times greater than advanced computational models. If the river flood follows a major precipitation event, the main cause of error in flood forecasts is uncertainty in the initial volume of precipitation. Where a network of weather radars, covers the whole area, the range of errors in total rainfall can be expected to be about a factor of 2 5 of the actual total This error is expected to reduce to a factor of 2 0 over the next 5 to 10 years. (Recent developments are described by **Kitchen et al 1994**).

In Africa without such a radar network, estimates of the likelihood of major flooding are derived from remote sensing of cloud-top temperatures (over certain large areas the total rainfall may only be in error by 20%, but in other areas closer to the equator where the procedure is not valid the error may be muchlarger eg **Grimes et al 1992**). More recently, satellite altimeter measurements of river/lake levels near the location of the precipitation, eg in the upper reaches of the Nile, have become available for this purpose (without the need for communication between different national agencies). [See Am.Met.Soc Bulletin March 1994].

2.2.4 Forecasts for post event and recovery actions

Disasters often do not come singly; and just as often the natural conditions remain adverse, even after the secondary events, because of continuing geological, atmospheric or hydrological disturbances. Forecasts are necessary during this period in order to plan actions immediately following the disaster; for example forecasts of the ground conditions, over several days and preferably extending to a season ahead (involving geological, solid mechanics, hydrology and meteorology) are necessary for planning the restoration of surface transport, buildings, agriculture etc. (The same kind of meteorological forecasts are regularly paid for by the construction industry and agriculture in countries with commercial meteorological and hydrological services; this certainly shows that they have some significant predictive skill and practical use!)

It is obviously necessary that forecasts of any possible recurrence of the disaster events should be provided during this stage. Such forecasts ought to involve a close attention to observations of the relevant geophysical processes and, at least, a correlation or rule-based approach; for some events deterministic models can be a valuable supplement or even, for certain periods, a more reliable replacement for the empirical approach.

3. **Organisation and communication of forecasts and warnings**

3 1 Data

Which organisations are responsible for making the necessary geophysical observations and converting them into data that can be used by forecasting centres? Through which organisations and communication channels does the data reach those making the forecast of the natural events? These are some of many procedural questions that have to be understood and answered in order that in future the data will be more complete, of better quality, and more conveniently delivered in order to keep improving forecasts! Figure 2 explains the problem schematically.

Currently geophysical data for forecasting primary or secondary events is supplied either from instruments (or humans) at the observation point (eg by a river bank or next to a volcanic lava flow) or indirectly from remote sensing instruments (seismic, radar, satellite etc). In most countries a number of separate governmental organisations are responsible for funding and administering the observations for different fields of geophysics. There are various informal links between those making seismic, volcanological, oceanographic, meteorological and hydrological data. In some cases there may be a single data centre for two or more of these groups; increasingly there are 'meta-data' systems that provide the means for using the different data bases.

In the case of meteorological data about 170 governments have joined the World Meteorological Organisation (WMO), a specialised agency of the UN system and also the International Civil Aviation Organisation (ICAO) which obliges them to make certain meteorological observations and communicate them internationally by agreed procedures. However there are no worldwide international agreements about the exchange of detailed data about other geophysical processes including those obtained from the very costly earth observing satellites that are only provided by certain countries (eg National Meteorological Services) for certain (eg non-commercial) purposes in other countries. Proposals for managing data about natural disasters and about recovery action were recently reviewed by **Davis & Bickmore (1993)**.

Once the observational data is obtained, it is transmitted by various means (which are increasingly changing from slow rates of teletypes at 50 bits/sec to the fast rates of 50 k.bits/sec using telecommunication by satellites) to the relevant national (NGC), regional (RGC) or international geophysical centres (ICG). These centres only make use of the data according to the type and scale of the event or the significance of the measurement. (A geophysical centre could be meteorological, oceanographic, geological etc. In some countries, such as Japan and the Philippines, many of these services are provided at a single centre)

It is not at all obvious which centre needs which set of data in order to make a relevant forecast or warning. So there needs to be a system of disseminating data on a network to which all the relevant forecasting centres and data providers are connected. Then there is no necessity of each data provider deciding in advance which forecasting centre should receive its data! This is the principle of the world wide network run by all National Meteorological and Hydrological Services (NMHS), through arrangements organised by the World Meteorological Organisation (WMO). This is not, regrettably, a service that all NMHS can utilise because certain data (eg remote sensing data) can only be received with the aid of advanced equipment (eg satellite receivers or fast communication links). This global telecommunication system (GTS) network organised by the NMHS is principally designed for meteorological data. However, it does also carry other geophysical data, namely oceanographic, hydrological and seismological.

These geophysical centres may also be data centres for receiving, quality controlling and storing data in an accessible form, so that it is available as a source of information on previous events and disasters - and thence for developing precautionary forecasts or the mixed deterministic-statistical forecasts discussed in Section 2.2.

It has been suggested that geophysical data centres may also be well placed to store information (at least the meta (or 'directory')-data) about the social, engineering, and economic aspects of 'disasters'.

3.2 Making forecasts

The forecasts made at geophysical centres have to be appropriate to the role of the centre and to the data available. NGC and RGC are uniquely well placed to provide short term (less than 6 hr) forecasts for certain primary events (eg using weather radar and local calculations to forecast the exact location and timing of very high precipitation) or to provide forecasts for most kinds of secondary events which always depend on particular local features. The RGC will often have to make forecasts for events that cover several countries (eg river flooding on some major international rivers).

By contrast International Geophysical Centres, which may be 6000 km away, have quite a different forecasting role. In meteorology they receive data from all over the world which enables them to make deterministic forecasts for all three groups of events (as described in Section 2.2). In the case of cyclones or hurricanes, and all the other events it is only possible to forecast their development as part of a global weather model, which is why IGC play a vital role in forecasting. These centres also provide 'risk' forecasts across the world because they often hold extensive data and records of previous hydrological and meteorological events.

The primary role of geological IGCs, until recently, has been in making remote measurements (notably seismic, but also satellite derived data) and in data management. However with the development of remote sensing technology for making frequent on-line measurements of earth movements and volcano levels, the forecasts of earthquakes and volcanic eruptions are beginning to change from just giving broad estimate of risks to giving specific probabilities for primary events at specific locations to occur in defined periods! While the geological IGCs exchange information between each other on an agreed scientific basis, they do not have the same kinds of formal data protocol that the operational NMHs have been developing for more than 100 years These protocols ensure that forecasts are in a form that conveys information unambiguously and efficiently, and that is acceptable to the sending and receiving centres (so for example the language used must be precise - eg 'lower than average rainfall' rather than 'drought').

Warnings convert scientific terminology of forecasts into popular form, usually with expressive terminology. They should contain advice that is directed to particular communities. This is why international and regional geophysical centres, at least in meteorology, generally exchange forecasts (that have a scientific rather than 'human' terminology) rather than warnings between each other (a point agreed in detail at a recent working group of WMO on severe weather warnings and Tropical Cyclones).

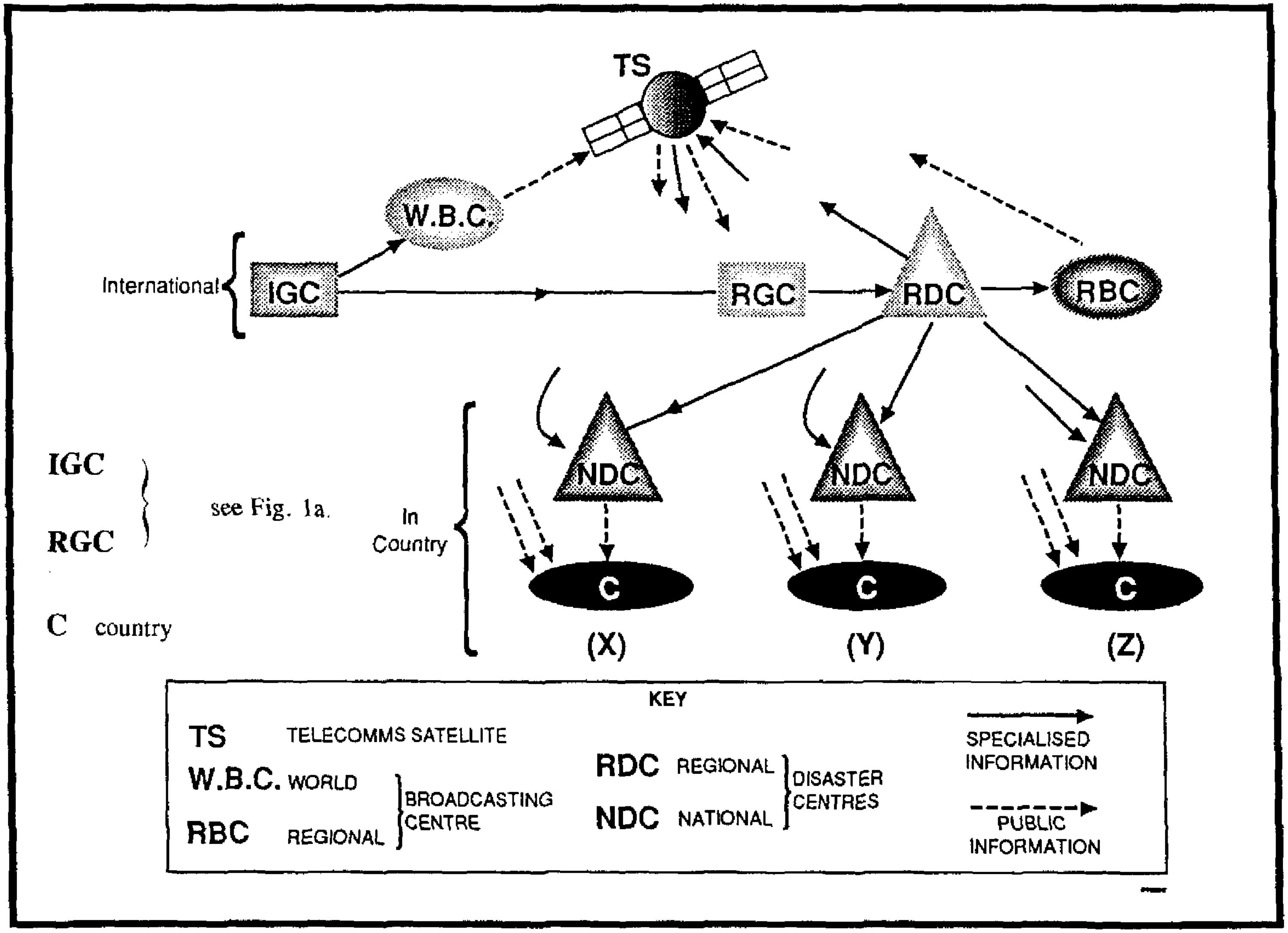
3.3 From Forecasts to Warnings by Specialised Agencies

A schematic diagram at Fig 3 indicates the different ways that information and warnings reach communities at present, even when it is meteorological information which is more regulated by international agreements than that of other geophysical events.

Starting with the IGCs; these provide specialist information to RGCs (in meteorology this could range from forecast atmospheric charts - or 'fields' - to simple direct information about forecast hurricane trajections or storm tracks; for longer term, seasonal forecasts for the equatorial regions are highly relevant to disasters because they include reasonably reliable estimates for droughts or extreme large precipitation). The forms of these kinds of direct information between NMHS have to be agreed in detail in order to avoid ambiguity or issues of national sovereignty that arise when it appears as if international 'instructions' are being given! In some cases (as in the latter example of seasonal forecasts) international disaster centres (IDC) such as those based in International relief agencies request this specialist information. (Such a decision has to be judged carefully because international agencies do not generally have the same knowledge of local conditions to interpret the forecasts and warnings, as compared to that of the local RGC or NGC. This is the opinion of a number of directors of NMHs in Africa.)

One of the most difficult aspects of organising warnings is deciding on the best use of TV and radio broadcasts World-wide and regional broadcasting systems (WBS or RBS) have requested information on natural events from IGC's and RGC's and have broadcast them widely, notably hurricanes, volcanic eruptions etc. However this information is given quickly and not usually in the form to guide local communities as to the best action. Furthermore it may conflict with the information given by national broadcasting systems or by national disaster centres. WMO is proposing procedures for meteorological and hydrological events involving WBS (or the NMHs informing the WBS) making

Fig. 3 NATURAL DISASTERS
WARNINGS – INFORMATION NETWORKS



contact with the local geophysical centres to ensure consistency, and to ensure that the WBS issues forecasts and warnings that are broad brush and not specific enough to duplicate or compete with local services. A similar approach might be considered for other kinds of geophysical warnings, perhaps along the lines of that being adapted by WMO?

At the regional level, the RGCs receive forecasts (and data) from more than one IGC (a wise policy since forecasts of hurricanes, seasonal climate and other geophysical events by IGCs may differ significantly!). These have to be evaluated and interpreted in terms of specific local conditions. At the regional level these forecasts for primary events have to be used as a basis for forecasts for secondary events and for potential disasters which requires the further consideration of the precise situation of vulnerable communities. The latter tasks, as explained above, may be undertaken by engineers and emergency officers in other institutions such as a regional disaster centre (RDC). Clearly an RDC can only provide forecasts and warnings and other operational services in different countries in its region if there are clear intergovernmental agreements in place

It seems that the procedures of WMO for agreeing, instituting and operating meteorological and hydrological forecasts and warnings would be quite suitable for other kinds of geophysical event and natural disaster. This opinion is shared by a wide range of geophysicists.

Forecasts of primary events of shorter periods (from minutes) events and disaster consequences are produced at NGCs and National Disaster Centres, integrating local observations (eg seismic or weather radar) with specialised forecasts and data (eg via satellites) from RGCs. In some cases NDC may also receive warnings direct from a RDC and from other sources which may differ - a problem that has to be considered carefully.

Finally the NDC (or other emergency service) is responsible to their national government for communicating 'warning' information about the impending event and its disaster consequences to the local communities; very often this is coupled with advice as to what to do before, during, and after the event.

4. Technical Improvements in Forecasting

The advantage of naming a decade for an identified problem is that it gives the world community working on that problem an opportunity both to calibrate its effectiveness, to work out how to make improvements, and, if it is ambitious, to identify targets for improvement. Governments and other donors are likely to help to help fund the necessary expenditure to improve forecasts and warnings of natural disaster, if this information is available.

In the fields of meteorology and hydrology forecasts and warnings are regularly reviewed nationally and internationally. Table 1 lists the current warning times and levels of accuracy of long term forecasts of the key meteorological events that may lead to natural disasters; these are provided by a major National Meteorological Service. Estimates are also given of the improvements that might be expected by the year 2005. There is a steady level of investment in the service. Note that the level of improvements vary considerably from one event to another; for certain short range forecasts greater investment will lead directly to improvements, while for other longer range forecasts, even with greater investment there may be fundamental reasons why substantial improvements are not currently possible based on our current scientific and technical understanding. The 20% reduction of the error in the location of landfall of hurricanes is consistent with the expected general reduction in error of global

Table 1

ADVANCED SHORT-TERM WARNINGS AND FORECAST SERVICES

	1993	Proposed 2005
Flash Flood Warnings		
Period of warning (minutes)	15	40
Accuracy of magnitude (per cent)	55	90
Number of events with no warning (per cent)	70	20
Severe Thunderstorm Warnings		
Period of warning (minutes)	13	25
Accuracy of magnitude (per cent)	70	95
Temperature		
Percentage of correct forecasts	82	90
Forecast accuracy of the onset of freezing temperatures	65	90
Snow Amount		
Forecast accuracy of heavy snowfall	35	75
Precipitation Forecasts		
Period of warning for 1 inch precipitation forecast with same accuracy as a 1-day forecast in 1971 (days in advance)	1.8	3.0
Tropical Cyclones/Hurricanes		
Accuracy of landfall (km) with 24-hour lead time	185	150

forecasts by several NMS. By the use of novel technology, such as remotely guided aircraft to take soundings in hurricanes, these errors could be further reduced **(Lighthill 1993)**.

As explained in Section 3, warnings differ from forecasts and have to be given in a form appropriate to different communities which perceive and react to disasters quite differently. For example, a WMO working group has found that quite different values of wind speed and rates of rainfall are deemed to be 'severe' in different countries (even within a single geographical zone such as Europe). There is no generally agreed way (yet) of establishing the effectiveness and accuracy of warnings in different countries. Such studies should help in making the 'business case' for improvements of disaster services.

In the UK warnings to the public emergency (or 'disaster') services are issued from 6 hrs up to 5 days ahead of severe weather events. In 1992/93, fourteen warnings were issued, of which only three were not justified. The New Zealand Met Service has a similar false alarm rate. It is expected that there will be about a 10% reduction in this rate over the next 5 years, as well as corresponding increases in accuracy of the 'confidence level', that is now also communicated along with the warnings.

These are examples of establishing baselines and improvement targets for forecasts and warnings. They need to be extended and applied to all types of event and natural disaster. It might be worth considering whether the baselines and targets should be classified according to whether they refer to primary or secondary events.

Deciding on these targets is dependent on the levels of technical and human resources that will be available, which in turn usually depend on the estimates of the economic and social benefit to the whole nation of introducing these improvements. Some developed countries have assessed these benefits as being 5 to 10 times greater than the costs! **(Friday 1994)**. In developing countries more communities are increasingly located in areas subject to severe geophysical events e.g. on hillsides, or deltas etc.

In addition, the rapidly growing population and the finite level of resources means that resources for preventative action against natural disasters have not been available for everyone so these communities are inevitably becoming more vulnerable to natural disaster. Therefore the effects of natural disasters must be mitigated by the most cost effective methods, which the evidence shows certainly include better forecast and warning systems.

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