World Meteorological Organization

GUIDELINES ON BIOMETEOROLOGY AND AIR QUALITY FORECASTS

PWS-10

WMO/TD No. 1184

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Chapter 1

INTRODUCTION

These guidelines are intended to provide useful advice to National Meteorological and Hydrological Services (NMSs) on methods of incorporating air quality forecasts and biometeorological information into the suite of products and services offered to the public. The guidelines were developed by the Public Weather Services (PWS) Expert Team on Product Development and Service Assessment at the request of the Commission on Basic Systems (CBS). It is acknowledged that several NMSs already provide this type of information and some others are on the verge of developing an air quality programme. However, all NMSs should find this document useful, especially those in developing countries that would be seeking to develop or improve their national public weather services delivery while, at the same time, attempting to come to terms with some aspects of the widening array of environmental issues.

There is a growing awareness of the linkages between human health and the weather and climate that should be incorporated into the content of national public weather services programmes. An increasing number of NMSs include specific environmental information into their public bulletins with the goal of improving public understanding of relevant environmental issues and to enable people to take actions to minimise adverse environmental effects or stress.

Timely air quality information can assist the public in coping with problems caused in urban and in some rural areas by ground-level ozone, sulphur dioxide, nitrous oxide! and particulate matter. Air quality advisories issued when predetermined pollutant thresholds are exceeded should result in actions to reduce pollution levels and encourage people to avoid polluted areas thereby alleviating adverse effects on health. Examples of actions that people can take in response to NMS air quality advisories include using public transportation, staggering of work hours or even staying indoors. Industry and regulatory agencies may decide on temporary shutdown of polluting factories, thermal power plants, banning some categories of vehicles from urban centres and closing government offices.

The pollen season is reasonably well known by many people but allergy sufferers benefit most from information on the exact time of ripening and release of pollen, so they can take action to minimise the adverse effects on their health. The presence of pollen, its density and trajectory, as well as the possibility of being removed from the atmosphere by showers, all depend on the day-to-day weather. Increased UV radiation has been shown to increase the incidence of skin cancers and eye cataracts in humans, and may also affect plants, aquatic organisms and other natural systems. The monitoring of UV values and incorporation of the measurements into a simplified UV-index can alert people to protect themselves during critical periods of elevated UV intensity by avoiding outdoor activities, wearing protective clothing and using chemical sunblocks.

Chapter 1 of this document introduces the importance of, and rational for the guide. Chapter 2 covers human biometeorology and concentrates on aspects of the atmospheric environment relevant for human health questions arising from heat exchange, solar radiation and air pollution. Chapter 3 deals with air quality forecasts, pollution measuring and monitoring, atmospheric transport modelling and cooperation on environmental issues at the national, regional and international levels. Evidently, the services required for the good health, safety and well-being of national communities can be significantly improved if NMSs are ready to tap into the existing body of knowledge, practices, research and technology to design and deliver appropriate biometeorological information and advisories to the public.

Chapter 2

HUMAN BIOMETEOROLOGY

2.1 ATMOSPHERIC ENVIRONMENT

The atmosphere is a part of the environment with which the human organism is permanently faced in maintaining the balance of life functions. Reactions of the organism can therefore be interpreted and comprehended as its response to changes in the physical and chemical state of the atmosphere. As a result, to more fully understand the effects of atmospheric conditions on human health, well-being and performance, it is necessary to transform the "primary" meteorological information so that it becomes biologically relevant. In analysing those aspects of the environment relevant for health issues three major complexes of effects can be distinguished: (1) the complex conditions of heat exchange i.e.the thermal environment, (2) the direct biological effects of solar radiation, i.e. the radiative conditions, especially in the visible and UV-range, and (3) air pollution including allergens such as pollen.

Human biometeorology is part of environmental meteorology. It covers a series of questions relevant to environmentally applied medical science. In investigating the spectrum of effects biometeorology uses almost the same epidemiological methodology to ascertain damaging potentials, to give information about limits of exposures which may affect human health, to discover the relationship between atmospheric conditions, diseases, and indisposition, and to define the importance of atmospheric environmental factors for the transition between health and disease. Complexity is inherent in research into these effects.

There are also many confounding variables such as smoking, socio-economic factors, individual health behaviour, living conditions, etc., which are often dominant. Epidemiological research investigates the occurrence of effects on morbidity and mortality due to heat, cold, air pollution and changes in the weather. The cause-effect relationships involved in human interaction and response to changing atmospheric constituents and characteristics are well known in principle and holistic approaches using specific weather classifications provide remarkable results when considering weather-related health effects. The biological relevance determines whether a meteorological parameter will become a biometeorological one.

Research in human biometeorology has the task of finding out which clinical manifestations and other disturbances in human well-being are influenced by atmospheric environmental factors, and precisely which factors exert an influence on health and well-being, and to what extent. As regards risk factors, biometeorology has to inform and advise the public and decision makers in politics and administration with the aim of recognizing and averting health risks at an early stage, in the framework of preventive planning, for example by making recommendations for ambient standards, by evaluation of site decisions, and by consultation on adaptive behaviour.

The state of knowledge in the field of weather and human health allows for the delivery of a number of advisory services. Products and services such as pollen information service, UV-information service, forecasts of perceived temperature (heat load, cold stress) can help people to better handle atmospheric loads. These services are based on the specific adaptation of synoptical products to meet the needs of the users.

It is a fact that the benefits of meteorological information are usually not realized before their application. Human biometeorology already possesses numerous tools to meet the needs of the users, even if further improvements and adaptations are still needed. The general aim is always to avoid or at least diminish unfavourable effects, to take advantage of positive effects, and to improve the quality of life of the general public. Thus services for improving health and well-being of the population can be provided as a result of the work of the NMSs.

2.2 THERMAL ENVIRONMENT

2.2.1 Thermal indices

The aim of thermoregulation is to keep an organism's core temperature constant at 37 °C. Under steady-state conditions heat production by activity and heat loss must be balanced. Due to the great importance of the thermal conditions for human beings more than one hundred simple thermal indices are known in literature. For warm conditions they usually consist of combinations of air temperature and some measure for humidity (due to the relevance of evaporative heat loss). For cold conditions combinations of air temperature and wind velocity are applied considering the turbulent heat flux. Often the concept of a temperature of a reference environment is used in which the same heat exchange conditions should occur.

Fundamentally, we know the mechanism of heat exchange between the human body and its thermal environment that is defined by air temperature (*ta*), water vapour pressure (*vp*), wind velocity (*v*), and mean radiant temperature (tmrt) that applies to all shortwave and longwave radiant fluxes reaching a human being (Fanger, 1972). Thermo-physiologically relevant assessment procedures that combine the above listed meteorological variables with metabolic rate and with due consideration of the insulation of clothing, require the application of complete heat budget models (VDI, 1998). Only such complete approaches are able to fulfil the condition that the same value of an index must always mean the same to the organism, and independently form the mixture of values of the input variables. There are some such state-of-the-art approaches available as SET* (de Dear et al., 1999), PET (Höppe, 1984) or Fanger's (1970) PMV.

A graphical representation of the PMV assessment equation is shown in Figure 1, where M is the metabolic rate, I is

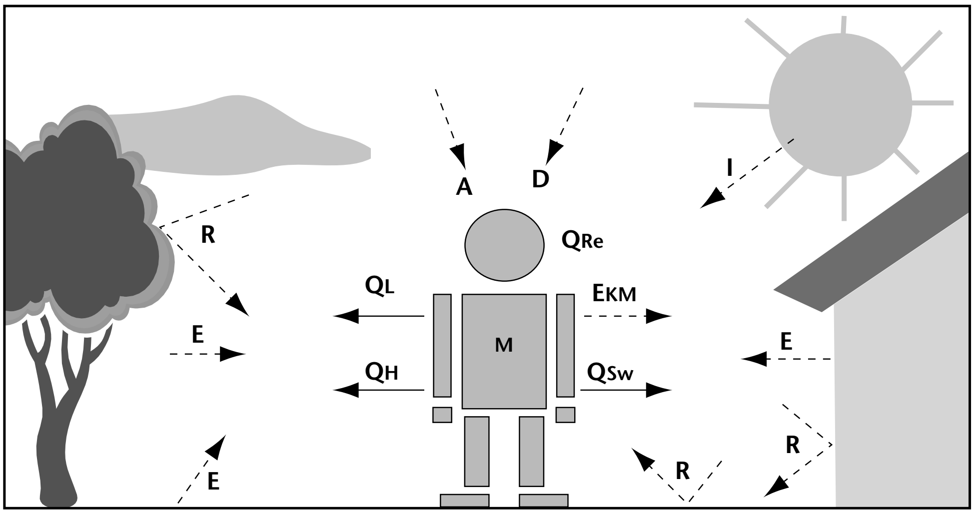

Figure 1—The Thermal Environment

direct solar radiation, D is diffuse solar radiation, R is reflected solar radiation, A is atmospheric longwave radiation, E is longwave emission of the ground, Ekm is longwave radiation from the surface of the human body, Qh is turbulent flux of sensible heat, Qsw is turbulent flux of latent heat due to sweating, Ql is turbulent flux of latent heat due to water vapour diffusion, and Qre is turbulent respiratory heat flux (sensible and latent).

The German Meteorological Service (DWD), for example, uses the Klima-Michel-model with the outcome "Perceived Temperature PT" (see section 2.2.1.1). The procedure is corrected by the PMV* approach of Gagge et al. (1986) in order to better describe latent heat fluxes. A commission (chair Gerd Jendritzky) of the International Society of Biometeorology (ISB) has been established under the aegis of WMO to develop a Universal Thermal Climate Index (UTCI). The index will be based (*a*) on the most progressive multinode thermophysiological modelling, and will be applicable (*b*) to all relevant biometeorological questions (Jendritzky et al., 2002). For more information, see:

http://arbmed.klinikum.uni-muenchen.de/biomet/Commission6.htm

2.2.1.1 *Perceived temperature (PT)*

Perceived Temperature or PT compares the actually existing outside conditions with the temperature that would prevail in a standard environment in order to experience an identical feeling of warmth, comfort or cold. The standard environment is deep shade, e.g. a forest, where the temperature of the surrounding surfaces, i.e. the leaves, is the same as the air temperature and where there is only a slight breath of air of 0.1 m/s. As the human being is usually active in the open air, an activity that corresponds to walking at 4 km/h is assumed. The person concerned attempts to adapt his clothing in such a manner that he continues to feel comfortable. PT then assesses in degrees C the thermal sensitivity of a man who is 1.75 m tall, weighs 75 kg and is approximately 35 years of age.

At the DWD, PT is calculated by means of the Klima-Michel-Model. The model needs a complete weather observation or a corresponding numerical weather forecast, the date and geographical coordinates as input quantities. In warm, sunny summer conditions with little wind PT rises far quicker than the air temperature itself. In an extreme case, it can amount to up to 15°C more than the air temperature in central Europe. In pleasant, mild conditions with light to moderate wind it can, however, sink to below the air temperature, as fast walking and adaptation of clothing is taken into consideration. In a cold and especially windy environment PT sinks by up to 15°C below the air temperature. Sun and lack of wind can, on the other hand, raise PT to above that of the air temperature.

PT is calculated hourly on the basis of input from the numerical forecast model of the DWD and serves *inter alia*, as basis for issuing warnings of thermal pollution for health resorts as well as for evaluating the thermal pollution in biotropic connection with the weather conditions.

Forecast of PT (heat load, cold stress)

The Klima-Michel-model has been integrated into the numerical weather forecast model LM (local model in 7 km grid) of

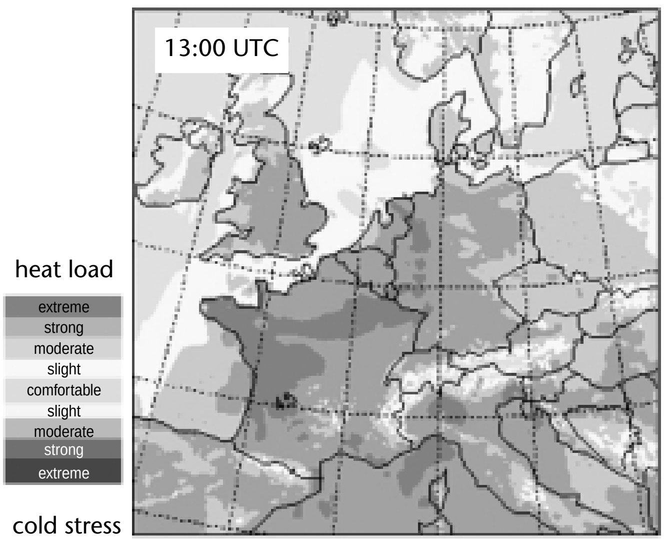

Figure 2—Example of a forecast of the PT field based on LM (7 km grids), August 9, 2003

DWD. Thus 48-hour forecasts of PT on an hourly basis are available for Central and West Europe in high resolution that can be used to inform the public with respect to heat load (including the basis for specific heat health warning systems), cold stress, comfortable conditions, behaviour measures etc. Additionally site/date-forecasts are produced for numerous places. Figure 2 shows an example of PT forecast.

2.2.1.2 *Heat Index*

The human body dissipates heat by varying the rate and depth of blood circulation, by losing water through the skin and sweat glands, and as the last extremity is reached, by panting, when blood is heated above 98,6 degrees. The heart begins to pump more blood, blood vessels dilate to accommodate the increased flow, and the bundles of tiny capillaries threading through the upper layers of skin are put into operation. The body's blood is circulated closer to the skin's surface, and excess heat drains off into the cooler atmosphere. At the same time, water diffuses through the skin as perspiration. The skin handles about 90 percent of the body's heat dissipating function.

Sweating, by itself, does nothing to cool the body, unless the water is removed by evaporation – and high relative humidity retards evaporation. The evaporation process itself works this way: the heat energy required to evaporate the sweat is extracted from the body, thereby cooling it. Under conditions of high temperature (above 90 degrees) and high relative humidity, the body is doing everything it can to maintain 98,6 degrees inside. The heart is pumping a torrent of blood through dilated circulatory vessels; the sweat glands are pouring liquid including essential dissolved chemicals, like sodium and chloride, onto the surface of the skin.

Heat kills by taxing the human body beyond its abilities. For example, in a normal year, about 175 Americans succumb to the demands of summer heat. Among the large continental family of natural hazards, only the cold of winter – not lightning, hurricanes, tornadoes, floods, or earthquakes – takes a greater toll. In the 40-year period from 1936 through 1975, nearly 20 000 people were killed in the United States by the effects of heat and solar radiation. In the disastrous heat wave of 1980, more than 1 250 people died. During the exceptionally hot summer of 2003 in Europe, an estimated 13 000 to 15 000 elderly people died as a result in France alone.

These are the direct casualties. No one can know how many more deaths are advanced by heat wave weather; how many diseased or aging hearts surrender, that under better conditions would have continued functioning. North American Summers are hot; most summers see heat waves in one section or another of the USA. East of the Rockies, they tend to combine both high temperatures and high humidity although some of the worst have been catastrophically dry.

Considering this tragic death toll, the US National Weather Service (NWS) has stepped up its efforts to alert more effectively the general public and appropriate authorities to the hazards of heat waves – those prolonged excessive heat/humidity episodes.

Based on the latest research findings, the NWS has devised the "Heat Index" (HI), (sometimes referred to as the "apparent temperature"). The HI, given in degrees Fahrenheit, is an accurate measure of how hot it really feels when the relative humidity (RH) is added to the actual air temperature.

As an example, if the air temperature is 95°F and the relative humidity is 55 per cent, the HI – or how hot it really feels – is 110°F. This is important since HI values were devised for shady, light wind conditions, exposure to full sunshine can increase HI values by up to 15°F. Also, strong winds, particularly with very hot, dry air, can be extremely hazardous.

The NWS will initiate alert procedures (advisories or warnings) when the Heat Index (HI) is expected to have a significant impact on public safety. The expected severity of the heat determines whether advisories or warnings are issued. A common guideline for the issuance of excessive heat alerts is when the maximum daytime HI is expected to equal or exceed 105°F and a night-time minimum HI of 80°F or above for two or more consecutive days. Some regions are more sensitive to excessive heat than others. As a result, alert thresholds may vary substantially from these guidelines. Excessive heat alert thresholds are being tailored at major metropolitan centres based on research results that link unusual amounts of heat-related deaths to city-specific meteorological conditions.

The NWS alert procedures are:

- Include HI values in zone and city forecasts;
- Issue Special Weather Statements and/or Public Information Statements presenting a detailed discussion of (1) the extent of the hazard including HI values, (2) who is most at risk, (3) safety rules for reducing the risk;
- Assist state and local health officials in preparing Civil Emergency Messages in severe heat waves. Meteorological information from Special Weather Statements will be included as well as more detailed medical information, advice, and names and telephone numbers of health officials;
- Release to the media and over NOAA's own Weather Radio all of the above information.

2.2.1.3 *Net effective temperature (NET)*

As another example of a heat index suited to local weather conditions and requirements by public, the net effective temperature (NET), routinely monitored by the Hong Kong Observatory can be considered. The NET takes into account the effect of air temperature, wind speed and relative humidity on human beings. For example, heat loss by a human body will be faster under lower temperature, higher wind speed and higher relative humidity conditions in winter and, as such, the feeling of coldness will also be more pronounced.

NET is calculated as follows:

$$\mathbf{NET = 37 - (37-T)/(0.68 - 0.0014RH + 1/(1.76+1.4v0.75))\\ - 0.29T(1-0.01RH)}$$

where T= the air temperature (°C), v = the wind speed (m/s), and RH = the relative humidity (%), and has a higher value when the temperature is higher, but its value will be lower at higher wind speed and relative humidity. Taking acclimatization into account, it is believed that people of a particular place will feel stressfully cold and hot when the value of NET is at the lowest and highest 2.5 per cent respectively. In Hong Kong, China, the Cold (or Very Hot) Weather Warning will be issued when the NET is forecast to be lower (or higher) than 2.5 per cent (97.5 per cent).

2.2.1.4 *Wind chill*

Wind chill is the chilling effect of the wind in combination with a low temperature. Humans do not sense the temperature of the air directly. When humans feel that it is cold, they are actually sensing the temperature of their skin. Because the skin temperature is lower when it is windy (humans lose heat from the skin faster than the body can warm it), humans feel that it is colder when there is wind. This sensation is what the wind chill index attempts to quantify.

Each year, in Canada, more than 80 people die from overexposure to the cold, and many more suffer injuries from hypothermia and frostbite. Wind chill can play a major role in such health hazards because it speeds up the rate at which the body loses heat. A recent survey indicated that 82 per cent of Canadians use wind chill information to decide how to dress before going outside in the winter. Many groups and organizations also use the system to regulate their outdoor activities. Schools use wind chill information to decide whether it is safe for children to go outdoors at recess. Hockey clubs cancel outdoor practices when the wind chill is too cold. People who work outside for a living, such as construction workers and ski-lift operators, are required to take indoor breaks to warm up when the wind chill is very cold.

Canada and the USA agreed to collaborate on the development of a new wind chill formula, and developed a process for its scientific verification and implementation. There was also agreement to use only a temperature-like index to report and forecast wind chill. The new formula, developed by Randall Osczevski of Canadian Defence and Civilian Institute for Environmental Medicine and Maurice Bluestein of Purdue University in Indiana, USA, makes use of advances in science, technology and computer modelling to provide a more accurate, understandable and useful formula for estimating the dangers arising from winter winds and freezing temperatures. Thereby, the new index has been harmonized with that used in the United States (where the Fahrenheit scale is used), thus giving a consistent index used throughout North America.

The new index is expressed in temperature-like units, the format preferred by most Canadians as determined through public opinion surveys. It must be noted that although the wind chill index is expressed on a temperature scale (the Celsius scale in Canada), it is not a temperature: it only expresses a human sensation. The index likens the way human skin feels to the temperature on a calm day. For example, if the outside temperature is -10°C and the wind chill is -20, it means that the exposed face will feel as cold as it would on a calm day when the temperature is -20°C.

The equation to determine the new index is the following:

$$W = 13.12 + 0.6215*Tair - 11.37*V10metre0.16 + 0.3965* Tair * V10metre0.16$$

where: W= the wind chill index, based on the Celsius temperature scale, Tair = the air temperature in degrees Celsius (°C), and V10metre = the wind speed at 10 metres (standard anemometer height), in kilometres per hour (km/h).

The new index is based on a model of how fast a human face loses heat. The face is chosen because it is the part of the body most often exposed to severe winter weather, assuming the rest of the body is clothed appropriately for the weather. The new index has been validated in clinical trials held in Toronto in June 2001, in a climate controlled wind tunnel with human volunteers. This index is expected to be much closer to what people actually experience when exposed to wind and low temperatures.

In addition, specifically, the new wind chill index has the following features:

- It uses wind speed calculated at the average height of the human face (about 1.5 metres) instead of the standard anemometer height of 10 metres. The correction is effected by multiplying the 10-metre value (what is indicated in weather observations) by a factor of 2/3;
- It is based on a model of the human face, and incorporates modern heat transfer theory, that is, the theory of how much heat is lost by the body to its surroundings during cold and windy days;
- It uses a calm wind threshold of 4.8 km/h; this value has been obtained by observing the speed at which people walk at intersections;
- It uses a consistent standard for skin tissue resistance to heat loss.

Additionally, an equation to approximate minutes to frostbite has also been developed for the 5 per cent most susceptible segment of the population. It is considered valid for winds of more than 25 km/h and times of less than 15 minutes:

$$t\,f = \{ (-24.5 \cdot [(0.667 \cdot V10) + 4.8]) + 2111 \} \cdot (-4.8 - Tair)-1.668$$

where: t f = time to frostbite, in minutes, for the 5 per cent most susceptible segment of the population, V10 = Wind speed, in km/h, at the standard anemometer height of 10 metres (as reported in weather observations), Tair = Actual air temperature in °C.

More information on the wind chill programme in Canada can be found at the following web site: http://www.msc.ec.gc.ca/windchill/index_e.cfm. Also at this site charts, on-line calculators and downloadable calculators are available.

2.2.2 Perceived temperature related mortality

Daily mortality rates (MR) of the 30-year period 1968 – 1997 for Baden-Württemberg (SW Germany) have been investigated (Laschewski and Jendritzky, 2002) with regard to possible impacts of the thermal environment (Klima-Michel-model with PT). Mortality data show a marked seasonal behaviour with a minimum in summer and a maximum in winter. It is remarkable that, despite the MR seasonal minimum in summer, death rates rise sharply with increasing heat load, reaching highest values during pronounced heat waves even in the moderate climate of southwest Germany. Under comfortable conditions, when demands on the thermoregulatory system of the body are minimal, mortality data show the lowest rates.

Increasing cold stress also causes death rates to rise. In all seasons, changes (on a time scale of one week) towards "warmer" conditions in terms of PT result in adverse effects, while changes to "colder" conditions provide relief. The daily correlation coefficients between the deviations of perceived temperature (dPT) and the deviations of mortality rate (dMR) on one side and the smoothed values on the other side show a pronounced seasonal behaviour. With strong day-to-day fluctuation the correlation coefficients differ significantly from zero between March and August. It is remarkable that from the end of June to the beginning of July about 25 percent of variance in dMR can be explained by the effects of the thermal environment. The winter values show only non-significant correlations, strong day-to-day variability, but marked time lags of 8 days and more, while in summer there is no significant time lag. When looking at extreme events, cold spells lead to less excess mortality rates and last for a short period of a few weeks. On the other hand, the mortality increase during heat waves is much more pronounced, but is followed by lower than average values in the subsequent weeks. It is assumed that apart from mortality, the thermal environment also significantly affects morbidity, well-being and efficiency of the human organism. Figure 3 shows the mortality rate in relation to mean perceived temperatures.

The more or less similar findings in different climates support the fundamental portability of L. Kalkstein's successful idea of Heat Health Warning Systems which is followed outside North America by the WMO/WHO/UNEP Showcase Projects on HHWSs, e.g. in Rome and (see 2.6.1) Shanghai. The need for implementation of such systems including locally adapted mitigation measures is evident also in moderate climates in order to mitigate excess mortality.

2.2.3 Bioclimate maps (meso- and macro scale)

Specific procedures have been developed to present the thermal conditions in space. The procedure is based on Klima-Michel-model which is applied to long (usually 30 years) time series of SYNOP-data. The assessments in terms of PT (monthly means or frequency of extremes) are transferred into the area using GIS-techniques. The resolution of the maps varies and for example covers ranges from 200 m to over 1 km for Germany, about 11 km for Europe (based on more than 900 principal weather stations) and to about 100 km for the global approaches that are based on the climate simulation of Max-Planck Institute MPI Hamburg (see Figure 4 as example).

2.2.4 Urban bioclimatology (UBIKLIM)

For urban planning purposes with the aim of creating and safeguarding healthy environmental conditions modelling seems to be the appropriate method to generate the relevant data. In order to meet the needs of urban planners the Urban Bioclimate Model UBIKLIM was developed by DWD as an expert system that utilizes available knowledge in urban climate science in an objective procedure for practical applications (Friedrich et al., 2001). Using GIS-techniques UBIKLIM simulates the thermal environment in the urban boundary layer that depends on the kind of land use, i.e. the given or planned settlement structure (these are the planning variables to be transformed into boundary layer parameters). Interactions between neighbouring structures, the topography (local scale), and the meso- and macro-scale climate are taken into account. As input data UBIKLIM needs a digital height model with a 10 m resolution and appropriate land use information. Here dividing the urban area into a limited number of districts is sufficient, each characterized by its own land use type. The main types are water, forest, parks, meadows, paved and unpaved open spaces and built-up areas. In order to be able to work out the varying urban structure, the built-up area is divided up further considering degree of pavement area, building density, building height, degree of greenery. The result is a widespread and detailed bioclimate map on the horizontal heat load distribution with 10 m resolution that provides the necessary information for urban planners, health professionals, and other decision makers.

2.2.5 Health resort climatology

The DWD human biometeorological unit serves as the main authority for the definition and updating of climatological

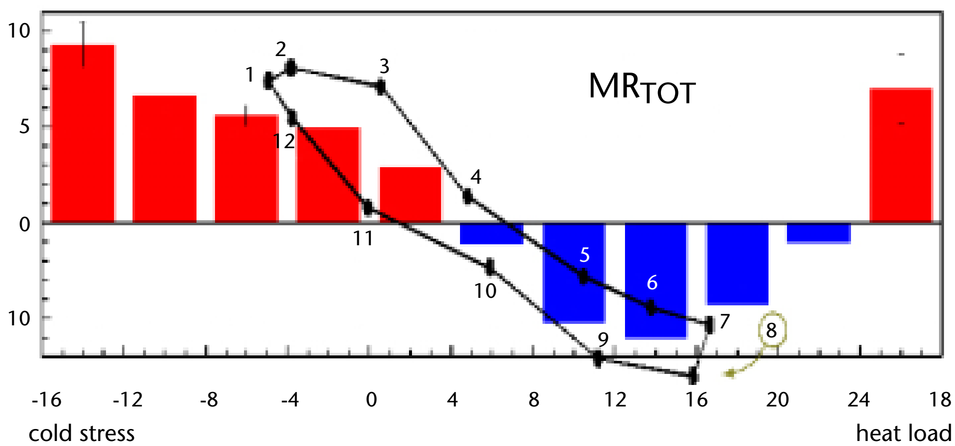

Figure 3—Mean relative deviation of MR for classes of mean PT of the previous day (class width: 4 K, range bars: confidence interval at the 0.05 significance level). The line shows the means seasonal relationship between the monthly means of MR and PT, resp. The numbers indicate the months.

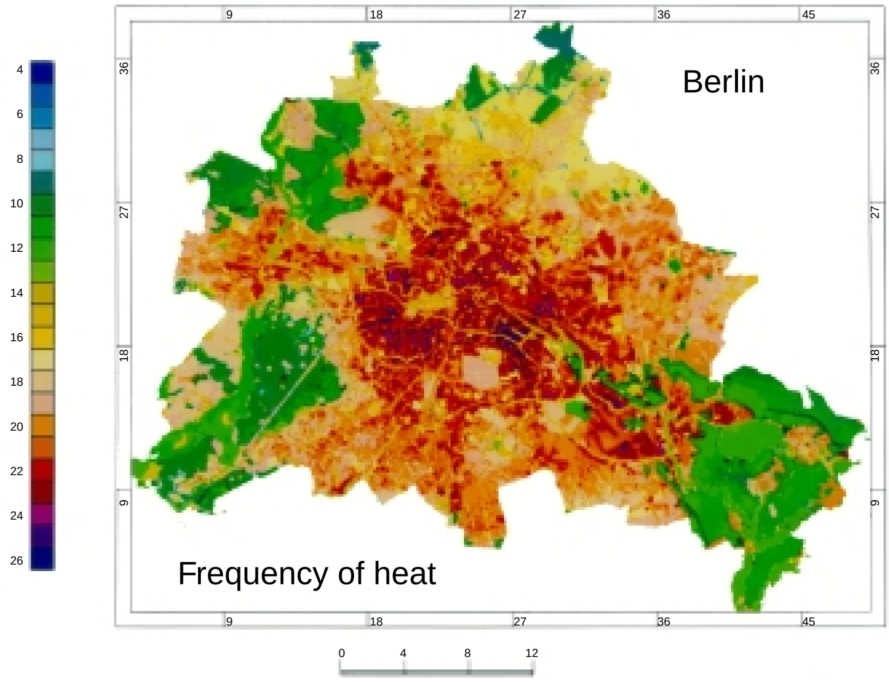

Figure 4—The frequency of heat load conditions in Berlin/Germany based on UBIKLIM-simulation in 10 m grids

guidelines and standards for health resorts and spas. A community only gets its status after having gone trough an approval process that is based on these standards. For special application in climatic health resorts the product KURKLIM has been developed that consists of several modules, such as (*a*) an evaluation of the fundamental suitability of the thermal environment for therapeutical applications (10 m resolution), (*b*) a thermophysiological assessment of the hiking trails, (*c*) a procedure to utilize real-time meteorological data of the health resort for therapeutical purposes.

2.3 RADIATION

2.3.1 UV-index

Depletion of stratospheric ozone has led to an increased exposure to ultraviolet-B (UV-B) radiation which in turn has affected the environment and human health. UV-B radiation is responsible for a wide range of potentially damaging human and animal health effects, particularly to the skin, eyes and the immune system. Human exposure to UV-B depends upon the location, the duration and timing of outdoor activities and precautionary attire such as sunglasses, long-sleeved clothings, sunscreen lotions, etc. UV-B contributes to severe damage of the cornea, lens and retina of the human eye. Long exposures to UV-B radiation can result in photokeratitis or "snow-blindness". Lifetime cumulative exposures contribute to the risk of cataracts and other forms of ocular damage.

In addition, excessive exposure may have consequences ranging from premature ageing of the skin to skin cancer, which has become one of the most common types of cancer. Frequent and intense exposure to sunlight with sunburn, especially in infancy and childhood, encourages the formation of malignant melanoma. The number of new growths of malignant melanoma has doubled every 7 to 8 years over the past 40 years. This can be attributed to the change in leisure behaviour which equates a sporty suntan with good health.

It should be noted that the UV flux received in countries situated near the equatorial zone is high and while the local population is better genetically adapted to the adverse effects of UV-B, often visitors from higher latitudes to these regions are exposed to high doses without getting adequate information and advice for protection, NMSs in such countries are encouraged to endeavour to provide information on the levels of expected UV radiation in their areas of responsibility for the protection of their own citizens as well as visitors. Nevertheless, ultraviolet rays also have positive properties. They stimulate the formation of vitamin D3, which is important for formation of bones. A very low dose of ultraviolet rays is, however, sufficient for this and lies far below the threshold of sunburn.

The UV index (UVI) is a simple means of measuring the strength of ultraviolet rays that cause sunburn and is given as a daily maximum. The UVI was developed through an international effort by the World Health Organization (WHO), WMO, the United Nations Environment Programme (UNEP), the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the German Federal Office for Radiation Protection. A booklet jointly prepared by these organizations entitled Global Solar UV Index, A Practical Guide contains valuable information about the scheme of reporting the UVI as well as sun protection messages and the Internet links of the organizations that report the UVI. Since its initial publication in 1995, several international meetings of experts have been convened with the aim to harmonize the reporting of UVI and to improve its use as an educational tool to promote sun protection. The index which is standard worldwide, takes cloud cover and the thickness of the ozone layer, which have a direct influence on the ultraviolet rays reaching the ground, into account. In central Europe the index has winter values of between 0 and 1 (low). In the summertime, the index values are in the range of 5 to 7 (high) in the northern, western and central Europe, whereas the values in the southern mainland Europe and islands such as the Canary Islands can be as high as 9 to 11 (very high to extreme). However, it should be noted that very high values of 9 to 11 may also be found in high Alpine regions in Europe.

An example of a country where extensive work on UV radiation has been done is Canada. Today there are 13 Ozone monitoring sites across Canada: 10 across southern/central Canada and 3 in the high Arctic at Resolute Bay, Eureka, and Alert. Exposure to ultraviolet radiation from the sun has always been a risk to human health. In the last twenty years, however, those risks have increased as man-made chemicals have caused a thinning of the ozone layer. With the depletion of the ozone layer there has been a corresponding increase in the ultraviolet radiation reaching the surface. Since 1982 a gradual thinning of the ozone layer has been observed. Measurements show that the ozone layer over southern Canada is today about 7 per cent thinner than it was before 1982. Ozone depletion is most pronounced in the springtime when photochemical activity is greatest in the stratosphere. At this time of the year, depletion rates as high as 10 to 20 per cent have occurred over central Canada.

It is estimated that more than 71 000 new cases of skin cancers were diagnosed across Canada in 2 000 and over 800 people died from a particular kind of skin cancer known as melanoma. Skin cancers take a long time to develop – anywhere from 10 to 30 years – so early prevention is very important. In 1998, Environment Canada in partnership with Health Canada started the Children's UV Index Sun Awareness Program. The programme teaches students under the age of 14 about the UV Index and how to use it to minimize the risk to their health from solar ultraviolet radiation.

In Canada, the UV Index ranges from 0 to 10 and is issued for 48 locations. The UV Index forecast is the maximum value expected for a given day usually around solar noon and are included as a routine forecast element in the public forecast bulletins from April through September. Generally, the UV index is higher at lower latitudes. However, the UV Index is also dependent on altitude, reflection, and clouds. Generally, the process for forecasting the UV Index is as follows:

1. The thickness of the ozone layer across North America is forecast using the computer weather prediction models.
2. These values are then corrected based on observations from the 12 ozone-monitoring stations across Canada.
3. This information along with variables on latitude and time of year, is then fed into mathematical algorithms to produce the clear sky UV Index for each desired location.
4. The cloud and precipitation forecasts are generated by meteorologists in each of the regional forecast centres across Canada and are assigned a transmission factor, which is then used to adjust the clear-sky UV forecast.

2.3.2 UV index in Europe

In dealing with UV radiation in Europe a dynamical forecast of ozone is performed using the global numerical weather prediction of GME (DWD) with initial fields from ECMWF. The radiation transfer calculations are realized with the help of STARneuro (System for Transfer of Atmospheric Radiation, neuronal network) that considers multiple scattering and absorption due to aerosol and gases. The basic result is the large-scale field of UV Index for clear sky at mean sea level that is additionally adapted taking elevation and clouds into account. For further information see Staiger (2003) or http://www.dwd.de/en/wir/Geschaeftsfelder/Medizin/uvi/index.htm. DWD plays the role of RSMC for large-scale UV Index forecasts for RA VI (Europe). The RSMC provides the basic UV fields, which would then be locally adjusted and presented to the public through national information channels.

2.4 AIR QUALITY MANAGEMENT AND ALLERGENIC POLLEN

2.4.1 Air quality in health resorts

As an example of air quality management, it is worth noting that besides European and national standards for air quality,

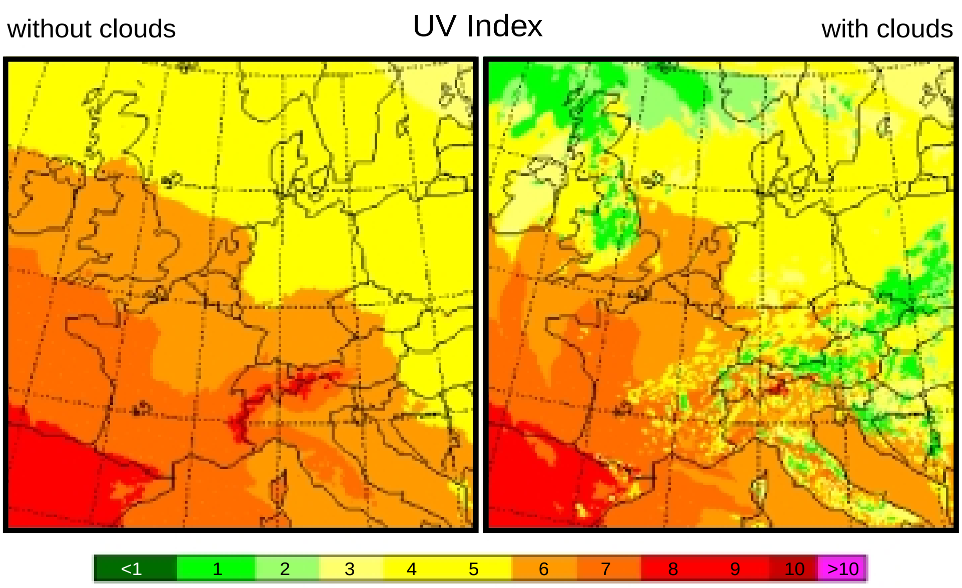

Figure 5—Forecast UV Index May 28, 2003

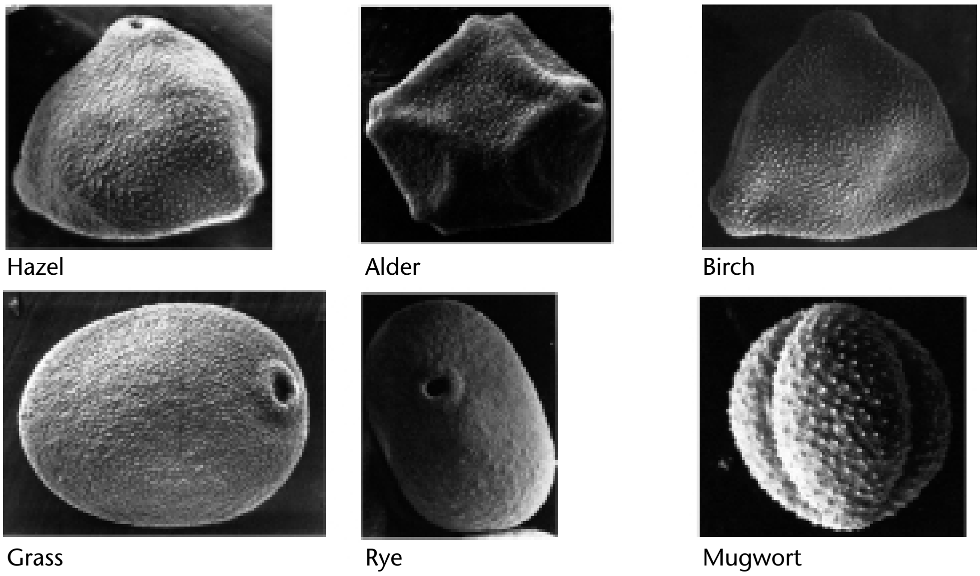

Figure 6—Main allergic pollen grains of Central Europe

special air quality regulations exist in Germany for health resorts. The goal is to prevent not only adverse effects on human health but to provide sufficient air quality for medical treatment and recovery. For this task special methods for air pollution monitoring have been developed by DWD especially for particulate matter, NO_2 and benzene. Passive sampling methods have been proved to be an appropriate technique and are in practical operation in German health resorts. These methods are characterised by their low cost and easy use.

2.4.2 Allergenic pollen grains

An example of how pollen is treated in relation to health problems is that of Germany. More than 10 per cent of the German population suffers from pollinosis, and this tendency is on the increase. The main allergenic pollen grains are from hazelnut, birch, alder, grasses, rye, and mugwort. The regionalised daily pollen forecast is based on the weather forecast of DWD (particularly on wind flow and precipitation), on measured pollen data from about 50 stations (network of Foundation Pollen Information Service), and on up-to-date phenological data. Forecast texts are automatically generated. A joint MeteoSwiss-DWD research project on automatic detection of allergenic pollen grains based on fluorescence microscopy and pattern recognition techniques was successfully completed recently (Ronneberger et al., 2002). This knowledge will be utilised in another multidisciplinary project to develop an automatic measuring device. The long-term objective is the establishment of a new pollen network.

2.5 WEATHER AND HEALTH (BIOTROPY)

Beyond the above discussed issues numerous independent studies verify the impact of weather, in particular of weather changes on human beings, resulting in deterioration in cardio-vascular and respiratory diseases, occurrence of blood clotting, aggravating inflammation and increased risks of occupational and traffic accidents. Other effects are subsumed under the term subjective impairment in well-being and include sleep disturbances, problems with concentration, headache and fatigue.

The human organism is obviously forced to respond to the weather-related stress called "biotropy" in order to remain homeostasis (in stable equilibrium). For weakened or impaired human beings the organism reacts insufficiently resulting in a so-called ARS (atmosphere related syndrome). Several independent public opinion polls last year found out quite consistently that about 50 per cent of the population feels concerned about weather-related stress. Increased biotropy can be interpreted as an increased health risk.

Studies in this field require problem-tailored weather classifications. As an example, one can note the procedure followed at DWD which is based on a vorticity approach in order to specify the different patterns of highs and lows with their typical advections and other dynamic processes. However, in spite of the successful use of biosynoptic classifications such a holistic approach does not really allow insight in cause-effect relationships. Every day DWD disseminates relevant medical-meteorological 48-hour forecasts for 11 regions (Medical-Meteorological Information Service).

2.5.1 Human biometeorological advice

"Weather" is the description of the meteorological part of the physical environment of the human beings in the form of a state or a change of state. It is very significant in people's consciousness due to its influence on so many aspects of life, including the health sector. Interfaces between the organism and weather can, on the one hand, be defined physiologically and thus causally, through the meteorological elements. On the other hand, such stresses can be defined only via stochastic relations, whereby mostly the symptoms of the reactions can be explained.

The influence of the weather is usually not ascribed to single meteorological elements, but registers as a collection of influences in which some elements can carry more weight than others. The type and intensity of the influence, as well as the reaction of the organism and also the psyche depend on many different, often single, factors, but above all on condition (age, fitness) and the state of health of the individual and, in the case of morbidity, on the type and severity of the primary disease. When interpreting the weather in relation to its influence on the organism, one can differentiate between stressful atmospheric conditions (strong irritation, high degree of adaptability required), stimulating atmospheric conditions, and atmospheric conditions with neutral effect.

The basis for assessing weather in respect to its influence on organisms is scientific studies based mostly on statistics but with significant results that have medical relevance. An analysis of the weather not only provides clues regarding the extent to which it presents a risk factor, but also allows the chance to take preventive action to counteract the risk. Up-to-date information on the effect of weather conditions such as stress, a risk factor for organisms weakened by age or illness, or warnings of certain thresholds being exceeded (thermal pollution, chilling stress, considerable change in the physical environment) can be of help to a doctor in recommending prophylactic measures, and to patients in adapting their activities (avoidance of additional stress). The effect of weather information in facilitating preventive measures provides support in the conditioning of the organism and rehabilitation.

Some European countries such as U.K., Austria, Hungary and certain broadcast companies e.g. "The Weather Channel" in USA currently issue biometeorological advice and warnings. Germany started in 1986 to provide public biometeorological advisories for those individuals who are hypersensitive to changes in atmospheric conditions. Since 1992 these reports also appear in the print media, as well as in radio and TV. The basic feature of the biometeorological advice is that only those diseases and adverse effects of the weather conditions that had been previously agreed on with the medical profession are mentioned, and the advisory would say that the preventive measures are prescribed according to medical advice.

2.6 INTERNATIONAL PROJECTS

2.6.1 WMO/WHO/UNEP showcase projects on Heat Health Warning Systems (HHWS)

One strategy to reduce the current burden of mortality due to heat waves is a Heat Health Warning System (HHWS). Such systems are defined as those that use meteorological forecasts to reduce heat-related impacts on human health. The essential components of such systems are the identification of weather situations that adversely affect human health, the monitoring of meteorological forecasts, mechanisms by which warnings are issued when a weather situation that could adversely affect health is forecast, and public health activities to reduce or prevent heat related illness and death.

HHWS are adapted to individual cities and therefore vary widely in the methods used. Based on the complexity of the warning and response three types of increasingly complex HHWS can be described. The following components are required for an effective heat health warning system (Auger, 2002):

- Sufficiently reliable heat wave forecasts for the population of interest (meteorological component);
- Robust understanding in the cause-effect relationships between thermal environment and health (epidemiological or biometeorological component);
- Effective response measures to implement within the window of lead time provided by the warning (public health component); and
- The community in question must be able to provide the needed infrastructure (public health component).

A HHWS first requires the identification of weather conditions associated with adverse impacts on health (the heat stress indicator). The accuracy of the meteorological forecast is important. False positives may result in resources being wasted, while false negatives will represent a missed opportunity for prevention. Both will result in a loss of confidence in the forecasts. As the complexity of the indicator increases, this increases the likelihood of an incorrect forecast.

An important factor is the timeliness of the warning in relation to the response. The heat stress indicator should be predicted at least 12, 24 and 48 hours in advance to give enough time for the response plan to be initiated and implemented (Auger, 2002). The maximum lead time for an extreme heat event is approximately 2 days as this is the limit for current numerical prediction models for accurate forecasting of local weather conditions.

A range of methods is used in order to identify situations that adversely affect human health. These methods can be grouped into simple and complex approaches. HHWS should take into account that different populations respond differently to the same meteorological conditions. The thresholds above which heat stress conditions become sufficiently hazardous to human health to warrant a health warning vary from one country to another depending on their baseline climate (discussed in more detail below). Further, the identification of the threshold is a practical decision and therefore subject to a range of other criteria such as credibility and cost (e.g.: the frequency of triggering a warning influences the cost of the warning system).

When a threshold is expected to be exceeded or an oppressive air-mass is forecast to arrive, a response is required. The warning procedures can be one-, two- or three-tiered. A one-tiered system has a single level of response (yes or no). In North America, many two- or three-tiered warning systems exist. These include a "watch" or an "alert" when a particular level of heat stress occurs or is forecast, and an emergency ("warning") stage when the heat stress is projected to exceed the threshold for the active response plan to be put into action. The Philadelphia system, for example, has a three-step warning procedure. The benefit of this multi-staged early warning approach is that response plans are graded as confidence in the forecast increases. It provides a maximum two day lead time for the intervention activities. This would give public health officials opportunity to weigh the costs of response actions against the risk posed to the public (National Academy of Science, 2000:87).

There are many different levels of response. The basic (passive) response is the issue of a warning of high temperatures (heat stress conditions) through the mass media (TV, radio, public websites). In the USA, NOAA issues special weather statements and/or public information statements presenting a detailed discussion of:

- The extent of the hazard, including MHI values;
- Who is most at risk;
- Safety rules for reducing the risk.

NOAA also assists state and local health officials in preparing Civil Emergency Messages in severe heat waves. Meteorological information from Special Weather Statements are included as well as more detailed medical information, advice, and names and telephone numbers of health officials.

Public warnings are aimed at the wider community in order to modify the behaviour of individuals and to increase awareness of the dangers that are connected with heat exposure in order to reduce heat related impacts. Therefore, warnings need to be linked to specific advice on how people recognise the problem and what they should do to protect themselves and others. The CDC (Centers for Disease Control and Prevention in Atlanta) have issued guidelines for reducing heat related illness. These guidelines summarise the general advice that is issued throughout North America, Australia and Europe. It is worth to remark that the advice concerning the use of fans is not quite correct. To use fans even when temperature exceeds 35°C can provide comfort, because normally the increase in evaporative heat loss is higher than the increase in sensible heat gain. However, there must be an increased intake in liquids to avoid dehydration.

The warning may be targeted at health or welfare service providers. Intervention activities that are in place in the United States include (Kalkstein, 2001):

- Media announcement that provide information on how to avoid heat related illnesses during oppressive weather;
- Promotion of the “buddy” system. Media announcements encourage friends, relatives, neighbours, and other volunteers to make daily visits to elderly persons during hot weather;
- Activation of “Heatline”, which provides information and counselling to the general public on avoidance of heat stress;
- Home visits, department of Health field teams make home visits to persons requiring more attention than can be provided over the Heatline;
- Nursing and personal care boarding home interventions. When a warning is issued, these facilities are informed of the high-risk heat situation;
- Halt of utility service suspensions during warm periods;
- Increased medical emergency staffing;
- Daytime outreach to the homeless.

Intervention plans should be best suited to local needs, through coordination between the local health agencies and meteorological officials (Cegnar & Kalkstein, 1999). A comprehensive warning system should involve multiple agencies, such as: city managers, public health and social services workers, and emergency medical officers. However, the vast majority of systems are controlled by the meteorological agency and have little practical involvement from other agencies.

Based on the good experience with the HHWS in Philadelphia and in some other North-American cities, WMO/WHO/UNEP sponsors Showcase Projects in Rome and Shanghai in order to show the value of these systems for all countries that sometimes suffer from heatwaves.

2.6.2 Climate Change and Adaptation Strategies for Human Health in Europe (cCASHh)

The key objectives of the cCASHh (climate Change and Adaptation Strategies for Human health in Europe) project funded by the European Commission are:

- To identify the vulnerability of European populations to adverse impacts of climate change on human health;
- To review current measures, technologies, policies and barriers to improve the adaptive capacity of human populations to climate change;
- To identify for European populations the most appropriate measures, technologies and policies, as well as the most effective approaches to implementation, in order to successfully adapt to climate change;
- To provide estimates of health benefits of specific strategies or combination of strategies for adaptation for vulnerable populations under different climate change scenarios;
- To estimate the costs (due to climate-related damage and the implementation of adaptive measures) and benefits (both of climate change and of adaptation strategies) including co-benefits independent of climate change.

Research within the cCASHh project is divided into eleven work-packages (WP1: coordination, WP2: conceptual framework, WP3: vulnerability assessment thermal stresses, WP4: vulnerability assessment extreme weather events, WP5: vulnerability assessment vector borne disease, WP6: vulnerability assessment water and food borne disease, WP7: policy analysis, WP8: economic analysis, WP9: integrated assessment model thermal stresses, WP10 integrated assessment model - vector borne diseases, WP11 dissemination and outreach). Work-package 3 deals with vulnerability to thermal stresses and has the following objectives:

- Identify populations in Europe who are particularly vulnerable to heat stress and identify and reduce this vulnerability;
- Identify and evaluate adaptation strategies.

As part of the WP 3 work and in collaboration with DWD, the London School of Hygiene and Tropical Medicine and the WHO European Centre for Environment and Health, a workshop was organised and conducted to:

- Identify the potential impacts of climate change on heat related morbidity and mortality;
- Review and evaluate existing short-term and long-term adaptation measures;
- Make recommendations for the implementation and evaluation of heat health warning systems and appropriate other strategies to reduce heat stress;
- Identify information gaps and research needs.

During the workshop, the current state of knowledge of the potential to reduce heat stress through urban planning and Heat Health Warning Systems was presented, with a focus on developing criteria for evaluation of their effectiveness.

2.7 APPROACHES TO MANAGEMENT AND OPERATION OF HUMAN BIOMETEOROLOGY PROGRAMS

2.7.1 Role of Regional Specialized Meteorological Centres (RSMCs)

RSMCs are centres established within the WMO framework to carry out specific functions in the different categories described below.

2.7.1.1 *RSMCs with geographical specialization*

RSMCs with geographical specialization are designated in WMO Regions, capable of preparing with the support of WMCs (World Meteorological Centres), and where applicable RSMCs outside the Region, analyses and short-, medium-, extended- and long-range weather forecasts with the highest possible quality and with meteorological content, geographical coverage and frequency required by Members and agreed for the system. Output products from RSMCs comprise:

(*a*) Analyses and prognoses at the surface and/or in the free atmosphere for short-, medium-, extended- and long-ranges, for the tropical, subtropical and extra-tropical areas, according to the obligations of each RSMC and as agreed by the Regional Association;
(*b*) Interpreted forecasts of specific weather parameters in map form or at specific locations (e.g. precipitation amounts, temperature, wind, humidity, etc.), subject to agreement between Members, where appropriate;
(*c*) Guidance on storm-position and track forecasts for the areas affected by tropical storms;
(*d*) Climate analyses, long-range forecasts, onset, intensity and cessation of the rainy season(s);
(*e*) Environmental quality monitoring and predictions, such as UV-B (see 2.3.1);
(*f*) Results of forecast verifications and intercomparison studies.

2.7.1.2 *RSMCs with activity specialization*

Regional Specialized Meteorological Centre (RSMC) with activity specialization are designated, subject to the formal commitment by a Member or group of cooperating Members, to fulfil the required functions of the centre and meet the requirements for the provision of World Weather Watch products and services initiated and endorsed by the relevant WMO constituent body or bodies concerned. The centre should be capable of preparing independently or with the support of WMCs, and where appropriate, other Global Data Processing and Forecast System (GDPFS) centres and disseminating to Members concerned:

(*a*) Global medium-range forecasts and related analyses;
(*b*) Extended- and long-range weather forecasts and related mean analysed values and anomalies;
(*c*) Tropical cyclone warnings and advisories, storm position, intensity and track forecasts for their areas;
(*d*) Three-dimensional environmental emergency response transport model trajectories, integrated pollutant concentration, and total deposition;
(*e*) Drought monitoring products such as drought indices.

2.7.1.3 *RSMCs with non-real-time activities*

The functions of an RSMC should also include the following non-real-time activities:

(*a*) Assistance in the management of non-real-time data involving:
    (i) Assistance to the WMC in management and maintenance of non-real-time data, in particular by obtaining late and delayed observational data for its area of responsibility;
    (ii) Storage and retrieval of basic observational data and processed information needed to discharge the non-real-time responsibilities of the RSMC;
    (iii) Making non-real-time data available to Members or research institutes upon request;
(*b*) Development and refinement of new techniques and applications;
(*c*) Carrying out comparative verifications of RSMC products and making results available to all Members concerned;
(*d*) Regular exchange with other centres of information on techniques and procedures used and results achieved;
(*e*) Providing opportunities for training of personnel in manual and automated techniques;
(*f*) Continuously updating and providing, on request, a catalogue of available products.

2.7.1.4 *Future developments*

Similar to the RSMCs described above, if established, centres with responsibility to issue human biometeorological and air quality products may benefit the general public as well as government authorities and decision makers through advice and information on human health issues related to weather and climate.

Chapter 3
AIR QUALITY FORECASTS

3.1 AIR QUALITY AND HEALTH

Air pollution comes from many different sources such as factories, power plants, automobiles and even from natural causes such as windblown dust, smoke from bush fires and volcanic eruptions. Air quality can be affected in many ways by the pollutants emitted from these sources. With the deterioration of air quality and a corresponding increase in health problems, many countries have started air quality monitoring programs, acid rain monitoring networks, ozone monitoring and even air quality forecasting.

Although the air quality monitoring activities may not be carried out by NMSs, nevertheless, weather plays an important part in the development, dispersion and transportation of particulates, ground-level ozone, pathogenic germs and gases. A few weather factors that will affect the changes in air quality include air temperature, amount of cloud cover, humidity, pressure, wind speed and the presence of temperature inversion.

Air quality indices have been developed in many countries for reporting the levels of the various pollutants in the atmosphere. These indices make it easier for the public to understand the health significance of air pollution levels. Air quality can be measured by a nationwide or local monitoring system that records pollutant concentration at strategic locations throughout the country.

One example is an Air Quality Index (AQI) which ranges from 0 to 500. The higher the AQI value for a pollutant, the greater the danger. The AQI scale has been divided into distinct categories, each corresponding to a different level of health concern. Table 1 shows the different categorization as prepared by the NWS of USA.

Deteriorating air quality has affected our health in many ways. Often, people exposed to deteriorating air quality experience respiratory-related symptoms such as coughing, irritation in the throat, rapid or shallow breathing or general discomfort in the chest, skin or eye irritation. Sometimes, damage can occur without any noticeable symptoms or they are too subtle to notice. People who live in areas where the air quality is unhealthy may find that their initial symptoms go away with time. However, this does not mean that they have developed resistance to the deteriorating air quality. In fact, even when the symptoms have disappeared, lung damage continues to occur. Hence, the best way to protect one's health is always to be aware of the air quality and take simple precautions such as minimizing outdoor activities whenever the air quality deteriorates.

Globally, the six principal pollutants that are monitored and analysed are Carbon Monoxide, Lead, Nitrogen dioxide, Ozone, Particulate Matters and Sulphur dioxide. Toxic air pollutants also cause a wide range of effects from lung disease to birth defects and cancer. Table 2 indicates the source and possible health effects of the various pollutants.

3.1.1 Tropospheric ozone

In the earth's lower atmosphere, near ground level, ozone is formed through the interactions of emissions of volatile organic compounds (VOCs) and nitrogen oxides in the presence of bright sunshine with high temperatures. Cars and gasoline-burning engines are major sources of VOCs. These compounds also come from consumer products such as paints, insecticides and cleaners as well as industrial solvents and chemical manufacturing. Nitrogen oxides are produced whenever fossil fuels are burned, primarily by motor vehicles and power plants. The highest ozone concentrations usually occur in the afternoon during summer and can reach unhealthy levels when the weather is hot and sunny, with light or no wind.

Ground-level ozone can irritate the respiratory system, causing one to cough and feel an irritation in the throat or experience an uncomfortable sensation in the chest. Ozone can also reduce lung function and make it more difficult to breathe deeply, especially when one is exercising or working outdoors. When the ozone levels are high, people who are particularly sensitive to this form of pollution (sufferers from asthma or other respiratory diseases), may experience attacks that will require a doctor's attention or the use of additional medication.

3.1.2 Stratospheric ozone

Stratospheric ozone is formed naturally in the upper atmosphere between 15 and 30 km above the earth's surface and protects us from the sun's harmful ultraviolet rays. The ozone can be produced by numerous chemical reactions, but the

Table 1—NWS Air Quality Scale

Ozone Concentration (ppm)	*Air Quality Index Values*	*Air Quality Descriptor*
0.0 to 0.064	0 to 50	Good
0.065 to 0.084	51 to 100	Moderate
0.085 to 0.104	101 to 150	Unhealthy for Sensitive Groups
0.105 to 0.124	151 to 200	Unhealthy
0.125 to 0.404	201 to 300	Very Unhealthy

Pollutant	Source	Health Effects
Carbon Monoxide	Automobile exhaust, industrial processes and fuel combustion in boilers and incinerators	Reduces the amount of oxygen delivered to the body's organs and tissues. It can cause nausea, dizziness, headaches, visual impairment, poor learning ability and difficulty in performing complex tasks. People with cardio-vascular disease are more at risk.
Lead	Industrial facilities such as smelters and battery plants. Also from the wearing away of old lead-based paint.	Since lead is not readily excreted by the body, it can affect the kidneys, liver, nervous system and other organs. It can cause anemia, kidney disease, reproductive disorders and neurological impairments such as seizures and mental retardation.
Nitrogen dioxide	Motor vehicle exhaust and stationary sources such as electric utilities and industrial boilers.	Irritates the nose, throat and lungs especially in people with asthma. Lowers resistance to respiratory infections such as influenza. Nitrogen oxides contribute to ozone formation that have adverse effects on terrestrial and aquatic ecosystems.
Ozone	Not emitted directly into the air by specific sources but created by sunlight acting on Nitrogen Oxides and Volatile Organic Compound from motor vehicles and stationary sources.	Irritates the lungs causing coughing and pain in the chest and throat. Induces respiratory inflammation and reduces the ability to exercise. Long-term exposure may lead to permanent scarring of lung tissues and lower lung efficiency.
Particulate Matters	Diesel cars, trucks and buses, power plants, industry, bush fires, volcanic eruptions and many other sources	Affects breathing and respiratory system, changes the body's defense against inhaled materials, damage to lung tissues, cancer and premature death.
Sulphur dioxide	Burning fuel containing sulphur (mainly from coal and oil) are burned, power plants, large industrial facilities, diesel vehicles and metal smelting.	Constricts the breathing passages, causes wheezing, shortness of breath and coughing. It also alters pulmonary defenses and aggravates existing cardiovascular diseases.
Toxic air pollutants including dioxins, benzene, arsenic, mercury and vinyl chloride.	Types of sources include motor vehicles and stationary sources such as manufacturing plants.	Can cause cancer, poisoning and rapid onset of sickness such as nausea or difficulty in breathing. Other effects include immunological, neurological, reproductive and developmental effects. Toxic air pollutants deposited into soil and rivers and lakes affect ecological systems and human health through consumption of contaminated food.

Table 2—Sources and possible effects of various pollutants

main mechanism in the atmosphere for its production and removal is absorption of ultra-violet (UV) radiation from the sun. The amount of ozone in the atmosphere varies according to geographic location (latitude) and season. Ozone is measured in Dobson units (DU), where 300 DU would be equivalent to a 3 mm thick layer of ozone if compressed to mean sea level pressure.

Stratospheric ozone is mainly produced in the tropics and transported to higher latitudes by large-scale atmospheric circulation during the winter and spring months. Over the past 2 decades, however, this protective shield has been thinning. Each year, an "ozone hole" forms over the Antarctic, and ozone levels fall to 70 percent below normal. At a given site as the ozone layer thins, more UV-B radiation reaches the earth's surface and it has been demonstrated that UV-B levels over most populated areas have increased.

Scientists have linked several substances associated with human activities to stratospheric ozone depletion, including the use of chlorofluorocarbons (CFCs), halons, carbon tetrachloride, and methyl chloroform. These chemicals are emitted from home air conditioners, foam cushions and many other products. Strong winds carry them through the troposphere and into the stratosphere. There, strong solar radiation releases chlorine and bromine atoms that attack protective ozone molecules.

3.1.3 Smog and acidification

Smog is a mixture of air pollutants, including gases and fine particles that can often be seen as a brownish-yellow or greyish-white haze. The two key components of smog are airborne particulates and increased ground-level ozone.

Although normally smog is a concern in most major urban centres, because it travels with the wind, it can also affect sparsely populated areas. Particularly vulnerable to smog are the elderly, those with existing heart or lung disease and small children. Even healthy adults can be adversely affected by high levels of smog.

Acidification is a serious environmental problem caused by emissions of sulphur dioxide, nitrogen oxides and ammonia. It has caused widespread damage to forests and soils, fish and other living organisms as well as to human health. Emissions of sulphur are the primary source of acidification caused by the burning of coal and oil from boilers in factories and plants or automobile fuel when the sulphur in the fuel is converted into sulphur dioxide. Another source of sulphur dioxide is the uncontrolled burning of bush fires. Nitrogen oxides are produced during combustion and most of the nitrogen oxides come from traffic and combustion plants.

Acid deposition describes a process that is a combination of wet and dry deposition. Most people are familiar with the wet acidic deposition known as acid rain. In the wet deposition process, sulphuric and nitric acids are incorporated into cloud droplets during cloud formation. These raindrops will eventually fall onto the ground in the form of rain and snow. When high concentrations of acid are present, the rain shows strong acidity.

Dry deposition refers to acidic gases and particles such as gaseous sulphur dioxide, nitrogen oxides and nitric acid, as well as acid aerosols which are deposited directly when they contact and adhere to the surface of vegetation, soil and other materials during fine weather. Dry deposited gases and particles can also be washed from trees and other surfaces by rainstorms. When that happens, the runoff water adds those acids to the acid rain, making the combination more acidic than the falling rain alone.

Acidic dry deposition often lingers for one to two days in the atmosphere before being returned to the ground. During this period, wind can carry these components hundreds or even thousands of kilometres away from the source of emissions. Hence, many thousand tonnes of acidic particulates are transported across national borders.

Chemical reactions occur between acids and alkaline substances in the atmosphere to form compounds which when inhaled, can affect human health. One of these compounds is ammonium sulphate, which is produced in large quantities during large-scale biomass burning events. The highly hygroscopic nature of ammonium sulphate allows it to absorb moisture under humid conditions resulting in a reduction of visibility or hazy conditions.

Sensitivity to acidification in the soil leads to a depletion of the mineral nutrients in the soil (such as calcium and magnesium), thus reducing the fertility of the soil. The acidification process also releases aluminium and heavy metals into the ground water that can harm the microorganisms in the soil that are responsible for decomposition, as well as animals and birds in the food chain. The sensitivity of individual species to acidification varies, with the most sensitive group being fish, moss, fungi and microorganisms.

Rain water is naturally acidic due to the presence of carbon dioxide and other naturally produced acidic gases in the atmosphere. The pH of rainwater varies at different locations. PH of rain water from remote islands is found to have a value of between 5.6 and 6.0. Generally, rain water with pH less than 5.6 is considered acidic.

3.1.4 Particulate matters

Particulate matters are mostly of microscopic dimensions floating around in the air, and as such cannot be seen by the naked eye. Particulates can come in almost any shape or size and can be solid particles or liquid droplets tiny enough to remain suspended or floating in the air for up to weeks at a time.

Particles originate from a variety of natural and man-made sources such as diesel trucks, woodstoves, and power plants and their chemical and physical compositions vary widely. Particulate matter can be directly emitted or can be formed in the atmosphere when gaseous pollutants such as sulphur dioxide and nitrogen oxide react to form fine particles.

Of greatest concern to the public health are the particles small enough to be inhaled into the deepest parts of the lung. These "coarser" particles, known as PM10, are less than 10 microns in diameter. Sources of coarse particles include mold, spores, pollens and dust from paved or unpaved roads. The "fine" particulate matter, known as PM2.5, has a specific range of 2.5 micron or less. Sources of fine particles include all types of combustion (motor vehicles, power plants, wood burning, bush fires, etc) and some industrial processes.

On any given day, scientists estimate that about 10 million tons of solid particulate matter are suspended in the atmosphere. The deposition of Particulate Matter on metals, wood, stone, electronics and fabric may cause soiling and discoloration and physical and chemical degradation of materials through the action of acidic particles. Particulate matter is also associated with reduced visibility and with poor air quality.

3.1.5 Environmental emergency response

Important release of hazardous materials (radiological, chemical, or biological) into the atmosphere and water bodies constitutes a major threat to life and safety of mankind and can take on international or even global dimensions. These environmental emergencies can be associated with unplanned events resulting from natural events (such as volcanic eruptions, wild fires caused by lightning, etc.), accidents (typically unplanned and sudden) and/or near misses. These environmental emergencies can also result from planned events such as wars and/or malevolent acts. Whatever the cause behind the environmental emergency, it is the task of NMHSs to supply the best possible advice and meteorological information to the government authorities responsible for environmental emergency response activities. And it is the purpose of the Emergency Response Activities programme of WMO is to coordinate with other relevant international agencies to ensure optimum programme effectiveness and to support NMHSs in their role as meteorological (and often hydrological) authority.

3.1.5.1 *Radioactivity*

Though radioactivity has both natural and anthropogenic sources the catastrophe of Chernobyl was the main reason of the development of modelling systems to forecast the atmospheric transport of radioactivity and to start the Emergency Response Activities programme of WMO.

Natural radiation has been part of the universe since its creation. It stems from the decay of nuclei in the earth's crust and from cosmic radiation. The levels vary geographically, depending on local rock formations.

In addition to natural radiation, radioactivity has also been artificially generated for medical purposes such as for use in radiotherapy, scanners, scintigraphy, etc. as well as in industrial instrumentation and in nuclear weapons and nuclear fuel plants.

Living cells can be damaged by ionizing radiation which is emitted during radioactivity. The dosage of radiation exposure depends first on whether the exposure is external or internal, the latter from inhaling or ingesting radionuclides. Other factors include the mobility of different radionuclides in the environment.

At low dosage, the main concern is an increased risk of cancer. Radiation can also affect germ cells increasing the risk of genetic damage. At higher doses, radiation above a certain threshold dose kills cells, causing radiation sickness. Most people exposed to such high doses have been in the vicinity of severe accidents with radioactive material, such as the fire fighters at the Chernobyl nuclear power plant in 1986 or near nuclear bomb explosions, such as the residents of Hiroshima and Nagasaki in 1945. The first symptoms of radiation sickness are nausea, vomiting and reddening of the skin.

3.1.5.2 *Chemical accidents*

The number and size of industrial and chemical plants have increased rapidly in recent years producing millions to billions of tonnes of chemical products each year. These plants are complex, releasing large amount of toxic materials daily into the atmosphere. Risk on human health and the environment posed by chemicals is determined by chemical-specific hazard properties as well as the amount of exposure to the chemicals.

The probability of the occurrence of a chemical incident, be it accidental or intentional release of hazardous or flammable materials, is on the increase. Weather parameters play an important role in the dispersion and transport of these chemical releases downstream. In order to support emergency response and rescue, current weather condition as well as forecasted condition will provide the necessary information needed to move people out of the danger zone. For a major chemical accident involving toxic gases, high precision environmental modelling software that can simulate the dispersion of pollutants emitted into the atmosphere under different conditions, can be used to provide more accurate information to combat the spread of the dispersion of these toxic pollutants as well as used in vacating people out of harm's way.

3.1.5.3 *Forest fires*

Although forest fires have been and still are considered a natural hazard, a variety of factors in the environment, such as ease of ignition, lack of moisture, environmental temperature, strong wind, etc plays an important role in the increased incidence of forest fires.

In 1997, the out-of-control forest fires in Sumatra and Kalimantan, Indonesia spewed out a thick blanket of haze over the whole South East Asia (SEA), pushing the air pollution over the whole region to extremely dangerous levels. The extremely dry weather conditions due to ENSO as well as indiscriminate burning led to this situation.

In response to the environmental disaster over the South East Asian Region, a monitoring and warning system for forest/vegetation fires was developed and implemented. Adopted from the Canadian Forest Fire Danger Rating System, the SEA Fire Danger Rating System (FDRS) produces the SEA Fire Danger Rating products on a daily basis.

The FDRS monitors forest/vegetation fires risk and can be used to predict fire behaviour. This product is useful as a guide for policy makers in developing action plans to protect life, property and the environment in the region.

3.1.5.4 *Volcanic eruptions*

In Volcanic eruptions, rocks and fragments are blasted into the air by explosions or carried upwards by hot gases in eruption columns. Such fragments range in size from less than 2 mm to more than 1 m in diameter. Large size particles fall back to the ground on or close to the volcano and progressively smaller fragments are carried away by the wind. It is the smallest fragments, the volcanic ash, that can travel hundreds to thousands of kilometres downwind from a volcano that has serious impacts on the environment.

Volcanic ash is disruptive to economic activity because it is highly abrasive, infiltrates almost every opening and it also affects the health of the population, in particular people with respiratory-related health problems. Volcanic ash can be a serious hazard to aviation even thousands of miles from an eruption. Airborne ash can diminish visibility, damage flight control systems, and cause jet engines to fail. In addition, its abrasive effects can lead to severe damage to the aircraft's exterior.

3.1.6 User requirements

Environmental monitoring, usage of environmental information and forecasts involve many sectors. For effective decision-making and usage, user requirements must be predetermined. Regular coordination meetings with all users including policy makers, enforcement agencies, health authorities, emergency response agencies are essential and feedback mechanisms must be in place to ensure usefulness of the information.

3.2 ATMOSPHERIC TRANSPORT MODELLING

Atmospheric transport models are important tools used for the forecasting and nowcasting of geographical distribution of air pollutants, simulating plume behaviour and predicting pollution dispersion and deposition over an area. They are also used by policy makers in assessing emission reduction strategies, estimating exposures and investigating economical aspects of air pollution, as well as being used in the decision making process.

Because of the diversity of air pollution problems atmospheric transport models have to be specially adapted to the various tasks. They may range from explosions and fast chemical reactions to climatological effects, and from very local events like the movement of heavy gases to the global scale. This short list already shows that some problems are out of the scope of the normal forecasting range of NMHSs. Heavy gas problems can neither be resolved by routine measurements nor by meteorological data provided by NWP models. On the other side of the spectrum, there is at the moment no deterministic model which is able to simulate the development of air pollutants on a climatological time scale.

The range of problems which can be solved by air pollution forecasting is therefore mainly determined by the time and/or space scale of emissions, health effects and the time which remains until the pollutant has reached a receptor point. Thus for chemical accidents like those of Bophal or Seveso which are mainly caused by explosions, air pollution forecast will come too late. But in case of fires when emissions extend over hours NMHSs may provide significant information also for local problems if they can forecast the veering of a polluted plume.

Typically, the problems to be handle by atmospheric transport modelling can be divided into two groups:

- **Routine air pollution forecasting**: the forecast of photochemical and London type smog, of particulate matter and all other chemical substances which are emitted regularly and from many different sources (area, line and point sources);
- **Environmental emergency response**: the forecast of material which is emitted accidentally or by malevolent acts.

The atmospheric transport models used in routine air pollution forecasting are operated similarly to NWP models. They are embedded in a daily operational forecast suite. Therefore, they can in principal also be included in general circulation and climate models and be used to forecast future changes of the chemical composition of the global atmosphere and its interaction with the meteorological and climatological parameter.

Because of the specific problems caused by accidental releases WMO has put in place in cooperation with the International Atomic Energy Agency (IAEA), a system of eight Regional Specialized Meteorological Centres (RSMCs) for transport calculations which will support the NMHSs which have no emergency response system of their own. Similarly, WMO co-operates with the International Civil Aviation Organization (ICAO) and the nine Volcanic Ash Advisory Centres (VAACs) in cases of volcanic ash incidents.

In its 6th Long Term Plan WMO has asked the NMHSs to extend their activities in air pollution forecasting. WMO's Coordination Group on Emergency Response Activities (CG-ERA) supported this initiative and voted also to include biological material like the foot-and-mouth (FMD) virus whose transport has already been studied in a research mode by some NMHSs.

3.2.1 Model systems

Model systems have to provide a forecast of emissions resulting from air pollutants emitted to the atmosphere. Therefore, a complete model system for air pollution forecasts will consist of the following elements or modules:

(*a*) An emission inventory and/or emission model;
(*b*) A data assimilation for air pollutants;
(c) A meteorological database; and
(*d*) An air pollution model.

As an additional element a (statistical) post processing may be added.

But depending on the forecasted air pollutant the model system can be simplified. There is a broad spectrum of possible model systems ranging from simple transport calculations (trajectories, advection of passive tracers) or statistical approaches based on the correlation between the meteorological parameter and air pollutants (i.e. temperature and ozone) to complex modelling systems which predict the transport, dispersion, and deposition of fifty or more chemical species and more than hundred chemical reactions.

The minimum requirements for an air pollution modelling system are a meteorological data base (normally a numerical weather forecast) and an air pollution model which is adapted to the specific problem. If the meteorological forecast and the air pollution forecast are performed simultaneously within one model using identical time steps it is called an on-line model. This can be useful and necessary if convective processes have to be calculated explicitly. But in most cases off-line models are applied where the air pollution forecast uses the results of previously computed weather forecasts.

3.2.1.1 *Modelling approaches*

Air pollution modelling and forecasting face several challenges.

(*a*) **Emissions**. There are different types of emissions: point sources, line sources, area sources, heavy gases, explosions which should preferably be handled by different types of models. Many emissions are often not well known and emission inventories are incomplete. Air pollution forecasting would also require an emission forecasting. This is complicated because anthropogenic emissions depend on human behaviour which has to be forecasted. In case of bush and forest fires a dynamic emission model is necessary because the emissions feed themselves depending on wind speed and direction, dryness of the soil and vegetation and the availability of inflammable material;

(*b*) **Measurements, data assimilation and model validation**. Measurements for a limited number of chemical species are available. But most of these measurements are performed near the ground and only some information on the vertical structure can be gained from ozone soundings, aircraft measurements and remote sensing. Furthermore, only few measurements are exchanged in near real time;

As a consequence in most cases data assimilation cannot be used to define the initial state and validation is severely hampered;

(*c*) **Emergency response – accidental releases**. Accidental releases of dangerous air pollutants, especially of radioactivity are rare events. Therefore, only few data are available to validate and improve model calculations. Additionally, users are not used to interpret the results;

(*d*) **Complex chemistry**. Because of the complexity of the chemical processes in the atmosphere the number of prognostic equations is increasing significantly when compared with numerical weather prediction. If operational forecasts are needed either larger computers are necessary or the horizontal and/or vertical resolution of the air pollution models has to be reduced;

(*e*) **Local problems**. Many air pollution problems need a high resolution modelling approach. Examples are urban air pollution or chemical accidents. Therefore, they also need a high resolution meteorological data base which cannot be provided by the regular operational numerical weather prediction and additional models or model runs are necessary to bridge this gap.

Because of the aspects listed above a great variety of model approaches adapted to the special tasks have been developed. But these can be grouped into classes mainly depending on the type of emissions and the chemical reactions.

The different Eulerian and Langrangean model types yield quite different results when they are applied to point sources (see Figure 7)

(*a*) In Eulerian models the emitted air pollutant is immediately distributed in a whole box and the plume is broadened because of the numerical dispersion;

(*b*) Lagrangean plume models are restricted to situations and thus not applicable in forecasting;

(*c*) With trajectories and Langrangean puff models three-dimensional pathways of polluted air parcel can be simulated. While trajectories only deliver the coordinates of the centre points, the puffs also simulate the concentrations as mean values for the puffs which grow in size because of the action of turbulence;

(*d*) In Lagrangean particle dispersion models the parcels do not expand during their travel through the atmosphere. The action of turbulence is simulated by a large number of particles subjected to a random walk process;

(*e*) In trajectory box models the physical and chemical processes in a volume transported along a trajectory are calculated.

Thus Eulerian models are mainly used in air pollution forecasting where the problem is not dominated by one or a few point sources. Typical examples are ozone forecasting or similar problems where the air pollutants are emitted from a large number of sources. On the other hand, if air pollutants are accidentally released from a point source Lagrangean type models deliver the best results.

3.2.1.1.1 *Lagrangean models*

In Lagrangean models the pathways of air parcels through the atmosphere are computed.

The simplest Lagrangean model is the trajectory which only yields the coordinates of the centre of mass of the parcel by solving the equation

$$x_i(t) = x_i(t_0) + \int_{t_0}^{t} v_i(\vec{x}(t'))\,dt' \qquad (i=1,2,3)$$

This implicit equation has to be solved iteratively and the velocity components at the place of the air parcel have to be interpolated in space and time. Normally, interpolation schemes of second or third order and only few iterations yield a sufficient accuracy.

If air concentrations and deposition is needed either the size of the puff or the random walk of great number of particles has to be calculated.

The basic equations for the growth of the dimension σ of a Gaussian puffs are

$$\frac{d\sigma^2}{dt} = \frac{2}{3}\int_0^{t'} \overline{v''(t)v''(t+\xi)}\,d\xi$$

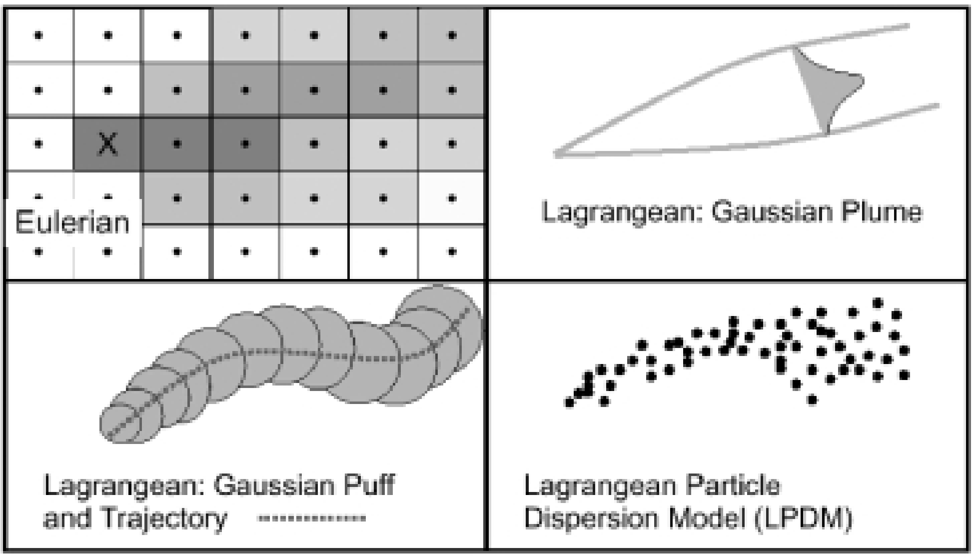

Figure 7—Model types used in atmospheric transport modelling

where v” are the velocity components relative to the movement of the parcel as a whole. The covariance $\overline{v''(t)v''(t+\Delta t)}$ depend on the turbulence in the volume and have to be parameterised. There are several approximations for the growth depending on the distance from the source. Lagrangean puff models are quite flexible tools. The air parcels can follow curved trajectories and grow in size depending on turbulence. But the position and the size are integral values of a parcel. It can happen that the parcel has grown to a size where diffluent wind fields have to be taken into account. The pentafolding mechanism (splitting one puff into five new plumes) of the model RIMPUFF tends to overcome this problem. But a better solution would be either to continue the calculations with a Eulerian model or to use a Lagrangean particle dispersion model.

In a Lagrangean particle dispersion model a large number (many thousand) trajectories of air parcels are computed by $x_i(t+\Delta t) = x_i(t) + \Delta t \cdot v_i(t)$ where the velocity is the sum of the mean velocity $\bar{v}_i$ and an additional turbulent component $v_i' : v_i = \bar{v}_i + v'_i$. The additional turbulent velocity is computed from

$$v_i'(t+\Delta t) = R_i(\Delta t)\ v_i'(t) + \sqrt{1-R_i^2(\Delta t)}\ v_i''$$

where the correlation functions and the random walk velocities have to be parameterised using the local turbulence information. The concentration is calculated from the sum of the particle masses in a box volume and deposition from mass fractions which particles may lose if they are either affected by rain or if they hit the ground. Other linear processes like radioactive decay can be taken into account. The only weakness of the model approach is the handling of non-linear chemical reactions which depend on the concentration. This would require a concentration calculation each time step and a redistribution of the reaction products to the parcels.

In contrast to the models described above trajectory box models are receptor oriented. After backward trajectories ending at a number of receptor points have been calculated concentrations in a box volume along the trajectory are evaluated by solving the equation:

$$\frac{dc_i}{dt} = E_i - L_i + \sum_j R_{ij},$$

where c_i are the concentrations, v_i the transport velocities (normally identical with the wind velocity except for gravitational settling), E_i the emissions, L_i the losses and R_{ij} the reactions between the species i and j.

Normally, the boxes and trajectories are considered to represent well mixed boundary layer volumes. Therefore, the change of the height of this mixed layer and the interaction with the overlaying free troposphere or a residual layer can be taken into account.

Except for Lagrangean particle dispersion models, all models of Lagrangean type treat moving air parcels which grow in size during their travel through the atmosphere due to the action of turbulence. Additional methods like the splitting of parcels (pentafolding) or the calculation of more than one trajectory in the boundary layer are only subsitutes. If information on a constant and fixed scale are necessary Eulerian models have to be used.

3.2.1.1.2 *Eulerian models*

In Eulerian models basically a number of mass conservation equations (one for each deterministically forecasted chemical species) have to be solved:

$$\frac{\partial c_i}{\partial t} + \nabla \bullet (\vec{v}_i c_i) + \nabla \bullet \overline{(\bar{v}_i' c_i')} = E_i - L_i + \sum_j R_{ij}$$

Additionally to the general problem in chemical modelling to specify the sources (E_i), sinks (L_i) and reactions (R_{ij}) Eulerian air pollution models require numerical methods which are (*a*) mass consistent and (*b*) non-negativity consistent (i.e. guarantee that concentrations cannot drop below zero) and (*c*) have a low numerical diffusion. As these requirements further increase the high computing costs resulting from the calculation of a larger number of chemical species, research in new numerical advection schemes is going on. The choice of the numerical scheme depends on the problem to be solved. London type smog is dominated by advection. There are only a limited number of chemical species which have to be forecasted and the numerical treatment of chemical reactions poses no major problem. The formation of Los Angeles or photochemical smog on the other hand is a complex process where a large number of chemical species are involved. The transport of these species as well as the reaction processes have to be calculated. As the reaction times vary over several magnitudes and as many of them are much shorter than the advection time step, special integration methods (time splitting and/or implicit) are needed to solve these equations. Typically about fifty chemical species have to be forecasted and more than hundred reactions taken into account.

Eulerian air pollution models are definitely the most flexible tool for all problems involving many different sources with continuous emissions. They are well known to meteorologists because they are similar to numerical weather prediction models. If the same grid is used in numerical weather prediction as in air pollution forecasting, a one-to-one transfer of data or even on-line version is possible where the meteorological and air pollution forecasts are calculated simultaneously.

But as in numerical weather forecasting Eulerian air pollution models need initial fields and in case of limited area calculations also boundary values.

3.2.1.1.3 *Hybrid models*

Hybrid models have especially been developed to improve the simulation close to major point sources. By using a Lagrangean puff model the artificial broadening of the plume which is inevitable in Eulerian models can be avoided. In the vicinity of the source, puffs are calculated and transported along the trajectory until they have reached a magnitude where they have overlapped several mesh sizes of the Eulerian model. The puffs are then interpolated to the Eulerian grid and advected using the normal numerical methods.

This hybrid treatment has been successfully applied in emergency response calculations. But it is also used in air pollution models when very strong emissions from only a few point sources strongly influence the concentration fields.

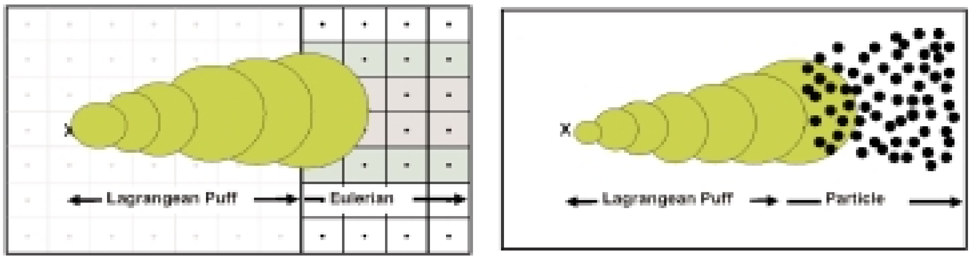

Figure 8—Schematic representation of hybrid models.

The Lagrangean puff model can also be combined with a Lagrangean particle dispersion model in order to use the more detailed wind field information further downstream of the source.

Examples for the application of hybrid models can be found in the Real-time On-line DecisiOn Support system (RODOS) which is implemented in several European countries. In the European version the transport of radioactive material is forecasted in the near field of the source by the Lagrangean puff model RIMPUFF and then handed over to the Eulerian model MATCH developed by the Swedish Meteorological and Hydrological Institute (SMHI). In the version used in Germany the Lagrangean particle dispersion model of the DWD provides the long range forecasts starting with the information of a puff predicted with RIMPUFF.

3.2.1.1.4 *Statistical models*

If many chemical species are involved air pollution forecasting may be very demanding with respect to computer time. Additionally, high quality emission data are needed to get a good forecast. It they are not available the air pollution forecast significantly looses its accuracy. In order to overcome these problems possibilities have been explored to get a forecast at lower costs. One typical method is to look for a correlation with meteorological parameters already available from the numerical weather forecasting.

There are at least two examples were the correlation with meteorological parameters can be used to generate an air pollution forecast. In both cases ozone is involved: ground-level ozone or stratospheric ozone as absorber of UV radiation.

In middle latitudes high concentrations of ground-level ozone develop under stagnant high pressure conditions during the summer. As these conditions also favour the increase of temperature a fairly close correlation between ozone concentrations and temperature has been observed. This has been used to develop different types of statistical models, auto regression models, neuro-fuzzy network models, statistical models based on Kalman filters and others.

One of the most simple models predicts the next day's ozone maximum $[O_{3max}]$ (t + 1) by:

$$[O_{3\max}](t+1)=k+a\,T_{\max}(t)+b\,T_{\max}(t+1)+c[O_{3\max}](t)$$

where k, a, b and c are regression coefficients. Other more elaborate models use a longer list of input parameters and correlation coefficients including wind velocity and speed, relative humidity, solar radiation and cloudiness, NO_x concentrations. Thus the model can be better adapted to the local conditions.

The regression equations for the total column ozone Ω and the ozone concentrations at pressure levels ω_k are quite similar:

$$\Omega^{(p)} = a_j + a_{0,j}\,\Omega^{(a)} + \sum_{k=1}^{M} a_{k,j}\,(T_k^{(p)} - T_k^{(a)}),$$

$$\omega_k = b_k + \sum_{l=1}^{N} (b_{k,l}\,T_l + c_{k,l}\,\Omega + d_{k,l}\,T_l\,\Omega)$$

where $T_k^{(a)}$ is the actual and $T_k^{(p)}$ is the predicted temperature at a number of pressure levels and a.., b.., c.. and d.. are regression coefficients. Neither the total ozone column nor the ozone concentrations directly depend on the temperature but there is a correlation between temperature changes in the tropopause region, vertical motion and total ozone. This is sufficient to produce an input to a radiation calculation which delivers a reasonable UV index forecast for the next day.

Statistical models are inexpensive models. They need neither a collection of emission data nor a complicated deterministic model. After the regression coefficients have been evaluated only a PC or a workstation is necessary to perform the forecast. But the correlation coefficients used in statistical models only reflect the present and regional conditions (e.g. emissions and geographical situation). Any changes or application to a different region require a recalculation of the statistical parameters.

Improvements in access to high speed computers, in our knowledge of emissions, and improved deterministic air pollution models lead to a shift from statistical to causal models. One example for this is the UV index forecast (see 2.2.2).

3.2.1.2 ***Requirements***

Different tasks and different model types imply that the requirements also differ. The only thing in common is the need for a weather forecast because this is the minimum input which all models need. Statistical models are satisfied with this input.

All other models need additional emission data and/or initial fields and perhaps information at the lateral boundaries.

3.2.1.2.1 *Initial fields*

Initial fields are always necessary whenever the result of the forecast depends on the specification of initial data. This is true for all Eulerian models except those used to predict a plume or puff emitted from an isolated point source (i.e. in emergency response situations). Initial data may also be needed as input to trajectory box models if the result of the computation significantly depends on the initial concentrations at the place and time of the start of the trajectory. This is especially true if the problem is dominated by transport. Within EMEP – the UN-ECE Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe – it could be demonstrated that the transport across the Atlantic Ocean influenced the result of the computation with the trajectory box model and that it could be improved by incorporating it as initial data for the trajectories.

Unfortunately, the current measurement network for air pollutants hardly supports the construction of sufficient initial fields due to the following factors;

- Observations are unevenly distributed with too many stations in the cities;
- Only a small number of species are observed;
- Most observations are performed close to the ground;
- There is no well organised international exchange of measurement data;
- There are only a few soundings and aircraft observations to get information from the third dimension;
- Only some species are observed from space with normally very low or no vertical resolution.

A Kalman filter approach is used in the Danish Atmospheric Chemistry FOrecasting System (DACFOS) which is based on backwards trajectories.

There is some very promising research under way including 4D-VAR schemes to generate initial fields for Eulerian models. But at the moment no operational scheme is available. Therefore, in most cases the initial fields are generated by the model itself using the forecasts of the pervious days. This strategy strongly depends on good emission data and an adequate model. The forecast of ground-level ozone starting from these initial fields yields results with a quality similar to the precipitation forecast. Thus there is room for improvement by generating better initial fields.

3.2.1.2.2 *Emission data*

Nearly all air pollution forecast models critically depend on emission data. Exceptions are only statistical models or models which treat stratospheric ozone as an inert tracer.

It is obvious that emergency response models which forecast the transport of air pollutants directly depend on information on emissions. As emergency response forecasts should reach the user as fast as possible source simulation models have been developed to generate information on emissions from damaged nuclear power plants, volcanoes, chemical installations, etc. From satellites the strength of emissions of forest fires can be estimated. But in each actual case the height, strength and composition of the source has to be evaluated or verified.

The preparation of emission data may be a very time consuming task if it is not possible to make use of already existing data. In most cases anthropogenic as well as biogenic emissions are involved. Obviously, the biogenic emissions depend on the actual conditions in the atmosphere (temperature, solar radiation, etc.) and the soil (availability of water). However, anthropogenic emissions are also influenced by the weather (amount of heating or cooling, human activities). Therefore, an emission model directly connected with the meteorological forecast would be the best choice. But normally the influence of meteorology on anthropogenic emissions is only taken into account by superimposing daily, weekly and annual variations over the basic data derived from the emission inventory.

During the last decades a lot of research - including field experiments - has been invested to improve emission data and inventories. Source-receptor relationships derived from air pollution simulation have been used to detect and to eliminate errors in emission inventories. In addition in order to get the best and comparable data guides have been published. One of these is the "EMEP/CORINAIR Emission Inventory Guidebook".

Satellite information is increasingly used to improve the emission data base. Examples for this are land-use data and the leaf-area-index (LAI).

3.2.1.2.3 *Boundary conditions*

Eulerian limited area models whether they are used for weather or air pollution forecasting need lateral boundary data. And in both cases the best choice is the nesting within a coarser scale model. When such a larger scale forecast is not available simpler solutions can be used. They range from:

(*a*) computation of boundary values with the help of a cheaper model like a trajectory box model;
(*b*) Using climatological values;
(*c*) Enlarging the integration area so that the forecast in the area of interest is not significantly affected by missing or imperfect boundary data.

3.2.1.3 *Validation of models*

All observational data, forecast products and forecast model outputs have to be verified to ensure that this information will effectively meet the needs of the public, the planners and the policy makers. With proper and regular assessment, product quality will be trustworthy and of high standard.

There are various stages of product verification, ranging from observed and analysed data to forecast products. All observed data have to be properly verified so that any instrumental errors could be detected through irregularity in the data. At the same time, instruments have to be properly maintained and regularly calibrated to ensure data accuracy.

The accuracy of atmospheric models must be validated as an indispensable part of the model development process so that users can assess the degree of reliability and accuracy inherent in a given model. As far as possible, forecast verifications should be produced in an objective way, free of human interpretation. The accuracy of a forecast is a measure of how close to the actual weather the forecast was. The skill of a forecast is taken against some benchmark forecast, usually by comparing the accuracy of the issued forecast with the accuracy of the benchmark. Reliability is the extent to which the forecast can be "trusted" on average.

The verification of air pollution models may be complicated due to the following:

- The measurement data are collected by different institutions, they are not freely available and in most cases not exchanged internationally;
- Individual measurements are not representative for a larger area, and the measurement networks are not planned to support verification;
- Measurements to derive information on vertical profiles are rare.

Successful attempts to establish national and international air pollution forecasting networks demonstrate that these problems are not insurmountable. New tools to check the representativity of data and to extract information from satellite observations are available. In several attempts the access to air pollution measurements performed by environmental protection agencies on national or regional levels and their (international) exchange have been successfully accomplished.

3.3 ENVIRONMENTAL EMERGENCY RESPONSE (EER)

Environmental emergency response covers all emissions to the atmosphere due to accidents. These may be accidents in nuclear installations, in chemical factories, during the transport, but also eruptions of volcanoes and bush or forest fires. Additionally there is a renewed discussion if damaged steamers (e.g. oil tankers) may be set on fire in order to prevent environmental catastrophes.

A common feature of these events is:

- They are rare events which may happen any time but normally without prior announcement;
- Because of this neither meteorologists nor decision makers are very familiar with the results and the reliability or the atmospheric transport calculations;
- In most cases the air pollutants are emitted from point sources;
- At the beginning of the event often only incomplete or nearly no information is available.

3.3.1 Requirements

Environmental emergency response poses special demands. Additionally due to the reasons listed above, a fast reaction is required because air pollutants are emitted which are an immediate threat to human health. This may include that only measurements of dangerous or toxic air pollutants are available but no source information.

An environmental emergency response system therefore has to fulfil the following requirements:

- It has to forecast the transport of dangerous air pollutants very fast and based on minimum input information;
- If only measurements are available but no information of a potential source a backtracking model is necessary.
- Good communication between all institutions and organisational units involved in emergency response has to be established. This includes:
  - regular tests and exercises, as well as
  - the production and distribution of guidance material;
- As specific data are rare new additional data have to be made accessible or produced. These may be tracer experiments or additional observations in case of an accidents.

Consequently, the forecasting systems of many NMHSs as well as of the Regional Specialised Meteorological Centres (RSMCs) for EER consist of

- A trajectory model which can quickly compute the path of a polluted air parcel; and
- An air pollution model which can forecast concentration and deposition values.

As it can be expected that in the early phase of an accident only few source data are available, default values of starting heights and the vertical distribution of emissions have been agreed and implemented.

With respect to **nuclear accidents** a close cooperation with the International Atomic Energy Agency (IAEA) and regular communication tests make sure that all NMHSs will get all available information via the GTS. Air pollution forecasts and a verbal description are produced by the designated RSMCs* for EER.

A similar cooperation exists concerning **volcanic ash** whereby nine Volcanic Ash Advisory Centers (VAACs) have been established.

Chemical accidents are normally small scale events. In most cases the dangerous concentrations are limited to only few kilometres around the source. Therefore, forecasts on the meso scale are needed. If heavy gases are involved the affected area may be even smaller. In most cases the time to produce a reliable forecast and to distribute it to the user may be very short. Thus, the first requirement is that meteorological data on this small scale can be provided. Though non-hydrostatic weather forecasting models are becoming operational at some NMSs they normally cannot be used for this purpose because of their too long computing time. Therefore diagnostic models for the boundary layer are needed.

Emergency response systems may also be applied to forecast the spread of **biological material** like infectious Foot-and mouth decease (FMD) virus. The Danish Meteorological Institute (DMI) has presented a study where a local scale model and a virus production model have been added to its emergency response system (DERMA).

An adequate emission model is also the main prerequisite to handle the airborne transport in case of bush or forest fires.

3.3.2 Tracer Experiments and Exercises

Tracer experiments and exercises are necessary because real accidents are (fortunately) rare events (no major release of radioactivity to the atmosphere after Chernobyl) and therefore additional data are needed to validate and improve model systems and practical experience has to be gained through exercises.

* Beijing, Obninsk and Tokyo for Asia, Montreal and Washington for the Americas, Exeter and Toulouse for Europe and Africa, Melbourne for South West Pacific

3.2.2.1 *Tracer experiments*

Neither the meteorological measurement network nor that of environmental protection agencies can provide data which allow a validation of transport model calculations starting from isolated point sources. Therefore, the model validation and improvement is severely hampered. The only possibility to get data are tracer experiments where an inert tracer is emitted and measured. Whereas several small scale or local tracer experiments have been performed the number of large scale experiments is limited. After the Chernobyl accident only one tracer experiment - the European Tracer EXperiment (ETEX) - was organized based on the experience gained by the two experiments over the North American continent CAPTEX (Cross Appalachian Tracer Experiment) and ANATEX (Across North America Tracer EXperiment).

Large scale tracer experiments are expensive and time consuming. The organization of ETEX by WMO, IAEA and the European Community (EC) took more than two years. A trace gas had to be selected and the background concentrations originating from earlier experiments had to be determined. The measurement devices had to be built or modified. Trajectory analyses and three dry runs were performed to select the best place, time, and conditions for the release. 168 samplers had to be distributed and installed in 17 European countries. Finally, in October and November 1994 two releases took place accompanied with real time forecasts from 24 institutions world wide and measurements from 3 aircraft during the first release. During the following years the data set has been repeatedly used. The most prominent example is the ATMES II exercise where the best available data from the European Centre for Medium range Weather Forecast (ECMWF) were provided to the group of participating institutions which had grown by 11 new members from America, Asia, Australia and Europe. The preparation of ETEX and the evaluation of the results of ETEX and ATMES II were accompanied by a series of meetings and publications.

The results and achievements of ETEX can be summarised as follows:

(*a*) ETEX real time experiment: Most of the models showed differences of 3 to 6 hours in arrival time and a factor of 3 in surface maximum concentrations. There is a satisfactory agreement between model results and measurements after 24 hours following the start of the release;

(*b*) ATMES II - reanalysis and use of meteorological data from ECMWF: The quality of the model results could be significantly improved not only because of a better meteorological data base but also because the ETEX data had been exploited to improve the model itself;

(c) For this exercise which consisted of a release from a point source, Lagrangean models (and especially Lagrangean particle dispersion models) demonstrated their superiority;

(*d*) The organisation of a large scale tracer experiment is a complicated, time consuming and expensive action. But it is indispensable to improve air pollution forecasts in cases of emergency response. During ETEX only the forecasts during westerly flow conditions could be tested. Further experiments covering different synoptic situations are necessary.

3.3.2.2 *Emergency exercises*

Experience shows that nearly no exercise happens without any problem, deficit or new questions. Either some fax or phone numbers are incorrect, measurement stations do not give a feed back, end users ask why a computed trajectory has changed its curvature in the new update run. Thus exercises are indispensable in order to minimise the problems in case of a real accident.

In an emergency many actors from different levels (local, national, international, meteorologists, environmentalists, politicians and decision makers) have to work together. Exercise plans have therefore to be developed to cover all situations. With respect to nuclear accidents, WMO has recommended principles of environmental emergency response exercises which are published in manuals or can be downloaded from the Internet.

The basic framework is given in Table 3 on page 26.

3.3.3 Collaboration with responsible authorities

Only in a few countries are environmental issues treated within the NMHSs. Moreover, the direct reaction to emergencies is the task of police, fire brigades or health institutions which themselves are attached to different government authorities. Thus in case of nuclear accidents the national focal points of the IAEA are often the ministries of internal affairs or of environment or even offices attached directly to the bureau of the prime minister. On the other hand, the expertise on meteorology and transport of air pollutant is concentrated at the NMS with additional support by the WMO and its RSMCs. Additionally both sides, NMSs and national focal points will be informed via separate information channels. Therefore, a good cooperation between the different authorities is necessary. All partners have to be informed and be aware of the individual tasks and experience of their counterparts. Even if an administrative action is strongly recommended by decision support system like RODOS or ARGOS, government departments should bear in mind that any meteorological and air pollution forecast has a limited predictability and needs an interpretation by a meteorologist.

A common method to study the skill of forecasts is through ensemble predictions. Compared with NWP ensembles based on modified initial fields or different NWP models, air pollution ensembles show an even larger spread when different atmospheric transport models are used. The construction of the best ensemble which allows to quantify the uncertainty of the forecast and to make probability statements is still under development. For the moment the ensemble predictions need a proper interpretation by meteorologists and are not suited to be handed over to decision makers. But in the future they may be included in decision support systems.

Even if the deterministic and ensemble forecasts are improved and can be directly used in follow-up models like decision support models, regular tests are needed to improve the cooperation of the different authorities.

	National	*Regional*	*Global*	*Special **
Coordinator	Appropriate national authority	WMO Regional Association	WMO/CBS	As appropriate
Purpose	To establish and strengthen the linkages between NMSs and IAEA contacts at national level	To strengthen the linkages between RSMCs, NMSs and IAEA at national and international levels	To strengthen the linkages between WMO, IAEA and other international agencies	To maintain preparedness with respect to pre-identified critical tasks
Frequency	At least twice a year	Once a year	18 months	
Communications	Notification, and products dissemination	Notification, coordination and products dissemination; should be done frequently for night and day scenarios	Notification, coordination and products dissemination; should be done night and day on a rotation basis	As required to maintain preparedness with respect to the critical tasks
Operations	As required based on national structures and procedures	Comparison and coordination of modelling results	Coordination of modelling results	
Product standards	User feedback on standards; coupling of standard products within national systems and databases	User feedback on standards	User feedback on standards	
Product Interpretation	Get feedback whether products are understandable	Get feedback on whether products are understandable; products intercomparison	Get feedback on whether products are under-standable; products intercomparison	
Assessment	Internal among national authorities	Done jointly by the RSMCs involved	Done by the WMO expert(s) using the inputs from all the participants	

* Details for special exercises are left open since the emphasis will change from one case to the other. Examples of such exercises are the monthly tests that RSMCs Montréal, Washington and Melbourne are doing for nuclear accidents or the communication tests between IAEA and RTH Offenbach.

Table 3—The basic framework for environmental emergency response exercises

3.4 ROLE OF NMSs

As the forecasting of atmospheric pollution is closely connected to the expected movement and nature of air masses, i.e. weather forecasting, all NMSs have important roles to play, nationally, regionally as well as globally. Many of these environmental issues are trans-boundary. Regional efforts in setting up environmental networks as well as information and resource sharing among NMSs will help in the effort to combat and reduce the impact.

3.4.1 Operational database

The operational database needed for air pollution forecasting includes:

- Meteorological data;
- Emission data; and
- Measurement data.

As meteorological data are normally provided by NWP models and a short summary on emission data and emission models has been given in 3.2.1.2.2 this paragraph will concentrate on measurement data.

3.4.1.1 *Environmental networks*

Though several measurements of atmospheric pollutants have been performed decades ago the systematic build up of measurement networks started in the 1950's. Following the discovery that the acidity in precipitation and in lakes in Scandinavia was increasing more and more, and when this was attributed to emission of sulphur from burning coal and oil and of nitrogen oxides in other parts of Europe, a monitoring and evaluation programme with a Europe-wide measurement network was set up. Thie programme later became the UN-ECE Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP). During the same time many countries started or enlarged their radioactivity measurement network because of the nuclear bomb tests. During the 1970s the threat of CFC's to the ozone layer and the potential global warming by the build-up of greenhouse gases in the atmosphere resulted in an intensification of observational programmes.

Up to now a great number of air quality networks have been set up which range from the global scale and climatological questions to the local and urban scale.

WMO started its Global Ozone Observing System (GO_3OS) in 1957, which then in 1989 became part of the Global Atmosphere Watch (GAW). GAW itself is connected with five data centres (ozone and UV, solar radiation, greenhouse gases, aerosols, precipitation chemistry) and more than 20 international networks and programmes.

Several regional networks and programmes have been established e.g.

- Acid Deposition Monitoring Network in East Asia (EANET);
- Air Pollution Information Network Africa (APINA);
- North American Research Strategy for Tropospheric Ozone (NASTRO);
- Programme for the Assessments and Control of Pollution in the Mediterranean Region (MEDPOL);
- European Monitoring and Evaluation Programme (EMEP) and European Environment Information and Observation Network (EIONET).

Finally, the measurement and observing activities are complemented by national or urban networks which are in most cases organised by environmental protection agencies or municipalities.

The radionuclide network set up by the Preparatory Commission to the Comprehensive Test Ban Treaty (CTBTO) is not available for air pollution forecasts due to confidentiality.

Though still a lot of gaps exist with respect to area coverage and species observed, the combination of data from all these networks allows a relatively good level of monitoring. These datasets are also extremely important for analysis and forecast and are necessary as input for environmental models. They should be shared with disaster and emergency agencies to plan out strategies and draw on past experiences to put forward the best plan in the cross-sectorial effort to reduce the impact of environmental hazards. Databases need not necessarily be at national level only but can also be at a regional level and information can be shared among the countries in the region.

3.4.1.2 *Surface observations and vertical soundings*

Surface monitoring networks with well-distributed monitoring stations form the back bone of air pollution data collection. These observations provide the basic data

- To diagnose the changes in the earth's atmosphere;
- To identify the need for research and greater understanding of the natural and man-made processes involved;
- For chemical data assimilation; and
- For model evaluation.

Some of the monitoring networks include

- Acid rain monitoring network, where rainwater samples are collected over a prescribed period of time and analysed for the presence of calcium, lead, manganese, iron, nickel, copper, magnesium, zinc, mercury, potassium, sulphate, nitrate, chloride, fluoride and ammonia as well as the conductivity and pH of the rainwater;
- Dry deposition network, where low volume sampler is used to collect aerosol samples on filters. The exposed filters are then analysed for acidic components;
- Air quality monitoring station, where high volume samplers or high volume PM-10 or TSP Samplers are used to monitor suspended particulates in the air;
- Ozone monitoring network Ozone monitoring network, whereby the vertical ozone profile can be measured by ozonesonde and the total column ozone observations can be made with a Brewer Ozone Spectrophotometer;
- Surface automatic atmospheric environmental monitoring network, including gases such as SO_2, No_x, CO, CO_2, and O_3. Particulates of PM10 and PM2.5;
- Atmospheric background monitoring network, where high volume samplers or high volume PM-10 samplers are used to monitor suspended particulates in the air, gases, pollutants such as SO_2, No_x, CO, CO_2 and O_3. Aerosols and solar radiation are also monitored automatically;
- National radioactivity measurement networks which normally have a higher spatial density for gamma dose monitoring and some nuclide specific measurements.

For numerical weather prediction it is a well-known fact that assimilation of measurements of vertical profiles of certain meteorological parameters has a large positive impact on the forecast skill. Regarding vertical concentration profiles of air pollutants this might also be the case for regional air pollution forecasting. However, apart from a few measurement campaigns, there is currently little known about the possible impact from measurements of vertical concentration profiles of air pollutants on the forecast skill for regional air pollution models. There are only some vertical profiles of ozone available from soundings performed one to three times a week at selected places. They are carried out with ordinary meteorological radiosondes equipped with light-weight ozone monitors. The sparseness of data is due to the costs of the instruments, which are lost in the soundings.

In case there is a sufficiently strong demand for profile data, it might be considered to use other methods. For instance, today many routine passenger aircraft are equipped with automatic instruments, namely, Aircraft Meteorological Data Relay (AMDAR), which measure a number of meteorological parameters while the aircraft is in flight. From a technical point of view, it would possibly be a simple task to add ozone monitors to such systems. Another possibility is the use of kites, which in recent years have been used for stratospheric ozone research in Arctic areas. The kites are made of high-strength light-weight material, and the instruments, which are mounted with a collar, are moved up the string holding the kite by the wind and are pulled back again by a thin line. This operation can be carried out many times per day – and the instruments are not lost. For regular use close to populated areas and air traffic corridors there are of course a number of safety issues to consider. A third possibility is ozone Lidars.

In emergency response situations some countries may additionally measure radioactivity and/or chemical species by using aeroplanes or helicopters. Equipping the research or leased aircraft with radioactivity monitors under emergency conditions and the subsequent measurement of vertical cross-sections has already been tested within the European Tracer Experiment (ETEX). In such cases a good feed back between forecasting and measurements is necessary because forecasts are needed to plan the flight track and then may be updated by using the observations. Helipods which allow the measurement of meteorological parameters as well as chemical species up to 100 m below helicopters are under development. They may significantly improve the results of air pollution modelling in case of chemical accidents because these measurements will improve the knowledge on the source and chemical species involved and the parameters governing the spread of the plume.

3.4.1.3 *Satellite data*

Satellites, both polar-orbiting and geostationary, have provided observations from instrument measurements providing continual datasets of global total column ozone measurements. Some of the products are listed below.

Total Ozone Mapping Spectrometer (TOMS) on board the Nimbus-7 platform produces a data set of global total column ozone measurements. The primary TOMS data product is total column ozone abundance in units of milliatmospheres per centimetre, commonly referred to as the Dobson Units (DU), which is the total amount of ozone in a 1-cm column extending from the ground to the top of the atmosphere.

The Earth Probe/TOMS which was launched in 1996 was positioned into a lower orbit to complement the ADEO/TOMS instrument to cover the development of the Antarctic ozone hole in the Austral spring as well as Arctic conditions during the northern hemisphere spring. On the other hand, the ADEOS/TOMS launched aboard the Japanese Advanced Earth Observing System (ADEOS) in 1996 was placed in a higher orbit and provides global coverage of total column ozone on a daily basis.

Moderate-Resolution Imaging Spectrometer (MODIS) is a multi-spectral cross-track scanning radiometer designed to measure parameters related to biological and physical processes on a global scale. The spectral bands of the scanning radiometer produce very high spatial resolution data products such as cloud cover, cloud optic thickness, aerosol optical depth and cirrus cloud cover which are useful for UV modelling.

Ozone Dynamics Ultraviolet Spectrometer (ODUS) is provided to NASA by the National Space Development Agency of Japan (NASDA) that will provide daily global ozone measurements in a similar fashion to TOMS instruments. Total column Nitrogen dioxide and volcanic sulphur dioxide emissions are also expected to be retrieved from the measurements.

Tropospheric Emission Spectrometer (TES) is a high-resolution infrared Fourier transform spectrometer that can operate either in a limb-scanning mode to derive vertical profiles of species such as ozone or in a downward-looking mode where it can provide high-resolution local coverage or global coverage of integrated column abundances of several atmospheric species.

The development of satellites dedicated to atmospheric composition measurements has long focussed exclusively on the stratosphere (e.g. TOMS, and the Upper Atmosphere Research Satellite, UARS). Recently, instruments such as MOPITT (carbon monoxide and methane) and IMG (methane), the Global Ozone Monitoring Experiment (GOME: ozone profiles, nitrogen oxide, and formaldehyde) have begun to explore the tropospheric composition. It is still difficult to extract information about the boundary layer from these instruments because they are hampered by clouds and for some species like nitrogen oxide only yield column observations. However, the techniques to retrieve lower atmospheric concentrations are in rapid development.

In the near future the SCIAMACHY and MIPAS on ESA's Environmental Satellite (ENVISAT) launched in 2002 will yield further information on tropospheric concentrations of ozone and its precursors. Similar opportunities will arise with the launch in 2004 of NASA's EOS AURA satellite with Ozone Monitoring Instrument (OMI) and the Tropospheric Emission Spectrometer (TES) on board. OMI has a relatively high spatial resolution that will allow it to look down to the surface in between the clouds. A series of three GOME-2 instruments are planned to be successively launched by EUMETSAT from 2006 onward. It can be expected that satellite data will play an increasing role in air pollution modelling and will improve the data assimilation significantly.

3.4.1.4 *Data exchange*

The exchange of air pollution data is not well developed and is a weak point which inhibits air pollution forecasting. Although a lot of data are exchanged within the framework of international programmes, this happens only a long time after the measurements. Thus they may be used for research and model improvements but not for data assimilation and ongoing model validation as is the case for NWP models.

On the other hand, some examples and research initiatives show that data exchange which supports air pollution forecasting can be organised as described below.

- Within the European Union radioactivity measurements may be exchanged using a specially developed data format;
- Ozone soundings are collected by the Chemical Coordination Centre (CCC) of EMEP;
- The air pollution forecasting consortium of France consisting of Météo France and different research institutions receives ozone measurements from the surrounding countries.

These examples demonstrate that an international transfer of air pollution data is possible. To support this a specification of the needed data and of formats is necessary. At a workshop on ground-level ozone forecasting which was jointly organized by the Network of European Meteorological Services (EUMETNET) and the European Environmental Agency (EEA) the participating members from research institutes, environmental agencies and meteorological services from Europe and the United States recommended that

- Ozone measurements data should be made publicly available on the Internet, preferably using a standard format. The data should appear in near real time, i.e. with a maximum delay of 6 hours. The measurement stations should include rural sites and should be less than 200 km apart;

- In addition to ozone, but with a smaller priority, real-time measurement data should be available for other air pollutants of relevance for the photochemical mechanism, viz. CO, NO_x and a few VOC compounds.

3.4.2 Operational forecasts

It is expected that states should inform their citizens on the state of the environment and on possible adverse effects on health. The inclusion of operational air quality forecasts in public weather bulletins can assist the public to take action with respect to air pollution and photochemical smog. Even if the nature of the problem will not allow to achieve an immediate reduction of air pollution levels, it may help the individual citizen to limit negative health effects by avoiding polluted areas or reducing of outdoor activities.

In countries where air pollution levels defined in national or international guidelines may be exceeded, an operational forecasting system or access to results of such n system is the best prerequisite to fulfil the obligation of informing the public. Even if the forecast itself is produced by a research institute or an environmental agency it should be distributed together with the weather forecast to reach the public. But as the air pollution levels are not so well known (as compared to temperature and other meteorological parameters) easily understandable indices or explanations may need to be provided.

In the cases of accidental release of hazardous material it is the primary task of a NMHS to give advice and information to government authorities responsible for emergency response which will then inform the public.

3.4.4 Reasons for the responsibility of NMSs

Weather can affect air quality in many ways. Formation of tropospheric ozone, transboundary pollutants and toxic air pollutants as well as dispersion and trajectory of these pollutants are very much dependent on the existing weather condition. Forecasting air quality relies very much on the current as well as on the predicted weather conditions.

One way weather can affect air quality is through high temperature and bright sunlight, the right conditions for the formation of ground-level ozone. The higher the temperature and the more direct the sunlight, the more ozone is produced.

Wind direction also affects ozone and other air pollution levels. For example, during the South-west monsoon in South-east Asia, the weather over the region is generally drier. The nomadic farmers in Sumatra and Kalimantan in Indonesia generally still practice traditional slash-and-burn shifting cultivation and with the drier weather in the region, they normally burn the field during this season. With the prevailing south-west wind, these pollutants are blown across to Malaysia and Singapore causing widespread haziness and unhealthy air quality.

The atmospheric profile also affects how quickly pollutants move away from a region. However, if a temperature inversion is present, then these pollutants are trapped inside and can't escape and after a while they may build up to unhealthy levels.

Many of the air quality models also include the weather forecast model as one of the components and/or require weather input. The weather parameter is very much an integral part of an air quality model. With the importance of the weather component in the prediction of the air quality, the NMS has to take on an important and active role in the prediction of the air quality.

3.5 COLLABORATION WITH NATIONAL AND INTERNATIONAL ORGANIZATIONS

3.5.1 WMO and other international organizations

Strong inter-governmental relations, good inter-organizational relations and conducive foreign policy will influence regional and international cooperation with regard to air pollution. Air pollution can be a transboundary problem (emission from one country being transported to another country) or a common problem shared by neighbouring countries. When problems are transboundary, relations amongst countries can become strained if there are no regional understanding and cooperations with regard to sharing of information, expertise and positive commitment.

The WMO's Global Atmosphere Watch (GAW) integrates many monitoring and research activities involving the measurement of the chemical and physical properties of the atmosphere. GAW serves as an early warning system to detect further changes in atmospheric concentrations including acidity and tosicity of rain as well as atmospheric content of aerosols. Approved by the WMO Executive Council in 1989, GAW provides framework design, standards, intercalibrations, and data collection systems for global monitoring and data evaluation. The Global Atmosphere Watch Measurements Guide (No. 143) provides a detailed description of the importance and methods of measurement of atmospheric gases, aerosols, radioactive substances, solar radiation and atmospheric deposition.

On the research side WMO has coordinated a number of projects under GAW. One of the most recent projects is WMO GAW Urban Research Meteorology and Environment (GURME) project which was started in 1999 in response to the requests from NMHSs. Because of their capabilities to collect information that is essential for the forecasting of urban air pollution and the evaluation of the effects of different emission control strategies, NMHSs have an important role to play in the study and management of urban environments. WMO established GURME as a means to help enhance the capabilities of NMHSs to handle meteorological and related aspects of urban pollution through coordination and focusing of current activities. More information about GURME can be found on the following Web site:

http://www.wmo.ch/web/arep/gaw/urban.html

On the operational side, WMO participates in environmental emergency response activities. By including members from IAEA, ICAO and CTBTO into its coordination Group for Emergency Response Activities (CG-ERA) WMO stresses the need for international cooperation. Eight RSMCs for atmospheric transport modelling further demonstrate WMO's active role.

3.5.2 National

At the national level air pollution activities are organized differently from country to country. Whereas in some countries NMHSs are entrusted with monitoring as well as modelling, in most cases the responsibilities are shared between the NMHS and environmental or health agencies at national, provincial and municipal levels. Additional research institutes play an active role in monitoring and model development and application. This may have the consequence that in some countries several daily air pollution forecasts are available, based on either the same meteorological forecast from the NMHS or on different meteorological data (own NWP model or from other centres). It depends on the conditions in each single case if the division of responsibilities and tasks inhibits the development and improvement of air pollution forecasts or leads to a fruitful competition and cooperation. An example of such a combination forecast is presented in Figure 9.

In contrast to the somehow complicated situation in routine air pollution forecasting (no forecast or a large number for the same region) there is normally (if any) only one forecast in cases of emergency response. In most cases NMHSs are entrusted with the responsibility for atmospheric transport calculations of radionuclides released by nuclear accidents in order to get only one forecast based on the best available meteorological information. This "single-voice-principle" is essential in all cases of emergency response.

Compared with modelling the establishment and maintenance of air pollution monitoring networks is very expensive. Therefore, the different partners need to cooperate in a very effective manner. Meteorological and air pollution measurements are either performed at the same site or the meteorological data needed to interpret the concentration measurements are shared between the partners.

In Malaysia for example, the Malaysian acid deposition monitoring network comprises of 22 stations throughout the country. All these stations are equipped with automatic wet-only samplers to collect rainwater samples over a prescribed period of time. The sampling frequency selected for wet deposition sampling is weekly. The samples are then analysed for the following elements: calcium, lead, manganese, iron, nickel, sodium, copper, magnesium, zinc, mercury, potassium, sulphate, nitrate, chloride, fluoride and ammonium. Additional instruments are also located at selected stations whereby the concentrations of acid gases are measured using passive and active samplers. Aerosols samples are collected with a low volume particulate sampler for determination of chemical composition.

In Germany the gamma dose monitoring is performed by the Federal Institute for Radiation Protection and the nuclide specific measurements by the DWD. The observations are then stored in a common data bank from where they can be retrieved by all partners at the provincial and national level.

3.5.3 Regional

At the regional level, coordinated efforts can be carried out by regional organizations to provide necessary tools, training, and general information for smaller nations in the region in the effort to provide better information on air quality. This is especially so if the air quality of the whole region deteriorates due to transboundary pollutants. An example of this effort is the Asean Specialized Meteorological Centre (ASMC) in

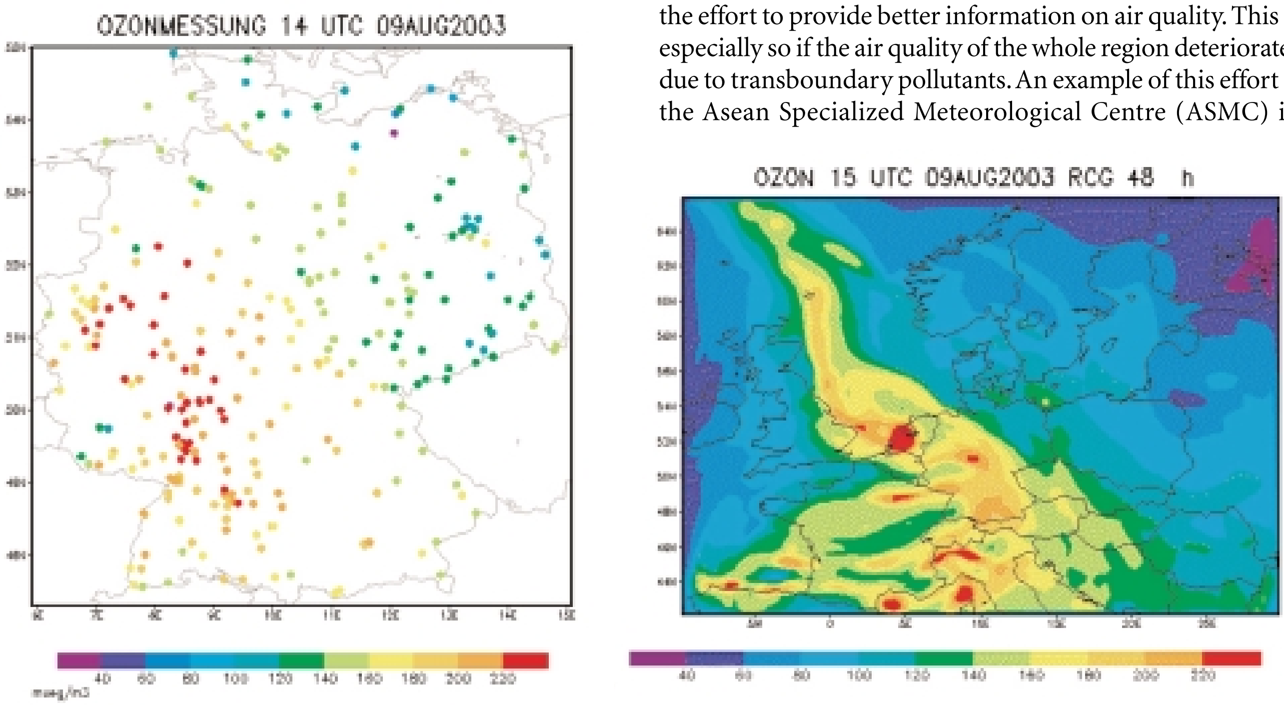

Figure 9—48h ozone forecast and measurements valid August 9, 2003

Meteorological forecast:	*German Weather Service*
Air pollution forecast:	*Free University of Berlin*
Measurements:	*Environmental Protection Agencies in Germany*

Singapore which provides daily hot spots locations of possible fires in Sumatra and Kalimantan in Indonesia, superimposed on the current prevailing surface wind chart as well as satellite imageries showing the hot spots locations and smoke plumes.

In Europe many models of all types from statistical to deterministic Eulerian have been developed to forecast ground-level ozone concentrations and in some cases also PM10 for various regions from the continental down to the urban scale. The major problem is that it is not always easy to find the place where the results are presented and that a validation and model intercomparison is missing. This will be achieved in the future by a new web portal called EFnet (Environmental Forecasting network) which is planned by the EUMETNET Working Group on Environment as a "system for ozone and aerosol forecasts for Europe operated by NMS cooperation".

3.5.4 International collaboration between NMHSs and research institutes

The scientific problems concerning atmospheric chemistry and the modelling of the transport, dispersion and deposition are far from been solved. Therefore, close collaboration between relevant WMO programmes, NMHSs and research institutes are necessary and should be further encouraged.

Some examples of existing cooperations are:

- In Australia, there are close collaboration between the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Bureau of Meteorology whereby the Australian Air Quality Forecasting System has been developed. The Bureau of Meteorology generates the high quality weather forecasts and CSIRO has created computer models to calculate pollution levels;
- WMO and several NMHSs from Europe and North America are active partners in European Monitoring and Evaluation Programme (EMEP);
- The European Tracer Experiment (ETEX) was commonly organized by WMO, IAEA, the Joint Research Centre (JRC) in Ispra and several weather services including the follow-up projects RTMOD and ENSEMBLE.

Chapter 4

OUTLOOK

There is no denying that NMHSs have an important role to play in environmental issues. With the already well-established global network of weather observing stations and a well-connected global telecommunication network (GTS), NMHSs only need to enhance their observation programmes to include environmental monitoring. Many of the air quality models also include weather forecast models as one of the components and/or require weather input. With the changing atmospheric conditions and the demand from the general public, it is becoming increasingly necessary to include air quality information as part of the routine weather forecasts issued.

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- *Global Atmosphere Watch Measurements Guide* No. 143
- *Global Solar UV Index – A Practical Guide*