Chapter 1

GENERAL

This Chapter was written by Kees Stigter, Wolfgang Baier, Ian Barrie, Orivaldo Brunini, Helmuth Dommermuth, Zipora Gat, René Gommes, Tom Keane, Chan Ah Kee, Jacob Lomas, James Milford, Andres Ravelo, Derk Rijks, R.P. Samui, Sue Walker, Wang Shili and Albert Weiss

The Chapter was heavily internally reviewed and parts were externally reviewed by Zipora Gat and Wolfgang Baier

External coordination was done by Kees Stigter

1.1 SCOPE OF AGRICULTURAL METEOROLOGY

Agricultural meteorology is concerned with meteorological, hydrological, pedological and biological factors affecting agricultural production and with agriculture's interaction with the environment. Its objectives are to elucidate such effects, and then to assist farmers to prepare themselves by applying this supportive knowledge and information in agrometeorological practices and through agrometeorological services (parts of Chapter 1 dwell on these issues and Appendix I illustrates all the above with essential literature).

Agricultural meteorology of land surfaces spatially extends from the soil layer of deepest plant and tree roots (pedosphere), through the air layer near the ground in which crops and trees grow and animals live (Chapters 9 to 12 of this GAMP), to the higher levels of the atmosphere in which processes such as the transport and dispersal of dust, seeds and pollen take place (Chapters 14 and 15). Its fields of interest go from agricultural (including horticultural) production (Chapters 9 and 10), forestry (Chapter 11), animal husbandry (Chapter 12), fisheries (Chapter 13) and other forms of outdoor (e.g. Chapter 16) and indoor (Chapter 9) production, agricultural planning (Chapters 5 till 7 and 17), processing, transport and storage (with examples in various Chapters) to agrometeorological components of food security (Chapters 6 till 8 and 14), poverty reduction and sustainable development aspects of the livelihood of farmers/producers (other parts of Chapter 1, Chapter 17) as well as of the use of their products (e.g. Chapters 6 and 9). Many other Chapters show details for these fields under their own subjects.

In addition to large and meso scale climate and its variations (e.g. Chapters 5 and 8), operational agricultural meteorology concerns itself with small scale climate modifications as brought about for example by wind breaks, irrigation, mulching, shading and frost and hail protection (Chapters 7 and 9). Other important subjects are agroclimatic characterisation (e.g. Chapters 5, 9, 14), pests and diseases and their safe control (Chapters 7, 9, 12), covered agriculture (Chapter 9), quality of agricultural products (Chapter 9), animal comfort aspects (Chapter 12), plant production for other than food purposes, including biomass as a renewable energy resource (Chapter 10), and ecological considerations (e.g. Chapters 7 and 16). Much attention is paid to (preparation for) the impacts of climate change and climate variability (Chapters 5 till 8 and 17), including phenological aspects (Chapter 6), monitoring (Chapters 4, 14), early warning (Chapters 4 till 8) and estimation of changes of the risks related to pests and diseases and to extreme events such as drought, desertification and flooding (Chapters 7 till 9, 14 and 15).

Specialised agriculture such as monocropping over large areas can be inimical to biodiversity while intensive agriculture affects the environment through the generation of air, soil and water pollutants, greenhouse gases (CO_2, methane and nitrous oxide), ammonia and tropospheric ozone. Other modes of production cause soil erosion by wind and water. Thus agricultural meteorology has a major role to play in understanding of emissions and pollutions from various unsustainable production systems (Chapters 7, 14, 15). Water management to ensure adequate supplies while maintaining the quality of surface and groundwater is a key topic (Chapters 8, 10). Applications to aquaculture and fisheries (food aspects, Chapter 13) range from site climatologies, hydrodynamics of rivers/reservoirs, estimation of contamination from agricultural run-off and of other ecosystem stresses, to using meteorological factors to predict the occurrence of toxic algal blooms.

Support systems to agrometeorological practices and services comprise data (so quantification, details in Chapter 2 till 4), research (Chapters 10 till 16), training/education/extension (Chapters 1 and 17) and policy environments (e.g. section 1.4). Especially in industrialized countries mathematical models are increasingly used in operational agricultural meteorology (e.g. Chapters 6, 11), in conjunction with Geographic Information Systems (GISs, Chapter 4) to provide inputs to Decision Support Systems (DSSs, also Chapter 17). These models have utilised meteorological observations (Chapters 2 till 4) but now there are also the outputs of operational numerical weather prediction and of climate prediction (Chapters 5, 8). These forecasts may be exploited to increase the utility of models to decision makers (Chapters 5 and 6) but this remains extremely difficult in practice (Chapter 17). Remote sensing provides access to additional biophysical parameters, e.g. vegetation indices and surface temperatures. Incorporation of such data into models is being undertaken (Chapters 4 and 6). The enormous potential of agrometeorological information and services (Chapter 17) makes the training of farmers and supportive environmental managers in the use of agrometeorological practices and services a matter of great importance (section 1.4).

There is overlap in subjects between various Chapters. This is how it should be, because the overlapping subjects are each time viewed from the different perspectives of these Chapters. In the Chapters of the GAMP referred to above, many specific references are given. Compared to the former edition, the emphasis is even less on basic agrometeorological sciences but wants to prepare more for agrometeorological services and information for decision makers (Stigter, 2007). A more detailed impression of what is presently considered to be in the scope of agrometeorology and its applications can be obtained from Sivakumar et al. (2000) and Salinger et al. (2005). This Guide has made a selection of Agricultural Meteorological Practices, within the scope given above and detailed in these two publications, through the choices of the agrometeorological volunteers that collaborated in writing, reviewing and facilitating it, guided by the CAgM Expert Team on the GAMP.

1.2 IMPORTANCE OF AGRICULTURAL METEOROLOGY

There is hardly a branch of human activities as dependent on the weather as agriculture. Agricultural production is for a large part still dependent on weather and climate despite the impressive advances in agricultural technology over the last half a century. More than ever, agrometeorological services have become essential because of the challenges provided to many forms of agricultural production by increasing climate variability and associated extreme events as well as climate change. They all affect the socio-economic conditions, especially of developing countries.

1.2.1 General importance

Knowledge in time and space of available environmental resources and on conditions from below the soil surface through the soil-air interface into the boundary layer of the atmosphere provides essential guidance for strategic agrometeorological decisions in long-range planning of agricultural systems. This applies to both favourable and unfavourable conditions and all are varying a great deal. Typical examples are designs of irrigation and drainage schemes, decisions related to land-use and farming patterns, and within these choices selections of crops and animals, varieties and breeds, and farm machinery.

In modern agriculture, ecology and economy are on equal terms; through environmental issues they are even interdependent. Shortage of resources, destruction of ecological systems and other environmental issues are becoming ever more serious. The large scale and uncontrolled use of chemical fertilizers and plant protection products is not only a burden to the environment but to quite a considerable extent to the farmer's budget, too.

Detailed observations/monitoring and real-time dissemination of meteorological information, quantification by remote sensing (radar and satellites) and derived indices and operational services are important for tactical agrometeorological decisions in short term planning of agricultural operations at different growth stages. A well organized, where possible automatic production and a co-ordinated dissemination of this information and related advisories and services are essential. Tactical decisions include „average cost"-type decisions in low external input sustainable agriculture (LEISA), regarding timing of cultural practices, such as ploughing, sowing/planting, mulching, weeding, thinning, pruning and harvesting. They also include, particularly for high input agriculture, „high cost"-type decisions, such as the application of water, extensive chemicals and the operation of costly crop-protection measures.

Regardless of the type of decision, an ever improving understanding of the effects of weather and climate on soils, plants, animals, trees and related production in farming systems, is necessary for decision makers (farmers and managers); to make timely and efficient use of meteorological and climatological information and of agrometeorological services for agriculture. To these ends choices have to be made of the right mixture and blending of traditional adaptation strategies, contemporary knowledge in science and technology and appropriate policy environments. Without policy support systems for agrometeorological services, yields with the available production means will remain below optimal (section 1.4).

1.2.2 Applications

The practical application of this knowledge is linked to the availability and accuracy of weather and climate forecasts or expected weather and climate patterns, depending on the time scale. The requirements range from accurate details of short-range weather forecasts (less than two days), via medium range forecasts (less than ten days) at certain critical times, to seasonal predictions of climate patterns. Development plans should not be rendered meaningless by a significant change in weather and climate behaviour. Therefore indications of possible climatic variability, and of increasingly frequent and serious extreme events in the context of global climate change, are necessary as agrometeorological services in addition to the application of other agrometeorological information.

Reliable long-term weather forecasts relevant to the agricultural community are not yet available on a routine basis all over the world. However, significant services may be provided by means of agrometeorological forecasts such as on the dates of phenological events, the quantity and quality of crop yields, and the occurrence of animal and crop epidemics. These forecasts make use of established relationships between weather effects at an early stage of development and the final event expected some time after the date of issue of the forecast. This approach of „crop prediction without weather forecasting“ is particularly promising for the assessment of crop conditions in order that potential production anomalies may be recognized and quantitatively evaluated as early as possible. Surpluses and deficits are organized in long-term planning or occur nationally, regionally and globally. Long-term planning of global food production must therefore take into account the effects of year-to-year fluctuations in weather patterns, as well as potential climatic variabilities and changes, on crop yields.

The global climate is influenced by a lot of factors. Two of the most important components are CO_2 and water vapour in the atmosphere. Beside the oceans, forests absorb CO_2 and release water vapour. Burning forests produce considerable masses of CO_2. So it is necessary to promote reforestation and protect forests against fire and human beings as well as against other destruction, such as by insects, diseases and pollutants. Forest meteorology as a component of agrometeorology provides useful information and services for application to the forest authorities, the foresters and in case of forest fires to the fire-brigades. Various reliable forecasting methods for probabilities of start and spread of forest fires were developed around the world that are in operational use.

Agrometeorological services in developing countries have to shoulder greater responsibilities due to greater population pressure and changing modes of agricultural practices. More and more demands pertaining to agrometeorological information and services are expected from the farming communities in the future on technologies, farming systems patterns, water management, weather based pest and disease control etc., preferably with local innovations as starting points. Thus the future challenges include the necessity to emphasize a bottom up approach so that forecasts, specific advisories and contingency planning reach even the small farmers for applications in their planning and day-to-day agricultural operations.

Agrometeorological services in developed countries focus on the provision of environmental data and information to national policy and decision makers; in support of sustained food production, sustainable development, carbon sequestration in agro-ecosytems and land management practices that affect exchange processes of greenhouse gasses. Because developed countries may have or develop technology to initially adapt more readily to climate change and climate variability, technology transfer may play a certain role but local innovations remain most important for application under the very different conditions in developing countries. Organizations such as WMO/CAgM, FAO and INSAM are playing a role, and will have to play an increasing role, in stimulating development and establishment of agrometeorological services and dissemination of agrometeorological information.

Advisories include among others (i) in drier climates information on average sowing date as well as expected sowing dates for the ongoing season, at various temporal and spatial scales, as well as on operational crop protection of all kinds and (ii) in more humid climates information on pest and diseases attacks, all based on weather information and agrometeorological services in location specific and user-friendly format. Other examples of important advisory fields that require attention are:

- Management and modification of microclimate.
- Preparation for environmental risk and disaster mitigation to increase protection and lower vulnerabilities.
- Prediction of El-Nino and other rainfall variability for agricultural planning.
- Information on weather based pesticides/insecticides applications.
- Meteorological information for planning, scheduling and guiding irrigation and drainage.
- Arial transport of pollutants and knowledge regarding low level winds for operational activities.
- Workday probabilities (e.g. in planning and scheduling soil cultivation or marine and lake fishing).
- Agrometeorological services for farmers on a regional level to strengthen and provide accurate forecasts and advisories for the farming community.
- Communication of information in a format/language understandable to users.
- Highland and mountain agriculture.

In more advanced agricultural production, with potential for technology transfer where the absorption capacity exists, we may add:

- Crop weather modelling with special emphasis on crop growth simulation models.
- Development of complex data collection systems and speedy processing and interpretation of large spatial data collections.
- Geographical information systems and their use for crop planning at smaller than present scales.

- The use of remote sensing technologies to generate information/ advisories for large areas.
- Quantifying Carbon sequestration.
- Use of audio-visual media and internet facilities for quick dissemination of information to the users.

Forecasts of significant meteorological phenomena that result in issuance of advisories and warnings for sufficiently long lead times are of tremendous value. Early warnings against natural disasters not only help to save the crop or reduce the damage, by adopting quick strategic planning, but also to advance or postpone agricultural operations. Dissemination of such warnings to the end users on a real time basis with the help of electronic media may become a key factor for crop production and protection.

1.2.3 Conditions and requirements

The effect of climate change on stream flow and ground water recharge are expected to follow projected changes in precipitation. The projected climate change could further decrease the stream flow and ground water recharge in many water stressed countries. On the other hand demands for sharing of water are likely to increase in industries and municipal areas due to population growth and economic development. This is likely to affect irrigation withdrawals, which depend on how increases in evaporation are offset by changes in precipitation. Higher temperatures leading to higher evaporative demands would cause an increase in irrigation demands in many countries.

Crop growth simulation assessments indicate that yield of some crops in tropical locations would decrease generally with even minimal increase in temperature under dryland/rainfed agriculture. Where there is also a large decrease in rainfall, tropical crop yields would be even more adversely affected. Some studies indicate that climate change would lower incomes of the vulnerable populations and increase the absolute number of people at risk of hunger. Climate change, mainly through increased extremes and temporal/spatial shifts, would worsen food security in some parts of the globe.

The economic value of weather information products is steadily increasing due to public awareness over the years. Facilities for data quantity and quality control, quick processing and analysis have made this possible. Thus generation of information and issuance of products on real time basis to the farming community for socio-economic activities have become possible, but organizing of such services is required. Although quite a lot is yet to be done, there are various specific agrometeorological requirements where beginnings have already been made. They are:

- Agroclimatology for land use planning and crop zonation.

- Operational crop monitoring and agrometeorological practices based on output of crop growth simulation models.
- Rainfall reliability statistics with respect to planting dates (date of sowing) and crop calendars.
- Weather requirements for crops and input applications.
- Forecasting and management strategies for droughts and floods.
- Some pests and diseases monitoring and operational crop protection using weather based warning models.
- Microclimatic management and manipulation.

Agrometeorological services in the form of technology recommendations appropriate at field level are often required for decision making processes of farmers. Limits imposed by availability of production resources can be well understood by using:

- Geographic information systems for easy retrieval and updating more recent data.
- Delineation of agrometeorological zones using environmental resource information.
- National level planning with expected outputs of production.
- Information on crop management such as cropping pattern, fertilizers, sowing/planting time etc.

No matter how favourable or unfavourable weather events are distributed over the globe, there remain, in the long run, insufficient food supplies to feed the world population adequately at its present rate of increase. This can only be changed when agricultural technology is greatly improved, natural resources are more efficiently used and national and international agencies responsible for planning and managing food supplies are provided with up-to-date information on crop conditions and potential crop failures as a basis for their decision-making.

The major role of present-day agricultural meteorology on a global scale is therefore to ensure that, under appropriate support systems, adequate and useful agrometeorological data, research tools and training are available to agrometeorologists, and relevant agrometeorological services to planners and decision-makers, in particular farmers, to cope with a variety of agricultural production problems. Local and regional organizations that are assuming their local parts of this role should find international organizations such as WMO/CAgM, FAO and INSAM ready to guide them in these matters. Recently adopted new structures and recent new initiatives in agrometeorology have to make this increasingly possible.

This section was written and internally and externally reviewed by the contributors respectively the reviewer typically from their own experiences of long years in agrometeorology. Because the GAMP does not want to be a textbook, neither specific nor general references, that each contributor could easily deliver for the above, appeared therefore to make sense at this introductory stage. If readers need more general introductions to all aspects of agricultural meteorology they should see the literature in Appendix IA, and for didactical purposes we refer to Wieringa and Lomas (2001). An agrometeorological core library, selected relevant WMO publications and references to a didactically balanced text in agrometeorology are also given there (see also Annex 1D to section 1.5). They were also included in the Appendix I.

1.3 ROLE OF THE COMMISSION FOR AGRICULTURAL METEOROLOGY (CAgM)

The Commission for Agricultural Meteorology is one of the eight technical commissions of the World Meteorological Organization, a specialized agency of the United Nations. Further background information may be obtained from the WMO Basic Documents and the current WMO Annual Report. A short history of the Commission for Agricultural Meteorology has recently been issued (WMO, 2006) and more details can be found there.

The definition of the role of the CAgM, as a “Statement of Need” in a CAgM vision document of 1999, is “to promote agrometeorology and agrometeorological applications for efficient, sustainable food, fodder and fibre production for an increasing world population in fastly changing environments”. CAgM motivates its Members to supply all needed agrometeorological services, such as agrometeorological advisories and relevant forecasts to the agricultural communities, for improved planning and operational activities.

The Terms of Reference of the CAgM (Annex IA) were kept without change, unlike the trend in the other Technical Commissions of the WMO. In Florence, at CAgM X (1991), and in Havana at CAgM XI (1995), it was explicitly decided to keep the Terms of Reference as they were. In Havana it was proposed that the Commission should give indications at that and each future session on their interpretation under new conditions. The CAgM Advisory Working Group then composed the vision document mentioned above under the title “CAgM Towards 2000 and Beyond” that was endorsed by CAgM XII (Accra, 1999) and WMO XIIIth Congress (Geneva, 1999). The Terms of Reference of the Commission were to be considered in the context of the “Statement of Need”.

At each CAgM session the actualization of these broad Terms of Reference is in the establishment of the contents of the working structure.

CAgM XII (Accra, 1999) was the last meeting where Working Groups and (joint) Rapporteurs were nominated for the various topics. A new working structure was decided on in CAgM XIII (Ljubljana, 2002) based on Open Programme Area Groups (OPAGs), Implementation/Coordination Teams (ICTs) and Expert Teams (ETs). Their new and rich structure, contents and composition are available on the CAgM web site. They were brought into operation to meet the new conditions in agrometeorology at the beginning of this new century, but still in the same guiding context of the broad original Terms of Reference. The new structure keeps the following continuing trends: more regional representation, strengthened links to the regional associations and increasing participation of experts from developing countries.

The responsibilities of CAgM are clearly defined in its terms of reference (Annex IA), established by WMO Congress, and actualized by the 1999 WMO/CAgM International Workshop on "Agrometeorology in the 21st century – needs and perspectives", in Accra. According to these terms, the Commission is responsible for the development of agrometeorological services of Members. The transfer of information to the agricultural communities should lead to the most practical use of knowledge concerning weather and climate for agricultural purposes. Use can be made of the most suitable products from what in Accra were called agrometeorological support systems in the fields of data, research, education/training/extension and policies. The trends within the Commission's role, towards more emphasis on applications of results of research and on operational services to agriculture, as indicated in the previous issue of this Guide, have been increasingly strengthened over the past two decades.

To further exemplify the contents of CAgM's responsibilities it held the 2002 WMO/CAgM Workshop in Ljubljana on "Reducing vulnerability of agriculture and forestry to climate variability and change". Intensive discussions took place on combating and mitigating increasingly severe natural disasters, and adaptations to their occurrences. It was concluded that in many countries the present conditions of agriculture and forestry are already marginal, due to degradation of natural resources, the use of unadapted technologies and other stresses. Developed countries have the technology to adapt more readily to the projected climate changes although shifts in cropping patterns can be disruptive. The ability to adapt is more difficult in the tropics and subtropics and in countries in transition.

In the new CAgM structure complying with these changing priorities, the Open Programme Area Groups (OPAGs) were established in exactly these three new key areas of the Agricultural Meteorological Programme of WMO:

- Agrometeorological services for agricultural production

- Support systems for agrometeorological services

- Climate change/variability and natural disasters in agriculture

The remaining priority issue of agrometeorological education/training and extension and that of support systems in policy making for agrometeorological services will be taken up throughout these key areas. For these priority issues separate coordinators have been appointed in the Management Group (MG) of CAgM. The use and applications of such an approach should also lead to decreasing costs and increasing efficiency in the use of water, labor, energy and other inputs.

Important challenges for the role of the Commission remain:

(i) to raise the interest and involvement of National Meteorological and Hydrological Services in agricultural meteorology;

(ii) to strengthen contacts and cooperation with relevant staff of Ministries of Agriculture, institutes of agricultural research, agricultural planning bodies etc., working as teams with intermediaries between applied science and farmers whenever needed and possible;

(iii) to strengthen the orientation of agrometeorology towards the clients and their needs;

(iv) to fill the gaps between the providers of agrometeorological products and the actual agrometeorological services in the livelihood of farmers.

In the context of these challenges, the Commission should pay attention in a very near future to policies on training and equipping extension intermediaries in agricultural meteorology in developing countries. In this way one may avoid mistakes made in agricultural extension in a number of developing countries, that tried to use provincial agrometeorologists and agricultural demonstrators that were not sufficiently trained and equipped. The role of the Commission will in this respect particularly be to advise on policies related to the training of such intermediaries. As well as to assist in the transfer and adaptation of actual agrometeorological services with which these intermediaries can make a difference in the livelihood of the majority of farmers that have not yet been reached.

1.4 TOOLS AND MECHANISMS IN AGRICULTURAL METEOROLOGY

For the planning of programs for agrometeorological services, supporting the decisions and actions of producers, and related training (section 1.5) and cooperation (section 1.6), it is important to recognize two basic challenges (also section 1.6). These are: (i) understanding the ways in which agrometeorological support systems and agrometeorological services are related (mechanisms) and (ii) realizing the wide spectrum of problems encountered and decisions to be taken in agricultural production in relation to weather and climate for which such services should be developed. This can only be done by using available tools as operationally as possible. To that end it must be clearly understood that agrometeorological information and services for governments and private organizations are different from those that were developed, or need to be developed directly for and/or by various groups of farmers.

1.4.1 ***A diagnostic and conceptual framework*** (an operational link between support systems and services)

A recent picture of that relationship under (i) above was derived from an initial recognition of the existence of a factual separation between these services and those support systems (Stigter et al., 2000). This was obtained from papers presented at the 1999 WMO/CAgM Workshop in Accra on "Agrometeorology in the 21st century - Needs and Perspectives (Sivakumar et al., 2000a). The separation was illustrated by interposition of a so-called B-domain to further increase the operational character of applied agrometeorology (Stigter, 2003a, 2007). This B-domain was positioned between an A-domain of the livelihood of farmers, in which operational agrometeorological services have to be established, and a C-domain of agrometeorological support systems (in what Daniel Murdiyarso at first sight called a simple diagnostic and conceptual framework, ANNEX IB, e.g. Stigter, 2004; 2005; 2007; Stigter et al., 2005a).

The B-domain contains the initial and boundary conditions for solving the problems mentioned under (ii) above that exist in the A-domain. The B-domain is suggested to have three components: (1) improved (traditional indigenous) adaptation strategies based on farmer innovations, (2) functionally selected contemporary science and technology and (3) an understanding of prevailing policy environments. These components may be supposed to form the operational building blocks of agrometeorological services. One of these components being incomplete will jeopardize the mechanisms of establishment of operational agrometeorological services (E2 in ANNEX IB) that can make a difference in the A-domain, the livelihood of farmers (Stigter, 2005).

Because low external input farming in developing countries is most vulnerable, and because generally less formally educated and more marginal and poorer farmers are found there, the problems of farming systems in such regions need major attention. In addition, higher input farming in industrialized countries constantly has to find new adaptation strategies, which require local and global support systems and policies. Such differences between various groups of farmers in industrialized highly urbanized countries and slowly urbanizing slowly industrializing regions need considerable differences in approaches (Stigter, 2005). The spectra of problems encountered related to weather and climate are very different.

The C-domain containing the basic support systems holds areas in which agricultural meteorology is best developed. From the beginning four types of support were identified: (basic) data, research, training/education/extension and policies (Stigter et al., 2000). Utilizing their wide possibilities, a first increase in using the support systems operationally in applied agrometeorology provided what may be summarized as "agrometeorological action support systems on mitigating impacts of disasters" (E1 in ANNEX IB). These are the early scientific/technological tools developed for problem solving in agrometeorology. Disasters being defined here as all weather and climate related events that have a strong negative impact on yields (quantity and quality) and/or farmers' income.

With the mechanisms having been dealt with above, some of these important agrometeorological tools are introduced below, where also some problem areas tackled by these systems to mitigate the impacts of disasters and the operational limitations encountered in those areas are exemplified. These will also be widely dealt with in the remainder of this Guide. This, however, already shows and supports the need for another increase in the operational use of tools, in the B-domain, leading to the much wider establishment of actual agrometeorological services directly supporting decisions/actions of farmers in the A-domain.

1.4.2 ***Agrometeorological research*** (basic, applied and derived operational research as tools)

Basic research in agricultural meteorology is an important part of the group of basic support systems of the C-domain. Applied agrometeorological research has played an important role in developing many of the other (E1) supportive tools that we will further discuss below. However, our acknowledgement of the existence of a B-domain and the recognition of the realities of the A-domain, in which agrometeorological services have to be made supportive to the actions of producers (E2), make it necessary to also characterize another class, of "derived operational" research. In the B-domain this operational research is derived from the necessity to constructively bring together and use the three building blocks of agrometeorological services. In the establishment of supportive agrometeorological services in the A-domain, this research is derived from the necessity to get such services operational for and with the farmer communities concerned, to better prepare them for disasters.

Many suitable research findings or products based on such findings are not at all transferred to the farmer's field through extension (Stigter, 1999). Too many of the products of research lay idle and will never be used supportively (Sivakumar et al., 2000). Agrometeorological research as a support system particularly needs constant regional, national and local prioritization, but as long as farmers do not get benefits out of need solving extension services based on research output, the latter remains limited to E1 support systems only (Murthy and Stigter, 2006). The Accra symposium derived the following research needs (Stigter et al., 2000):

- efficiencies of the use and management of resources, including the whole production environment: climate, water, light, nutrients, space (above and below the soil surface), germplasm, biomass;
- research on agrometeorological aspects of management in agriculture at different scales for different purposes;
- validation and application of models (e.g. phenology; morphological predictions; yields), limitations of models, models for specific users;
- research methods and approaches at the eco-regional level, including the assessment of socio-economic effects of weather/climate variability on food production;
- determination of the impact of climate change/variability and matters of climate forecasting and prediction in general;
- research on the reduction of impact of natural disasters (including pests and diseases and anthropogenic hazards);
- consideration of ways to ensure that results of research are adopted by farmers: holistic, interdisciplinary field studies, of sufficient duration and coordination, on the operational scale;
- natural climate variability.

This rewritten Guide to Agricultural Meteorological Practices attempts to show how much of the above is presently already attended to and how much the present research trends should change to become better in line with the above. The wording of the above research needs also confirms the necessity of more research work in the B-domain and the A-domain. It has been suggested that a database of sound and dependable supportive ("derived") research results should be developed by agrometeorologists in various application fields. Ongoing research programs may have to be recast by looking much more functionally into the problems and priorities for developing and organizing operational agrometeorological services for specific farming systems (Murthy and Stigter, 2006).

1.4.3 ***Data, quantification, statistics and beyond, from indices to modeling, in agrometeorology*** (primary research tools)

The availability of adequate and quantitative agrometeorological data is an absolute prerequisite for analyzing, researching and managing production processes in agriculture, including livestock and forestry. The observation of meteorological conditions of importance in agricultural production encompasses physical measurements, from the upper level recordings of radiosonde equipment, to the soil surface and then some depth below it, where nutrient movements occur towards root systems. Recent advances in communication and computer technologies have allowed the establishment of measuring systems at different geographic scales such as experimental fields, farms, cropping areas, administrative or eco-climatic regions and countries.

Quantification by physical methods is the basis of researching and understanding of processes that explain phenomena determining growth, development and yields of important plant and animal species in agriculture. When the extent of measurements is limited, agrometeorological indices are a first attempt to relate phenomena like drought or erosion (semi-)empirically to such observations. A limited research approach to understand which factors are most involved in occurring phenomena is the use of more complex statistics beyond the classical statistics of data adequately sampled in space and time.

When cause and effect relationships are better known, mechanistic modeling assembles such knowledge to mathematically represent the processes involved, while still using empirical values for parameters and even empirical representations of sub-processes wherever necessary, to simulate phenomena, but error analyses are often weak (e.g. Monteith, 2000). Unfortunately even these days, in many fields of agricultural research, statistics are still relied upon too frequently and the principles and advantages of the tools of the physical approach, also outside modeling, are insufficiently recognized and applied.

In many poorer countries agrometeorological observations remain grossly inadequate, and are still a major concern as well as a limiting factor for operational purposes, but improvements have been made in quantifications in general (see Chapter 2). New, low cost and reliable networks, including automatic ones, form the core of many private networks in urbanized industrialized countries, supplementing the networks supported by National Meteorological and Hydrological Services (NMHSs). Archiving, retrieval and display systems are also rapidly improving there and provide essential links between those who collect observations and the larger communities that can understand and utilize them.

Long-term good quality and parallel climate and agricultural records are necessary as tools for agrometeorological research and services. Data collection and management should continuously be the focus for improving and maintaining good agrometeorological services and information. Processing, quality control, archiving and timely access are other components making agrometeorological data valuable for research and direct applications. This all applies to classical routine data as well as to more specific data necessary from within agricultural environments and specific agro-ecosystems.

1.4.4 ***Agrometeorological monitoring and early warning*** (tools to warn using preparedness strategies)

Observing and measuring agrometeorological parameters with sufficient density in time and space has created monitoring systems that can be used as tools to follow developments and where necessary issue warnings. From observing the phenology of crops through to using satellite acquired data we may have adequate insight on conditions in the agricultural environment by continuous monitoring. Remote sensing (RS) techniques are playing an ever increasing role in local and global monitoring systems. This trend is expected to continue following the launch of new satellite platforms - e.g. MeteoSat Second Generation (MSG) with enhanced capability in the area of environmental monitoring.

Geographical Information Systems (GISs) are computer assisted tools for the acquisition, storage, analysis and display of geographic data, including agrometeorological ones. GIS technology is an expansion of cartographic science, enhancing the efficiency and analytic power of more traditional methodologies (Maracchi et al., 2000). The facilities offered by versatile software like GIS and the internet are rapidly transforming many of the standard functionalities of data monitoring systems. Integrating GIS and RS data provides a platform for wider applications of agrometeorological information. Integrating thematic layers in GIS databases with a Digital Elevation Model (DEM) greatly enhances the accuracy and usefulness of the spatial distribution of such topographic information on a grid basis, which provides a three-dimensional representation of the land, started from contour lines. This is a basic information layer in agrometeorology for GIS applications, such as in comprehensive zoning for agricultural planning and the determination of climatic suitability for crops, for example in mountain areas or with changing climates.

Monitoring as such only becomes an agrometeorological service if those to whom the results are made available can access, absorb and apply the results as tools for decision making without further assistance, or when specific assistance is available to react or to teach how to react. The same applies to early warnings based on such monitoring. Higher educated and richer farmers are therefore normally better off, while marginal and poorer farmers need either other kinds of services or extended measures as part of the agrometeorological services, to better prepare for using early warnings as tools in operational mitigation of consequences of disasters.

1.4.5 ***Forecasting and prediction in agrometeorology*** (tools to guide preparedness with probabilities)

Just like most of the tools already exemplified above, forecasting and prediction in weather and climate for agricultural production will be extensively discussed in this Guide. Agrometeorological decision making in agricultural operations for well growing crops or crops endangered by pests, diseases and/or other environmental disasters needs weather forecasting and climate prediction where that is possible to the required accuracies. Much progress has been made scientifically and successful applications in industrialized countries have increased, also for example with respect to heat and cold stress forecasting systems in poultry and sheep. Results with richer farmers in developing countries, related to predictions of sowing date, timing of irrigation and fertilizer use strategies are slowly on the rise but the probabilistic character of forecasting remains one of its larger difficulties in wider applications.

It has been noted recently that multilateral agencies are urging that climate forecasts be made available to small farmers (Blench, 1999). Disaster preparedness strategies, both of governments and NGOs, have begun to take account of such forecasts and there is considerable interest in assigning them an economic value. However, field studies of the impact of recent forecasts in southern Africa and north-eastern Brazil suggest that there is presently still a considerable gap between the information needed by poor, small scale farmers and that provided by NMHSs and other governmental institutes. This was confirmed by investigating the role of intermediaries (Stigter, 2004).

A number of crop monitoring systems and yield forecasts are now being implemented worldwide, upscaling to regional scales being an important trend. In these, commercial crops like soybean, maize, wheat, sorghum etc. are continuously monitored and forecasted for/by government and private institutions. Crop-weather models that are mainly used for operational yield forecasting and prediction of phenological development have been generated for a large number of crops. They have different degrees of complexities. More mechanistic models are now available but many of these models need to be further refined and tested before widespread practical application may be expected. Current research is focusing on detailed soil-water-crop relationships, determining adjusted crop genetic coefficients, bridging simulation model outputs with user needs for applications and developing practical decision support systems. They should after all address the composite problem of global climate, regional weather variability, agricultural productivity, decision making and economic responses. They have therefore barely been used in non-urbanized, non-industrialized countries (Meinke et al., 2001), but some adaptation and testing is taking place.

For real-time forecasts in agrometeorology, the reliability of regular, specialized information is critical. A common problem encountered in some countries is the general lack of reliability in these forecasts, which leads to a lack of trust in them (e.g. Jagtap and Chan, 2000). Despite advances in related technologies, there are few other areas than agriculture where accurate short and extended period forecasts can create such a material benefit. There is an important distinction between systems, which supply tools leading directly to solutions/services, rather than forecast information in isolation. Farmers often have difficulties in interpreting weather forecasts and intermediaries between these products and agrometeorological services based on these products are in such cases highly valued (section 1.5).

1.4.6 ***Agrometeorological aspects of crop, forest and livestock protection*** (direct preparedness strategies)

Weather effects on plant, tree and animal discomfort and injury, as well as crop, forest and livestock losses are highly complex. Protection can take the preparative form of (a) planning crops, varieties and sites to avoid or mitigate the effects of the relevant meteorological extremes detrimental to plants or (b) improving sites to reduce or avoid the impact of these extremes. Response farming is the best example of the former (Stewart, 1991). Microclimate management and manipulation is the best example of the latter (Stigter, 1994). There are three main issues that have to be addressed. Firstly, growing plants are exposed to direct weather hazards (frost, floods, drought, moving sand etc.). Secondly, the biology of many crop, forest and livestock pests and diseases are influenced by both current and past weather conditions. Finally the harvesting and storage of crops is strongly influenced by weather conditions at the time of harvest and through to the post harvest period.

Arguably, the key role of meteorologists in crop, forest and livestock protection is one of offering better preparedness strategies by environmental avoidance or mitigation through improved understanding of the processes and phenomena involved. To this end, good progress has been made worldwide in local strategic planning of crops, trees and animals as well as their varieties, in irrigation techniques and strategies, and in crop storage design and management. Also general and sometimes location specific information on the occurrences of droughts and floods, heat waves and cold or dry spells, frost or hail or blasting sand, strong winds and other extreme events, have improved. In all these cases, however, preparedness strategies with agrometeorological components can be drastically improved, particularly for small-scale farmers in general and marginal and poor farmers in particular. Case studies should be collected in which agrometeorology related measures with small cost/benefit ratios have been successfully taken to locally reduce damage to agricultural production in disaster preparedness management (Stigter et al., 2003).

Equally agrometeorology can play a significant role in reducing the negative impacts caused by pests and diseases. An appropriate, preferably integrated, pest management system using meteorological and microclimatological information can reduce pre- and post-harvest losses appreciably. Agrometeorologists are now collaborating not only in the experimental stages but also during the operational stages of pest and disease control. The tactical use of weather information in the prediction of pest and disease development allows for near optimum use and timing of pesticides and/or release of predators. Progress in the latter areas has been considerable in industrialized countries, with many examples of nationally based warning and prediction systems. However, collaboration at the international level has been less evident, possibly due to the empirical nature of most of the operational models. Exceptions to this would for example include the CERES range of crop models, where international co-operation has been excellent. Participative integrated pest management introduction using farmer field classes has also met with some successes in non-industrialized countries.

Increasing variability of rainfall increases risks in livestock production systems, especially in drier areas. Because of this, pastoral or fully nomadic livestock systems, which are probably among the most efficient in exploiting niches of low productivity areas in arid and semi-arid regions, are declining. This trend is expected to continue and countermeasures have already led to several serious conflicts between nomads and sedentary farmers. Infrastructure such as roads and watering points are exacerbating negative environmental effects by encouraging resource use beyond the carrying capacity of the land, which already in some places has led to desertification (Onyewotu et al., 2003). Resorting to feed supplements as a preparedness strategy may be one part of the land protection solution. Services on animal disease forecasts are only available in some richer countries.

Major applications of meteorology and climatology to forest operations include pest and disease control, frost protection and fire prevention. In many cases, meteorological data collected by NMHSs are sufficient for use by foresters in management and protection operations. Specialized observations are necessary in relation to biomass moisture and combustibility, and may be made at forest fire stations. Foresters have developed forest fire rating systems, which combine and translate relevant meteorological variables and properties of combusting materials into indices that indicate the vulnerability to fires and their subsequent spread. These indices are used in daily management of forested areas subjected to forest fire risk. Also long-term records of these indices can be used for planning purposes.

1.4.7 ***Policy matters related to agrometeorology*** (initial and boundary conditions set by socio-economics and the environment)

All the major international conventions, to which most countries are now committed, emphasize that governments should implement policies aimed at greater sustainability (Sivakumar et al., 2000b). The various projects implemented under the WMO Agricultural Meteorological Programme covered some of the key issues in such sustainable agriculture (WMO AMP WebPages).

Policy matters when considered as tools may not be explicitly in the present terms of reference of CAgM, but one of the challenges of the Commission derived in section 1.3 was: "to fill the gaps between the producers of agrometeorological knowledge and the actual agrometeorological services in the livelihood of farmers". The framework in Appendix IB was developed to show the gaps and the mechanisms to fill them. Policy matters occur twice. Under the basic support systems, basic policies should be considered to be any policy matters that foster the development and application of other relevant agrometeorological tools. The preceding sections have exemplified such tools as well as their limitations as far as farming was concerned. The optimum operational use of agrometeorological knowledge in agrometeorological services developed in the domain of the livelihood of farmers is the key function to which these tools have to contribute. Proper incorporation of agroclimatic considerations in the development of improved farming strategies requires a much longer time frame than has been used in the past (Sivakumar et al., 2000b).

Appropriate policy environments are given as one of the building blocks of agrometeorological services in the B-domain, in which initial and boundary conditions are determined for solving well identified problems in the livelihood of farmers through such services. In general these initial and boundary conditions are set by the prevailing social and economic concerns/constraints and by environmental considerations (see also the sections on resources assessments below). Norse and Tschirley (2000) worded the paradigm transformation that technological change should no longer be driven by science but by environmental objectives and social concerns, like farmer innovations are, operating through the market where appropriate. This way knowledge should be made most operational.

Suitable policies for the determination of the most appropriate preparedness and adaptation strategies, to improve and protect crops/forests/animals, their yields and income generation, have to do with local, (biased) international and global markets and prizes as well as their manipulation. They have to do with infrastructural and other facilities (such as for education/training/extension and related to health services) as well as with the basic policies mentioned above. Social and environmental constraints in preparedness strategies have to be met by special policies as tools that can make those farmers that do need this most also benefit most from agrometeorological services. Without in this way changing the initial and boundary conditions in problem solving, marginal and poor farmers will remain without proper operational services geared to their particular needs.

1.4.8 ***Climate resources assessment for agrometeorology***

There are a few issues related to resources that should be separately dealt with from the point of view of agricultural meteorology. Resource assessment as a tool is basic to agrometeorology because without a proper agricultural resource base and its protection from (further) degradation, development can not be sustainable.

Rational use of climate information in agricultural production still requires knowledge of two types, (a) specific influences of climatic factors on the growth and development of living organisms throughout their physiological cycle (or what may be called their climatic requirements); (b) climatic characteristics specific to a given farming area expressed in basic statistical terms. Recent interest and concern related to increasing climate variability and climate change needs to be able to assess the influence of changes in (b) as consequences for (a). Farmers and other policy makers want to know whether climatic resources are changing in character or value and consequently are becoming more threatening or are easing limiting factors in agricultural production.

The following tools are current good practice in the assessment of climate resources in agrometeorology (in a sequence of diminishing applications):

- determination of crop weather/climate requirements;
- classification of land into crop suitability zones, integrating both climate and soil factors;
- fitting appropriate probability distribution functions to all climatic elements (of different periods, because of climate change) for a better description of their behaviour with respect to their tendencies and variabilities;
- determining in more detail differences in impacts of climatic events, particularly recurring events like (ENSO or not ENSO related) droughts, floods, cyclones under different preparedness strategies.

The use of climate in for example land-use planning, scheduling agricultural activities and preparing crop calendars as well as in crop, forest and livestock protection have benefited the agricultural communities of many regions, but there is still insufficient use of such information in poorer nations. Information like (changes in) return periods, frequencies of occurrences & intensities of extreme events and assured rainfall in different growing periods are valuable in (changing) choices for preparedness strategies. The effectiveness of such agrometeorological services depends increasingly on abilities to handle large volumes of ground and remotely sensed data and the skills to generate from them timely, useful and relevant services and information for farmer communities and to get them actually applied. For this last activity the use of agrometeorological intermediaries has been proposed (see section 1.5).

1.4.9 *Water resources assessment for agrometeorology*

Planning water use amongst numerous types of consumers in towns, industry, recreation and agriculture is currently the basis of water resources assessment. Because of the scarcity of water in many places of the world, prudent water management and increasing water use efficiency are essential, the more so in arid and semi-arid regions. Good examples of traditional methods and farmer innovations in efficient water management were collected by Stigter et al. (2004).

Global and national policies and strategies are now being developed to increase awareness of water shortage, promote water conservation and water harvesting, redress mismanagement of ground water, increase water use efficiencies (including changes in cropping patterns), promote the use of additional sources of water and promote recycling of water. Even in more humid areas, where dry spells have always been a widely occurring serious problem, increasing climate variability and climate change are forcing water use planners to adopt and promote more efficient water use and water management techniques.

In many nations, substantial resources have been used to monitor floods and droughts and to design appropriate irrigation and drainage systems for agriculture. Water budget/balance calculations, including elaborate evapotranspiration calculations based on physics and plant factors, and soil moisture determinations are widely applied tools in water waste determinations and water use planning in agriculture at the level of policy makers. To use such assessments as tools in developing agrometeorological services for farmers is appreciably less advanced, particularly in non-industrialized countries.

1.4.10 *Soil resources assessment for agrometeorology*

Climate and weather affect the chemical, physical and mechanical properties of soil, the organisms it contains and its capacity for retaining and releasing heat and moisture. Rainfall, on the one hand, adds chemical constituents to the soil but, on the other hand, washes out soil nutrients. Weathering is an important factor in determining the nature of soil. Topsoil composition, vegetation cover with surface contact and local weather factors largely determine the existence and extent of the problems of wind and water erosion. The state of the soil as affecting cultivation, pest control and harvesting is also much influenced by weather conditions. The above picture given in the former Guide is still sufficient for a first soil resources assessment in agrometeorology. The in that Guide also already signaled loss of valuable agricultural land to urbanization, recreation and industrialization was rechallenged in Accra (Sivakumar et al., 2000a).

Soil degradation has chemical and physical components but both are of importance in soil resources assessments. With the system of soil mining and abandoning (slash and burn or shifting cultivation) no longer extensively possible, due to lack of land, degrading soils because of insufficient contents of organic matter and nutrients have to be much more widely confronted. Exposed agricultural land losing topsoil from effects by wind and water must be stabilized and covered, preferably for purposes such as perennial grassland or afforestation that keep the soil covered in economically useful ways (see also 1.4.11). Deterioration of soil composition, flora and fauna and groundwater pollution by excessive applications of manures and fertilizers worries agronomists in many places.

Detailed information on physical characteristics of different soil types in a region, like bulk densities, field capacities, wilting points and water holding capacities are valuable for many operational purposes in agricultural production related to water use efficiency and management. With this information obtained, geographically referenced and stored in a GIS database for agricultural areas, it will greatly enhance analysis and application of this information in agriculture if the products can be absorbed and used by the farmer communities concerned, where necessary with the assistance of intermediaries (see section 1.5).

1.4.11 *Biomass resources assessment for agrometeorology*

In considering both the prevention of water and soil runoff on sloping land with contour hedgerows, and mulching to obstruct unwanted redistribution of received rainfall, the importance of soil cover by vegetation or undergrowth with extensive surface contact cannot be overemphasized. This also applies to the rehabilitation of completely desertified areas with (a combination of) shelterbelts, scattered non-forest trees and shrubs/bushes together with grasses as well as to the suppression of wind erosion in the source areas of serious sand and dust storms through the establishment of economically useful vegetation with additional benefits. The latter include the prevention of long distance transport of material and nutrients. Crucial tools in fighting these problems are the determined implementations of strategic land use and soil conservation policies.

Man's increasing utilization of forest land for intensive logging, agriculture and other purposes has caused weather and climate to change locally, regionally and even globally. Forest fires are also a serious source of local and transboundary air pollution and atmospheric degradation. Correct application of meteorological and climatological information can be of considerable benefit to the protection, sustainable development and conservation of forest resources, greening of degraded areas through forest rehabilitation, afforestation and reforestation. Policy matters, however, are again crucial components. The necessity of political will and the need for political initiatives to counter the misuse of biomass resources with effective and practical measures shows once more the importance of working in the B-domain (Annex IB). Measures should be enforced on those involved, exemplified by those practicing large scale burning for clearing land, but with development of alternatives (such as happened for slash and burn agriculture in Latin America) or compensation for the poorest groups this way affected.

1.4.12 *Agrometeorological services*

Agrometeorological services were recently defined and exemplified for our purposes by Murthy and Stigter (2006). A positive influence on management operations, through the application of weather based decision systems would be one of the most practical contributions, through Agenda 21 principles, to sustainable development. The Ministry of Agriculture, Fisheries and Food (now DEFRA) in the UK has, for example, promoted the protection of air, water and soil through the adoption of codes for Best Management Practices. The creation of an accessible database, consisting of an inventory of proven, practical techniques (including information and communication techniques) and effective agrometeorological services, would be very useful.

In recent years, mostly in industrialized countries, there has been a host of systems introduced which address such diverse issues as pest and disease control, livestock housing and welfare, work days for machinery planning, crop storage and drying, bespoke agricultural weather forecasts and fire risk management for range-lands and forests. The reason why there is a need to assess the economic value of such agrometeorological services is that policy-makers need to know whether such services are really useful. Since most policy-makers are familiar in making decisions based on their economical returns/values, the best approach agrometeorologists should take is to evaluate their services in terms of success, gain and profit. To do so is not easy and one needs to quantify effects but a commonly used method is the cost/benefit analysis.

Agrometeorological information/products and services need to be developed to best meet the needs of clients (Rijks and Baradas, 2000). In industrialized countries, agrometeorological information can be made easily and rapidly available to a wider spectrum of users by using modern Information and Communication Technology (ICT). Considerable agrometeorological information is now available in the websites of NMHSs. Some of the information is also accessible by telephone and e-mail (see for example Chapter 5). Near real-time data should be rapidly disseminated so that farm-level decisions can be made to avert negative effects of unfavorable weather and to benefit optimally from favorable weather (Sivakumar et al., 2000a). However, we repeat that agrometeorological information and services for governments and private organizations are different from those that were developed, or need to be developed, directly for and/or by various groups of farmers. This has mainly to do with facilities and education, and therefore with absorption capacity for information and services. In non-industrialized countries, training of intermediaries would go a long way in solving these problems for various groups of all but the richest and best educated farmers (section 1.5). WMO/CAgM has a task here in facilitating related policies (Stigter, 2003a).

1.5 TRAINING, EDUCATION AND EXTENSION IN AGRICULTURAL METEOROLOGY AS SUPPORT SYSTEMS TO AGROMETEOROLOGICAL SERVICES

1.5.1 *General considerations*

The Commission for Agricultural Meteorology continuously reviews the requirements for training, education and extension in agricultural meteorology and recommends developments in programs of higher education, programs of training for agrometeorological technicians, and at other vocational levels where agrometeorology is involved. So far it did this only sporadically and not very explicitly at the level of end-users (for example farmers in field-classes). It also encourages the development of teaching materials for use in workshops and seminars and by visiting lecturers. However, while the scientific principles are the same in all countries, the potential applications and the conditions under which they have to be used vary greatly between countries in different climates and at different stages of development. Hence this also applies to education, training and extension to put them into effect. Training programs at all levels must therefore be adapted to national and regional needs (Lomas et al., 2000a). In recent operational developments this includes developing extension agrometeorology around the establishment of agrometeorological services, particularly in non-industrialized countries (Stigter, 2003b).

A major responsibility of WMO/CAgM is to encourage training in agrometeorology and to assist in co-ordinating the training of agrometeorological personnel of all grades. There are requirements for training personnel at a number of levels, from carrying out well-established routines to using and developing the tools and mechanisms dealt with in section 1.4. The latter personnel works mainly in NMHSs, generating the products in agricultural meteorology that are to be used by decision makers, be it governments, private organizations or farmers. They also have to be able to develop new applications of agricultural meteorology in interaction with agriculturists. However, in non-industrialized countries they should not be the ones in direct contact with the agricultural communities. That should be the task of agrometeorological intermediaries.

1.5.2 *Training at the intermediate level*

At the intermediate level, education and training for agrometeorological extension has been proposed to be in two steps (Stigter, 2003b; 2005). The first class of agrometeorological intermediaries would be close to the centers where the agrometeorological information products useful for decision-makers in agricultural production are generated. Forecasts of weather and climate, monitoring and early warning products for drought, floods or other calamities, advisories for agrometeorological services that could increase the preparedness of the population long in advance, all have to be made into products that can be absorbed. This has to be done in the B-domain of Annex 1B to section 1.4. Such extension intermediaries need a good education in farmers' needs as well as in how agrometeorology can be used in the A-domain, using information from the B-domain. They should themselves work in the B-domain, guiding establishment of agrometeorological services to support the actions of producers or their advisors (E2).

The second class of (agrometeorological) extension intermediaries should be closest to the farmers and operate exclusively in the A-domain, establishing and using agrometeorological services (E2). They should learn to articulate the needs of the farmers' communities better and seek for agrometeorological components that need attention. They should match this with what is or should become available as agrometeorological services, in strong contact with the first class of intermediaries rather than with the generators of the raw weather/climate products and general advisories (E1). In this two step approach, meeting points for the two classes of intermediaries have to be created by the government and/or NGOs. The NMHSs should organize the first class, while the existing extension services, the government and NGOs should organize the second class of intermediaries and their contacts with the farmers.

1.5.3 *Challenges*

The education and in-service training (Lomas, 1999; Murthy and Stigter, 2006; Walker, 2005) of these two classes of agrometeorological extension intermediaries is an essential part of the new challenging approach that appears necessary in education, training and extension in agricultural meteorology. In spite of the efforts by WMO and NMHSs, local progress in agrometeorological support systems and services is often hampered by a lack of suitably trained personnel at all levels. This problem is particularly serious in non-industrialized countries where economic development and the level of food production depend to a large extent on the assessment of their resources through surveys and on the on-farm implementation of agrometeorological services. These assessments of resources were mentioned as tools under sections 1.4.8 till 1.4.11. Lomas et al. (2000) gave three reasons for the scant use of agrometeorological services in agriculture, of which one, the absence of economic benefits is contradicted by much new information in Sivakumar et al. (2000) and Salinger et al. (2005). More likely reasons are therefore the other two:

- lack of co-operation between the institutions providing information and relevant advisories and those responsible for their transfer to the farming community;

- insufficient education and training of the user community, including the farm advisory services, that provide specific agricultural advice from general weather information.

The challenge is to use the training of intermediaries as explained in section 1.5.2 to address these serious problems. The usefulness of the advice to farmers, foresters and other users depends considerably on their ability to interpret, absorb and apply extension messages intelligently. There is thus a major need for instruction in agricultural meteorology to non-meteorologists (e.g. Lomas, 1999; Lomas et al, 2000b), to create extension agrometeorologists and intermediate people that can make the existing products more client-friendly. This training could be done at institutes where advanced agricultural education is already provided or in special training courses comprising agricultural and meteorological components. These people must then also be able to deliver the agrometeorological aspects of users' training through field classes which appear to be a fruitful approach (Murthy and Stigter, 2006).

The successes, failures and experiences from such extension efforts will have to be brought back into the curricula of agrometeorological personnel of the NMHSs and into those at vocational schools and universities to enlighten the classical C-domain training and strengthen its usefulness.

1.5.4 *Specialization in agricultural meteorology*

Within agricultural meteorology education, training and extension some need for specialization may be recognized. Annex IC lists recently brought up examples of needs for training/education/extension, and directly related issues such as international co-operation and technology transfer, where specialists could be useful.

Another broad classification for specialization, from the angle of observations and measurements could include

(a) climate monitoring and analysis leading to planning applications and early warnings of climate anomalies as agrometeorological services;

(b) real time monitoring leading to the provision of operational advices in agrometeorological services, as for example in determining irrigation efficiency;

(c) microclimate manipulation and prediction, within crops, soils and managed environments (glass houses, stores etc.) leading through measurements to management options as agrometeorological services;

and

(d) special problem areas largely concerned with preparedness as agrometeorological services for agricultural hazards (including pests and diseases).

Also using the tools of section 1.4 leads to such a specialization division, from alternative angles, that partly overlap the other specialization divisions above.

1.5.5 *Consequences for training, education and extension in agrometeorology*

The above approach has consequences for our subject. For too long non-industrialized/southern countries have been tied to and have been imitating educational systems and their underlying values from industrialized northern countries which are alien to their rural cultures (van den Bor and Shute, 1991).

Classical high-level training in agrometeorology (e.g. Wieringa and Lomas, 2001 and the core library proposed there) takes place in the C-domain. This also applies to books specifically written for non-industrialized countries (e.g. Baldy and Stigter, 1997; Murthy, 2002). There is a large additional need to develop explicit education and training in the extension focused B- and A-domains for the fields of agrometeorological services as outlined above. This would indeed be a new approach and the results should be worked back as case studies into the education of the C-domain, particularly in non-industrialized countries. That way the latter domain could become better focused on supportive undertakings (E1) and on the necessary connection between E1 and E2 guidance. This adaptation in the C-domain would much enhance the operational qualities of agricultural meteorology.

Such an approach will demand changes in the classical education and training in agrometeorology, making agrometeorological students and trainees much more aware of application needs and actual applications of agrometeorological services developed with the methodologies they learn so much about. It will also demand increased and differently focused attention to agrometeorology in other agricultural curricula and changes in in-service training of purely agrometeorological personnel and agrometeorological intermediaries.

1.5.6 *Syllabi for instruction and other observations on curricula contents*

As agrometeorology covers a wide range of both temporal and spatial scales, topics throughout both ranges need to be included in highest level basic curricula. So for the temporal scale measurements and applications go from the scale of seconds through hours, days, pentads, decades, months to seasonal, annual and long-term data analysis. The range of spatial scales needs to go from the molecular level, organ level, plant, crop micrometeorological level through the meso-meteorological level of districts and regions to national, continental and global levels. In this way, the whole range of influences of the weather and climate on agricultural production over various time scales and spatial dimensions can be studied (Walker, 2005). This is also the way dynamic modeling works, from one level to the next, both in time and in space.

An example of a high quality C-domain basic syllabus recently developed for WMO is in Annex ID (Wieringa and Lomas, 2001). Subjects such as *National and international framework of agrometeorology*, *Training in multi-disciplinary problem solving, Projects and seminars on specific regional problems and interests in agrometeorology* should be added to have direct contacts with the B-domain and A-domain agrometeorology. This also applies to *Study tours on case studies of agrometeorological services*, such as for example in irrigation management and determination of water use efficiency and in the application of statistics for critical evaluation of risks (and research results!).

Agrometeorologists are working in an applied field, where the principles of meteorology are interacting with the practical field of agricultural production. In order for them to provide a good service, top level personnel and researchers in agrometeorology need to understand the bio-meteorological interrelationships between weather and climate and crop and livestock production, including the effects on pests and diseases. The applications addressed by agrometeorologists are mainly in two areas - for planning purposes and for operational management purposes. The climatic long-term data sets and seasonal global applications are mainly used together with the crop or livestock requirements (such as temperature and water) for crop/livestock-climate matching. This planning level is for example of vital importance when introducing new varieties and breeds into an area or evaluating the effects of global warming on agricultural production in a specific area. For this type of applications in agrometeorology, a good understanding of the availability of long-term data sets and climate analyses as well as of global climate models and seasonal forecasts is needed by top NMHS and research agrometeorologists. At an operational level, the data analysis and application is usually at a more local, district or on-farm level during the growing season.

Therefore, data analysis skills need to be taken through to decision-making trees to be of practical use to farm managers, for irrigation scheduling, crop/livestock disease and pest control and other daily/weekly farm operations (such as weeding and fertilization). For such agrometeorological services, NMHS and research agrometeorologists need a good basis in fundamentals and applications of short term weather forecasting together with the crop/livestock requirements of temperature (i.e. critical values), day length and water (Walker, 2005).

Syllabi for agrometeorological intermediaries will have to be written from the understanding to be obtained by collecting and reviewing the experience with existing agrometeorological services in the A-domain. There is also need to gathering information from the users on actually existing needs that have not or not yet been met by such services (Blench, 1999). After hands-on experience obtained in the B-domain and the A-domain in Africa, collection of such information is being attempted at various places in Asia (Stigter et al., 2005b). It is expected that better guidance (E2) may be defined for the establishment of such services from these exercises. From the same experiences training at the level of agrometeorological intermediaries can then be developed. Several preliminary attempts in Africa and Asia to work with such intermediaries have had limited success because of a lack of appropriate training (Stigter, 2003b).

To promote widespread use and application of agrometeorological techniques and concepts, another level of training is also needed. This outreach by agrometeorologists can be at various levels of the general public and in schools. What is vital here is that the basic concepts and ideas of agrometeorology are communicated in simple every day language without much technical jargon. It is also recommended that agrometeorology courses be included in all undergraduate biological and agricultural degrees. This would promote a better cooperation and understanding of the role of agrometeorological information by agronomists and animal scientists. A further group that needs some training in agrometeorological basic concepts contains practitioners in the media. Because they often explain and discuss messages from meteorologists and climatologists to the public at large, it is vital that they have a good basic understanding of weather and climate (Walker, 2005).

1.6 CHALLENGES MET AND REMAINING IN AGRICULTURAL METEOROLOGY

1.6.1 *A challenge met*

The earlier version of this Guide, more than 25 years ago listed "Services by meteorologists to agriculturists", "Services by agriculturists to meteorologists" and "Joint services by meteorologists and agriculturists". The earlier version aimed at "joint experts" in agricultural meteorology. The world has become more complicated than that such a solution would still work (see for the approach below also Gommes, 2003).

There are too many areas covered in agricultural meteorology and no one would agree on their borders. Earlier parts of this Chapter show this also. Take irrigation, which according to WMO falls under agrometeorology and according to FAO under agricultural engineering. Consider desert locust outbreaks, an "extreme agrometeorological event" for WMO, and a plant protection problem to the FAO. Another example are crop models that to modelers may be part of crop ecophysiology, physiology, micrometeorology etc. with a big soil science component, while a scientist or technician who wants to do crop-weather modeling may assign them to agrometeorology. Take pest development rates etc.

One may call it a policy decision, but also as a challenge met we redefined in this Guide the scope of agricultural meteorology (section 1.1). This redefinition has implications for the characterization of weather/climate resources (section 1.4.8), climate/weather impact assessment methodologies in agricultural production (sections 1.4.4.; 1.4.5; 1.4.6) as well as for how agrometeorological knowledge will be used (sections 1.4.1; 1.4.2; 1.4.8). This approach makes agrometeorology much more service-oriented.

1.6.2 *Challenges remaining, in a new perspective*

The new approach was necessary because of the increased importance of agricultural meteorology that we lately witness almost everywhere, be it sometimes under another name. This new awareness is caused by deteriorating agricultural environments due to increasing climate variability and climate change, in addition to other vagaries of weather and non-agricultural interests encroaching into agricultural land. Moreover, multidisciplinary departments, teams and approaches are everywhere recognized as a bare necessity in problem solving in agricultural production. They are still not without difficulties, but in agricultural sciences and technology there is much more collaboration between people of different disciplines than there was 25 years ago. However, this is for the time being much less so in some services providing government organizations. In particular the Administrative Structure of NMHSs, presently often disfavoring agricultural meteorology and the products related to instruments and type of data, software tools, training of officers etc. should be much more geared towards the provision of generic or specialized services by intermediaries (Gommes, 2003). These are practical challenges springing from the new service orientation chosen for agrometeorology.

Another remaining challenge definitely is to have better quantitative estimates and better methods to derive these quantitative estimates, of the actual role of weather/climate in agricultural production of various farming systems. What would be necessary is to jointly determine the links between change and variability, mainly in terms of impacts, and to make sure that present needs are covered (Gommes, 2003).

The sudden change in appreciation and importance of agricultural meteorology has caught professionals rather unprepared. This has a historical background. In the course of the eighties, a trend of decreasing importance of weather and climate with increasing external inputs into changing modes of production could only partly be counteracted by increasing emphasis in CAgM on "operational agrometeorology" and "economic benefits of agrometeorology".

Simultaneously even more emphasis was given to developing countries, where attention for agrometeorology, and so funds, remained very low and were mainly or for a large part external. In advancing industrializing developing countries this gradually improved but still remains much below what was needed. In countries in transition and China, especially isolation was an insurmountable problem.

Environmental concerns due to intensification of production were already rising when climate change and particularly increasing climate variability struck hard. In the nineties agricultural meteorology tried to regroup its now relatively meager forces and to keep stock of (i) the environmental requirements of crops, forests and live stock, particularly in low external input agriculture, and (ii) the sustainability of the agricultural resource base, everywhere but with different emphases. Agrometeorologists appeared only very partially able to cope with these demands, mainly because of the virtually non-existence of suitable agrometeorological services (Olufayo et al., 1998).

Presently, the proven urgent need for better on-farm preparedness (Stigter et al., 2003) is equivalent to a revival of response farming with relevant innovations. These improved preparedness strategies, for (a) the chronic deficiencies of weather, its micro-variability in time and space, and (b) more, and more serious, extreme events in weather and climate, are creating an additional and growing demand for agrometeorological services (compare also section 1.5.4). This is again true for industrial and non-industrial countries alike, but again with very different emphases due to the very different modes of production.

Also in agrometeorological services it is a remaining challenge to define our priority beneficiaries. In most countries, there has never been any serious market research to identify potential customers of agrometeorological services, including commercial customers (Gommes, 2003). The US, where the potential user can these days get a menu of choices from private services, is one exception for the latter case. Plantations, livestock and other commercial farmers, land and ocean fisheries, banks, traders etc. might also elsewhere be in a position to pay for services and, indirectly, fund activities aimed at poorer customers (Weiss et al., 2000).

1.6.3 *The challenges of decision support systems*

Agricultural meteorology is concerned with how parameters influence managed and natural ecosystems. Thus the first challenge of a decision support system is to ensure that accurate relevant input data are available on a timely basis. Aside form actual measurements, interpolation schemes, algorithms to predict specific meteorological parameters, or remotely sensed data may be used to complete the necessary meteorological parameter data set.

Monteith (2000) showed how emphasis had shifted between the early issues of a journal like Agricultural and Forest Meteorology and recent issues, from data collecting to modeling. He also confirmed that the quality of basic surface data has been constantly deteriorating over that same period. Instead, we have new sources of data, which are very useful but no substitute for real data. Statistical or other proxies are presently largely dominating the data landscape. Deeply indirect estimates are now for example used in drought monitoring and flood forecasting and are used by the crop monitoring community throughout Africa, at the expense of observed data, and with several types of risks for decision makers. Knowing the limitations of such data sets is an absolute challenge for decision making. In non-industrialized countries, on the other hand, automatic data collection is often very risky in terms of costs and, even more important, continuity of data (Gommes, 2003).

The next challenge of a decision support system is to go from input data to biologically meaningful results. This is often accomplished through a simulation model that includes parameters of biological importance to the ecosystem that is being simulated. The simulation model plays a key role in changing data into useful information via a decision support system. The simulation model also helps focus research. The change from data to information ideally should be independent of location, because it should be based on the best available scientific knowledge (Weiss et al., 2000).

Many simulation models are tied together by assumptions and empiricisms (Monteith, 2000). The validity of these assumptions and the generality of these empiricisms are important research areas for the improvements of simulation modeling. Specifically, different cultivars may respond differently to the same environment and this has to be brought into the modeling by quantification of these differences, as a main challenge.

In order for a decision support system to be effective, the intended audience for this system must be carefully identified and appropriate information for this audience must be developed. It means that the information must have economic value. Introduction of such information from a decision support system as an agrometeorological service to the community should be a careful process, with appropriate feed back mechanisms, to avoid unintended negative consequences (Weiss et al., 2000).

In some cases the end users of the information will gain new insights into specific problems, to the point that they can continue operating independently of the initial decision support system. In other cases specific additional training is necessary in field classes. Intermediaries with socio-economic knowledge on the farming systems concerned and an extension background should be trained to ensure that the resulting information is effectively absorbed and used (sections 1.4.5, 1.4.12 and 1.5). This is the final challenge of each and every decision support system.

REFERENCES

BALDY, C. and C.J. STIGTER, 1997. Agrometeorology of multiple cropping in warm climates. INRA, Paris, France + Oxford & IBH Publ. Co., New Delhi, India + Science Publ. Inc., Enfield, USA, 237 pp.

BLENCH, R., 1999. Seasonal climate forecasting: Who can use it and how should it be disseminated. *Natural Resources Perspectives* 31, ODA, London, 4pp.

GOMMES, R., 2003. Agrometeorological policy between necessity and fashion. *European Society for Agronomy Newsletter* 25: 4 pp.

JAGTAP, S.S. and AH KEE CHAN, 2000. Agrometeorological aspects of agriculture in the sub-humid and humid zones of Africa and Asia. *Agricultural and Forest Meteorology* 103: 59-72.

LOMAS, J., 1999. Education and training in agricultural meteorology – current status and future needs. *WMO-Bulletin* 48: 379-384.

LOMAS, J., J.R. MILFORD and E.MUKHALA, 2000a. Education and training in agricultural meteorology: current status and future needs. *Agricultural and Forest Meteorology* 103: 197-208.

LOMAS, J., J. COLLINS, S.GACHARA and S.MUKHOPADHYAY, 2000b. Education and training in agrometeorology. CAgM Report 78, WMO/TD No. 990, WMO, Geneva, 31 pp.

MARACCHI, G., V. PERARNAUD and A.D. KLESCHENKO, 2000. Applications of geographical information systems and remote sensing in agrometeorology. *Agricultural and Forest Meteorology* 103: 119-136.

MEINKE, H., W.E. BAETHGEN, P.S. CARBERRY, M. DONATELLI, G.L. HAMMER, R.SELVARAJU and C.O. STOCKLE, 2001. Increasing profits and reducing risks in crop production using participatory systems simulation approaches. *Agricultural Systems* 70, 493-513.

MONTEITH, J.L., 2000. Agricultural Meteorology: evolution and application. *Agricultural and Forest Meteorology* 103: 5–9.

MURTHY, V.R.K., 2002. *Basic principles of agricultural meteorology.* Book Syndicate Publications, Hyderabad, India, 261 pp.

MURTHY, V.R.K. and C.J. STIGTER, 2006. Operational agrometeorological services for extension needs and the supportive role of agricultural research. Pp. 199-208 in: Strengthening Operational Agrometeorological Services at the National Level, Proceedings of a Regional Meeting, Manila, Philippines, 2004. AGM-9, WMO/TD-No. 1277, WMO, Geneva [Also available on-line at the WMO/CAgM website].

NORSE, D. and J.B. TSCHIRLEY, 2001. Links between science and policy making. *Agriculture, Ecosystems and Environment* 82: 15-26.

OLUFAYO, A.A., C.J. STIGTER and C. BALDY, 1998. On needs and deeds in agrometeorology in tropical Africa. *Agricultural and Forest Meteorology* 92: 227-240.

ONYEWOTU, L.O.Z., C.J. STIGTER, A.M. ABDULLAHI, J.A. ARIYO, E.O.OLADIPO and J.J. OWONUBI, 2003. Reclamation of desertified farmlands and consequences for its farmers in semiarid northern Nigeria: a case study of Yambawa rehabilitation scheme. *Arid Land Research and Management* 17: 85 – 101.

RIJKS, D. and M.W. BARADAS, 2000. The clients for agrometeorological information. *Agricultural and Forest Meteorology* 103: 27-42.

SALINGER, J., M.V.K. SIVAKUMAR and R.P. MOTHA (EDS.), 2005. Increasing climate variability and change. Reducing the vulnerability of agriculture and forestry. *Climatic Change* 70, 362 pp.

SIVAKUMAR, M.V.K., C.J. STIGTER and D. RIJKS (EDS.), 2000a. Agrometeorology in the 21st Century – Needs and Perspectives. *Agricultural and Forest Meteorology* 103, 227 pp.

SIVAKUMAR, M.V.K., R. GOMMES and W.BAIER, 2000b. Agrometeorology and sustainable agriculture. *Agricultural and Forest Meteorology* 103, 11-26.

STEWART, J.I., 1991. Principles and performance of response farming. Pp. 361-382 in: R.C. Muchow and J.A. Bellamy (Eds.), *Climate Risk in Crop Production: Models and Management for the Semi-Arid Tropics and Sub-Tropics,* CAB International, Wallingford.

STIGTER, C.J., 1994. Management and manipulation of microclimate. Ch. 27 (Pp. 273-284) in: J.F. Griffiths (Ed.), *Handbook of Agricultural Meteorology,* Oxford University Press, New York.

STIGTER, C.J., 1999. The future of agrometeorology: perspectives in science and services. *WMO-Bulletin* 48: 353–359.

STIGTER, C.J., 2003a. Support systems in policy making for agrometeorological services: bringing the work of CAgM OPAGs, ICTs and ETs in a diagnostic and conceptual framework for action support. Policy paper for the first meeting of the Management Group of CAgM/WMO in Washington DC. WMO, Geneva. Also available on the INSAM web site (www.agrometeorology.org) under "Needs for agrometeorological solutions to farming problems".

STIGTER, C.J., 2003b. The future of education, training and extension in agricultural meteorology: a new approach. In: Zheng Dawei et al. (Eds.), *The Future of Agrometeorological Education in China.* Proceedings of a Workshop, China Agricultural University, Beijing.

STIGTER, C.J., 2004. The establishment of needs for climate forecasts and other agromet information for agriculture by local, national and regional decision-makers and users communities. Pp. 73 – 86 in: Applications of Climate Forecasts for Agriculture. Proceedings of the Expert Group Meeting in Banjul, the Gambia (December 2002). AGM-7/WCAC-1, WMO/TD-No. 1223, WMO, Geneva. [Also available on-line at the WMO/CAgM website].

STIGTER, C.J., 2005. Building stones of agrometeorological services: adaptation strategies based on farmer innovations, functionally selected contemporary science and understanding of prevailing policy environments. Opening key note lecture at the FPEC Symposium, Fukuoka, Japan. *Journal of Agricultural Meteorology* (Japan) 60: 525–528.

STIGTER, C.J., 2007. From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: A simple conceptual and diagnostic framework. *Agricultural and Forest Meteorology* 142, 91 – 95.

STIGTER, C.J., M.V.K. SIVAKUMAR and D.A. RIJKS, 2000. Agrometeorology in the 21st century: workshop summary and recommendations on needs and perspectives. *Agricultural and Forest Meteorology* 103: 209-227.

STIGTER, C.J., H.P. DAS and V.R.K. MURTHY, 2003. Beyond climate forecasting of flood disasters. Fifth Regional Training Course on Flood Risk Management (FRM-5) of the Asian Disaster Preparedness Center (Bangkok) and the China Research Center on Flood and Drought Disaster Reduction (Beijing), Beijing. Available from ADPC (Bangkok) on CD-ROM.

STIGTER, C.J., ZHENG DAWEI, L.O.Z. ONYEWOTU and MEI XURONG, 2005a. Using traditional methods and indigenous technologies for coping with climate variability. *Climatic Change* 70: 255-271.

STIGTER, C.J., J. KINAMA, YINGCUI ZHANG, K.O. OLUWASEMIRE, DAWEI ZHENG, N.K. NASR AL-AMIN and A.T. ABDALLA, 2005b. Agrometeorological services and information for decision-making: some examples from Africa and China. *Journal of Agricultural Meteorology* (Japan) 60: 327 – 330.

VAN DEN BOR, W. and J.C.M. SHUTE, 1991. Higher education in the third world: status symbol or instrument for development. *Higher Education* 22: 1-15.

WALKER, S., 2005. Role of education and training in agricultural meteorology to reduce vulnerability to climate variability. *Climatic Change* 70: 311-318.

WEISS, A., L. VAN CROWDER and M. BERNARDI, 2000. Communicating agrometeorological information to farming communities. *Agricultural and Forest Meteorology* 103: 186-196.

WIERINGA, J. and J. LOMAS, 2001. *Lecture notes for training agricultural meteorological personnel.* Second Edition. WMO-No. 551. WMO, Geneva, 196 pp.

WMO, 2006. *Commission for Agricultural Meteorology (CAgM). The First Fifty Years.* Compiled for CAgM by Wolfgang Baier, Ray Motha and Kees Stigter. Integrated by Kees Stigter. WMO-No. 999, WMO, Geneva, 44 pp.

ANNEX 1A

Terms of Reference of the Commission for Agricultural Meteorology

[As they were in Supplement No. 3 (VIII. 1993)]

ANNEX 1B

Conceptual and Diagnostic Framework

A = Sustainable livelihood systems

B = Local adaptive strategies (knowledge pools based on traditional knowledge and indigenous technologies)
- **+ Contemporary knowledge pools (based on science and technology)**
- **+ Appropriate policy environments (based on social concerns and environmental considerations, scientifically supported and operating through the market where appropriate)**

C = Support systems to agrometeorological services: data + research + education/training/extension + policies

```
A   -------|--------      B      ------|--------    C
           |                           |
           |                           |
           E2                          E1
```

E1 = Agrometeorological Action Support Systems on Mitigating Impacts of Disasters

E2 = Agrometeorological Services Supporting Actions of Producers

ANNEX IC

Needs for training/education/extension (and directly related issues) recognized as priorities in the Accra symposium (Sivakumar et al., 2000)

- technology transfer (in the sense of adapting proven information and services applications to the realities and needs of non-industrialized countries);

- methods, procedures and techniques for disseminating agrometeorological information to cooperative extension services and other users, that understand its value;

- awareness and training for disaster mitigation and climate disaster prediction;

- training assistance focused on priority services and on priority needs mentioned under data, research, policies and education;

- methods, techniques, software packages for specific applications by the clients themselves;

- interdisciplinary extension services for local development;

- agrometeorological networks, including CLIPS products;

- training in agrometeorology in general, with additional emphasis where agriculture is on the decline;

- international cooperation (on the needs formulated above).

ANNEX ID

Outline of a recent classical basic syllabus in agrometeorology (Wieringa and Lomas, 2001)

1. *Agricultural meteorology - its scope and aims*
Aims; Range of subject matter: soil and water, plants and crop microclimate, farm animals (farm livestock), diseases and pests of crops and animals, farm buildings, equipment and operations, artificial modification of meteorological regimes, climate change; Use and provision of agrometeorological information.

2. *Radiation and the surface energy balance*
Solar energy ("short wave" energy) from sun and sky: direct and diffuse components of solar short-wave radiation, estimation of global radiation on a horizontal surface, emission and reflection of radiation, energy in the visible spectrum - light; The energy balance and its components: the long-wave budget; surface radiation temperatures; total radiation budget and complete surface energy balance; Special aspects of radiation and temperature in agriculture.

3. *The soil and its heat balance*
What is "soil"; Transmission of heat in the soil; Soil freezing, and the role of snow cover; Diurnal and annual variations of soil; temperature and moisture; A model of soil temperature diurnal course at different depths.

4. *Water and the hydrological cycle in agriculture*
Water and vegetation; Moisture characteristics of soils; Determination of water loss from land surfaces: fundamentals of the evaporation process, existing methods to determine evaporation, energy balance estimation of evaporation, aerodynamic estimation of evaporation; "Combination" methods of Penman and others: development of the original Penman equation, evaporation formulae of Priestley-Taylor and Penman-Monteith; Special forms of precipitation: dew, snow; Soil moisture budgets - irrigation need.

5. *Small-scale climate, representativity, and their dependence on topography*
Micro-, topo- and meso-climatology; Observation representativity, exposure and sampling; Wind behaviour in common inhomogeneous terrain: wind around barriers of varying porosity, wind reduction by shelterbelt arrays, wind representativity at toposcale; Toposcale representativity of meteorological observations; Topoclimatological effects arising from landscape variations: effects of slope on incoming solar radiation, soil temperatures on slopes, effects of slopes and hills on airflow, local mesoscale circulations.

6. *Agrometeorological management at microscale and toposcale*
Introduction; Soil cultivation and treatment: effects of surface colour on soil temperature, mulching, surface geometry effects on temperatures; Crop management and layout: spacing of crop rows, shading, cover crops and weeding; Wind shelter: effect of wind shelter on microclimate, windbreaks against damage and erosion; Irrigation and drainage; Frost and protection against frost damage: passive methods of protection against frost, active methods of protection against frost, short-term frost forecasting; Artificial climate in glasshouses and stables.

7. *Weather hazards adversely affecting agricultural output*
Drought; Artificial stimulation of precipitation; Hail: distribution of hail in space and time, active suppression of hail; Fire in vegetation; Atmospheric transports: elementary aspects of transport over meso-scale distances, point sources, line sources, e.g. sea-salt transport.

8. *Operational agrometeorology*
Alternative forms of agrometeorological decision-supporting activity; Operational modelling for tactical agrometeorology; Protection of crops against pests and diseases; Agroclimatological surveys: agroclimatology of the Sahel-an example of presentation, Irrigation need-a climatological case study, agroclimatological analysis of a rainfed semi-arid situation; Computer weather modelling for agriculture; Modelling of heat stress for avocado - a case study; Agrometeorological weather and climate information.

9. *Agrometeorological instruments and observation*
Basic observation rules: agrometeorological networks and documentation, dynamic responses of meteorological instruments; Agrometeorological instruments: air temperature, grass-minimum temperature and radiative surface temperature, soil temperature and soil heat flux, wind, radiation and sunshine, humidity, dew and leaf wetness, evaporation and evapotranspiration; Observations of "state of the ground" and soil moisture: state of the ground, soil moisture; Biological observations: observations for research and for operational use, observations of natural phenomena for agroclimatological use, specific examples of biological/phenological observations: wheat, maize, avocado; Remarks on experimental procedures.