THE METEOROLOGY ACT 1955

METEOROLOGY

No. 6 of 1955[1]

An Act relating to the Commonwealth Bureau of Meteorology.

[Assented to 23rd May, 1955]

[Date of Commencement, 20th June, 1955]

Be it enacted by the Queen's Most Excellent Majesty, the Senate, and the House of Representatives of the Commonwealth of Australia, as follows:

1. This Act may be cited as the *Meteorology Act* 1955. — Short title

2. The *Meteorology Act* 1906 is repealed. — Repeal

3. In this Act, unless the contrary intention appears- — Definition
"the Bureau" means the Commonwealth Bureau of Meteorology established by this Act;
"the Director" means the Director of Meteorology.

4.[1] This Act extends to all the Territories of the Commonwealth. — Extension to Territories

5. — The Commonwealth Bureau of Meteorology
(1) For the purposes of this Act, there shall be a Commonwealth Bureau of Meteorology and a Director of Meteorology.
(2) The Bureau shall be under the charge of the Director, who shall, subject to the directions of the Minister, have the general administration of this Act.

6. — Functions of the Bureau
(1) The functions of the Bureau are-
(a) the taking and recording of meteorological observations and other observations required for the purposes of meteorology;
(b) the forecasting of weather and of the state of the atmosphere;
(c) the issue of warnings of gales, storms and other weather conditions likely to endanger life or property, including weather conditions likely to give rise to floods or bush fires;
(d) the supply of meteorological information;

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[1]Amended by No.123 of 1973

ATTACHMENT B

BUREAU OF METEOROLOGY CHARTER, GOALS AND OBJECTIVES

The Commonwealth Bureau of Meteorology is the National Meteorological Authority for Australia. The ultimate legal basis for its existence is the Commonwealth Constitution which, through its Section 51 (viii), empowers the Federal Parliament to make laws for the peace, order and good government of the Commonwealth with respect to ' ... meteorological observations'. The Bureau was established by the Meteorology Act 1906 and formally came into existence on 1 January 1908 through consolidation of the separate Colonial/State Meteorological Services which had existed prior to that time. The Bureau currently operates under the authority of the Meteorology Act 1955, which establishes the explicit legal basis for its activities and, together with the Convention of the World Meteorological Organization and other national and international agreements and treaties, provides the basic charter for its operation.

THE CHARTER OF THE BUREAU OF METEOROLOGY

PURPOSE

The purpose of the Bureau of Meteorology is to contribute to Australia's social, environmental, economic and cultural goals through the performance of the functions of a National Meteorological Service in the public interest generally and in particular:

(a) for the purposes of the Defence Force;

(b) for the purposes of navigation and shipping and of civil aviation; and

(c) for the purpose of assisting persons and authorities engaged in primary production, industry, trade and commerce.

MISSION

The overall mission of the Bureau is to observe and understand Australian weather and climate and provide meteorological, hydrological and oceanographic services in support of Australia's national needs and international obligations. This overall mission involves four separate basic missions:

- **Monitoring** — Observation and data collection to meet the needs of future generations for reliable homogeneous national climatological data;
- **Research** — Research directed to the advancement of meteorological science and the development of a comprehensive description and scientific understanding of Australia's weather and climate;
- **Services** — Provision of meteorological and related data, information, forecast, warning, investigation and advisory services on a national basis; and
- **International** — Coordination of Australia's involvement in international meteorology.

FUNCTIONS

The Meteorology Act defines the functions of the Bureau as:

(a) the taking and recording of meteorological observations and other observations required for the purposes of meteorology;
(b) the forecasting of weather and of the state of the atmosphere;
(c) the issue of warnings of gales, storms and other weather conditions likely to endanger life or property, including weather conditions likely to give rise to floods or bushfires;
(d) the supply of meteorological information;
(e) the publication of meteorological reports and bulletins;
(f) the promotion of the use of meteorological information;
(g) the promotion of the advancement of meteorological science, by means of meteorological research and investigation, or otherwise;
(h) the furnishing of advice on meteorological matters; and
(i) cooperation with the authority administering the Meteorological Service of any other country in relation to any of the matters specified in the preceding paragraphs.

POWERS

The Act confers on the Director of Meteorology such powers as are necessary to enable the Bureau to perform its statutory functions and in particular to:

(a) establish meteorological offices and observing stations;
(b) arrange with any Department, authority or person to take and record meteorological observations and transmit meteorological reports and information;
(c) arrange means of communication for the transmission and reception of meteorological reports and information; and
(d) arrange for the training of persons in meteorology.

SUPPORTING ACTIVITIES

Under the authority of the powers of the Director, the Bureau carries out a number of supporting activities as follows:

(a) collection and dissemination of meteorological and related environmental data and products;
(b) analysis and prognosis of meteorological and related environmental conditions;
(c) archiving of meteorological and related environmental data and products;
(d) provision of automatic data processing facilities and support services;
(e) provision of engineering support services;
(f) training in meteorology and other fields related to the operations of the Bureau;
(g) provision of public information and public education in meteorology;
(h) operation of a National Meteorological Library and provision of other technical support services;
(i) conduct of necessary supporting research and development;
(j) coordination of information on Australian scientific and technical programs in meteorology;
(k) establishment and maintenance of meteorological offices, observing stations and facilities and provision of accommodation for staff at remote locations; and
(l) provision of necessary internal management support services.

CHARGES

Under Section 8 of the Meteorology Act, the Director may, subject to any directions of the Minister, make charges for the forecasts, information, advice, publications and other matter provided in pursuance of the Act.

THE GOALS AND OBJECTIVES OF THE BUREAU OF METEOROLOGY

GOALS

All of the activities of the Bureau of Meteorology are directed ultimately at the following national goals:

- reduction of the social and economic impact of natural disasters;
- economic development and prosperity of primary, secondary and tertiary industry;
- safety of life and property;
- national security;
- preservation and enhancement of the quality of the environment;
- community health, recreation and quality of life;
- efficient planning, management and operation of Government and community affairs;
- provision for the needs of future generations;
- advancement of knowledge and understanding of our part of the world;
- fulfilment of Australia's international obligations; and
- promotion of Australia's interests in the world.

OBJECTIVES

OVERALL OBJECTIVE

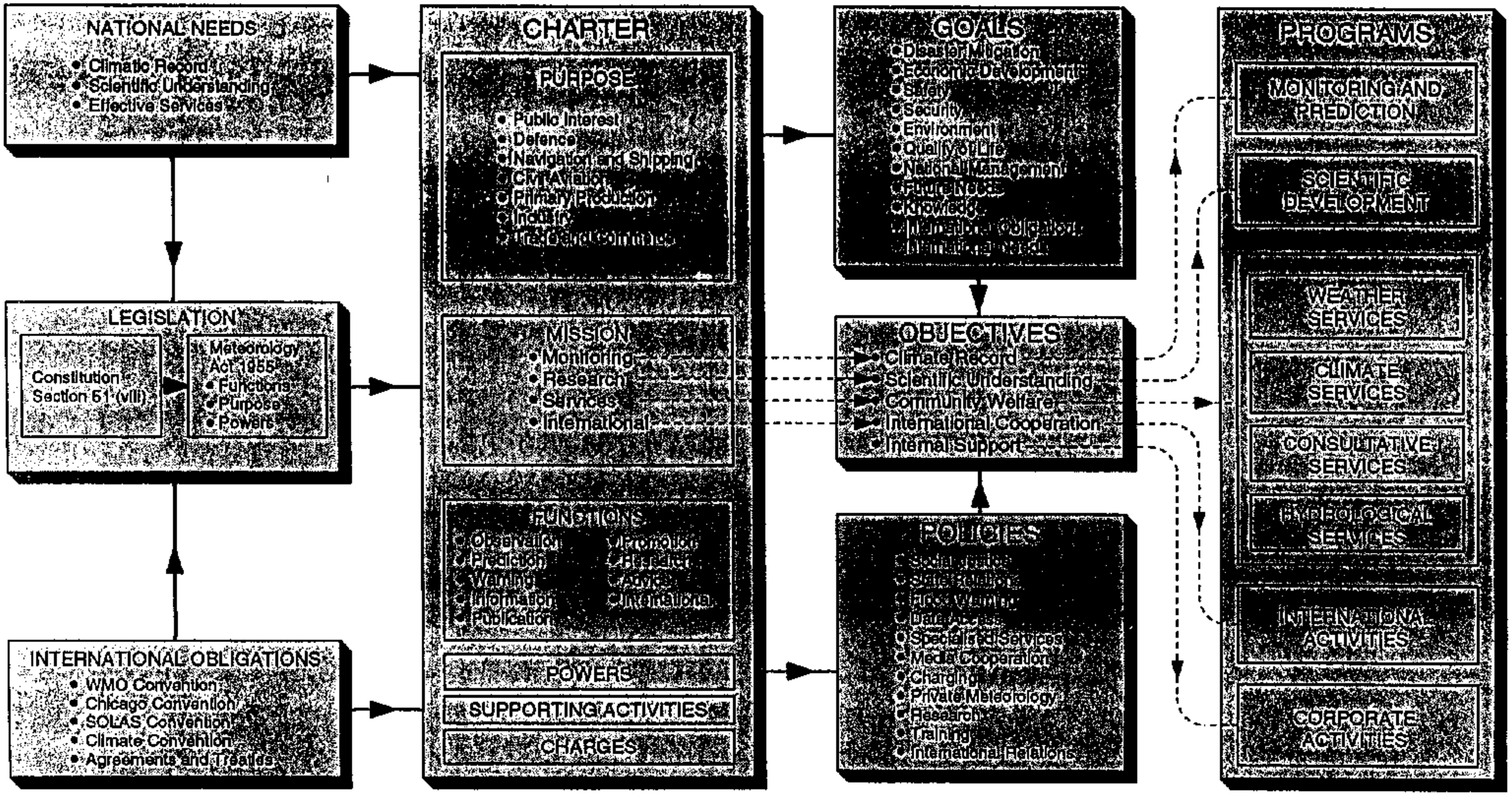
To meet the needs of all Australians for the meteorological information, understanding and services that are essential for their safety, security and general well-being and to ensure that meteorological data and knowledge are effectively applied to Australia's national and international goals.

BASIC OBJECTIVES

- **Climate record.** To meet the needs of future generations for reliable homogeneous climatological data.
- **Scientific understanding.** To advance the science of meteorology and develop an integrated comprehensive description and scientific understanding of Australia's weather and climate.
- **Community welfare.** To contribute effectively to:
  - reduction of the social and economic impact of natural disasters;
  - economic development and prosperity of primary, secondary and tertiary industry;
  - safety of life and property;
  - national security;
  - preservation and enhancement of the quality of the environment;
  - community health, recreation and quality of life; and
  - efficient planning, management and operation of Government and community affairs;

  through the development and provision of meteorological and related services.
- **International cooperation.** To meet Australia's international obligations and advance Australia's interests in and through international meteorology.

THE ORIGIN OF THE CHARTER OF THE BUREAU OF METEOROLOGY AND ITS INFLUENCE ON THE GOALS, OBJECTIVES, POLICIES AND PROGRAM STRUCTURE OF THE BUREAU



CHARGING FOR METEOROLOGICAL SERVICES

Basic Principles

The Bureau's charging policy is set down in twelve principles which, inter alia, take into account the primary public interest role of the Bureau, the 'public good' characteristics of many Bureau products, the recommendations of various inquiries (CIBM, 1976; Bosch, 1984; HRSCE 1986) and Australia's commitment to various international Conventions and Regulations arising therefrom. The twelve principles are:

Principle 1. The provision of the basic national meteorological infrastructure needed to collect and process the data required to meet the needs of future generations, to fulfill Australia's international obligations under the World Meteorological Convention and to support the provision of basic meteorological services to the community is the responsibility of government and should be fully funded through taxation.

Principle 2. Meteorological data collected at public expense should be regarded as public property, accessible to all for the costs of making them available.

Principle 3. Meteorological data and products should be made available without charge to the National Meteorological Services of other countries in accordance with the international convention of free and unrestricted exchange between nations.

Principle 4. There should be a basic national meteorological service (known as "The Basic Service") encompassing basic weather, climate and advisory services made available free of charge to the community in the public interest.

Principle 5. The basic public forecast, warning and information service (The Basic Weather Service) should be provided free of charge to the public through the media.

Principle 6. Services provided to other government agencies as part of the joint fulfilment of shared missions in the public interest should be regarded as part of the Basic Service and should not be charged for.

Principle 7. The user-pays principle should apply to all services provided in addition to the Basic Service.

Principle 8. The costs attributable to each Service should be determined on an incremental basis using a cost accounting system and should include salaries, operating costs, capital and appropriate overheads.

Principle 9. Charges for services provided to other government agencies in support of direct public interest missions or provided to fulfill Government requirements should cover direct costs and overheads only.

Principle 10. Services provided to identifiable users in competition or potential competition with the private sector should be charged for at commercial rates.

Principle 11. The charging schedule should be simple and the administration of the charging system should be cost-effective; eg. debit action should only proceed when the charge for the service exceeds the administrative cost of the recovery process.

Principle 12. The charging policy should be implemented in a way which promotes customer and community goodwill.

ATTACHMENT D

REVIEW OF THE OPERATION OF THE BUREAU OF METEOROLOGY

March 1996

ATTACHMENT E

AUSTRALIA

CAPTURING OPPORTUNITIES IN THE PROVISION OF METEOROLOGICAL SERVICES

A study of the scope to enhance revenue generation in the Bureau of Meteorology

ATTACHMENT F

FINAL (1999) GOVERNMENT RESPONSE TO THE RECOMMENDATIONS OF THE SECOND SLATYER REPORT

	RECOMMENDATIONS	GOVERNMENT RESPONSE
	Bureau Funding	
1	The Government should place the Bureau's funding on a rolling triennial or quintennial basis.	Accepted. For effective operation the Bureau requires stable, ongoing funding. New arrangements, should be developed between the Bureau and the Department of Finance and Administration aimed at maximising the Bureau's earnings from specialised services in a fashion consistent with the effective discharge of its public interest responsibilities.
	Modifications to the Charging Principles to enhance service provision through cost recovery and commercial activities.	
2	A subset of the Basic Service, termed the Basic Product Set, should be produced. It will contain the full range of meteorological products normally provided to the public via the print and electronic media. The Basic Product set should be reviewed regularly by the Director of Meteorology.	Accepted. Slatyer suggests that a subset of the present basic service, termed the Basic Product Set, should continue to be provided free of charge. There may be good reason for modifications to the basic subset products in different Regions, but generally the content of the Basic Product Set should be consistent between Regions. The content of the Basic Product Set should be determined on the advice of an independent committee, initially the Implementation Committee (c/f Rec 15), and reviewed from time to time with the Implementation Committee to recommend means of review.
3	The Basic Product Set should be made available free of charge to the public only through the mass media and the Internet and to not-for-profit emergency services.	Accepted.

	RECOMMENDATIONS	GOVERNMENT RESPONSE
4	Cost recovery should apply to those products in the Basic Service that are not provided through the Internet or the mass media, or to not-for-profit emergency services.	**Accepted. Access to the Basic Product Set should be provided free through the Internet or the mass media. Products that are in the Basic Service but outside the Basic Product Set, as well as services that are provided through mechanisms other than the mass media or Internet, should be subject to incremental cost recovery. Or, if they have been subject to further value-adding by the Special Services Unit (SSU), charged for at commercial rates.**
5	Services provided to other Government agencies, in support of public interest activities or as part of the joint of shared missions in the public interest, could be subject to reduced charging at the discretion of the Director of Meteorology.	Accepted. As a part of its charging policy the Bureau will prepare guidelines, with advice from the Implementation Committee, to ensure that reduced charging is offered on a consistent basis and is also consistent with the Government's overall competitive neutrality policies. The guidelines for charging will not reduce the scope for revenue opportunities in line with Government objectives.
6	All services in addition to the Basic Service, and all products customised for particular users, should be provided on a commercial basis by the Bureau in competition with other meteorological service providers.	Accepted, with the reservation that where safety or public interest issues are involved services may be provided by the Bureau on some other basis.
7	Access agreements with the individuals and organisations should permit them to customise Bureau products for particular media outlets or for other users, but would preclude them from: • changing the wording of warnings • preparing forecasts that differ materially from those of the Bureau • altering basic data in such a way that future users would be unaware of the alteration. • failing to acknowledge the Bureau as the source of the basic data and products.	**Accepted, with the reservations that:** • **Any restrictions on the use of Bureau products must be consistent with the Government's Competition Policy and the *Trade Practices Act (1974)*;** • **This recommendation applies to commercial organisations, and to organisations publicly re-distributing Bureau data and products.**

	RECOMMENDATIONS	GOVERNMENT RESPONSE
8	Charging for the products listed as a part of the Basic Service should be based on incremental cost recovery. That is, users should pay the cost of making products available over and above the cost of the basic service, including a charge for system maintenance and development.	**Accepted. The Bureau will continue to apply incremental charging to its cost recovery activities.**
	Australian Meteorological Data and Information Services System (AMDISS)	
9	The Bureau should phase in at the earliest opportunity, and actively promote, the use of AMDISS as the main means of access to the Basic Service and the Bureau's commercial services.	Accepted. The *Australian Meteorological Data and Information Services System* (AMDISS) will be progressively implemented over the next few years as a corporate priority of the Bureau.
	Financial Arrangements	
10	Agreement should be reached with the Department of Finance and Administration on a basis for revenue sharing that would provide adequate incentives for the Bureau to seek to maximise revenue generation.	**Accepted. The Bureau will enhance its service distribution arrangements through the retention of revenue under Section 31 arrangements in a manner consistent with the effective fulfilment of the Bureau's purpose and objectives.**
	Competitive Neutrality	
11	The Bureau should aim to conduct its commercial activities in such a way as to be able to demonstrate competitive neutrality if so required. To achieve this it will need to review and revise its existing practices for cost determination mechanisms, and in doing so develop a new cost allocation supplement to the *Charging Manual*.	Accepted. The Bureau, assisted by the Implementation Committee, will progressively review and, where appropriate, upgrade cost determination and cost allocation procedures to ensure proper application of its charging policies.

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BUREAU OF METEOROLOGY CHARGING MANUAL

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January 2001

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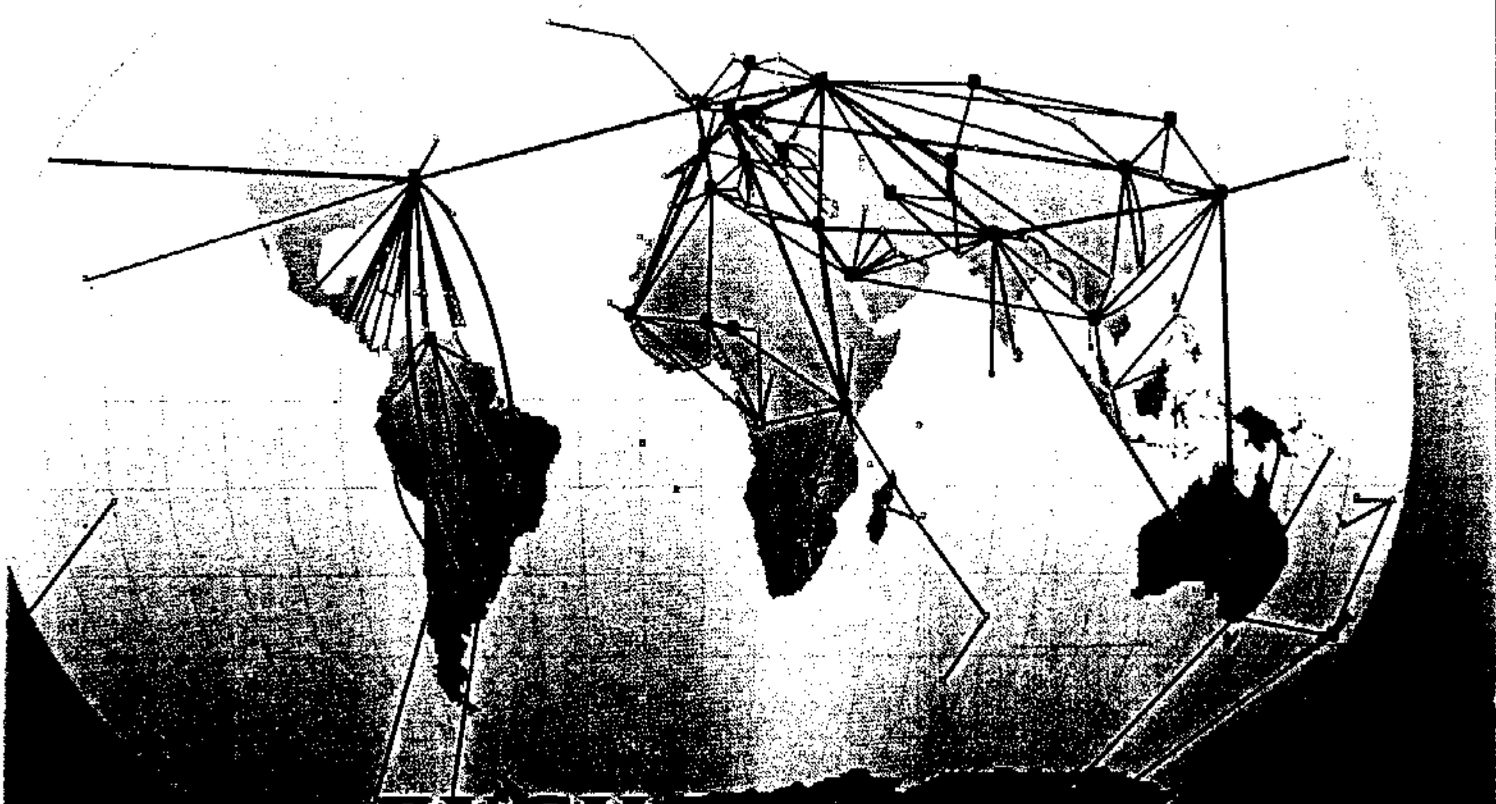
WORLD METEOROLOGICAL ORGANIZATION



ATTACHMENT I

WORLD METEOROLOGICAL ORGANIZATION

BULLETIN

Volume 48 No. 2
April 1999

THE NATIONAL METEOROLOGICAL SERVICE

By John W. Zillman*

Abstract

The national Meteorological Service (NMS) is a fundamental component of the national infrastructure of all countries. Its basic purpose is to meet governments' responsibilities to contribute to the safety, security and general well-being of their citizens, to ensure the ongoing collection and long-term custodianship of a reliable national climate record for use by future generations and to fulfil countries' essential international obligations under the Convention of the World Meteorological Organization. Though the basic role of the NMS has long been widely understood and greatly valued by national communities, recent developments associated with the implementation of alternative arrangements for the provision of many services that have hitherto been funded and provided by the public sector, have underscored the need for a clear definition of the essential rationale, charter, and *modus operandi* of the NMS to ensure informed decision-making on future arrangements for meteorological infrastructure operation and service provision at both the national and international levels.

Introduction

Two of the most fundamental obligations accepted by governments through the ages have been the protection of the safety and welfare of their citizens and the collection and safeguarding of important historical records for future generations. For more than a century, virtually all countries, large and small, have fulfilled their obligations to minimize the adverse impacts of weather and climate on community safety and welfare and to provide a comprehensive and reliable national climate record through the operation of an integrated, publicly funded NMS.

The original trigger for the establishment of State meteorological institutions and for the free exchange of information among them was to help ensure safety of life at sea and to contribute to better scientific understanding of the phenomena of the natural world. But with the growth of civil aviation and increasing awareness of the substantial social and economic benefits accruing to individual citizens and to overall national planning and development from the availability and application of reliable information on current and future weather and climate conditions, the concept of an NMS as an essential component of the basic national infrastructure of all countries became widely adopted around the world.

Because meteorological services in support of the safety of life and property and the general well-being of all citizens have long been seen in most countries as a basic community necessity and right, and because they possess the intrinsic properties of "public goods" (Harris, 1995), their provision has always been accepted as a fundamental responsibility of government. Only in very recent times, as governments in some countries have sought to divest themselves of

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The views in this paper are those of the author and do not necessarily represent those of the Australian Government or of WMO.

many of their traditional responsibilities, have there been suggestions that such services might be provided through mechanisms other than the traditional State-funded NMS; and alternative approaches (WMO, 1999) such as the commercialization, corporatization or privatization of meteorological service provision have been canvassed in several countries and pursued vigorously in a few.

These recent developments have, however, impacted dramatically and mostly adversely on the long-established tradition of international co-operation among the NMSs of individual nations. Because of the scientific complexity and global interdependence of weather- and climate-forming processes, meteorology is one of the most inherently international of all fields of science and human endeavour. Since the establishment of the non-governmental International Meteorological Organization (IMO) in 1873, the NMSs of virtually all countries have worked together in an increasingly close global partnership, now under the auspices of the intergovernmental World Meteorological Organization, a specialized agency of the United Nations (UN), which has become widely regarded as a model of international cooperation within the UN system (Davies, 1986).

There is no doubt that the citizens of all nations expect to continue to enjoy the range and quality of meteorological services which modern science and technology and the unique WMO system of international cooperation have made possible in the closing years of the 20th century. But there is also reason to believe that this will only remain possible if the foundation on which the WMO system of international cooperation is built, the integrated data collection, research and service role of the NMSs of the individual nation States, is preserved and strengthened as a bastion of cooperation in an increasingly competitive and contestable world.

It is the purpose of this paper to take stock of the role and operation of the NMS and to set down some basic considerations which might serve as a useful point of reference in addressing future arrangements for the provision of meteorological and related services at the national level in the present uncertain and rapidly changing times.

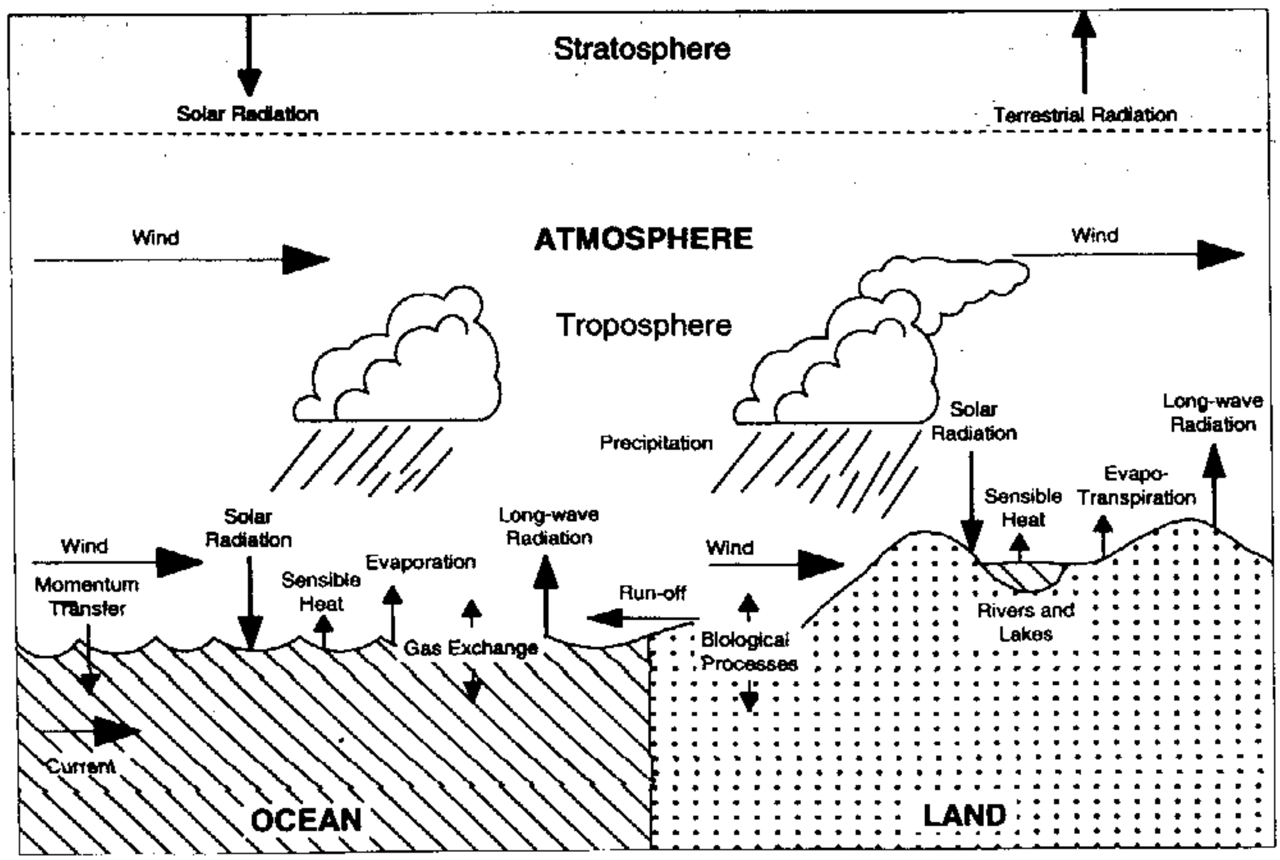

Figure 1 — The atmosphere as part of the total Earth system. Meteorology encompasses all aspects of the science of the atmosphere, including its chemical composition, structure and movement and the nature and mechanisms of weather and climate phenomena. It is particularly concerned with the integrated response of the atmosphere and the underlying land and ocean to the incoming shortwave radiant energy from the Sun and its transfer and transformation through physical, chemical and biological processes and ultimate re-radiation to space at longer (infra-red) wavelengths. It deals with the phenomena of both the troposphere and the stratosphere and their coupling with the underlying land and ocean and the ionized layers of the upper atmosphere respectively.

Meteorology

Meteorology is both a field of science and a profession. In the words of the International Meteorological Vocabulary (WMO, 1992) it is the "study of the atmosphere and its phenomena". More explicitly (WMO, 1996) it is the "science of the atmosphere, dealing in particular with its structure and composition, interactions with the oceans and land, movements (including weather-forming processes), weather forecasting, climate variability and climate change" (Figure 1).

The phenomena of the atmosphere which impact on society and hence fall within the domain of interest of an NMS span a huge range of time- and space-scales (Figure 2). Although there is no universally agreed dividing line, they subdivide broadly, according to time-scale, into the phenomena of weather and climate. While it is information on the day-to-day sequence of weather events and forecasting of their behaviour for a few days to a week in advance for which NMSs are best known (often in their role as national Weather Services) it is important to realize that it is information on the behaviour of the atmosphere on longer time-scales (from months to centuries) both past and future, which is, in many respects, of even greater long-term significance to humanity.

Meteorology thus embraces both weather and climate (Meteorological Office, 1972) and climatology, which is defined by WMO as the "study of the mean physical state of the atmosphere together with its statistical variations in both space and time as reflected in the weather behaviour over a period of many years" (WMO, 1992), must be regarded as an integral part of the science and profession of meteorology.

Although meteorology deals with all aspects of the atmosphere, including its composition, structure and movement, many features of its behaviour, especially when viewed over long time-scales, depend on its interaction with the underlying land and water surfaces and on processes taking place within the oceans. On climate time-scales, in particular, there is thus a substantial area of overlap between meteorology and its sister sciences of hydrology (and related land-surface processes) and oceanography (Figure 3).

Meteorological services as public goods

The timely and reliable meteorological information—especially forecasts and warnings—which communities need to help ensure their safety and security and contribute to their general day-by-day convenience and well-being constitute what,

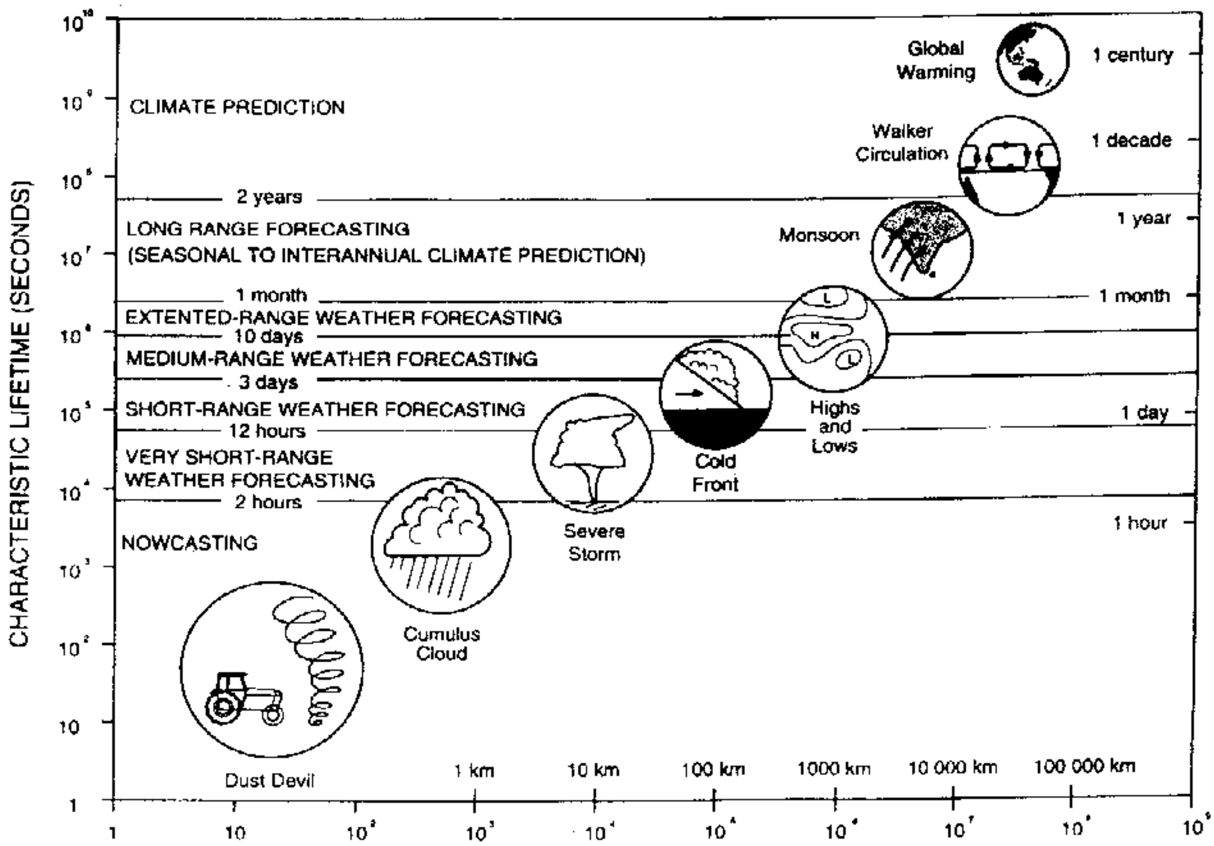

Figure 2 — The characteristic size and lifetimes of some typical atmospheric phenomena. The internationally agreed terminology used to describe weather and climate forecasting lead times is also shown.

in economic terms, are referred to as pure public goods. The defining characteristic of pure public goods (Baumol *et al.*, 1992; Self, 1993; Bannock *et al.*, 1998) is that they are both:

- Non-depletable, in that their use by one member of society does not reduce their availability or value to everyone else; and
- Non-excludable, in that once they have been made available to some members of society, it is not possible, or at least not realistically practicable, to exclude others from benefiting from them.

Economic analysis further elaborates some essential conditions which apply to the provision of pure public goods as follows (Heald, 1983; Bailey, 1995).

- Because they are collectively owned and no property rights can be vested in them, markets will fail to exist for their provision;
- The decision on whether they should be provided, and at what level, must be taken by government;
- The costs of their provision must be fully met by taxation; and
- The beneficiaries are the whole of society and the total benefit to society is the greater the more widely they are consumed.

While the provision of basic public weather services to the community at large through the mass media is often cited as the example *par excellence* of a public good (e.g. Heilbroner and Thurow, 1994), other meteorological services and phenomena can be identified which possess only some of the characteristics of a public good. It is important to recognize, in particular, the economic characteristics of:

- Goods which are non-depletable but excludable, such as weather information additional to the public service which, while potentially widely useful, is only made available through restricted communication channels to those who are prepared to pay; and
- Goods which are non-excludable but depletable, such as the quality of the global atmosphere, which is progressively depleted as more consumers use it as a sink for pollution.

There is finally a class of private (or market) goods which are both depletable and excludable and for which markets will automatically develop, such as specialized weather information, prepared and provided on a customer-specific basis, which permits a decision to be taken that bestows a competitive advantage not available to a subsequent user. This is an area where, at least on economic grounds, meteorological services should be seen as being no different in principle from other traditional goods and services and where, except in the special situation of market failure due to the high degree of specialization involved or the limited size of the potential market (e.g. in developing country economies), it is inappropriate to apply a public good perspective.

In economic terms, therefore, there is a clear distinction between basic public meteorological services made promptly and widely available through the mass media in the interests of the safety and welfare of the entire community (pure public goods) and specialized services provided to meet the needs of particular users (impure public goods and private goods), for which markets can be expected to determine, or at least strongly influence, the optimum level of supply.

Social, economic and environmental benefits of meteorological services

The benefits to a nation, its social structure, its economy and its natural environment and, in particular, to the general safety and welfare of its individual citizens from the provision of state-of-the-art meteorological services have, historically, been seen as self-evident and the resources needed for their maintenance and continuing improvement self-evidently justified by the scope and scale of the benefits derived (Zillman, 1997(a)). The benefits to all of humanity from the effective integration of the two great technological developments of the space age into operational meteorology, through global cooperation in meteorological satellites and numerical weather prediction (NWP), themselves have gone far towards repaying the massive scientific and technological investments of the superpowers during the cold war era. The inability of governments in many developing countries to fund the provision of their basic national meteorological infrastructure and essential public services to optimal levels has reflected the realities of short-term funding pressures and other barriers to technological uptake (Crouthamel and Scotti, 1997), eventually to be made good as part of the development process, rather than any doubt that the increased investment would repay itself many times over in the longer term.

Nowadays, under the pressures of intense competition for both public and private sector

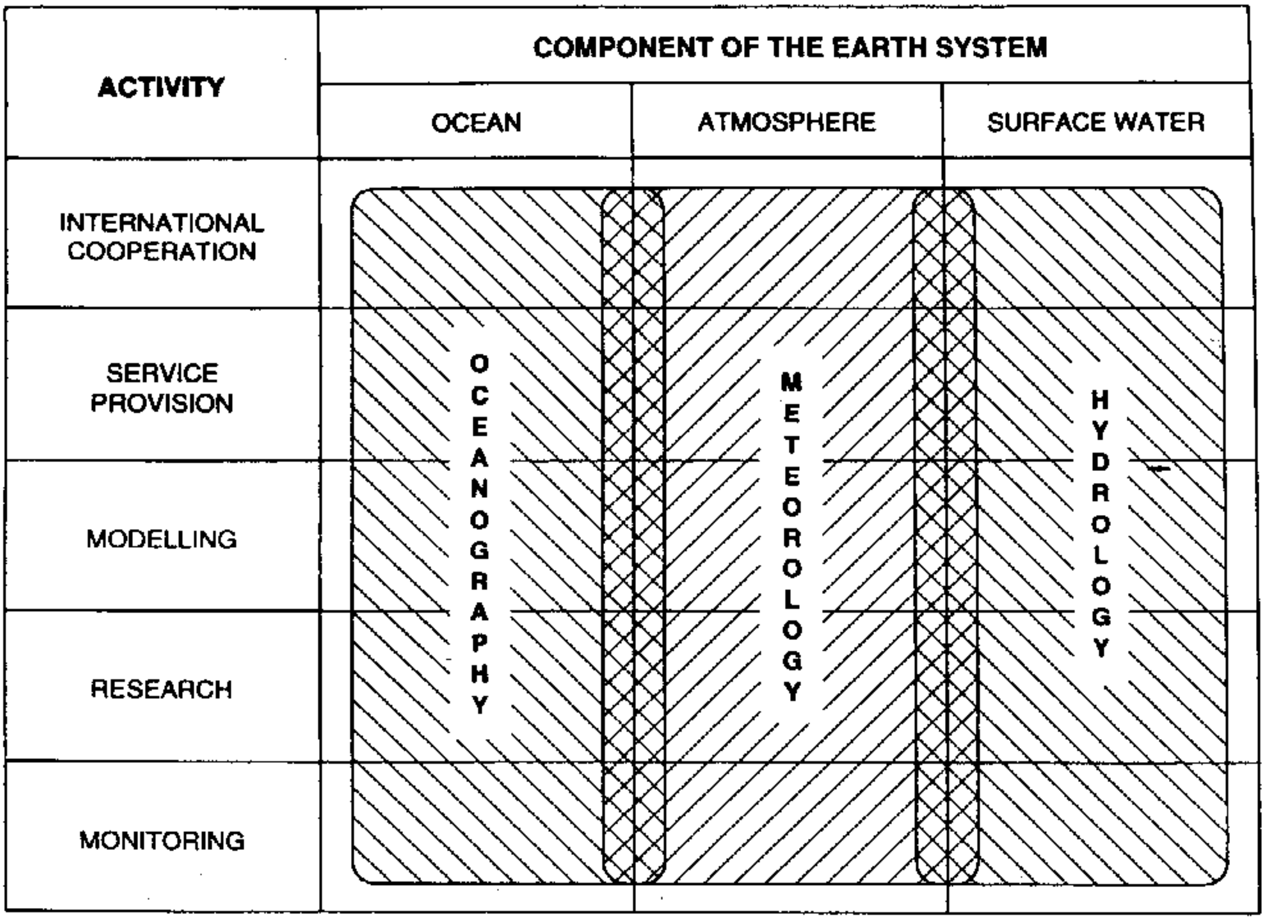

Figure 3 — The interrelated and overlapping sciences of oceanography, meteorology and hydrology (including related land-surface processes) dealing with the systematic observation (through monitoring), understanding (through research) and prediction (through modelling) of the behaviour of the fluid Earth system and their useful application through the provision of a wide range of services to national communities and exchange of data and products with the international community

resources in a rapidly globalizing world economy (Bryan and Farrell, 1996; Kuttner, 1997; Mander and Goldsmith, 1996; Gray, 1998; Porter, 1998; Soros, 1998; Yergin and Stanislaw, 1998), it has become increasingly important to government and industry priority-setting and decision-making that the full range of benefits flowing from the operation of an effective NMS system be clearly documented and plainly evident to both the public and private sector beneficiaries of its services. Over the past decade, WMO has built substantially on a number of earlier studies (e.g. Gibbs, 1964; Mason, 1966; Maunder, 1970; Freebairn, 1979) to establish a broader understanding of both the methodologies and findings of research into the valuation of meteorological services and to foster further work in this area (WMO, 1990, 1994). Important recent reviews are provided by Anaman *et al.* (1995, 1998), Nicholls (1996) and Katz and Murphy (1997).

It is important to recognize that the pre-eminently important benefits of meteorological services in most countries are of a social nature, relate principally to safety of life and limb, and are largely taken for granted by the citizens of virtually all advanced countries. They include:

- The avoidance of the immense loss of life that would occur, in even the best engineered societies, if communities and individual citizens had no source of advance warning of the onset of hurricanes, typhoons, severe storms, floods, blizzards, bushfires and other severe weather events. While they still claim more than 100 000 lives annually (Cornford, 1996, 1997, 1998; De and Joshi, 1998) mostly in developing countries, there is little doubt that this would be at least an order of magnitude greater in the absence of the severe weather warning systems that now operate in virtually all countries;

- The enormous contribution to the safety and security of the travelling public, especially those travelling by air and sea, through the availability, under the overall framework of international conventions on air transport and safety of life at sea, of effective aviation and marine meteorological services. While today's passenger aircraft and ships are physically far less vulnerable to the elements than those of earlier times, the numbers of travellers and the potential for loss of life from a single mishap have increased dramatically over the past century. Every citizen who flies in the 1990s flies far more safely because of the coordinated global system of meteorological services which support the thousands of round-the-clock decisions on operating routes, flight plans, in-flight operations and take-off and landing procedures;

- The ubiquitous contribution to the day-by-day safety, comfort, enjoyment and general convenience of citizens through access to information which assists in their decisions on what to wear, where to go, what to do and when to do it. Given the generally high levels of skill now available in public weather forecasts out to at least three to five days and the high percentage of citizens (in excess of 90 per cent in some countries according to surveys (e.g. Anaman and Lellyett, 1996; American Meteorological Society, 1998)) who make use of the services, the aggregate social benefit from community use of public weather services is clearly great;
- Many other direct and indirect forms of social benefit, including the ease of mind of having access to the latest information on developments affecting threatened communities in distant places, the cultural value of reliable records of major natural events, the contribution to the integrity of the justice system from the many legal uses of official weather records and the pleasure and satisfaction for young and old from increased understanding of the phenomena of the natural world.

While most of the most important social benefits of public meteorological services defy valuation in strictly economic terms (what value a human life?), many public good services and virtually all those services which are of the nature of private or mixed private and public goods also serve as input to decisions which have direct or indirect financial impacts for individuals, households, firms, industry sectors and national economies and may thus be valued in money terms through the normal techniques of economic analysis. The adaptation of relevant economic concepts and methodologies to the special case of meteorological services is described in Katz and Murphy (1997). These include, in particular, use of the economic theory of information value and decision-making under uncertainty (Johnson and Holt, 1997) and lead to the use of both prescriptive and descriptive methodologies including simulation modelling involving economic optimization (often based on cost–loss ratio concepts), cost function analysis and direct user surveys (Anaman *et al.*, 1995). Some of the major difficulties encountered include those associated with the development and use of appropriate transfer functions (e.g. crop models) to interface the meteorological information with the economic decision process; and those associated with scaling up from individual decision situations to industry sectors and national economies (noting that an economic advantage for one firm based on good meteorological information may turn out to be a disadvantage for its competitor with, on occasions, little or no net advantage in the sector concerned).

Studies suggest that, above a certain threshold of forecast accuracy and skill which is well below that of current state-of-the-art forecasting systems, weather and climate information (past, present and future) can contribute positively—and in many cases, substantially—to economic benefit (increased income and/or reduced costs) in virtually all the hundred or more major economic sectors normally recognized in national accounts. Those for which significant benefits have been identified include, in particular (Freebairn and Zillman, 1999): agriculture; animal husbandry; aviation; banking and financial services; communications; construction; disaster management; energy generation and supply; environmental protection; fisheries; food production; forestry; health and medical services; insurance; legal services; leisure; manufacturing; maritime transport; offshore operations; port and harbour management; retail; sport; tourism; urban planning; and water resource planning and management.

The most comprehensive and quantitative assessments have been carried out in the key sectors of:

- Agriculture and animal husbandry, where substantial economic benefits are available from:
  - Avoidance of crop losses due to protective or pre-emptive action in the face of expected threatening weather (frost, hail, rain, wind, flood);
  - Protection of newly born or newly shorn sheep from cold snaps or other extreme weather events;

- More efficient scheduling of time, man-power and machinery in planting, management and harvesting of crops in the light of forecast weather and climate information;
- Efficient use of climatological probability information in crop selection, irrigation system design and investment in drought protection measures,
- Increased production and sales from optimum use of fertilizers, pesticides, etc in the light of forecast weather conditions;

- Aviation, especially national and international regular public transport, where major operating cost savings are available, relative to the no-meteorological-information situation through:
  - Reduced fuel consumption as a result of selection of optimal flight paths to take advantage of forecast head or tail winds, etc.,
  - Reduction in the fuel consumed in carrying additional fuel to cover the risk of diversion to alternate terminal airports, given reliable forecast of terminal weather conditions;
  - Minimization of the substantial costs (e.g. for overnight hotel accommodation for passengers) resulting from diversions due to terminal weather conditions;
  - Improved scheduling of flight arrival and departure in the light of observed and forecast weather conditions;
- Disaster reduction where, in addition to the enormous social benefits associated with the minimization of injury and loss of life, effective meteorological services permit major cost savings to individuals, organizations and governments through:
  - Minimization of damage costs from wind, rain, hail, fire and flood as a result of emergency preparedness measures put in place on receipt of hurricane or other severe weather warnings;
  - Minimization of search and rescue costs and of international aid and rehabilitation costs of affected communities,
  - Saving of the costs of deploying emergency management (e.g. bushfire fighting) staff and facilities in forecast no-danger situations;
  - Minimization of the costs of drought relief and recovery through effective stocking policies and optimal use of relief aid in the light of specific climate monitoring and forecast services.

The several hundreds of valuation studies conducted in these and other sectors such as tourism, mining, water-resources management and offshore operations, confirm the existence of actual or potential economic benefits far in excess of the total cost of operation of the NMS system, often even from a single sector alone. Benefit-cost ratios for individual services range from of the order of 2:1 up to many hundreds to one (Katz and Murphy, 1997).

Despite these large direct economic benefits available to individuals, firms, sectors and national economies from meteorological services supplied on a provider-customer basis in a market or quasi-market environment, by far the largest economic benefit still accrues to nations from the sum of the benefits of all the economic decisions by individual members of the community on the basis of the universally available public weather service. Quite apart from the economically unquantifiable social benefits associated with increased public safety and security, some useful methodologies have been developed (e.g. Walsh, 1979; Anaman and Lellyett, 1996) for economic valuation of public good meteorological services. Their application suggests an aggregate economic value of the public weather service far in excess of the total cost of both the service itself and the entire national infrastructure which supports it. Formal benefit-cost assessments of increased expenditure on improved service provision (e.g. Chapman, 1992) provide compelling evidence for an increased level of investment in even the most advanced Services.

Notwithstanding the much greater integration of economic and environmental values over recent years, particularly since the Rio Earth Summit in 1992, the potential benefits of meteorological services to sound environmental management are so significant as to warrant separate consideration in any national balance sheet of the benefits and costs of maintenance of an effective national meteorological service system. The most obvious environmental benefits from meteorological services include:

- The capability for consistent long-term monitoring of some of the most basic indicators of the state of the environment;
- Contribution to the minimization of release of toxic substances and other pollutants into the atmosphere, ocean and inland waters;
- Effective management of local environmental quality by control of emissions on days

of forecast high air pollution potential and the like;

- The observational and scientific basis for addressing major global environmental issues such as stratospheric ozone depletion and human-induced climate change.

In the 1960s, Kingsland (1964) and Mason (1966) offered preliminary estimates of the overall economic benefit-cost ratio for NMSs of the order of 10:1 to 40:1. Notwithstanding all the difficulties and uncertainties involved, the substantial body of research by the meteorological and economics communities over the past three decades (e.g. Teske and Robinson, 1994) provides no basis for reducing these early estimates. All things considered, a conservative estimate for the significantly improved meteorological services of the 1990s (Zillman, 1997(b)) would suggest an overall benefit-cost ratio for an effectively operating NMS system of at least 20:1.

The need for an official service

In addition to the fundamental public good rationale for governments having assumed responsibility for funding the provision of the essential elements of the NMS system, there have been three powerful reasons why, historically, governments have accepted responsibility for the provision of an official NMS:

- First, the need for a high level of standardization and long term continuity in the observational networks which provide the common data needed both to secure a homogeneous and high quality national climate record (sufficiently reliable, for example, to detect and map very slow long-term changes of climate due to the enhanced greenhouse effect) and to support operational forecast and warning services for civil and defence aviation and other purposes which can impact critically on the safety of life and property;
- Second, the need to ensure the highest levels of professional integrity and objectivity in the preparation of the forecasts which bear on safety of life and property, based on full cooperation from all possible providers of data and avoiding the competition that would lead inevitably to the withholding of vital data and/or the provision of dangerously confusing information to the public, especially in life-threatening situations; and to ensure the existence of a single authoritative source of warning information as a basis for coordinated preparedness action in potential disaster situations; and:
- Third, the need for a single authoritative source of internally consistent information and advice to meet the country's international obligations under intergovernmental conventions governing the provision of meteorological support for the safety, regularity and efficiency of international air navigation and the safety of life at sea.

With the increasing dominance of market economies in both the developed and developing world (Bryan and Farrell, 1996), these considerations apply with more force now than ever before. It is essential to recognize that market forces will not provide, and user pays regimes will not support the maintenance of, the long-term high-quality data-collection and processing infrastructure needed to ensure the professionally sound and reliable meteorological services which modern communities demand and future generations are entitled to inherit. Neither, in an increasingly litigious world, will the private sector be in a position to accept the consequences of community recrimination for deficient or erroneous forecasts and warnings resulting from the level of infrastructural underpinning and professional competence that would result from the operation of market forces alone.

Legal and institutional basis

The legal basis for operation of NMSs varies widely among countries. Some NMSs are formally established under national laws (acts of parliament, presidential or royal decrees, etc.) specific to meteorological service provision, some are based on the provisions of relevant sections of other laws (e.g. on civil aviation or defence), some are established and empowered by regulations or other subsidiary forms of legislation and some are simply established by administrative decision of the government of the day. In several countries, the basic legal charter of the NMS sets out its mission, functions and powers in considerable detail. In others there is just a brief outline of its purpose and core functions and responsibilities on departmental files.

Institutionally, some NMSs operate as self-contained statutory agencies reporting directly to ministers, prime ministers or presidents but having a high level of operational autonomy and freedom from day-to-day political or bureaucratic control. Others are themselves constituted as departments of state reporting to ministers or their equivalents in non-ministerial systems. Still others are established as parts of departments, quasi-autonomous departmental outriders or separate agencies. In a few cases, former NMSs have been re-established as corporations operating under standard company legislation and providing services under contract to government.

Terminology

Although both the concept and the terminology have been well established for a long time, and the original 1947 text of the Convention of the World Meteorological Organization (WMO, 1990) includes several references to the Meteorological Services of Member States, there is no widely accepted definition of a National Meteorological Service. Established WMO usage refers to national Meteorological Services (responsible at the national level for meteorology), national Hydrological Services (responsible at the national level for operational hydrology) and national Hydrometeorological Services (responsible at the national level for meteorology and operational hydrology) with abbreviations as follows:

- NMS—national Meteorological or Hydrometeorological Service;
- NHS—national Hydrological Service;
- NMHSs—national Meteorological and Hydrological Services.

The *International Meteorological Vocabulary* (WMO, 1992) defines the term "meteorological service" as "National or regional technical scientific and administrative organization whose activities are concerned with the different theoretical and practical branches of meteorology" and identifies "meteorological institution", "meteorological office" and "weather bureau" as acceptable synonyms.

For the purposes of this paper, a useful working definition of the NMS is "an organization established and operated primarily at public expense for the purpose of carrying out those meteorological and related functions which governments accept as a responsibility of the State in support of the safety, security and general welfare of their citizens and in fulfilment of their international obligations under the Convention of the World Meteorological Organization".

The purpose and role of an NMS

The WMO Fourth Long-term Plan (WMO, 1996) points out that the ultimate purpose of all NMHSs is to contribute to the economic and social benefit and welfare of their communities. The purpose of an NMS may thus be defined in terms of its contribution to the following fundamental national goals:

- Reduction of the impact of natural disasters;
- Economic development and prosperity of primary, secondary and tertiary industry;
- Safety of life and property;
- National and international security;
- Preservation and enhancement of the quality of the environment;
- Community health, recreation and quality of life;
- Efficient planning, management and operation of government and community affairs;
- Provision for the information needs of future generations;
- Advancement of knowledge and understanding of the natural systems of the planet.

According to the Fourth Long-term Plan, the most important role of most NMHSs on a day-to-day basis is to provide weather and climate information, and forecasts and warnings of severe meteorological and hydrological events, and to ensure the assessment and forecasting of the quantity and quality of water resources. As the weather systems of the world are always interactive, no one country can be fully self-sufficient in providing for all of its meteorological services. The national networks of meteorological stations are integrated into a global weather and climate observing network under the framework of the WMO World Weather Watch and the Global Climate Observing System. Thus, in carrying out their day-to-day functions in support of national economic and social activities, NMHSs serve both the interests of their own citizens and those of the wider global community.

The most important role of NMHSs in aiding longer-term national planning for sustainable development is the collection, archival, interpretation and application of climatological, hydrological and related information. This role is a rapidly growing part of the work of numerous NMHSs and WMO has developed specific guidelines to assist them in enhancing their contribution to the goals of sustainable development (WMO, 1993).

Mission and functions

The overall mission of a modern integrated NMS, operating within the international framework of WMO, is to observe, understand and predict the weather and climate of its country and to provide meteorological and related services in support of its national needs and international obligations. It is thus involved in an essentially five-fold mission: monitoring; research; modelling; service provision; and international cooperation.

Although each country must be expected to design its NMS in support of its mission according to its own national needs and circumstances and its allocation of other meteorology-linked functions among its own particular combination of public and private sector agencies, there are many basic functions which have, historically, been common to almost all NMSs, irrespective of size, economic system, geographical region and state of development. The usual basic functions of an NMS of a Member country of WMO may be summarized as follows:

- The planning, implementation, operation and maintenance of surface and upper-air observing networks over its territory;
- The provision and maintenance of systems for the collection and quality control of the observational data and their processing for the provision of real-time weather, climate and related environmental services, assembly of the national climate record and support of meteorological research;
- The advancement of meteorological science and technology and the development and improvement of its own operations and services through supporting research and development;
- The provision and operation of meteorological prediction models and systems appropriate to its geographical region of responsibility;
- The provision of a range of weather information, forecast and warning services to the community at large, mainly through the mass media;
- The provision, on either a public interest or "user pays" basis, of a range of user sector-specific operational meteorological services, through the mass media and other channels, to such major user groups as agriculture, shipping, aviation and national defence;
- The provision of meteorological support to related environmental services such as hydrological forecasting and air quality protection;
- The maintenance of a national climate archive and the provision of climate data and climate monitoring and prediction services;
- The provision of advice on meteorological matters, as a basis for government policy formulation, and for other purposes, to other government agencies and to its national community;
- The education of its national community on weather and climate processes and issues and in the beneficial use of meteorological and related services;
- The fulfilment of its obligations under the Convention of the World Meteorological Organization and the furthering of its national interests by participation in the programmes and activities of WMO.

Associated with these basic functions, and carried out to varying extent by almost all NMSs, is a range of other supporting activities which may be managed as an integral part of the operations of the NMS or may be provided from external, including international, sources such as:

- The provision and operation of telecommunications systems for ensuring prompt and reliable national and international exchange of NMS data and products;
- The training of specialist meteorological staff for NMS operations;
- The operation of supporting information technology facilities;
- The publication of meteorological reports and bulletins;
- The maintenance of a national meteorological library of data and scientific publications.

The practice varies widely amongst countries in respect of the extent to which the NMS is also assigned national responsibility for monitoring, research and service functions in the related environmental/geophysical disciplines of oceanography, hydrology, seismology and ionospheric physics. Several NMSs also operate as, or include within their meteorological responsibilities the functions of, National Oceanographic Services (NOSs). Some 50 or more NMSs also include hydrological (especially flood forecasting and warning) responsibilities and some are also responsible for seismological monitoring and prediction. These arrangements need to be understood in terms of the provisions of the Convention of the World Meteorological Organization, under which WMO is responsible for operational hydrology within the UN System (complementing UNESCO's responsibility for scientific hydrology) and shares the international responsibility for operational oceanography with the IOC (Intergovernmental Oceanographic Commission) of UNESCO but has no explicit formal responsibility, at this stage, for seismology or ionospheric monitoring and prediction.

Concept of operation

The basic concept of operation of an NMS is summarized schematically in Figure 4 in terms of the essential components of its mission, which mirror the integrating framework of Figure 3. Figure 4 depicts, in particular, the central role of the basic observational, data-processing and modelling infrastructure in providing a common core of information on which virtually all the services and other outputs of the NMS (including research findings and data and products for international exchange) depend. In this representation, the supporting component of research and other unallocated common internal support activities, such as personnel, property and financial services, may be grouped separately or notionally attributed on a pro rata basis to the various services and other outputs. Alternatively, but equivalently in terms of its implications for cost attribution, the basic infrastructure may be viewed as providing the foundation for a range of services and

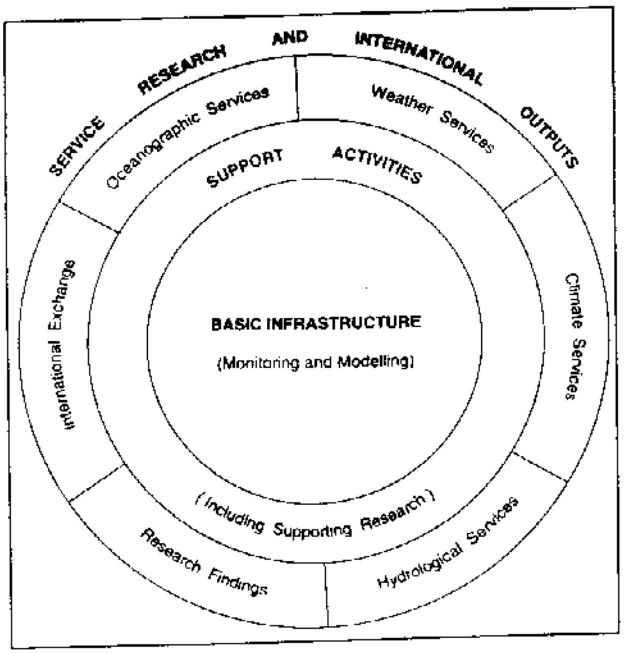

Figure 4 — The concept of operation of a national Meteorological Service with an integrated monitoring-research-modelling-service-international mission. The basic national meteorological data collection, processing and modelling infrastructure serves as a common core on which all the services and other outputs of the NMS are based. In this model of the operation of an NMS, the general management and other support costs are notionally attributed pro rata across the outputs.

other outputs (including the research and international outputs) with supporting research and other support activity costs attributed pro rata across the outputs as shown on the left side of Figure 5. The right side of Figure 5 depicts a different approach, in which the basic infrastructure and the incrementally costed services, research and international exchange activities are regarded as a separate set of outputs with the general support costs attributed pro rata amongst them for output budgeting purposes.

The overall concept of operation depicted schematically in Figures 4 and 5 is elaborated in more operational terms in Figure 6. As shown schematically in Figure 6, the operation of an NMS is based on an array of observational networks and systems (both surface- and space-based) to obtain information on the current ("initial") state of the atmosphere and the underlying land and ocean. This information is collected rapidly through a variety of communication systems and, together with similar information from overseas, is used by National Meteorological Centres (many of which nowadays run some form of computer-based prediction model) to produce forecast patterns of the main meteorological variables out to a week or more in advance. These are then used by the National Meteorological Centre itself, or distributed to decentralized forecasting offices, to support a range of information, forecast and warning services to the community at large and to the various major user groups. They are also usually made readily accessible to private sector providers of specialized services to individual customers.

In parallel with these "real time" operations and services, the basic data are channelled through quality control and other processes into the non-real-time part of the NMS, whose principal task is to produce and maintain the national climate data archive as the basis for a wide range of climate services, including services to the in-house and external research communities. Increasingly, thanks to modern information technology, the distinction between traditional real-time and non-real-time activities of the NMS are disappearing as NMSs implement fully integrated data-processing systems and engage in the "seamless" provision of a wide range of interdependent weather and climate services.

Monitoring and modelling

The role of the NMS as the national authority for long-term monitoring of the state of the atmos-

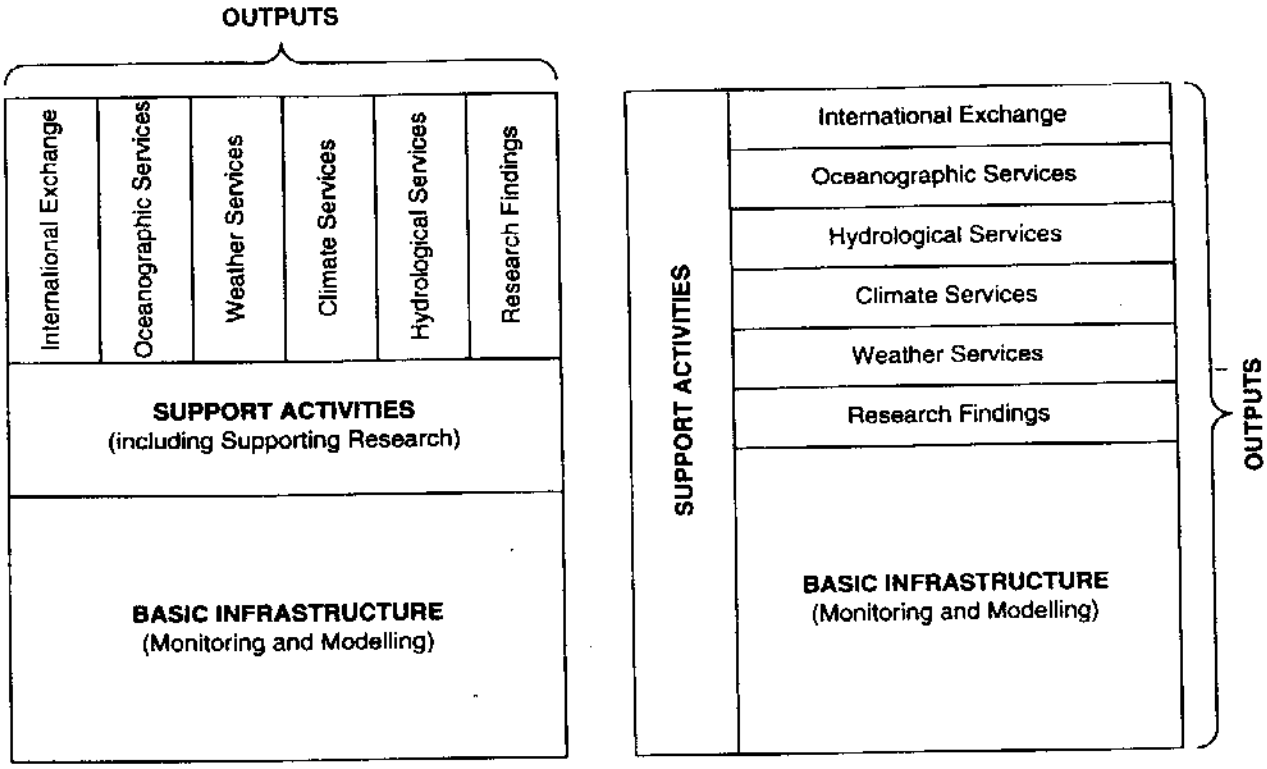

Figure 5 — Two alternative models for attribution of the costs of common support activities amongst the total set of outputs (*left*) and across the basic infrastructure (here treated as an end in itself) and the incremental outputs (*right*)

phere is of fundamental importance and is well established in most countries. It is essential, both to the integrity of the national climate record and the contribution which each country makes to integrated global observation of the atmosphere (Figure 7) under the WMO World Weather Watch (Figures 8 and 9), that the monitoring function be carried out to the highest standards using observational practices and measurement techniques which conform to agreed international standards. It is usual for national observing networks to serve, as far as possible, the totality of national needs with essentially the same data being processed into the climate record as are used for operational forecast and warning and advisory services.

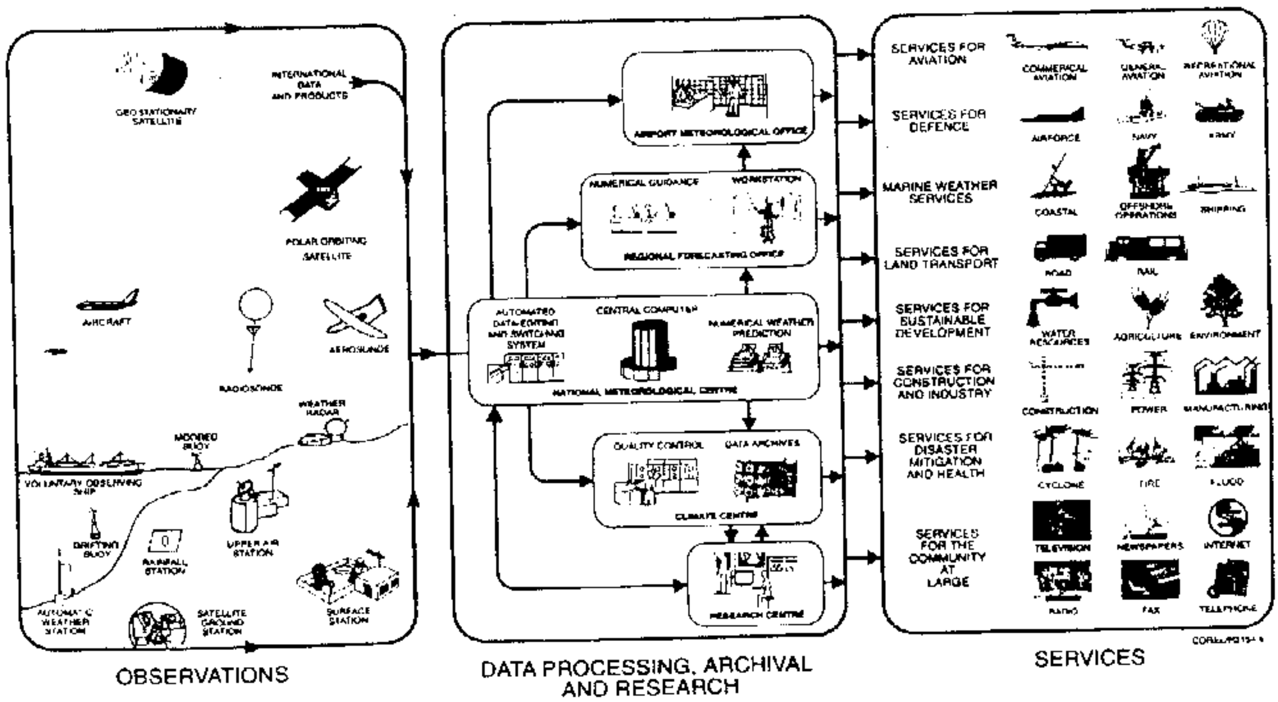

Figure 6 — The operation of a national Meteorological Service based on a series of observation networks and systems (*left*), data processing, archival, research and modelling facilities (*centre*) and service provision through a variety of delivery mechanisms to a wide range of users (*right*)

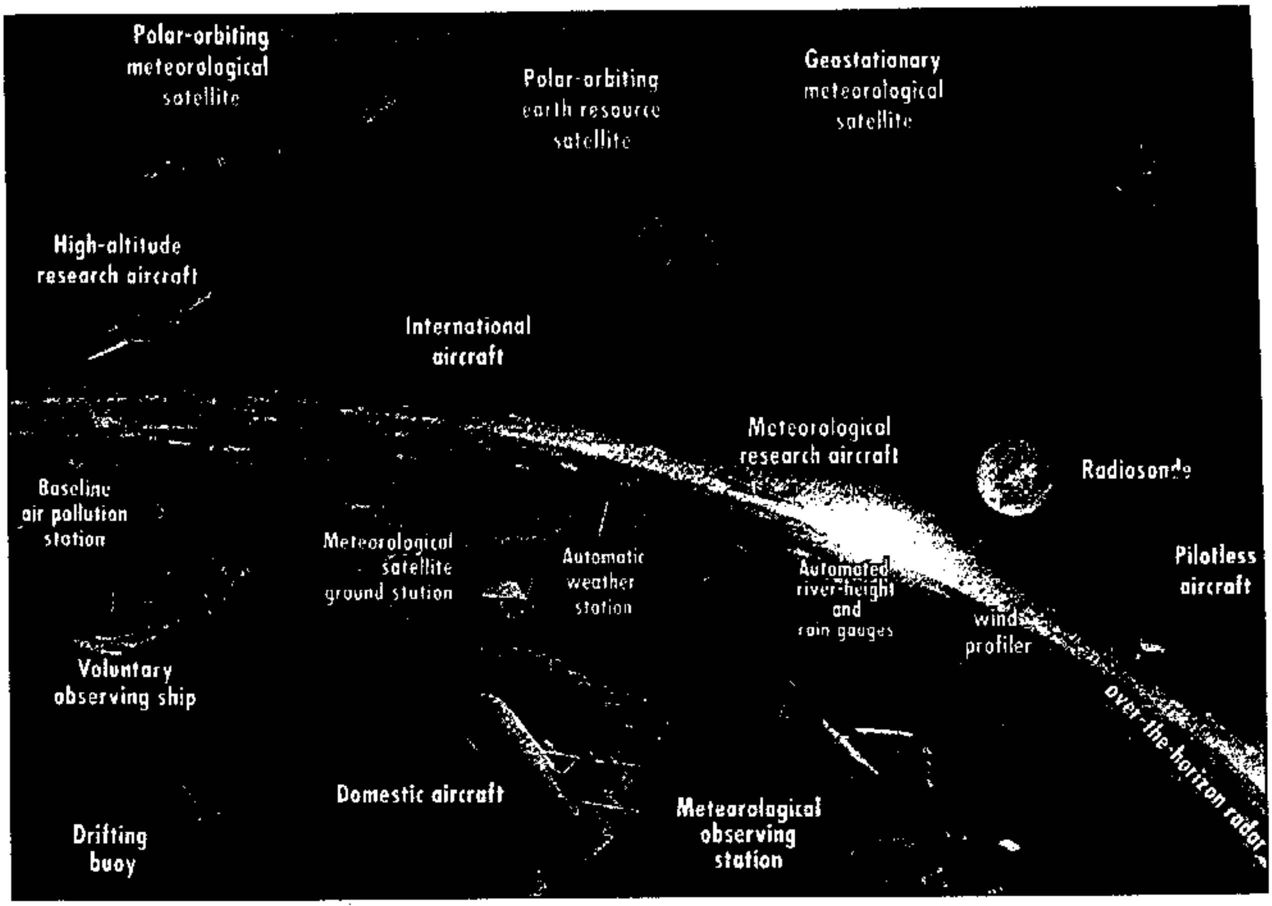

Figure 7 — The essential elements of an integrated global observing system for the atmosphere based on the contributions of national Meteorological Services of WMO Member countries

Some countries employ a basic multipurpose network configuration with additional, more specialized networks for particular purposes such as aviation, agriculture, etc. Others also maintain a limited number of higher-quality climatological stations for benchmark purposes and to detect possible long-term trends in climate. Most countries employ a much larger network of operational rainfall stations for climate purposes than are normally available for real-time monitoring.

The routine national monitoring networks operated by an NMS usually consist of:

- A small set of full synoptic and upper-air stations staffed round-the-clock and providing two or four times daily upper-air and hourly or half-hourly surface synoptic observations. These are often collocated with weather watch radar facilities;
- A larger network of surface synoptic stations operated on either a volunteer or contract basis, usually by non-NMS staff;
- A much larger network of rainfall stations usually maintained on a volunteer basis;
- A number of special purpose observations or networks (solar radiation, ozone, etc.) operated either by NMS or other collaborating or contract staff;

with each of these contributing to the appropriate component of the Global Observing System of the World Weather Watch (Figure 8).

The data-processing and numerical modelling role of the global network of National Meteorological Centres (Figure 9) and the communication channels through which they collect and disseminate their data and products similarly serve as basic components of the World Weather Watch Global Telecommunication System and Global Data-processing System (GDPS). The GDPS is made up of the data processing and modelling (NWP) functions of the three-tiered system of World, Regional/Specialized, and National Meteorological Centres shown in Figure 9.

Research

The extent to which the national research role in atmospheric science is integrated within the NMS varies from country to country. Although the scientific basis for meteorological service provision makes it virtually essential that the NMS maintain some supporting research capability in order to continue to develop and improve

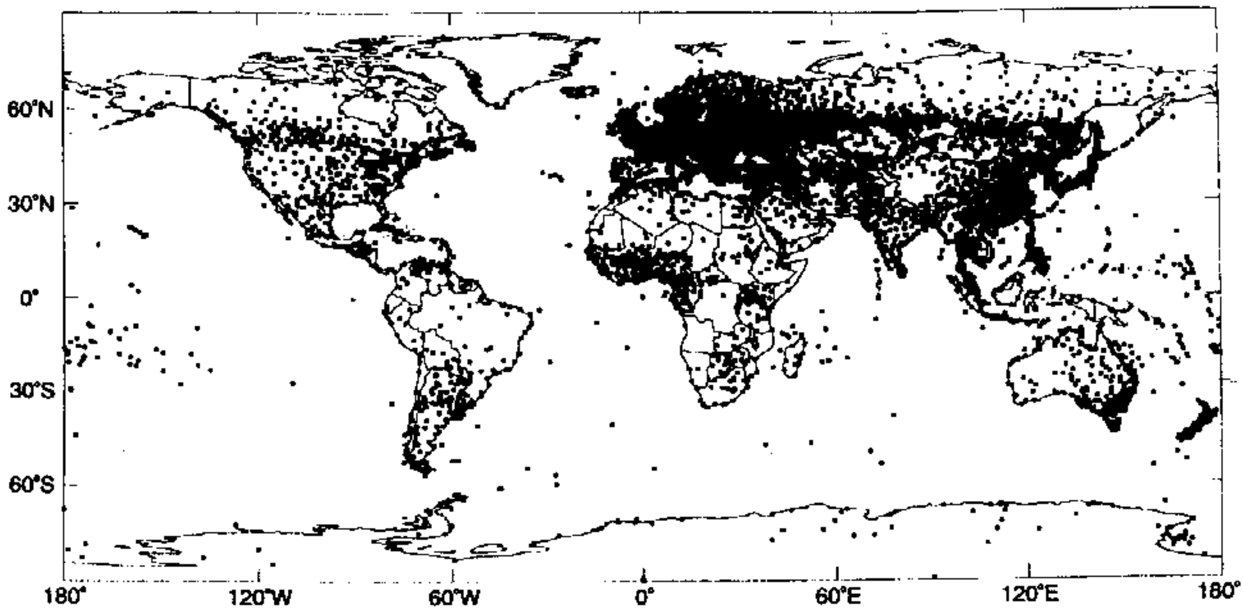

Figure 8 — The Surface Observing Network of the Global Observing System of the World Weather Watch, based on some 10 000 synoptic stations operated by WMO Members

its services, some countries also maintain separate national meteorological research agencies, including meteorology departments in universities, which interface with the NMS in the provision of strategic research support for NMS operations and services. One of the substantial advantages of the integrated research-service model of operation of an NMS is the greater flow-through of staff from research to services and vice versa and the resulting more effective translation of scientific progress into service improvement. In those countries where the integrated model has been adopted, the NMS is usually more likely to be seen as a significant part of the national scientific infrastructure.

The dual thrusts of the NMS research mission may conveniently be reflected in the charter of its research arm, where it exists, through identification of the separate objectives of:

- Advancing the scientific understanding of weather and climate; and
- Supporting the internal operations and services of the NMS.

One of the more problematical issues which arises in those countries which maintain a large multidisciplinary government-funded research agency is how to manage the domain of intersection between the NMS, as a monitoring, research and service provision agency specializ-

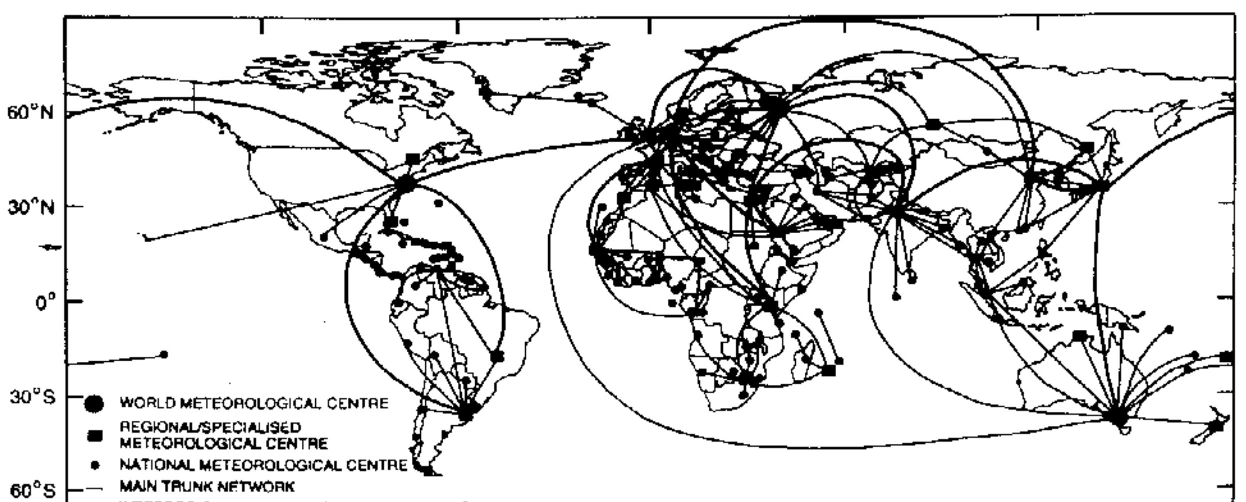

Figure 9 — The global network of National, Regional/Specialized and World Meteorological Centres of the WMO World Weather Watch and the relevant communications links of the World Weather Watch Global Telecommunication System

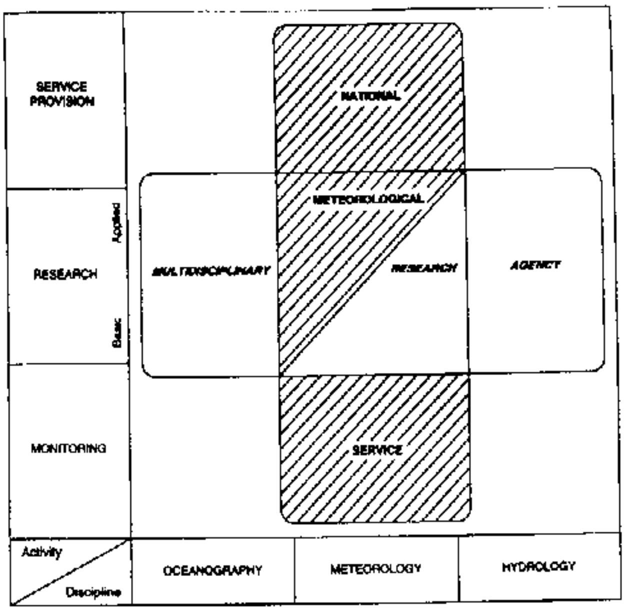

Figure 10 — A useful model for the division of research roles between the national Meteorological Service and the national multidisciplinary environmental research agency

ing in meteorology (and closely related oceanography and hydrology) and the multidisciplinary research agency which operates right across oceanography, meteorology, hydrology and other disciplines but extends only slightly into the domain of routine monitoring and service provision. A conceptual model for the division of responsibility found useful in some countries is shown schematically in Figure 10. Under this model, the NMS concentrates its research effort near the applied end of the research spectrum with only a limited involvement in fundamental research. The multidisciplinary research agency, on the other hand, concentrates its effort at the fundamental end of the meteorological research spectrum with a much smaller amount of applied research and development. An interagency coordination mechanism is usually needed to manage the interactions and joint activities at the interface.

Service provision

The NMS is best known, in most countries, for its role as the provider of a wide range of services to virtually all sectors of the community. Its services focus on the provision of information on the state of the atmosphere (weather, climate and, in several countries, air quality) and, to a lesser extent, the state of the underlying ocean and inland waters. These fall into five broad groups (Figure 11):

- Provision of information on past conditions from the historical record;
- Provision of information on the current state of the atmosphere, ocean or surface water;
- Provision of forecasts of future conditions, especially warnings of severe weather and

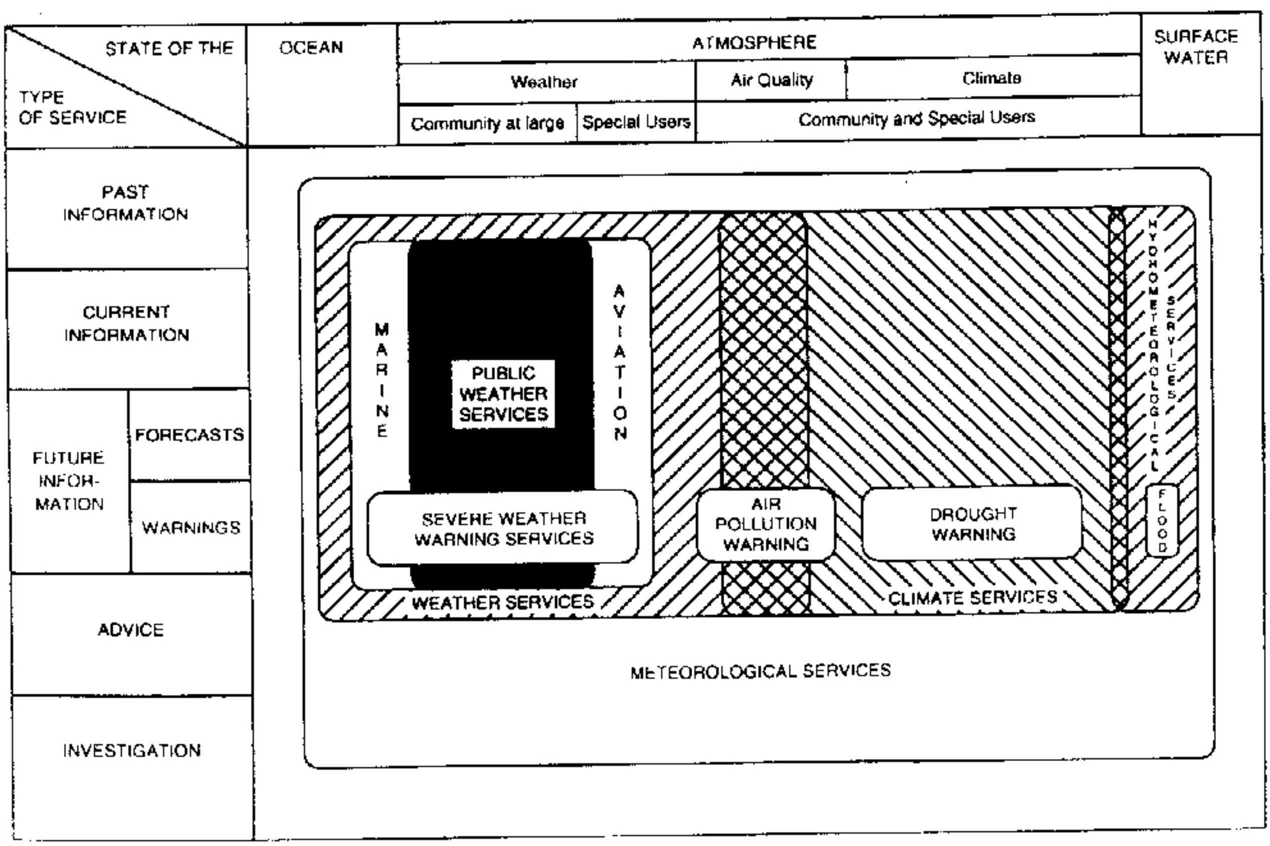

Figure 11 — The structure and scope of meteorological services normally provided by a national Meteorological Service.

climate events, including possible future human-induced climate change;

- Provision of advice on meteorological, hydrological or oceanographic science and its application to community needs; and
- Conduct of investigations into specific scientific problems of the atmosphere, ocean or inland waters.

The boundary between what are colloquially referred to as "weather" and "climate" services is somewhat arbitrary and is located differently in different countries. Air pollution monitoring and forecasting is normally of greatest interest on "weather" time-scales but long-term trends in air quality are of central importance to the determination of future patterns of global and regional climate on decade to century time-scales.

While the range and organization of services provided varies greatly from country to country in response to national needs and capabilities, there are several basically important services which are given priority by most NMSs.

Severe weather warning services

In most countries, especially those which are subject to frequent natural hazards such as hurricanes, typhoons, tornadoes, severe storms, floods, droughts and bushfires, the provision of reliable severe weather warning services is regarded as the highest priority function of the NMS. In many countries, it is seen as the primary rationale for its existence and, in particular, for its operation as a publicly funded arm of government.

Although, worldwide, the annual loss of life from natural disasters of meteorological origin may frequently exceed 100 000, with economic losses of more than US$ 100 billion, increasing rapidly in recent years under the influence of rising population density on coasts, flood plains and other disaster-prone areas, there is compelling evidence that these losses would be far higher—probably an order of magnitude or more—were it not for the preparedness and disaster-reduction action made possible by the provision of early warning information from the NMSs of the affected countries.

The warning services operated by NMSs span a wide range of natural and human-induced hazards (De and Joshi, 1998; Saltbones and Nielsen, 1998; Zillman, 1999) including watch and/or warning services for:

- Severe weather phenomena
  - Blizzards and winter storms
  - Fire weather (forest-, bush- and grass fires)
  - Gale-, storm- and hurricane-force winds;
  - Sand- and duststorms
  - Severe thunderstorms (hail, lightning, squalls, damaging wind gusts)
  - Snow (snowstorms, blowing snow, snow-squalls, whiteout)
  - Tornadoes and waterspouts
  - Tropical cyclones (including hurricanes and typhoons)
  - Turbulence
- Other hazardous weather conditions
  - Cold snaps (cold waves, frosts, road, river and lake ice)
  - Fog and low cloud
  - Freezing rain and drizzle, sleet
  - Heat waves
  - UV-B radiation exposure
- Air quality hazards
  - Acid rain
  - Radioactive fallout
  - Poisonous gas release
  - Smoke haze
  - Urban air pollution (brown haze, smog)
  - Volcanic ash
- Climatic hazards
  - Crop diseases
  - Drought
  - Pest invasions (grasshoppers, mice, etc.)
- Marine hazards
  - Currents (rips and other dangerous currents)
  - Icebergs
  - Sea ice (pack ice and fast ice)
  - Storm surge
  - Tsunami
  - Waves and swell
- Hydrological hazards
  - Algal outbreaks (low flow conditions)
  - Erosion and landslides
  - Flooding (including flash flooding)

Of course, not all countries are subject to all of these hazards and the warning role of the NMS must be tailored to the particular needs and vulnerabilities of the country or region concerned. The design and operation of the warning systems must also draw on a wide range of other national organizations and disciplines. It is particularly important that the warning system operates as an integral part of a total national counter-disaster system (Zillman, 1999) and that the meteorological and hydrological warning service is embedded within the broader public weather service to the community to ensure a high level of responsiveness and essential consistency of official advice in life-threatening situations. Although some countries allow the public dissemination of conflicting public weather forecasts through the mass media, virtually all countries insist on the public dissemination of only one official warning service to avoid community confusion and ensure the most effective preparedness action possible in potentially life-threatening situations. The declaration of the Potsdam Early Warning Conference (EWC, 1998) stressed that "early warning must be tailored to serve people's needs, their environments, and their resources. Successful early warning requires unrestricted access to data that are freely available for exchange. Ultimately, all resulting information must be credible, and emanate from a single officially designated authority.". In all countries, the enlistment of the mass media as an essential partner in the operation of the warning system is of critical importance to its effectiveness in reducing the toll of natural disasters.

The actual operation of the warning system can be regarded as involving a number of fairly well defined elements as follows (Figure 12):

- Data collection;
- Routine monitoring;
- Hazard detection (including detection of environmental conditions conducive to hazard genesis);
- Hazard prediction;
- Watch and warning formulation;
- Information dissemination;
- Community response and feedback; and
- Post-disaster support.

Organizationally, these may be integrated into the daily routine of the National Meteorological Centre or Regional Forecasting Office or, in some countries, specialized warning centres may be established with national watch-and-warning responsibility for one or more groups of severe weather phenomena.

A prerequisite for the effectiveness of a warning service is a high level of awareness of the threat and appropriate response action on the part of the threatened community. NMSs have a vital role to play in educating the national communities on the nature and extent of the threat of severe events and the optimum preparedness and response measures, including, especially, how to make best use of the information provided through the public warning service. This is particularly important in those countries,

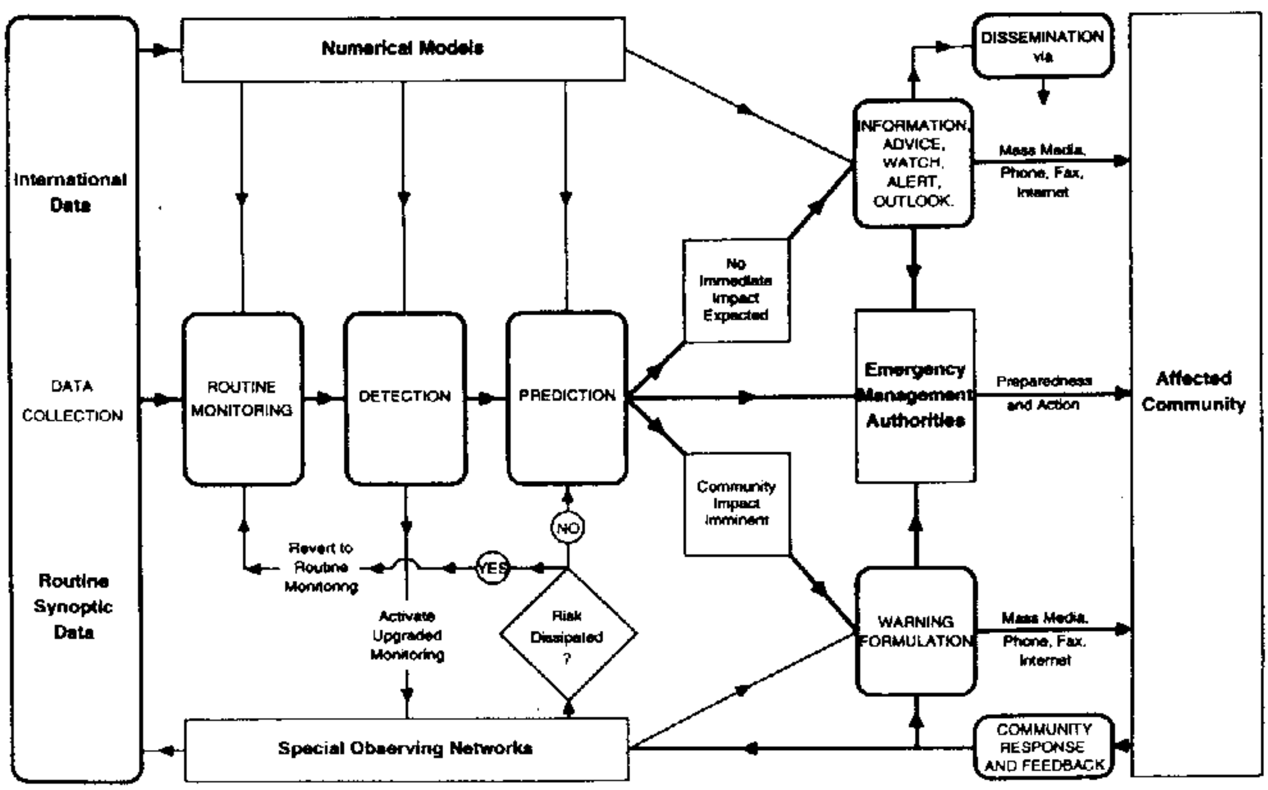

Figure 12— The essential elements of the operation of a meteorological warning system involving the key steps of data collection, routine monitoring, detection, prediction, watch or warning formulation, dissemination and community response and feedback

mostly in the tropics, where the frequency of natural hazard occurrence is usually fairly low. Significantly, however, it is often those countries which experience severe events very rarely that are most vulnerable when they do occur.

Public weather services

In virtually every country in the world, the most publicly visible face of the NMS is the routine public weather service distributed to the community at large through the mass media, often supplemented by a variety of individual user-access arrangements. The public weather service usually consists of a set of current weather information (maximum and minimum temperatures, rainfall, etc., over the past 24 hours), a description of the current and forecast synoptic charts, and a set of forecasts and warnings extending out to one to 10 days, depending on the skill levels achievable.

The emphasis given to the different delivery systems varies greatly from country to country but virtually all rely heavily on the cooperation of the print and electronic media. Following the formal establishment of the WMO Public Weather Services Programme in 1991, increasing emphasis is being given in many countries to the concept of a public interest partnership between the NMS and the mass media in meeting an important community need (WMO, 1996(*b*)). Some countries have established formal agreements between the NMS and media organizations which specify the general practices and standards to be observed in communicating the information to the community. Communities are generally intolerant of conflicting weather information in weather-sensitive situations and NMSs find themselves under considerable pressure to find ways of ensuring consistency of output between media outlets. The concept of an "official" public weather service is especially important in this regard.

Beyond the mass media, a range of other delivery mechanisms such as dial-in facsimile and recorded telephone messages, play a key role in getting pertinent information to those in need. Over the past few years, the Internet has emerged as a major source of weather information for a wide range of users complementing such special-purpose communication systems as weather radio and television weather channels which operate in several countries.

Marine weather services

One of the most important roles of the NMSs of maritime countries is the provision of marine meteorological and related oceanographic services in support of the safety of shipping and other offshore activities. In addition to current, wind, wave and weather conditions and forecasts and warnings of gales and other severe weather conditions for coastal waters in support of the safety of fishing, coastal transport and pleasure craft, which are provided by virtually all maritime NMSs on a public interest basis, many NMSs also fulfil their national obligations accepted by Contracting Governments to the International Convention for the Safety of Life at Sea ((SOLAS), 1974) and its subsequent amendments and revisions. Under SOLAS, which, in its original form, was created in the aftermath of the *Titanic* disaster, the Contracting Governments undertake to encourage the collection of meteorological data from ships at sea and to cooperate in carrying out a number of important activities in support of the safety of marine navigation. These include:

- Warning ships of gales, storms and tropical cyclones by the issue of information in text and, as far as practicable, graphic form, using the appropriate shore-based facilities for terrestrial and space radiocommunication services;
- Issuing, at least twice daily, by terrestrial and space radiocommunication services, as appropriate, weather information suitable for shipping containing data, analyses, warnings and forecasts of weather, waves and ice. Such information is transmitted in text and, as far as practicable, graphic form, including meteorological analysis and prognosis charts transmitted by facsimile or in digital form for reconstitution on board the ship's data processing system;
- Arranging for a selection of ships to be equipped with tested marine meteorological instruments ... and taking, recording and transmitting meteorological observations at the main standard times for surface synoptic observations ...;
- Arranging for the reception and transmission of weather messages from and to ships using the appropriate shore-based facilities for terrestrial and space radiocommunication services;
- Endeavouring to obtain a uniform procedure with regard to the international meteorological services already specified, and, as far as practicable, to conform to the technical

regulations and recommendations made by WMO, to which Contracting Governments may refer, for study and advice, any meteorological question which may arise in carrying out the Convention.

National obligations under the 1988 Amendments to SOLAS for the Global Maritime Distress and Safety System (GMDSS) are met under the auspices of arrangements developed through the WMO marine broadcast system for the GMDSS. Under this system, forecasts, warnings and synoptic and other meteorological reports are prepared by specified individual NMSs and disseminated by a smaller group of NMSs which have accepted responsibilities for defined ocean areas (Figure 13). The defined Metareas are identical to the IHO (International Hydrographic Organization) Navareas for the dissemination of navigational warnings, with which the meteorological forecast and warning services are fully coordinated.

Aviation weather services

As with shipping, there are two major groups of users for aviation meteorological services: the domestic aviation industry and international civil aviation. Domestic aviation requirements cover the needs of both high-level regular public transport and general aviation and are usually provided under the terms of domestic aviation legislation. Meteorological services in support of international civil aviation must be provided within the framework of the Chicago Convention on International Civil Aviation, which requires, *inter alia*, that each country/State will provide, in its territory ... meteorological services ... to facilitate international air navigation in accordance with the standards and practices recommended or established ... pursuant to the Convention. In particular Annex 3 to the Chicago Convention:

- Provides that the objective of meteorological service for international air navigation shall be to contribute towards the safety, regularity and efficiency of international air navigation;
- Provides that this objective shall be achieved by supplying operators, flight crew members, air traffic service units, search-and-rescue units, airport managements and others concerned with the conduct or development of international air navigation with the meteorological information necessary for the performance of their respective functions;
- Requires each contracting State to determine the meteorological service which it will provide to meet the needs of international air navigation;
- Requires each contracting State to designate the authority, referred to as the meteorological authority, to provide or to arrange for the provision of meteorological service for international air navigation on its behalf.

In many, but by no means all, countries, the NMS has been formally designated as the meteorological authority for the purposes of the Chicago Convention. In others, the national aeronautical

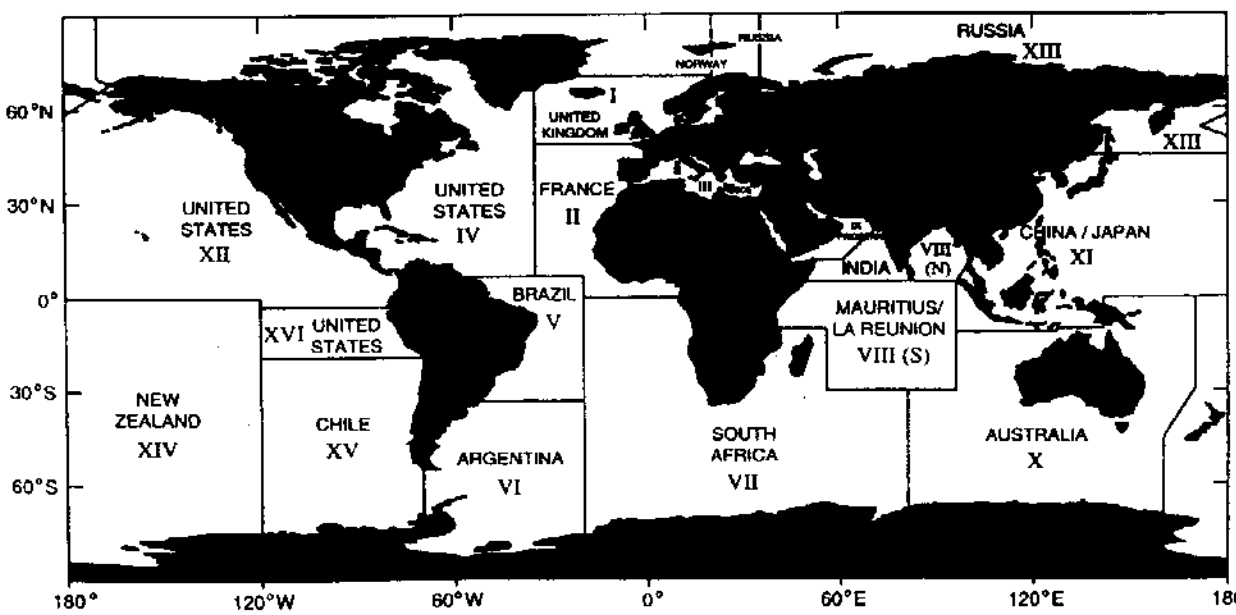

Figure 13— Agreed Metareas for meteorological broadcasts under the Global Maritime Distress and Safety System. The responsible national Meteorological Service for each area is shown. Broadcasts are made via the SafetyNET service of INMARSAT, except for Arctic waters, where, currently, only NAVTEX services are available.

authority is itself the designated meteorological authority but arranges with the NMS for the provision of the required services. In a few other countries, however, a self-contained aviation meteorological service exists separately from the NMS but usually draws on basic information and products prepared by the local NMS as well as internationally provided products from the two World Area Forecast Centres (WAFCs) of the World Area Forecast System (WAFS) in Bracknell and Washington.

In both its domestic and international roles, the NMS (or other provider) is involved in producing a range of terminal (Figure 14), en route and area forecasts of meteorological conditions including significant weather information for wide distribution through aeronautical communication channels. At both the national and international levels, the provision of the aviation meteorological service is essentially incremental to, and often integrated with, the public weather service with the same staff in the same offices often engaged in provision of both services. In a decreasing number of countries, the NMS maintains a number of special purpose airport meteorological offices for local forecasting and pilot briefing purposes. In other cases, the NMS aviation meteorological unit may be collocated with air traffic control or in the operations centres of individual carriers.

Defence weather services

Both historically and currently, meteorological services represent a critically important input to the operations of all three arms of the national defence force. Although, in several countries, the armed services maintain their own meteorological support services, in many others, the NMS is charged with providing meteorological services in support of air force, navy and army requirements. In some cases, NMS personnel on air force bases maintain their civilian status while, in others, they serve in uniform. Naval tradition normally requires uniformed meteorological staff at sea although many former separate defence weather services are making use of the economies of scope and scale achieved from providing essential meteorological services directly from the NMS. Historically, special arrangements are put in place in times of war.

Climate services

Except for a small number of countries where the national climate responsibility has been separated from the weather service, the provision of climate data, information, monitoring and prediction services is becoming an increasingly important and highly visible function of the NMS. Many countries operate national climate centres which channel the observational data collected for real-time forecasting purposes into a quality control and archival process, which then provides the database for an increasing range of climate-data services in support of planning, design and operational management in the rural, industry and various other sectors.

The international research effort into the mechanisms of climate over the past two decades since the establishment of the World Climate Research Programme (WCRP) has provided the scientific foundation for a vastly expanded and more proactive role for the NMSs of all countries in providing socially, economically and environmentally valuable information on current and future climate patterns to their national communities. Particularly within the framework of the WMO CLIPS (Climate Information and Prediction Services) initiative and drawing on the output of international climate monitoring and modelling centres within an operational framework akin to the operation of the WMO World Weather Watch on weather time-scales, many NMSs are now operating effective systems for the wide dissemination of monthly and seasonal to interannual climate forecasts in forms that are directly valuable to farmers, pastoralists, water-resource managers, governmental planners, financial services organizations and many others. There is little doubt that the NMS role in the provision of climate services, appropriately integrated with its more widely known role in the provision of public weather services, will be one of the most dramatic growth areas over the next decade. It will be important that NMSs work closely with the potential user communities, as well as with other government agencies providing related services, to ensure that the full potential benefits from their emerging capabilities flow on to both individual users and the overall sectoral and national economies.

Another vitally important dimension of the climate services role of the NMS is the provision of scientifically sound advice to governments and national communities on the basis for, and evidence of, human-induced long-term climate change. The NMS has a particular responsibility to provide an effective conduit to its national policy community for the scientific findings of the WMO-co-sponsored Intergovernmental Panel on Climate Change (IPCC) which was established in 1988 to provide objective assessments of the

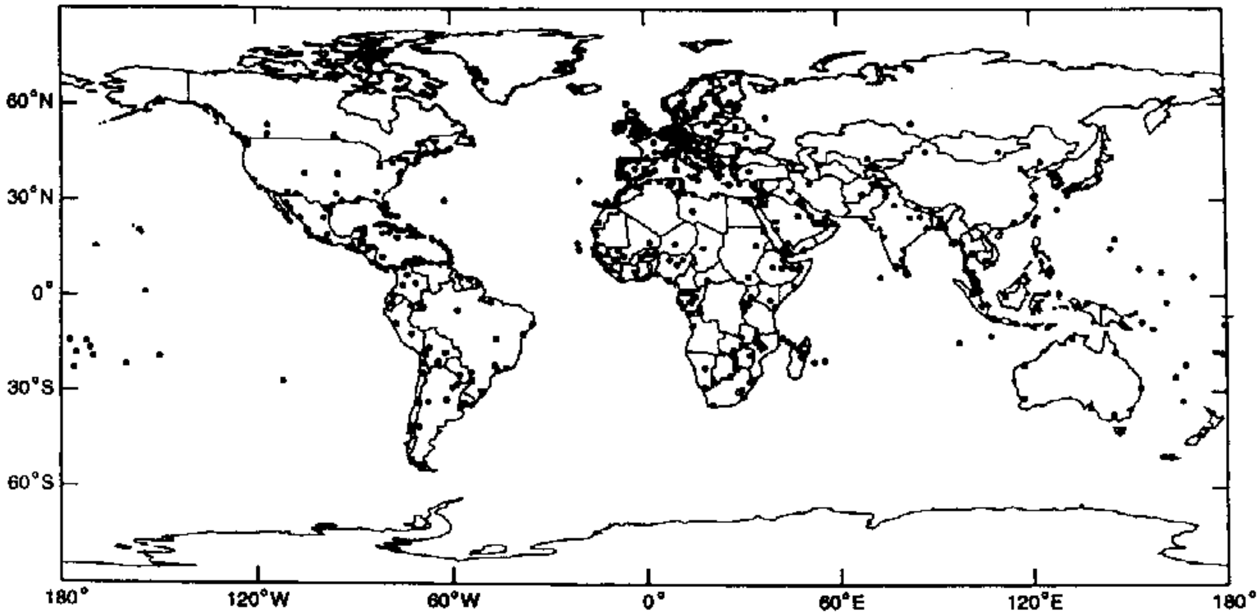

Figure 14 — The airports for which national Meteorological Services (or, in a few cases, special aviation weather service organizations) are required to prepare routine terminal area forecasts (TAFs) for international civil aviation. In addition to the forecasts for international aviation, a much larger number is required for other airports serving domestic aviation.

science, impacts and possible response measures for human-induced climate change.

Environmental services

In one important sense, all meteorological services must be regarded as environmental services in that they deal with the monitoring, understanding and prediction of the state of the most fragile and pervasive component of the human environment. In the narrow sense of services in support of environmental protection objectives, the environmental role of the NMS may be characterized in terms of three main functions spanning a wide range of activities as follows:

Support for pollution abatement and control

- Air pollution forecasting
- Modelling of the atmospheric transport of contaminants
- Support for the management of marine oil spills
- Provision of advice on appropriate times for operation of pollution emitting facilities
- Provision of wind- and solar-energy records for research into alternative energy sources
- State of environment reporting

Support for nature conservation

- Climate forecasting for improved land management
- Drought monitoring and forecasting
- Vegetation monitoring and modelling
- Water-resources assessment
- Floodplain management
- Beach protection
- Input of climate conditions into land-use policy development.

Support for national participation in global environmental issues

- Advice on the science and potential impacts of climate change
- Advice on the role of climate variability in desertification
- Advice on the behaviour of the stratospheric ozone layer
- Advice on the characteristics and behaviour of *El Niño* and other global climate anomalies
- Contribution to global environmental monitoring,
- Operation of climate change detection networks as part of its integrated observational role
- Input to relevant international fora and programmes such as the IPCC, Commission for Sustainable Development, United Nations Environment Programme and the Conference of the Parties to the Framework Convention on Climate Change.

In some countries, the responsibility for all of these functions and activities sits alongside that for the conventional NMS functions in a single "meteorological and environmental protection" agency, albeit the environmental, regulatory and enforcement roles are usually organizationally separate from those associated with the more traditional NMS role.

More usually, however, the meteorological and environmental roles are institutionally separate and the NMS finds itself working alongside the national Environmental Protection Agency and Nature Conservation Agency in either the same or different ministries. The key questions, then, for the NMS become:

- What services should it provide to the environmental agencies in support of the objectives of nature conservation and environmental protection?;
- How does it most effectively work together with its environmental counterparts on those issues for which an NMS/environment partnership is essential to a sound outcome?

Organization

The organizational structures through which NMSs perform their functions and deliver their services vary widely, according to the pattern of historical development and current national circumstances.

Some NMSs operate essentially as ministerial departments or as major parts of ministerial departments such as transport, communications, environment, water supply, science, defence and various others. Some are located with major client departments such as aviation, defence, agriculture or environment, while others, as a matter of policy, are located with a neutral policy or general service ministry. As indicated above, some have a formal statutory basis, while others are essentially dependent on administrative decisions of the government of the day for the charter for their ongoing operations. Some typical organizational structures adopted by NMSs are shown schematically in Figure 15.

Setting aside the special features of those NMSs which include national oceanographic or hydrological functions, the typical NMS usually involves:

- A policy and administrative headquarters;
- A series of headquarters operational units such as the National Meteorological Centre (often including a National Climate Centre), the National Meteorological Research Centre (where this exists) the National Meteorological Library and the National Meteorological Training Facility;
- A geographically distributed system of observing stations and meteorological service offices.

Within their headquarters policy structure, many NMSs maintain small programme offices responsible for the national coordination of key activities such as observations, as well as services to major user sectors such as agriculture, aviation, defence and the marine community.

The role of the various headquarters operational units is to achieve the necessary coordination and economies of scope and scale in carrying out essential national functions and supporting the decentralized provision of services.

While some services can be best provided and disseminated centrally, the bulk of public and user-specific meteorological services are most efficiently provided as close to the user interface as possible. It is thus usual to find a structure of geographically decentralized meteorological offices, often with their boundaries of responsibility coinciding with convenient administrative boundaries such as state or provincial borders, which interact directly with their user communities.

Funding

For most of the past century, most governments have accepted full responsibility for funding the operation of their NMSs although, in most developing countries, the available funds have fallen far short of those needed to maintain the standards of infrastructure and service provision to which the community aspires. In some countries, both developed and developing, however, partial funding has historically come from one or more major user groups, such as the civil aviation industry, either through volume-of-service-based charges, incremental charging for user-specific services, industry-specific taxation measures or direct percentage-based contribution to the costs of the total operation.

On the whole, however, in most countries, the NMS has been seen, along with the police, the army, the national radio broadcaster and a few others as an essential component of the national taxpayer-funded government infrastructure. This has provided a sound international framework for the conduct of activities whose benefits apply widely to the community and to future as well as to present generations but it has not made easy the assembly of the necessary resources for effective operation.

Over the past two decades, with the widespread introduction of user pays regimes for many former government-provided services, several governments have experimented with

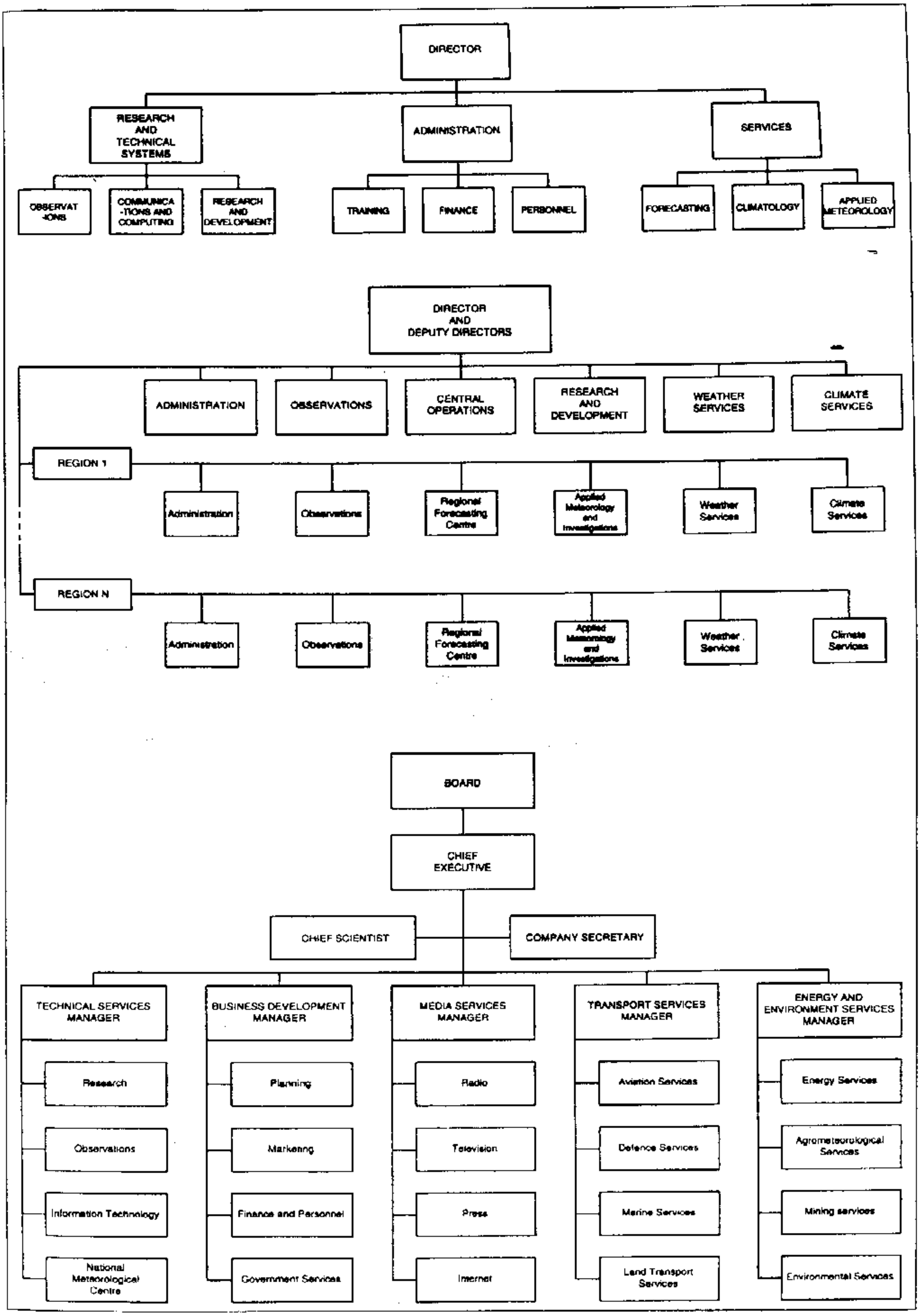

Figure 15 — Schematic representation of three typical models for organizational structuring of a national Meteorological Service: a simple divisional structure (*top*), appropriate, in particular, for Services without large regional structures; a matrix model (*middle*), appropriate for Services with a number of major geographic subregions; and a business unit model (*bottom*), suitable for corporatized or commercially oriented services

alternative approaches to funding the operations of their NMSs. Among the various models now in place are the following:

- The fully taxpayer-funded NMS providing essentially all meteorological services to both the community at large and major specialized user groups;
- The NMS in which the government funds the core costs of the basic infrastructure (Figure 4) and essential public services; and specialized services, based on the universally available information, are provided on an incremental cost-recovery or commercial basis either by the NMS itself, by a separate financially decoupled commercial arm of the NMS or by the national or international private meteorological sector;
- A range of commercial or corporate models including:
  - The "partially commercialized" NMS in which user charges are directed not just towards the funding of the provision of particular specialized services but also make some contribution (pro rata or otherwise) to the core costs of the basic infrastructure;
  - The "fully commercialized" NMS or "trading fund" operation in which all costs of operation must be found from real or surrogate customers, many of whom may be other government departments and agencies;
  - The "corporatized" or "privatized" service in which the NMS operates, not as an arm of government, but as a "business", subject to normal company law and accounting practices and aimed at providing a dividend to its shareholders (which may be the government itself).

Experience at present is insufficient to provide a definitive assessment of the long-term viability of the more recently introduced commercial and corporate alternatives to the traditional model, albeit their introduction as part of across-the-board public sector "reform" in several countries has been a major destabilizing influence on the overall international system (see below).

The overall level of funding (and staffing) of NMSs varies widely among countries, reflecting the wide range of national circumstances—size, geography, population density, history, stage of development, economic circumstances, government policies on service provision—and so on; also, in terms of national statistics, on what is and is not regarded as included in the NMS budget. It appears, however (Figure 16), that most NMSs are funded in the range of 0.001 to 0.04 per cent of national GDP and that meteorological staff numbers per 1 000 km^2 range from less than one up to 20 or more. There are, however, several outliers to the distribution of funding and staffing shown in Figure 16, reflecting particular national circumstances, including, especially, some very small island States, where land area is not a useful indicator of funding needs for the provision of services.

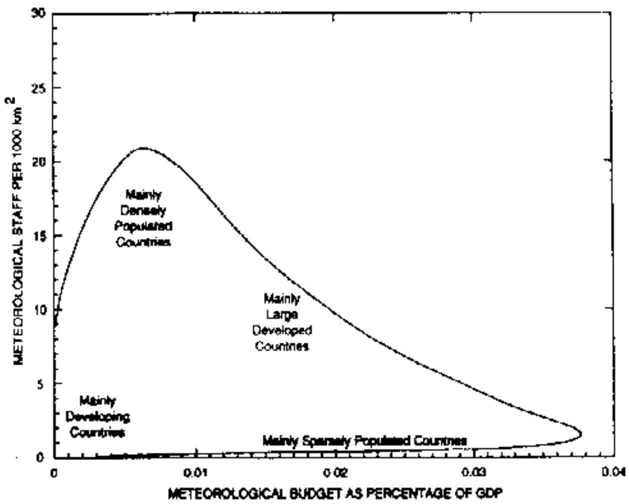

Figure 16 — Worldwide distribution of funding and staffing of NMSs in terms of the two key indicators of NMS budget per unit of GDP (horizontal axis, per cent of GDP) and NMS staff per unit of land area of the country covered (vertical axis, meteorological staff per 1 000 km^2).

Staffing

Although practices differ among countries, especially between the developed and developing Members of WMO, and are determined to varying degrees by broader national public sector training and staffing policies, most NMSs include at least two major specialist staffing streams: a technical specialist group trained in observational and/or equipment maintenance and/or data processing and communication functions; and a professional stream of university-qualified scientists, who are usually employed in operational forecasting, research, systems development and the provision of specialist professional advice on meteorological matters.

WMO has historically recognized four separate classes of meteorological personnel as follows:

- Class I: university graduates capable of engaging in both research and professional service provision;

- Class II: applications/service specialists usually without university graduate level qualifications;
- Class III: senior technical personnel responsible for planning and management of observational programmes and operational facilities;
- Class IV: basic meteorological observational and support staff;

This system is currently under review with a view to its replacement by a simpler, two-category (meteorologist and meteorological technician) system based on consideration of the necessary basic educational level in the core disciplines and additional training qualifications in a range of specialist technical/applications areas.

Areas of specialization

Most NMSs, even the smallest and least developed, are normally organized to undertake a range of specialist functions and activities with the specialization based either on technical functions (e.g. meteorological telecommunications) or field of application (e.g. aviation forecasting). Among the most frequently identified fields of specialization of NMS staff are the following (WMO, 1984): dynamic meteorology; physical meteorology; synoptic meteorology; weather modification; numerical weather prediction; climatology; marine meteorology; aeronautical meteorology; agricultural meteorology; hydrometeorology; atmospheric chemistry and air-pollution meteorology; meteorological instruments; meteorological telecommunications; meteorological data processing; meteorological satellite applications; and applications of meteorology to economic and social development.

Planning and management

Most Directors and senior executives of NMSs in both developed and developing countries have traditionally risen through the ranks with observing and/or forecasting and occasionally research backgrounds, albeit a few countries have tended to appoint Directors from the external academic meteorological community and, in recent times, several have come from a general administrative, scientific or business background. On the whole, however, the expertise of senior NMS staff is primarily in meteorology and secondly in management.

Over the past decade, as downward pressures on resources have become more intense in many countries and the traditional approaches of public sector administration have given way to the more business-oriented management approach of the private sector (e.g. Osborne and Gaebler, 1992; Lange, 1998), NMSs have given increasing emphasis to the introduction of modern private sector management techniques and the disciplines of corporate planning.

While the approaches to corporate planning vary substantially from NMS to NMS, the introduction of long-term planning into WMO in the early 1980s (Zillman, 1984, 1998) has had a significant influence on the planning framework for developing country NMSs in particular. The WMO rolling 10-year long-term plans have been used by many NMSs to set the broader environmental framework for national planning, particularly in respect of the likely future trends in relevant meteorological science and technology. Several NMSs have adopted the general planning methodology of the WMO Long-term Plan as a basis for their own strategic plans with particular emphasis on capacity building in developing countries. Many have adopted variants of the overall programme structure of WMO as a basis for their own meteorological service programme planning and management.

WMO has played a particularly important role in assisting NMSs in the development and implementation of appropriate management systems and processes. WMO-sponsored workshops on management of Meteorological Services have been held in most Regions and a substantial body of expertise and literature has been accumulated on the applicability and usefulness of various management models in the meteorological environment. A particularly important WMO contribution, supported by the Government of the Netherlands, led to the development of a set of WMO Guidelines on Management of National Meteorological and Hydrometeorological Services (WMO, 1997) which synthesizes much of the accumulated experience of NMSs in a form which is particularly appropriate for the use of senior management of small developing NMSs.

Performance assessment

While NMSs have a long tradition of systematic objective performance assessment and there is probably no profession in the world whose practitioners face more directly, or more regularly, the need to assess and build on the lessons from yesterday's performance, the past decade has seen the disciplines of modern organizational performance management introduced progressively into many NMSs. To some extent, these have helped reinforce the traditional NMS commitment to go beyond the mere provision of reliable data and accurate forecasts to help ensure that the recipients of the information use it effectively in the decision-making process to derive the full potential benefit available from the service. A perfect forecast that is not received in time or is misinterpreted or not used effectively is of little or no value to the community. It is thus important to assessing the overall effectiveness of the NMS to consider how well it is able to educate the potential user community in the use of its services—a demanding task in an era of mostly declining resources and an ideological commitment to the need for organizations to stick to their "core business".

NMSs must, of necessity, seek to maintain a balance, in their use of limited resources, between careful systematic monitoring of their performance in their core functions, especially in predictive skill, and the search for the ultimate measures of the effectiveness of their services in generating maximum benefit for the user community. It is important also, however, that they do not become consumed by assessment for assessment's sake to the point where resources which could be used to generate improved services and deliver real benefit to the user community are directed instead to the generation of performance information which, while providing satisfaction to the NMS itself, does not contribute usefully to the progressive improvement of its services.

External interactions

Among the most important external relationships which an NMS must maintain with its national community are those with:

- Other government or volunteer agencies or individuals who assist in its data-gathering functions;
- The local university and other academic meteorological communities in respect of both national data availability for research and carrying out of research in support of service improvement;
- Its national print and electronic media which, in almost all countries, play a vital role in conveying essential public forecast and warning services to the community at large;
- Other government agencies with which it must operate in partnership in certain vital community functions such as bushfire and other emergency services agencies, police, agricultural extension agencies aviation safety administrations, defence departments, etc.;
- Major user-sector representatives, such as the aviation and shipping industries, rural organizations, sporting bodies, etc. and, especially
- Private sector providers of specialized meteorological services;
- Private sector suppliers of meteorological equipment and facilities.

The relationship with the private sector

Historically, in most countries, the NMS has provided the full range of basic public meteorological services and some or all of the specialized services for individual users or user groups. Essential services to civil aviation and defence have normally, because of their strong public good characteristics, also been provided by the NMS although, in several countries, additional tailored services have been provided to individual operators on a commercial basis by private meteorological service companies. The USA has been notable for its long history of a public-private partnership in which the NMS provides those services that government must provide for the protection of the safety of life and property of all citizens and the private sector, with full and free access to all the information and products prepared by the NMS, provides the specialized services on a commercial basis. Several other countries have also followed this model to varying degrees and, in many countries, an effective complementary relationship has developed between the NMS and the private sector.

Considerable stress developed in these relationships in many countries during the 1980s under pressure of government policies requiring NMSs to achieve higher levels of cost recovery or self-funding and, in some cases, to move aggressively into the commercial market for specialized services. At the same time, several private sector operators, both national and multinational, sought to cultivate markets in areas of public service provision that had historically been seen as the exclusive domain of the NMS. These tensions over the "commercialization of meteorological services" in turn placed the traditional WMO system of free and unrestricted exchange of meteorological data and products under increasing stress (WMO, 1995(*b*)).

Although the issues have evolved differently in different countries, the delegations to the Twelfth World Meteorological Congress (1995), representing, as they are required to do, the total interests of their countries including both their NMSs and the private sector, agreed on two important steps towards a framework for long-term stable relationships between NMSs and the private sector at the global level:

- As one of its nine major policy objectives for the next decade, WMO committed itself "to build an effective harmonious and mutually supportive relationship between the public and private sectors of the meteorological and hydrological communities in the provision of commercial meteorological and hydrological services";
- Through unanimous adoption of its Resolution 40, the Congress agreed on a set of guidelines on relations between NMHSs and the commercial sector, which seek to define the essential features of a working framework of "sound, fair, transparent and stable relations" between NMSs and the private sector, which will help to broaden and enhance the free and unrestricted international exchange of meteorological and related data and products on which both sectors, individually, and the global user community, collectively, depend so greatly.

The operationalization of these broad policy commitments at the national level in line with WMO Member countries' obligations under Article 9 of the Convention of the World Meteorological Organization is clearly an evolving process, which is being approached differently in different countries. In most countries, the approach adopted appears to be consistent with the understanding that:

- The NMS should carry out the basic public good responsibilities of government, particularly those related to long-term data collection and public-safety-related forecasting and warning and, where it competes with the private sector in commercial service provision, should do so on a competitively neutral basis;
- The private sector should operate in a complementary relationship with the NMS in their communication and dissemination of meteorological information which could impact on public safety and should conform with accepted trade and intellectual property law and market principles in the provision of specialized services on a commercial basis; but they should do so in a way which recognizes the overarching global importance of maintaining the continuity and stability of free and unrestricted international exchange of meteorological and related data and products.

The NMS Director as permanent representative

One especially important feature of the role of the NMS on the national scene in most countries is the part played by its Director as Permanent Representative of his/her country with WMO and hence as the coordination point for all national involvement, including that of both government and non-government organizations and activities outside the NMS, in the programmes and activities of WMO.

This arrangement, which most countries have in place, although to varying degree, is based on the provision of Regulation 6(a) of the WMO General Regulations, which prescribes that:

> Each Member shall designate by written notification to the Secretary-General a Permanent Representative who should be the Director of the Meteorological or Hydrometeorological Service to act on technical matters for the Member between sessions of Congress. Subject to the approval of their respective governments, Permanent Representatives should be the normal channel of communications between the Organization and their respective countries and shall maintain contact with the competent authorities, governmental or non-governmental, of their own countries on matters concerning the work of the Organization.

The national coordination role of the Director of the NMS is, to a substantial degree, underpinned by the role of the national members of the WMO technical commissions. Although there is no requirement on them to do so, many permanent representatives designate at least one of their members on each WMO technical commission from within their own Service thus providing, to the extent that national liaison and coordination is achieved among the members of each commission, a useful vehicle for ensuring coordination amongst the various national activities relevant to the individual WMO programmes.

International cooperation

There is virtually universal agreement within the international meteorological community, evidenced by the unanimous adoption by the Twelfth World Meteorological Congress of its Resolution 40 (WMO, 1995) that it is in the interests of all countries to preserve the long-standing practice of free and unrestricted international exchange of basic data and products between NMSs to assist them in the provision of essential meteorological services within their own countries and for the extra-territorial areas for which they have assumed responsibility in support of the safety, regularity and efficiency of international aviation and shipping.

There is also a widespread agreement, following the 1992 Rio Earth Summit, that international cooperation in monitoring the state of the global environment and the free and unrestricted exchange of the information collected must be an integral part of any serious long term strategy for the sustainable development of the planet.

It has, however, already become clear that we are now confronted with the potential clash of two powerful paradigms:

- That of international and national cooperation in the free and unrestricted exchange of information and technology as part of a global partnership aimed at supporting the provision of universally available meteorological services within countries and underpinning global strategies for sustainable development—consistent with the Convention and long-standing traditions of international cooperation through WMO;
- That of international and national competition in the provision of goods and services in response to market forces and in consonance with the General Agreement on Trade in Services (GATS) and the rules and regulations of the World Trade Organization. (Dunkley, 1997; Griesgraber and Gunter, 1997)

This clash of paradigms has surfaced at the national level in some countries in the form of allegations that NMSs, in the provision of their important public forecast and warning services to the community through, and in cooperation with, the media, are in breach of national competition legislation. At the international level, it has generated a wide range of tensions and threats to the maintenance of the principle and practice of free and unrestricted exchange in an international system composed of NMSs which now span the full spectrum of the funding models described above. There are at present encouraging signs that more countries have begun to recognize the essentiality of mutually respectful coexistence between the explicitly cooperative regime required for effective meteorological service provision and that based on commitment to the achievement of efficiency through competition and contestability.

Conclusion

It is clear that most aspects of the environment within which the traditional State-funded NMS has operated, and even the nature of the NMS role itself, are evolving rapidly. With communities' and nations' basic requirements for reliable meteorological data and services and the pressures for their application to a wide range of economic, social and environmental objectives continuing to increase, it will be extremely important that the evolution process be well and wisely managed at both the international and national level lest, in seeking to achieve the potential benefits from new ideological paradigms and technological capabilities, the essential foundations for what has already been achieved are irreparably damaged or destroyed. One expensive lesson for the corporate world of the early 1990s was that the degree of radical change called for, and often implemented, was in reality disastrous to the long-term interest of the organization involved (Macdonald, 1998).

It will be especially important that, in exploring new approaches to public sector service delivery modelled on the experience of the business world, national governments be fully informed of the unique nature of the international arrangements which underpin meteorological service provision at the national level and of the damage that would befall all nations if the precipitate actions of one or more players were again to destabilize the international system (Zillman, 1997(*a*), (*b*)).

The stability of this system is critically dependent on governments' continued recognition that the availability of essential public meteorological services to the standards now enjoyed in many countries, and towards which others can realistically aspire to progress, is the product of a global partnership; a partnership which is based overwhelmingly on cooperation rather than competition and in which each country contributes what it reasonably can to the common effort while ensuring that its own use of the common pool of information from which it draws to serve its national community does not threaten the willingness and ability of others to maintain their contribution.

The key responsibilities which governments must continue to accept if the stability of these overwhelmingly beneficial arrangements is to be maintained may be summarized as follows:

- Funding of the infrastructure for integrated collection of the meteorological and related data needed to provide the national climate record and underpin the provision of meteorological services to the community at large;
- Funding of those meteorological services which are essential to community safety and welfare and are of the nature of a pure public good;
- Guaranteeing continued free and unrestricted access to the products of their national data collection and processing to the global community in fulfilment of national obligations accepted under the various international environmental conventions and in accordance with the letter and spirit of WMO Resolution 40 (Cg-XII);
- Contributing, within their capabilities, to the international pool of knowledge of the behaviour of the global atmosphere.

It follows that the interests of all nations, both individually and collectively, will be best served if, as part of the current worldwide reshaping of the public sector, governments:

- Clearly identify the charter of their NMS through a legal or other formal instrument which will provide ongoing protection of the integrity and continuity of its core mission;
- Explicitly commit themselves to the ongoing funding of the core public good functions of the NMS;
- Formally identify their NMS as the single official source of public forecasts and warnings bearing on the safety of life and property;
- Put in place durable administrative arrangements, consistent with national competition policy and other relevant influences such as international regimes for intellectual property protection and trade in services, for ensuring an appropriate competitive regime for the provision of specialized services which go beyond the official public service and which are of the nature of private or market goods;
- Formally confirm their commitment to the principle of free and unrestricted international exchange of essential meteorological data and products and to rigorous adherence to the letter and spirit of Resolution 40 (Cg-XII).

As long as governments are provided with the necessary information for informed decision-making on the key issues and the meteorological community itself is enabled to respond to the enormous opportunities opened up through the continuing rapid progress in meteorological science and technology, there is no doubt that the NMS will serve an increasingly vital role in contributing to the social, economic and environmental progress of all countries during the next century.

For their part, one of the greatest challenges facing NMSs will be to establish an effective partnership with the private sector operating within their country so that the greatest possible benefits can flow to national communities from their combined and complementary strengths and capabilities. The ultimate objective must be an efficient, effective integrated and user-oriented national and international environmental science service system which exploits to the full the enormous benefits which the atmospheric sciences hold in store for the 21st century.

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ECONOMIC BENEFITS OF METEOROLOGICAL SERVICES

(Running title - Economic Benefits)

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expenditure on meteorological service provision. The final section provides a summary and some conclusions.

2. Meteorological and economic background

Meteorological services involve the provision of information on the state of the atmosphere (often subdivided into the overlapping domains of weather and climate with air quality sometimes considered as a third category) and, to a more limited extent, that of the underlying ocean, land surface and inland surface water. As illustrated in Figure 1, these services can be conveniently considered as made up of five broad groups: provision of information on past conditions from the historical record; provision of information on the current state of the atmosphere, ocean, land surface and surface water; provision of forecasts of future conditions, including warnings of severe weather and climate events, general forecasts for the community at large and for a range of specialised users, and projections of future climate including both seasonal to interannual and longer term fluctuations and possible human-induced climate change; provision of advice on meteorological, hydrological or oceanographic science and its application to community needs; and conduct of investigations into specific scientific problems of the atmosphere, ocean or inland waters (Zillman, 1999). In addition to their categorisation according to the type of information provided, meteorological services are also frequently subdivided, on the basis of major user sector served, into basic and specialised services. Basic services are those made freely available to the community at large, usually through the mass media, in the public interest, while specialised services involve value adding tailoring to the special needs of individual users or groups of users. The World Meteorological Organization (WMO) has distinguished between 'basic' and 'special' meteorological services in the following terms (World Meteorological Organization, 1990):

- Basic meteorological services are those services provided by a National Meteorological Service in discharging its government's sovereign responsibilities to protect the life and property of its citizens, to contribute to their general welfare and the quality of their environment, and to meet its international obligations under the Convention of the World Meteorological Organization and other relevant international agreements.

- Special meteorological services are those beyond basic services and may include the provision of special data and products, their interpretation, distribution and dissemination, and consultation advice.

Weather and climate conditions have pervasive effects on human welfare. Further, and this is the important point in estimating the economic value of meteorological services, the information provided by meteorological services can be used to change decisions in ways which raise human welfare. At a general level, the benefits from the allocation of scarce national labour, capital and other resources to the provision of meteorological services are given by the increase in human welfare that flows from the better decisions which result where outcomes are weather and climate sensitive. Measures of the economic value of meteorological services include extra profits, lower costs, and assessments of the willingness to pay, by household, business and government decision-makers, for the information contained in the services which they use in formulating and adjusting decisions to yield higher payoffs.

There is no exhaustive listing of either the economic choices and outcomes which are weather and climate sensitive or of those choices which potentially could, or actually do, use information provided by meteorological services. Potential beneficiaries of meteorological services include: individuals; households; firms; government organisations and institutions; economic sectors; regions; national economies; the global economy; and future generations. Virtually every sector of every country makes some direct or indirect use of general or user-specific meteorological services. These include: agriculture; aviation; banking and financial services; construction; disaster management; energy generation and supply; environmental protection; fisheries; forestry; health; insurance; leisure; manufacturing; military; port and harbour management; retailing;

transport; sport; urban planning; and water resource planning and management. Typically there is a complex chain of communication, analysis, understanding and decision making that operates between the provision of meteorological services and the realisation of the potential benefits in terms of better outcomes for decision makers and for society.

One of the most fundamentally important of all the services performed by NMSs is the operation of the basic national and international meteorological infrastructure which is necessary to provide the data base for assembly of the long-term climate record for use by future generations as well as for the support of a wide range of real-time operational services with immediate economic and social benefits for society. In economic terms, meteorological infrastructure and weather, climate and air quality forecasts and warnings have non rival consumption or use properties. This means that the economic benefits to society from meteorological services are given by the sum of the benefits reaped by the very many and diverse users of the services, both now and in the future.

An economic framework for evaluating the economic benefits of meteorological services and for determining the allocation of resources to these services can be expressed in terms of a model of total benefits and costs, or a model of marginal benefits and costs which is the conventional economic model of competitive supply and demand determination of prices and quantities. The top panel of Figure 2 presents total costs and total benefits of meteorological services as a function of the level or volume of services. The volume of meteorological services might be measured as units of historical or current data on rainfall, wind, temperature, etc, or in terms of temporal or spatial resolution of model output, or as measures of forecast accuracy and forecast lead time, or by the scope of the service in terms of effectiveness of communication or tailoring to specific user needs or, more generally, as the quantity and quality of information provided on weather and climate. The total cost function, TC, reflects an up-front or fixed cost component OA plus an operating cost component which is shown as a convex function reflecting the need for increasing extra inputs per unit increase in the volume of meteorological services. It should, however, be noted that, while some measures of volume (eg forecast skill) may require larger and larger increases in resources for small increases in volume, modern technology makes it possible to produce almost limitless increases in volume for other measures (eg the number of locations for which spot forecasts can be produced as the output of numerical weather prediction models) with a negligible increase in costs. The total benefit function, TB, represents the increase in well-being of decision makers as the additional and improved meteorological information enables them to make choices which lead to the avoidance of losses and the achievement of gains which would not otherwise have occurred. A threshold volume (measured in terms of skill, availability, etc) of meteorological services, OB in Figure 2, is usually required before weather or climate sensitive decisions are changed. The total benefit function, on the other hand, becomes concave and ultimately plateaus as increased amounts of meteorological information lead to smaller and smaller additional benefits in terms of better decisions.

The bottom part of Figure 2 shows the more conventional economic model of the demand for, and supply of, meteorological services. The demand for meteorological services, D, is in fact the marginal benefits curve, MB (or the first derivative of the total benefits curve in the top part of Figure 2). In the relevant zone for choosing the resources to allocate to the provision of meteorological services, the demand curve is downward sloping because extra information on weather and climate leads to smaller and smaller additional improvements in the results of weather and climate sensitive decisions. The supply cost of meteorological services, S, the marginal cost curve, MC (or the first derivative of the total cost curve in the top half of Figure 2), is an upward sloping function reflecting increasing costs of producing further increases in the volume (quantity and quality) of meteorological information.

The information on benefits and costs in Figure 2 enables determination of the level of resources to allocate to the production and use of meteorological services. The volume of meteorological services Q* which maximises social well-being is given by the volume where the supply and demand curves equate. It also maximises the difference between total benefits and total costs in the top part of Figure 2. To the right of Q*, additional resources used to increase the volume of meteorological services add more to costs than to benefits and, in so doing, detract from national welfare. To the left of Q*, too few resources are allocated to meteorological services in the sense that marginal benefits exceed marginal costs and net gains can be had by expansion.

In estimating the economic benefits of meteorological services, it is important to be clear whether total benefits, as in the top part of Figure 2, or marginal benefits, as in the bottom part of the figure, are being estimated. That is, if the current volume of meteorological services is Q*, it is important to be clear as to whether total benefits, shown as having the value V in the top part of Figure 2, are being estimated or marginal benefits, shown as P in the bottom part of Figure 2. From the perspective of decisions on whether to allocate more or less resources to meteorological services, data on marginal benefits and costs need to be considered.

Most of the meteorological services depicted in Figure 1 have non rival consumption properties. That is, once the information is available, its use by one set of users does not reduce the information available for use by other users. In this circumstance, the social benefits are given by the sum of the benefits of the different users. Figure 3 illustrates the situation for just two users of a particular service, eg. two individuals using a daily weather forecast, or two airline companies using broadcast information on in-flight or landing conditions. The marginal benefit functions (derived as derivatives of total benefit functions) are MB_A for user A and MB_B for user B. For a given volume of information Q_1, user A values the last unit at P_A and P_B is the marginal value for user B. The value to society is given by $P = P_A + P_B$. Generalising, when making choices for society about the benefits of meteorological services with non rival consumption properties, the total benefit and marginal benefit functions in Figure 2 should be the sum of benefits for all users as illustrated for the two users in Figure 3.

3. Measurement methodologies

Several techniques have been used to estimate the total benefits, and in some cases the marginal benefits, of meteorological services for particular groups of decision makers. In terms of the concepts elaborated in Figures 2 and 3, these are the curves TB_i or MB_i, or the values V_i and P_i, where the subscript i denotes a particular group of decision makers. For convenience, the different methodologies are discussed here under the sub-headings of: market prices; normative or prescriptive decision making models; descriptive behavioural response studies; and contingent valuation studies.

3.1. Market prices

In several instances, market prices can be used as a measure of the marginal benefits to users of some types of meteorological services. The technique has applicability for those services which have private good characteristics of rival consumption and ease of exclusion. For those services with public good properties of non rival consumption and high costs of exclusion, markets fail. Where the characteristics of non rival consumption and excludability are combined to give mixed public and private goods, market prices may provide some measure of the benefit gained. However, the dominance of public good properties, particularly for the basic infrastructure and for general public forecasts and warnings, limits the applicability of market prices for valuing meteorological services.

In the case of private good meteorological services, such as specialised forecasts for particular users or value adding processing and interpretation of climatological data, customers will purchase the services up to the volume where the marginal value to them equals the price. That is, recorded price and volume fall on the marginal benefit or demand curve, MB = D in the bottom half of Figure 2. Price, then, is the marginal value of the last unit of value added meteorological information to that group of buyers.

There are examples where prices paid by intermediaries in the communication of meteorological services provide a lower bound estimate of the value of the services to final users. For example, in some countries, newspapers, TV and radio pay fees to their NMSs, or to private meteorological service providers, for weather and climate information which they (the media) then publish or broadcast to the community. They all incur direct costs in presenting the weather and climate information - and the space and time allotted to providing this meteorological information have opportunity costs. Media outlets willingly incur these costs on the assumption that readers, viewers and listeners value the meteorological information at more than the costs they outlay, either directly or in putting up with advertisements.

Sometimes a monopoly supplier of private good meteorological services can be imposed on particular users. For example, the NMS or a nominated private firm could be given sole rights to offer and supply specialised services to a specific industry. In this situation, in addition to charging the marginal cost for the value added information, the monopolist also can add an up-front, lump-sum charge. The lump-sum charge plus the user charge cannot exceed total benefits, otherwise - except in the situation of a regulatory requirement to do so - the users will choose not to purchase the value adding services. The extent to which the total charges underestimate total benefits is a difficult empirical problem.

An advantage of market prices is that they explicitly reveal the value users place on, and are willing to pay for, particular categories of meteorological services. However, their applicability is limited by the public good properties of much meteorological information.

3.2. Normative or prescriptive decision-making models

By far the most common set of techniques used to estimate the benefits of meteorological services has been the prescriptive or normative models. Johnson & Holt (1997) and

Wilks (1997) provide good outlines and references to applied studies. Simplified optimising decision models for businesses (and also for households and governments, but these have been few) under conditions of imperfect knowledge about weather or climate conditions are solved. The models are resolved for different levels of meteorological services provided. The gain in expected payoffs, including more profits, lower costs and higher utility, are a measure of the marginal benefits of the increased services, that is the MB_i term. The models have been applied to both climatological information and forecast services.

Most reported prescriptive model applications have been for individual decision makers. In particular, changes in decisions following the use of extra or better meteorological information are assumed not to alter the decisions of others, nor to change the prices of outputs or the costs of inputs. The cost/loss model and the Bayesian rules for using additional information, in this case more and more accurate meteorological information, are common (with excellent descriptions of the procedures and examples in Johnson & Holt (1997), and Katz & Murphy (1997b)). While most studies have an objective function in the model for maximising profit or minimising cost, several use more general utility functions which recognise risk aversion. Simple one-period decision models have been extended to multi-period problems which recognise the temporal interdependence of decisions. The individual decision maker models can be, and have been, used to measure the marginal benefits of partial improvements in the accuracy of forecasts as well as the benefits of perfect forecasts.

Results from the individual decision-making model can be extended to represent an industry, region or larger aggregation of users and, in these models, costs of inputs and prices of outputs can be allowed to change as part of second round reactions to the use of additional meteorological services. Models regularly used to evaluate the benefits of research and development (R&D), and the distribution of these benefits, can be used (see, for example, Alston *et al.*, 1995). R&D leading to the adoption of new technology or better work and management practices increases output per unit input, or reduces costs per unit output. Similarly, a larger volume (quantity and quality) of meteorological services enables producers to choose decisions which yield more output at lower costs.

By way of illustration, consider a single product market for an agricultural commodity, such as corn, and the use by farmers of skilful seasonal rainfall and temperature outlooks to enable them to make better decisions on, for example, variety choice and the timing and quantities of irrigation and fertiliser to apply. The essential features of a partial equilibrium model for this market are illustrated in Figure 4 and elaborated in the appendix.

The main conclusions which emerge from such partial equilibrium models are as follows. First, much as for the individual decision maker model, a lower bound estimate of the benefits of meteorological information in improving decision making sensitive to weather and climate outcomes is given by the cost saving per unit output times the output to which the cost saving applies. This output might be industry output, output from a particular region, or output of identified users of meteorological services. The society gain will be slightly larger to reflect increased producer and consumer surplus (see appendix) obtained from an increase in output. Second, the social benefits of better decisions resulting from the use of meteorological services, such as from using a higher volume of meteorological services, will be shared between producers of the products and buyers of the products because the product price falls. In a market context, as opposed to the single producer model where output price is held constant, some of the benefits of a greater volume of meteorological services are passed on to buyers, in the same way as are the benefits of other investments, say in R&D and equipment, which raise productivity.

The market model can be extended as illustrated in Figure 5 and explained in the appendix, to the case where only some producers effectively use additional meteorological services to improve their decision choices. Here, buyers of the product gain from lower product prices, users of the extra services (the adopters) gain more from the cost reductions than the price fall, the non-adopting producers lose, and there is as net gain for society in aggregate.

Prescriptive models for estimating the benefits of meteorological services have a number of advantages and disadvantages. If the models are realistic simplifications of a complex real world in the sense that decision makers optimise the chosen objective function, the assumed restraints are realistic, and the meteorological information is used to adjust decision choices as assumed, then the derived estimates of the gains from better decisions are good estimates of the real benefits of meteorological services by the users. However, realism of the models is a strong requirement – some would say an heroic set of assumptions. In principle, additional detail can be added to any model. Descriptive behaviour studies, discussed below, find that many decision makers do not respond in the ways predicted by normative models. In particular, many households and firms do not interpret and use meteorological information as assumed in optimising models. In particular, the assumption of zero costs for the information collection, analysis and decision adjustment processes often over-simplifies decision making. If meteorological information is valuable, as illustrated in Figure 5, in the longer run, competitive forces for survival of the fittest will see the adopters and users of meteorological services dominate the non-adopters. Nonetheless, criticisms of over-simplification of many reported prescriptive models are well made, and more attention needs to be given to realism, including through drawing on the data from descriptive studies.

3.3. *Descriptive behavioural response studies*

Descriptive behavioural studies can be used to make estimates of the value of meteorological services by inferring values from the observed behaviour of individuals, businesses and governments. User surveys of decision making, and especially about the use of, and responses to, meteorological information, natural experiments, potentially laboratory experiments, and regression methods have been proposed, and there have been some applications reported in the literature.

One set of studies seeks information about the decision making processes of individuals and firms, and on how they use meteorological information in these processes. Stewart (1997) provides a good overview and references to applied studies. Mail, telephone and personal interviews may be used for samples of potential users of meteorological services. Responses are sought on decision choices whose outcomes are affected by weather and climate, what information is used in making these decision choices and, in particular, whether meteorological information is used, and if yes, how is it accessed, how is it used to modify decision choices, and what decision changes are made. Further information may be sought on what meteorological information users would like, and how would they use it, with the questions being open-ended or for specific proposed changes in services offered.

In special circumstances, natural experiments may be used to estimate the value of meteorological services. These are cases of clearly measured differences in the supply of meteorological services and data on observed changes in behaviour between the different meteorological service states. Craft (1998), for example, uses the natural experiment of a one-year closure of about a half of the meteorological services to the Great Lakes in 1870 to measure cost savings in damage to shipping. Both political and economic considerations caution against conducting such radical experiments. Another example of a natural experiment is provided by observed decision changes during the 1997-98 Australian drought using forecasts based on models of the El Niño-Southern Oscillation phenomena relative to behaviour in previous droughts when no such forecasts were available (Bureau of Meteorology, 1998). This provides the opportunity to evaluate decision responses and the value of extra information resulting from the research, forecasting and communication associated with the El Niño phenomenon.

Regression models may be used to assess the effects of meteorological services on decisions and to measure the value of the services. Decisions, for example, on enterprise activity levels, or measures of economic performance such as yields, costs and profits, may be regressed on conventional explanatory variables such as resource inputs, prices, measures of technology innovation, and the volume of meteorological services. The approach involves using the regression to estimate the contribution of more meteorological services while accounting for the contributions of other explanatory variables. The regression model approach requires data with sufficient independent variation of the different explanatory variables, including measures of the volume of meteorological services, if the estimates are to have reasonable precision or confidence bounds. At this stage, the absence of data with sufficient variation seems likely to rule out the regression model for all but a few special cases which are close to natural experiments.

The advantages and disadvantages of descriptive studies often are compared with those of prescriptive studies, but they also can be seen as complementary tools. Descriptive studies have the advantage of being based on, and recording, actual behaviour, and therefore they can be considered more realistic. However, in attributing changes in decisions and extra benefits to meteorological services, and to increases in the volume of meteorological services, a common difficulty is that other parts of the decision environment are also changing. Asking questions about decision responses to increases in the volume of meteorological services involves hypothetical situations which make them vulnerable to the same criticisms that are raised against prescriptive studies.

3.4. Contingent valuation studies

An approach sometimes used to estimate the benefits of public goods, particularly environmental services but also defence and the arts, is the contingent valuation method. Here users are asked to nominate the sum they would be willing to pay for a particular level of public good. Although the procedure is somewhat controversial, the contingent valuation method has been used to obtain estimates of the value of meteorological services by Chapman (1992) for the US, Teske & Robinson (1994) for Great Britain and Anaman & Lellyett (1996) for Australia.

The general structure of the contingent valuation study method is as follows (for more details see Mitchell & Carson (1989) or Portney (1994) and references therein). Information is sought from a sample of users of meteorological services, which may be individuals or businesses. To be useful, the sample should be a random sample, and "representative" samples need to be used with caution. Mail, telephone or direct survey methods may be used. With experience, most now argue that the more costly direct interviewing method is necessary to ensure respondents fully understand the context of the willingness to pay questions and to allow for cross-checking of answers. An artificial, or hypothetical, market situation is created in which users are asked to indicate, in dollars, their willingness to pay as between different options. For example, what would you be willing to pay to have access to currently available general forecasts relative to no forecasts; or, if the accuracy of rainfall forecasts for the next season were to be increased by 50%, what would you be willing to pay for this extra accuracy? A number of good practice components of a credible contingent valuation survey can be noted (see, for example, Hanemann (1994), and Diamond & Hausman (1994)). It is necessary to clearly describe and illustrate the optional states being compared, and to ensure that respondents understand the differences that they are being asked to place a valuation on. Greater realism is obtained by indicating the process by which their nominated willingness to pay would be realised, for example by higher taxes or a monthly charge, and by asking respondents to indicate their nominated dollar payment in the context of their income and other expenditure choice options.

Once the answers on willingness to pay for individual users are obtained, the next step is to aggregate these answers for a measure of society willingness to pay. For those meteorological services with public good characteristics, especially non rival consumption, the strict public good model, as depicted in Figure 3, would sum the willingness to pay by each of the respondents, scaled up by their respective numbers in the population of users. Alternatively, some studies use the estimated median willingness to pay and multiply this by the number of users. The median estimate has support from political theories of the median voter determining election outcomes, including expenditure on public goods, and it has the advantage that extreme individual high and low estimates of willingness to pay are ignored.

The use of contingent valuation surveys to make estimates of the value of meteorological services is likely to remain controversial, as is its use for estimating the benefits for other public goods. The questions are hypothetical and many respondents may not know what they really value about meteorological services and what they would pay. Others recognise that any answer will do and that they cannot be held accountable for the answers given. Besides, there is ample scope for the survey design and interview procedures to bias estimated willingness to pay upwards or downwards. Good practice, and this usually comes at considerable cost, can help to allay some of these criticisms of the method, but it cannot eliminate the reservations.

4. Estimated Benefits

Summaries of over a hundred studies reporting estimates of the economic value of meteorological services for a range of users are provided in Nicholls, 1996; Katz & Murphy, 1997a; Anaman *et al.*, 1998; and Stern & Easterling, 1999. Rather than duplicate these reviews, this section highlights some particular aspects of the studies relating to the procedures used, the estimated benefits reported, and the interpretation of these estimates for the total benefits and marginal benefits of meteorological services.

Most reported studies with estimates of the benefits of meteorological services have used prescriptive models of decision making by individual businesses, and then with a heavy emphasis on agriculture. Very few prescriptive studies have gone on to incorporate market reactions. Descriptive studies have been concerned primarily with the use made of meteorological services, and only a few have provided estimates of benefits. In recent years, a number of contingent valuation surveys have been undertaken. Given that many originally fully publicly funded NMSs now impose charges for some of their services (recovering up to ~~50%~~ of their total costs of operation in a few countries), and some
40x

private sector value adding services have emerged, the use of market prices becomes more relevant. However, the dominance of public good properties of most meteorological infrastructure and services described in section 2 will require further use of descriptive, prescriptive and contingent valuation methods.

The available estimates of the economic benefits of meteorological services cover a wide range of activities and much of the economy. Most individuals and firms are directly or indirectly affected by weather and climate, and, importantly, at least in principle, most also can use meteorological services to alter decisions to achieve better outcomes as illustrated by prescriptive models. However, the descriptive studies find a significant proportion of potential users, in many cases more than a half, do not use meteorological services in decision making, and this high level of non-use is reflected in a zero willingness to pay found for many respondents in contingent valuation studies. Nonetheless, it remains the case that very large numbers of individuals and businesses do make extensive use of meteorological services and they receive economic benefits from the improved decision choices which result.

Estimated economic benefits from the use of meteorological services in reported studies vary widely. Many of the estimates per individual or business are low, but many decision makers often are involved. For example, the Anaman & Lellyett (1996) contingent valuation estimate of the average value of public weather services to Sydney households is just A$24 a year per householder, and for a number of agricultural decision predictive model estimates the estimated gains are of the order of A$1 per acre (for example, Wilks & Murphy, 1985; and Bosch & Eidman, 1987). But, often, there are millions of households and acres to which these per-unit benefits apply. At the same time, some studies of the benefits of meteorological services for large construction projects, for the airlines (for example Leigh, 1995 and references therein), and for other large businesses report estimates in the tens of millions of dollars. For these examples, there is usually only a small number of other actual users of the particular meteorological services.

Despite the number of innovative and excellent studies reported in the literature, available estimates of the economic benefits of meteorological services are too limited for the purpose of deciding whether too many or to few resources are allocated to the production of meteorological services at the national level in most countries. The many case studies of particular value adding services for specific users based on prescriptive models and market prices are helpful for decisions on those specific value adding services; in particular, in situations where the marginal benefits and marginal costs of the value adding services can be compared.

However, fully informed decisions on the allocation of resources for public forecasts and warnings and for the provision of general climatological data where the public good properties of non rival consumption and high costs of exclusion are dominant are difficult on the basis of current estimates. Economic benefit estimates have been reported for only some of the uses and for some of the users of these public good meteorological services. In the context of Figure 3, we might have data for the MB_A curve (ie. measures of benefits for some users of the services) but we have no estimates for the MB_B curve (ie. measures of benefits for services and users not picked up in available published studies). Further, we have little idea what share the measured benefits are of the total user benefits, ie. P_A/P. Given the very diverse uses of meteorological services throughout the economy, compiling the required inventory of the different uses and estimates of the values of these different uses clearly is an enormous task. Inevitably, some uses and users of public good meteorological services will be missed, and, as a consequence, summed estimates of measured benefits will underestimate economy-wide benefits of the services.

For most decisions on whether to add or reduce resources allocated to the provision of particular meteorological services, the key benefit measure is marginal benefits rather than total benefits. Unfortunately, most of the so-far published studies focus on estimates of the total benefits of current levels of meteorological services. Of course marginal benefit estimates require some degree of hypothetical reasoning in the case of prescriptive models and some hypothetical questions in the case of descriptive models and contingent valuation surveys.

5. Conclusions

The outcomes of an enormous number of decisions by individuals, businesses and governments are weather and climate sensitive, and potentially the decisions and outcomes can be improved by using currently available meteorological services, with further gains possible if the quality and quantity of services are increased. Normative or prescriptive models clearly indicate the wide range of sources of potential economic benefits of improved, and improved use of, meteorological services. Descriptive studies and contingent valuation studies confirm that many do change decisions with the use of meteorological services and that the information is valued. But, also, these studies highlight the variety of decision making methods, the dangers of oversimplification with predictive models, and the fact that not all decision makers use meteorological services. There is a growing number of examples of market transactions for meteorological services, especially specialised value adding services for specific users, in which market prices paid indicate significant economic benefits.

Because most meteorological services have public good properties, it will remain difficult to obtain comprehensive estimates of either the total benefits or the marginal benefits of the basic infrastructure, the climatological record or the public forecasts and warnings provided to the community at large. The appropriate benefit measure is the sum of benefits for all users of the public good information. Even though a large number of studies of the economic benefits of meteorological services has been undertaken, they are better interpreted as case studies or anecdotal indicators rather than as a random sample from an unknown population of potential users.

To assist in industry, national and international decision making on the provision and funding of meteorological services, it will be necessary to continue to work with market prices, prescriptive models, descriptive models and contingent valuation methods for estimating the economic value of the full range of meteorological services. The different approaches have different advantages and disadvantages which vary across the spectrum of meteorological services and users. For many users of meteorological services, the different benefit measurement procedures complement each other.

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Appendix: normative market models

This Appendix develops partial equilibrium, or single product, models for estimating the economic benefits of the use of meteorological information, or of an increase in the volume of information, to increase the average payoff from decisions whose outcome performance is sensitive to realised weather and climate conditions.

Consider an agricultural commodity, such as corn, and the use by farmers of seasonal rainfall and temperature forecasts which enable them to make better decisions on, for example, variety choice and the timing and quantities of fertiliser and irrigation to apply. The initial market situation for the corn market in terms of expected or average longer term demand, supply, price and quantity is as described in Figure 4. Buyer demand is given by the curve D and farmer supply by S, and together they determine the market price and quantity of corn at P and Q, respectively.

Next, suppose the farmers are supplied with skillful seasonal forecasts which they use to change their decisions on variety, fertiliser and irrigation levels. Using individual decision models, perhaps for a representative farmer, but desirably for an appropriate random sample of farmers, it is estimated that, on average, farmer costs per bushel of corn fall by K. K is the individual decision-making model estimate of the marginal benefits, MB_i, of using the meteorological information.

Lower costs flowing from the effective use of reliable meteorological information will shift down the farmer supply curve S by the expected cost saving K to S^1 in Figure 4. For simplicity, a parallel downwards shift of the supply curve is assumed. The expected or average longer term market for corn produced with the assistance of the meteorological services is given by the same demand curve for corn D and the new corn supply curve S^1, resulting in a lower market clearing price P^1 and a larger corn quantity Q^1. Comparing the initial market outcome and the new market outcome permits assessment of the benefits of using the meteorological services for buyers of corn, farmers and society. The lower price benefits buyers. This benefit can be measured by the increase in consumer surplus as area P^1PAB, which also is $(P - P^1)(Q + 0.5(Q^1 - Q))$. Farmers' gain from the lower cost of K per unit output, but market price falls. Since the price fall is less than the cost reduction, farmers gain. This benefit can be measured by the change in producer surplus, or quasi-rent return to farmer land and labour, as area $P^1BG - PAC$, which can be expressed as $(K - (P - P^1))(Q + 0.5(Q^1 - Q))$. The net gain for society is thus simply the sum of the buyer plus farmer gain, ie the economic surplus gain of $K(Q + 0.5(Q^1 - Q))$, which is the area GCAB.

Some observations about the measured benefits of meteorological services, and the distribution of the benefits, when second round responses of product prices are recognised, should be noted. First, producers using the meteorological services continue to gain, but a part of the initial cost savings is eroded by lower prices. Second, buyers become beneficiaries from the fall in product prices, as they are from R&D and business investment generally which lower production costs. The individual decision-making model assuming constant product prices does not pick up this subtle redistribution. Third, for the measure of society benefits from more meteorological services, the scaled up estimate of the individual decision-making model, KQ where K is the cost saving per unit output and Q is industry output, is a slight underestimate of the actual gain, KQ + 0.5 K (Q^1 – Q). In most cases, the gain associated with the extra product output, Q^1 – Q, is relatively small. The main challenge for analysts is to obtain an estimate of K, the average cost saving per unit output across the industry made possible by better decision choice outcomes realised as a consequence of increased and improved meteorological services.

A variant of the market model can be used to assess the distributional effects of meteorological services which are used to advantage by only a subset of firms in an industry or by firms in only one (or several) of many regions. Some firms may not use the services because the extra information is not applicable to them, because they are unable or unwilling to use the extra information, or whatever. A development of the market model to illustrate this situation is given in Figure 5. Suppose corn farmers can be split into two groups: adopters who use additional meteorological information to change decisions which reduce production costs; and, non-adopters who, for some reason, do not, or cannot, use the extra information. Initially the supply of corn by non-adopters shown in the left hand panel is S_n and that of adopters shown in the middle panel is S_a. Total market supply is given in the third panel by the (horizontal) summation of the supply by non-adopters and adopters as $S = S_n + S_a$. Against market demand D, initial period market price and quantity are P and Q, respectively.

With additional meteorological information that enables adopters to reduce their costs by K per unit output, their supply curve shifts down to S^1_a. Meanwhile, the supply curve for non-adopters remains at S_n. Then the new market supply shifts down to $S^1 = S_n + S^1_a$. As a result with the unchanged market demand D and the new market supply S^1, price falls to P^1, and this fall applies both to adopters and to non-adopters. The adopters win because the cost reduction K exceeds the price reduction P - P^1. But, non-adopters who have no cost savers lose from the lower market price. Buyers gain from the lower price.

The simple illustrative models of Figures 4 and 5 can be extended and generalised in many ways. They can be extended to several products and ultimately to a computable general equilibrium model for the economy allowing for second-round behavioural changes to all product prices, input costs and factor returns throughout the economy, or even the globe. Sumner *et al.* (1998) illustrate how various types of trade restrictions and other government policy interventions can be incorporated into models. The idea of Figure 5 can be generalised to many categories of producers, with categories classified by economic, social and other circumstances, and by the level of use of, or changes in the volume of, meteorological services.

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LISTS OF FIGURES

FUNDING METEOROLOGICAL SERVICES

(Running title - Funding Meteorological Services)

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Funding meteorological services

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Different options for funding the provision of meteorological services and for charging for the information provided are described and evaluated. The basic infrastructure and general forecasts and warnings have public good properties of non rival consumption and high costs of exclusion. For these, direct government funding and free provision to all are favoured. Value added meteorological services for use by small groups of specialised users have mixed good properties, and in some cases private good properties. In this case, setting fees at marginal incremental costs for value added services is favoured for reasons of efficiency and practicality. The other options considered include government funding with zero price, and loading user fees for a contribution to funding the public good supply costs.

1. Introduction

Historically, general taxation revenue allocated to government owned and operated National Meteorological Services (NMSs) has been the dominant source of funds for the production and dissemination of meteorological services. This public funding strategy has come under increasing pressure in recent years as a result of more and more claims on limited taxation revenue, and greater emphasis on application of the user pays principle for government services. Many NMSs now depend on fees for services for part of their income with approximately 20% of the annual budget of the Australian Bureau of Meteorology met from user charges (Bureau of Meteorology, 1999) and up to 40% or more in some countries. Also, there has been significant growth in the number and importance of private sector providers of value added meteorological services operating on a commercial basis. The funding and pricing of meteorological services is part of the broader national economic problem of allocating scarce labour, capital and other resources among food, health, defence, environment and so on, as well as to meteorological services.

The purpose of this paper is to describe and evaluate different options for the funding and pricing of meteorological services. The options include: government funding from taxation revenue and zero pricing; marginal cost pricing for value adding services; marginal cost pricing plus a loading on value added services with the loading being a contribution to overhead costs; and two-part tariffs for value added services involving a contribution to the costs of provision of the basic infrastructure. Comparison of the different options depends importantly on the rivalry and excludability properties of the different stages or components of meteorological service provision. Full government funding has more advantages for the public good infrastructure which is characterised by non rival use and high costs of exclusion. User pays fees become more attractive for value added services where private good characteristics of rival consumption and especially ease of exclusion dominate. The different funding and pricing options for different meteorological services are evaluated in terms of: revenue collected and fees paid; guidelines for the efficient allocation of resources to the production and use of meteorological services; incentives for suppliers and users to adopt cost-saving technology and to innovate; and feasibility and simplicity.

The rest of this paper is organised as follows. Section 2 describes the economic characteristics of meteorological services, with particular focus on the rival and excludability properties of different services. A simple upstream-downstream model for public good infrastructure and private good value added services is presented in section 3. Sections 4, 5 and 6, respectively, consider the different funding and pricing options for the upstream public good infrastructure and public services, for private good value adding meteorological services, and for mixed good value adding services. Section 7 outlines some institutional structural options available to countries and Section 8 provides conclusions.

2. Economic characterisation of meteorological services

Meteorological services involve the provision of information on the state of the atmosphere and, to a more limited extent, that of the underlying ocean, land surface and inland waters (Freebairn & Zillman, 2000). These services conveniently can be considered as falling into five broad groups: provision of information on past conditions from the historical record; provision of information on the current state of the atmosphere, ocean, land surface and surface water; provision of forecasts of future conditions, including warnings of severe weather and climate events, general forecasts for the community at large and for a range of specialised users, and projections of future climate including both seasonal to interannual and longer term fluctuations and possible human-induced climate change; provision of advice on meteorological, hydrological or oceanographic science and its application to community needs; and conduct of investigations into specific scientific problems of the atmosphere, ocean or inland waters. A substantial basic national and international meteorological infrastructure is necessary to provide the database for the long term climate record for future generations as well as for the support of a wide range of current operational services (Zillman, 1999).

Economic and social benefits of meteorological services arise when individuals, businesses and governments make decisions whose outcomes are influenced by weather and climate conditions and the information provided enables them to achieve better outcomes than otherwise. Virtually every sector of the economy in virtually every country makes some direct or indirect use of general or user specific meteorological services. Nicholls (1996), Katz & Murphy (1997), Anaman *et al.* (1998) and Stern & Easterling (1999) provide specific examples and reviews of published studies which have reported estimates of the benefits of a wide range of meteorological services. From the perspective of an efficient allocation of scarce national resources to the production and use of meteorological services, the quantity provided should be that which equates marginal social benefits to users of the information with marginal social or opportunity costs of using the resources for other purposes (Freebairn & Zillman, 2000).

A useful simplified representation of the concept of operation of an NMS is given in Figure 1. In most countries, the basic infrastructure, data and products have traditionally been provided by government and made freely available to all, including those inside and outside the NMS. This free flow of essential information extends across international borders, as recently reasserted through Resolution 40 of the Twelfth World Meteorological Congress (World Meteorological Organization, 1995). The basic infrastructure provides the foundation for a range of further information processing activities and generation of more useful forms of information for decision making by individuals, businesses and governments. There is little point in having more than one provider of the basic infrastructure, and the need for strict adherence to international standards and for long term continuity requires extensive government oversight if not direct control and operation.

Basic weather and climate information, general public forecasts and warnings of severe weather and climate events usually are seen as a basic community necessity and right, and provision of the basic service (the next layer up in Figure 1) is generally accepted as a fundamental responsibility of government. However, most of the dissemination to the community usually occurs through the mass media and, in some countries, the media themselves are charged fees for access to both basic and enhanced public weather information. Individual users seeking access to the basic service through channels other than the mass media are often charged the specific cost of access (e.g. through telephone or facsimile) to the basic publicly available information.

As we move further up Figure 1, the provision of special services entails value adding and tailoring to the specific needs of particular industries, regions or even individual users. For these services, the identity of users may be apparent and the specialised information may be of little use or value to decision making by others. In these situations, there are opportunities for charging for the value added services, beginning with incremental costs and potentially adding more as a contribution to the costs of the basic infrastructure if that is seen as appropriate from a policy perspective. Other issues arise as to whether the NMS or private commercial service providers should provide the specialised services, and the conditions, including cost, of access to the basic infrastructure, data and products become important policy issues.

From an economic perspective, the options for the funding and pricing of meteorological services, and the achievement of an efficient allocation of scarce resources to different categories of services, depend on the rivalry and excludability properties of the different types of service shown schematically in Figure 1. Meteorological services include those with public good properties of non rival consumption and high costs of exclusion; those with private good properties of rival consumption and low costs of exclusion; and mixed goods with non rival consumption and lower costs of exclusion (Figure 2). There are also mixed goods with properties of rival consumption and high costs of exclusion, but these are relatively unimportant in the case of meteorological services.

Much valuable information provided by NMSs and other service providers for enhanced decision making has the property of non rival consumption. Use of this information by one decision maker does not reduce the quantity available to others. Once the information is available, the marginal cost of its supply to additional individual, business or government decision makers is, in many situations, close, if not equal, to zero.

In the case of the basic infrastructure and the public weather and climate services provided by NMSs, the services are characterised by high costs of exclusion as well as by non rival consumption. Once the information is available, it is available to all and it would be difficult or very costly to exclude potential users from accessing the information and using it to improve the outcomes of weather and climate sensitive decisions. Typically there is a very large number of users of the information, including current users in a country, users in other countries and future generations. Further, the total and marginal benefits of meteorological services both vary widely across the large number of users, and the NMSs have little information on the individual user valuations. Non rival consumption and high costs of exclusion mean basic meteorological infrastructure and public weather and climate services are classic public goods.

From the national perspective of the efficient allocation of resources to meteorological services with public good characteristics, the chosen quantity of services should equate the sum across users of the marginal rates of substitution in demand of the public good and private goods with the marginal rate of transformation in production of the public good and private goods (Myles, 1995; Stiglitz, 2000). This quantity would also equate the sum of marginal benefits of the meteorological information to the different users with the marginal cost of its production. Note that all users would receive the same quantity, because of non rival consumption, but their marginal valuations and willingness to pay at this quantity are likely to vary widely from user to user. Given the nonexcludability property, different users have an incentive to free ride and not to reveal their willingness to pay for the service. Private markets fail demonstrably in the provision of public goods, including, in particular, in the provision of public meteorological services.

In the case of specialised value added meteorological services, the possibility of the supplier appropriating from users a fee for service and thereby avoiding most of the free rider problems of a pure public good becomes a serious option. In many situations, the enhanced decision making benefits of value added services arise for only a small number of clearly identifiable users. Here restrictions via access to phone, fax, internet or personal contact with the supplier enable the supplier to exclude potential users at low cost from the value added meteorological service. Small numbers of users mean also that it is easier to assess the total and marginal benefits that the different users attach to the specialised value added meteorological services and, in turn, to bargain user fees.

Various examples of value added meteorological services can be given to illustrate where costs of exclusion may be small. Specially processed climatic data for use in the design of structures in a particular area so as to be robust against extreme events, while also minimising costs, are valuable initially to the developer and a few potential builders at the tender stage and, once a successful tender has been chosen, the data are valuable to the developer and to the one builder. Flight-specific presentation of forecasts for use by individual airlines can be restricted to the paying airline, or consortium of airlines, using a particular route - as opposed to basic aviation meteorological services which are made widely available in line with international conventions and national regulatory requirements. Specialised meteorological information for use by farmers producing a particular crop in a particular region to assist, say, programs of weed and pest control can be restricted to paying individual farmers or to a cooperative or consortium of farmers. Even for general weather forecasts, costs of exclusion can be low for the provision of more detailed information, or for priority provision of the information, to a limited number of media outlets.

Where valued added meteorological services have the combined properties of non rival consumption and low costs of exclusion, the appropriate economic classification is as a mixed public and private good. In particular cases of a single user, or consortium of users, consumption, in effect, is rival and a private good framework can be applied. For private goods, market forces of demand, based on marginal benefits of meteorological information to users, and of supply, based on the marginal costs of service provision, combine to determine the price and the quantity produced and consumed of the private good meteorological service which maximises society welfare. For a mixed public and private good meteorological service, the efficient quantity equates the sum of marginal benefits of the different users with the marginal cost of supply. A price discrimination pricing strategy with user charges set at the marginal value of the welfare maximum quantity for each user will equate society marginal benefits with marginal cost.

Figure 3 depicts the economic classification of the various components of national meteorological service provision, with a distinction between information for national and for international use, and categorisation by type of economic good, with a distinction between public good, mixed public and private good, and private good. The categorisation by economic good is suggestive rather than definitive. For example, some fees may be charged for the mass media, some specialised services may be offered free, and technology can alter the costs of exclusion and, in turn, the economic classification of particular meteorological services. Nonetheless, there is a clear pattern of public good properties of the basic infrastructure which is a necessary input for both basic public weather and climate services and for specialised value added services. The more specialised value added meteorological services have less general application, and options for low cost exclusion are available. These opportunities for exclusion move such meteorological services into a mixed good classification and, in an extreme case, into a private good classification.

3. A simple model

Consider a two-stage production process for meteorological information which improves the decision outcomes for choices affected by weather and climate. There is an upstream provider of basic infrastructure and general forecasts with public good characteristics, and a value adding downstream producer of specialised services with private good characteristics. The NMS will usually be the upstream producer. Then, specialised units (perhaps part of the NMS or, alternatively, independent commercial firms) use the public good information, plus extra resource inputs, to produce a more valuable set of tailored meteorological information for specialised users, such as return-period estimates of various wind speeds and rates of rainfall for the design of structures or forecasts of sailing and flying conditions for individual ships and aircraft and specific times and routes.

A formal representation of the two stage production model is:

$$Q = f(X) \quad (1)$$

$$Q_j = f(Q, X_j) \quad (2)$$

where Q is the quantity or volume of public good meteorological services, Q_j is the quantity or volume of private good meteorological services with j = 1, 2, ..., n representing different specific purpose value added information types for user class j, X is the labour, capital and other resources used in producing the public good, and X_j is the additional resources, in conjunction with the public good meteorological services input Q, used in producing each value added specialised service.

The production functions in equations (1) and (2), together with information on the resource input costs, can be used to derive cost and supply functions for the Q and Q_j products. Note, however, that the public good Q is a common cost input for all the value adding Q_j outputs. From an economic perspective, the allocation of the common cost of the inputs X used to produce Q in the production of different value added Q_j products is not easily determined and requires data on demands and costs for each of the j = 1, 2, ..., n value added products.

Demand for each private good Q_j is given by the marginal benefits of better decision making attributable to use of the meteorological information, or by the marginal willingness to pay function. In the case of the public good Q, demand is given by the sum of the marginal benefits of direct users of Q plus the sum of the derived demands for Q by each of the specialised service providers as an input in producing each Q_j.

4. Funding and pricing: public good

Against the criteria of economic efficiency and practicability, the public good components of meteorological services primarily should be government funded with household and business users being charged only marginal attributable costs associated with their provision to particular users. The non rival consumption property of basic infrastructure and general weather and climate information means that the marginal cost of public good meteorological services to a particular user of the information is negligible, if not zero. Marginal attributable costs would include any extra processing costs of the public good information for the specific needs of particular users plus identifiable communication and distribution costs to the user.

All users, and in fact all individuals and businesses in society, are provided with the same quantity of public good meteorological services. At this quantity, total and marginal benefits of the information will vary widely from user to user. As well as the usual free rider problems and the absence of incentives for individuals and businesses to reveal their willingness to pay for public good meteorological services, the practical task of measuring the benefits of the information to most users appears to be insurmountable. Further, the impacts of technological change result in frequent shifts in user valuations of meteorological services over time. The very high costs involved in excluding users from gaining access to public good meteorological services means that charging systems easily can be avoided. All these practical considerations rule against the application of user fees to collect much revenue to fund public good meteorological infrastructure and services.

In determining the level or volume (quantity and quality) of public good meteorological services to be provided, and the associated draw upon taxation funds, recognition must be given to tax administration costs, tax compliance costs, and the deadweight or efficiency costs of taxation on economic decisions. As a result, the social cost of a dollar of tax revenue exceeds the dollar collected. In most countries, government tax administration costs in collecting revenue are around 1% of revenue collected. Individual and business costs of tax compliance costs can be of the order of 10% of tax paid (see, for example, Sandford, 1995). Taxation distorts decisions on work versus leisure, on spending now or in the future, on the choice of which goods and services to produce and consume, on the form of business organisation, and so forth, with resulting efficiency costs, often in excess of 20 cents per dollar of tax revenue (see, for example, Musgrave & Musgrave, 1991; Myles, 1995; Campbell & Bond, 1997; Feldstein, 1997; Stiglitz, 2000). Then, the social cost of a dollar of tax revenue likely exceeds $1.30. In the special case where the benefits of public goods, in this case basic meteorological infrastructure, data and products and general public forecasts, are distributed roughly in the same way as is the extra tax revenue to fund them, Kaplow (1996) and Ng (2000) argue that, even after recognising the social costs of tax revenue, government should expand public good services to the level at which the social marginal benefits (that is the sum of marginal benefits across all users) per extra dollar of government expenditure equals unity.

5. Funding and pricing: private good

Consider next the funding and pricing of private good meteorological services. Generally these are value added weather or climate forecasts or specially processed data for the particular decision needs of specific users, the Q_j outputs of equation (2). Examples are services provided for offshore oil and gas operations, tourist operators, construction projects, energy utilities and groups of farmers. While there is significant debate as to whether the users of specialised private good services should also contribute to the funding of the public good infrastructure input Q, there is little controversy that they should fund the incremental costs for the X_j inputs in equation (2).

One option, however, is to use taxation revenue to fund not just the basic infrastructure but also the production of the value added services and provide them free of charge. That is, both the Q and the X_j inputs in equation (2) are funded from taxation revenue and the price to users of Q_j is zero. Given the social opportunity cost of the value added production inputs, X_j, zero pricing of private good meteorological services will lead to excess production and consumption with marginal social costs exceeding marginal social benefits. The national efficiency costs of excess production and consumption become greater when due recognition is given to the administration, compliance and efficiency costs associated with the collection of tax revenues.

A more attractive funding and pricing option for private good meteorological services in terms of efficiency and feasibility criteria is to charge users a price equal to the marginal or identifiable incremental costs of the value added services. That is, users are charged a price per unit of Q_j information in equation (2) equal to the marginal cost of the X_j inputs per unit of Q_j output, and implicitly, or explicitly, leaving (or assuming) a zero charge on the public good, Q, infrastructure input costs.

The revenue and funding implications for the NMS of a strategy of marginal cost pricing of value added downstream services depends on the circumstances as depicted in Figure 4 and analysed in more detail in the Appendix. If demand is at a quantity (Q_2) where the average cost of producing the value-added services is constant, marginal cost pricing will cover the costs of the value adding X_j inputs but there is no contribution to the cost of the X inputs used in producing the infrastructure services. If average costs of producing the value added services are rising (as for quantity Q_3 in Figure 4), marginal cost pricing covers costs of the value adding inputs and makes a contribution to the costs of infrastructure; and the converse where average costs are falling (Q_1 in Figure 4). The actual situation depends on demand and the technology for producing the value adding specialised services, and it likely will vary for different services.

The option of providing the public good meteorological service input Q free of charge to value adding providers, whether they be a component, preferably an independent component, of the NMS or a private commercial firm, has both advantages and disadvantages. Open and competitive access to a key input provides for contestability in supply of the value added private good meteorological services. This unleashes competitive pressures, with incentives and rewards for innovators to expand the technological frontier. If the contestability leads to prices and quantities where marginal cost and marginal benefits are equated, static economic efficiency follows. However, government expenditure to fund the public good basic infrastructure costs still has to be incurred.

Several options can be considered so that the price charged on the value added meteorological services covers not only the costs of the extra inputs but also contributes to the costs of provision and operation of the public good infrastructure. These include: a tax levied on the marginal cost price of the value added product, or a tax on the inputs used in producing the value added outputs, with the tax revenue being used as a contribution to the cost of funding the public good input; or a two part tariff consisting of a lump sum access fee and a per unit service charge set at marginal cost as above. The access fee can be as high as buyer economic surplus (i.e. the area between the marginal benefits or demand curve and the price line), and it becomes a contribution to the costs of producing the public good input Q.

Some degree of monopoly right for the supply of the value added private good meteorological service will be required for the two-part tariff system to be sustainable. Monopoly power could come from economies of size, meaning it is much cheaper to produce Q_j with one supplier rather than having several producers, or from some form of government regulation raising barriers to entry. In the absence of a monopoly, and recognising the public good properties of non rival consumption and high costs of exclusion to the use of the public good input, alternative suppliers can enter the industry and produce the value added meteorological services, Q_j, at marginal cost. The new entrants avoid paying the access fee and thereby undercut the price of the incumbent producer. Ultimately the new entrants drive the incumbent out of the market, with the result that no contribution via an access fee is made to funding the cost of providing the public good meteorological infrastructure and products.

The static efficiency effects of the tax and two-part tariff options for collecting funds to contribute to the public good infrastructure meteorological services are different. The tax option in effect shifts upwards the marginal cost and supply curves for the value added meteorological service, Q_j. This results in a higher price, a fall in consumption to a level where marginal social benefits exceed marginal social costs, and an associated efficiency loss from too little production and consumption of the value added meteorological service.

In principle, a set of Ramsey taxes with the tax set higher for value added meteorological services with relatively low responses of quantity to demanded price, or lower demand elasticities, will minimise the overall deadweight costs of meeting an aggregate revenue target contribution to the public good meteorological service input Q. Given the options of funding the basic infrastructure services by taxation revenue and incurring the social costs associated with the administration and compliance costs of taxation and the deadweight distortion costs of taxation, or funding them by input taxes on value added services, Laffont & Tirole (1993) show that a non-zero markup improves overall efficiency.

By contrast, the option of using a two-part tariff structure for value added private good meteorological services to fund a part of the basic meteorological infrastructure involves no static efficiency loss associated with too little consumption. The access fee effectively is a lump sum tax. It is non-distorting in its effect so long as it does not absorb all the benefits, or consumer surplus, to the user of the value added service. Then, from a static economic efficiency perspective, the two-part tariff is preferred to the tax markup model for collecting a contribution to public good infrastructure costs. However, the required monopoly status of the supplier of the value added meteorological services necessary to sustain the two-part tariff price may itself lead to efficiency losses. A monopoly supplier facing competitive buyers can increase its own profit by restricting output of the value added service below the socially efficient level. But, since the excludability property for a private good in the context of value added meteorological services generally requires that there be only a few buyers, or an organised cartel of buyers, a more likely market structure is one of buyer concentration and monopsony power as well as seller concentration and monopoly power. Such a bilateral monopoly bargaining industry structure may or may not choose a socially efficient quantity of value added meteorological services. Alternatively, the users of the value added services may vertically integrate and organise themselves to become the supplier of the value added meteorological services and, in this context, choose a level of output that closely equates marginal social costs and benefits; or regulations could be imposed on the monopoly supplier of the value added services to price according to marginal cost. Clearly regulations are subject to various failures of their own, and hence they will involve some errors and efficiency losses.

Probably a greater concern with monopoly supply of private good value added specialised meteorological services is the potential loss of dynamic efficiency. And these problems arise with either a publicly owned monopoly, say the commercial arm of the NMS, or a private commercial firm with sole supplier rights. Both the production of meteorological services and the use of meteorological services are subject to rapid and often unpredictable changes in information technology and other innovations. A competitive environment, particularly one that minimises barriers to entry for new suppliers of value added meteorological services, provides incentives and rewards for innovation and improvements in productivity. By contrast, a monopoly structure dulls the incentives for, and rewards of, productivity improving innovations.

There are difficult-to-quantify trade-offs between the competitive structure and monopoly structure models for providing value added private good meteorological services for specialised users. Competition in the provision of specialised services is best fostered by government funding of public good infrastructure services, but the associated distortions associated with taxation to provide government funds involve social costs. However, in the case of public good meteorological services providing benefits across most members of society and if, as seems likely, the distribution of the benefits is roughly comparable to the distribution of the burden of the extra taxes paid for their funding, Kaplow (1996) and Ng (2000) argue that most of these costs can be ignored in determining the output of public good meteorological services. By contrast, monopoly providers can set user fees for the specialised private good meteorological services which provide a contribution of funds to the public good as well as covering the incremental costs of the private good services. A competitive structure, and in particular the opportunity for and threat of entry of new suppliers, is more conducive to innovation and productivity growth than is a monopoly. Choice between the two options will vary with circumstances and ultimately becomes an empirical issue.

6. Funding and pricing: mixed public and private good

Relative to the preceding discussion of private good meteorological services, funding the services where mixed goods are concerned opens up the option of a more refined funding strategy based on the principles of price discrimination in addition to those already discussed.

Mixed public and private good meteorological services have the properties of non rival consumption and low costs of exclusion. For example, special purpose forecasts of flying conditions (ie forecasts that go beyond those required to be generally available to conform with regulatory requirements) are non rival for different airline companies operating the same route(s) and the supplier can restrict the availability of the information to the different airline companies. Other examples include individual farmers in a similar climate regime, different utility companies supplying into a common market, and different construction companies tendering for the design and building of infrastructure in a particular region.

A supplier of a mixed good meteorological services may be able to distinguish between the different potential users of the information in terms of the total or marginal benefits each places on the information. For example, one of the airline companies may operate more frequent flights, have aircraft with different sensitivities to weather conditions, or have different operational and management systems for using the meteorological services to adjust decisions to achieve better outcomes than the other airline users of the non rival services. Then, a revenue maximising supplier would charge the different airline companies different prices based on their assessed ability or willingness to pay for the same information. Such a price discrimination strategy extracts greater revenue from the users, and hence a larger source of funds to contribute to the costs of the public good infrastructure, than the strategy of a common fee for all users.

7. Institutional structure options

The use of competition, even if only the threat of competition entry, to stimulate innovation in both the supply of, and use made of, value added meteorological services has been emphasised. Achieving a competitive structure raises questions about the involvement, and by implication also the pricing practices, of the NMS. In particular, it may be considered desirable to preclude the NMS from using its monopoly position in the supply of the public good infrastructure to compete unfairly against private sector suppliers of value added meteorological services.

One simple industry structure is to restrict the NMS to providing public good meteorological services, including the basic infrastructure and general forecasts, with full government funding, and leave the production of value added meteorological services with private good and mixed good properties to private firms. Private firms would use the readily available public good services at zero charge, then employ, and pay market prices for, extra resources to produce value added services, and charge what the market will pay. The forces of competition would provide effective incentives and rewards for private firms for developing and adopting innovations in both the production of value added meteorological serves and in the uses made of the information. With the NMS effectively excluded and all having equal access to the public good meteorological information, different private sector firms compete amongst each other on level terms.

However, in additional to the safety considerations which may make it undesirable that a major user sector (eg aviation) base its decisions on information which could be inconsistent with the widely available public forecasts and warnings, at least three sets of arguments against excluding the NMS from involvement in the production of value added services need to be considered. First, there may be economies of scope which result in cost savings in using skilled forecasters, computers and other NMS resources in joint production of value added services as well as the basic infrastructure and public services (although, as pointed out by a reviewer, private downstream suppliers could hire or rent at market rates the services of skilled staff, computers, and so forth from the NMS). Second, as has been noted earlier, the delineation of public good meteorological services as the limit of the domain of the NMS is a vague and somewhat arbitrary exercise. Further, the demarcation will change with rapid technological change, and it will be subject to inefficient strategic and political gamesmanship. Third, for many, and maybe most, value added services, it is likely that economies of size will mean it is cost effective to have just one supplier, although the importance and extent of economies is an empirical issue and one which may have different answers for different value added services. Where economies of size are such as to favour a natural monopoly it may be necessary to choose between a regulated public supplier, the NMS, or regulation of a private firm monopoly supplier and, in this situation, there is no clear answer.

Alternatively, the supply of value added meteorological services could be structured to achieve a close-to-level playing field for fair competition between the NMS and actual and potential private sector suppliers. The public good meteorological services used as an input for producing value added services would be made available to all producers on exactly the same terms, of which a zero price is one option, and the NMS sets prices for the value added services it produces to at least cover the incremental production costs, as would a commercial private business competitor. While the delineation of what is a public good to be funded by the government and provided free of charge to all, and what is a value added meteorological service, will be arbitrary, so long as the distinction is clear and explicit, it has a limited impact on achieving competition in the value added specialised meteorological services market.

8. Conclusions

Meteorological services which provide individuals, businesses and governments with information to enable them to make better higher-pay-off decisions span the spectrum of public, private and mixed goods. The lines of demarcation are vague, and they change over time. Given these real difficulties, a general strategy for funding the provision of meteorological services to meet efficiency and feasibility criteria can be suggested.

Basic infrastructure data and products for national and international use, and basic public weather and climate forecasts and warnings, primarily have public good properties. The information is non rival in consumption, there are very many actual and potential users from most sectors of the economy, and costs of exclusion are high. Other than for the identifiable costs of their distribution to individual users, economic efficiency and practicality considerations mean these public good services should be provided free of charge to actual and potential users. General taxation revenue should provide most of the funds for public good meteorological services.

Specialised value added meteorological services provide extra information which enhances decision making by smaller groups of individuals and especially businesses. Here many of the specialised services have mixed good properties of rival consumption and low costs of exclusion. In some cases with one user, or effectively one user, the non rival consumption property can be ignored leaving a private good situation. The value added services use both the basic infrastructure information as an input plus relatively easily identifiable additional inputs for production. User charges for the value added meteorological services set at the marginal cost of the additional inputs result in economic efficiency. Further, the associated zero charge on the public good input provides a low entry cost and neutral field for competitive rivalry. Provided that, at current demand quantities, the average variable costs of the value added activity are constant or rising, the marginal incremental cost pricing strategy will fund the costs of the extra inputs.

Options to include in the price or user fee for value added specialised meteorological services an extra charge to contribute to the funding of the public good infrastructure are controversial. In terms of the criteria of efficiency and extra revenue collected, a two-part tariff is preferred to a tax on the value added outputs or on the extra inputs used in producing them. Monopoly power is, however, necessary to ensure sustainability of a two-part tariff. Unfortunately, decisions by the monopoly supplier are likely to involve static and dynamic efficiency losses. These efficiency losses or costs have to be compared with the social costs of using tax revenue to fund the basic infrastructure.

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Appendix - marginal cost pricing and funds

Figure 4 shows a general picture of the average variable cost and marginal cost of producing value added meteorological services. Average variable cost, AVC_j, and marginal cost, MC_j, associated with providing a particular value added meteorological service, Q_j, refer only to costs of the value added input, X_j, and assume a zero charge for the public good infrastructure inputs, Q. Three plausible situations in Figure 4 can be identified. These depend on the position of the demand curve for the value added specialised meteorological services relative to whether average costs are falling, constant or increasing, with the three different situations shown with demand as D_1, D_2 and D_3. The demand curves reflect the marginal value of the extra information to more effective and higher pay-off decisions in the face of weather and climate influences. In case one, demand at D_1 occurs where average variable costs, AVC, are falling because of economics of size and scope, and by definition MC < AVC. Here, setting price equal to MC, that is P_1, results in a short-fall of revenue in the sense that the revenue collected, P_1Q_1, is not enough to cover the value added input costs A_1Q_1. In case two, demand at D_2 occurs where average costs, AVC, are approximately constant, and by definition AVC = MC. In this situation, pricing the value added private good specialised meteorological service at P_2 = MC = AVC covers the costs of the extra, or value added inputs, X_j, but provides no contribution to funding the public good infrastructure inputs Q. Case three is where demand D_3 is at a quantity where average costs, AVC, are rising, and by definition MC > AVC. Here, marginal cost pricing, P_3, generates enough revenue to cover the value added inputs, X_j, plus a surplus or contribution equal to P_3 - A_3 per unit value added meteorological services output. This surplus could be used to contribute to the cost of producing the overhead or public good infrastructure input, Q.

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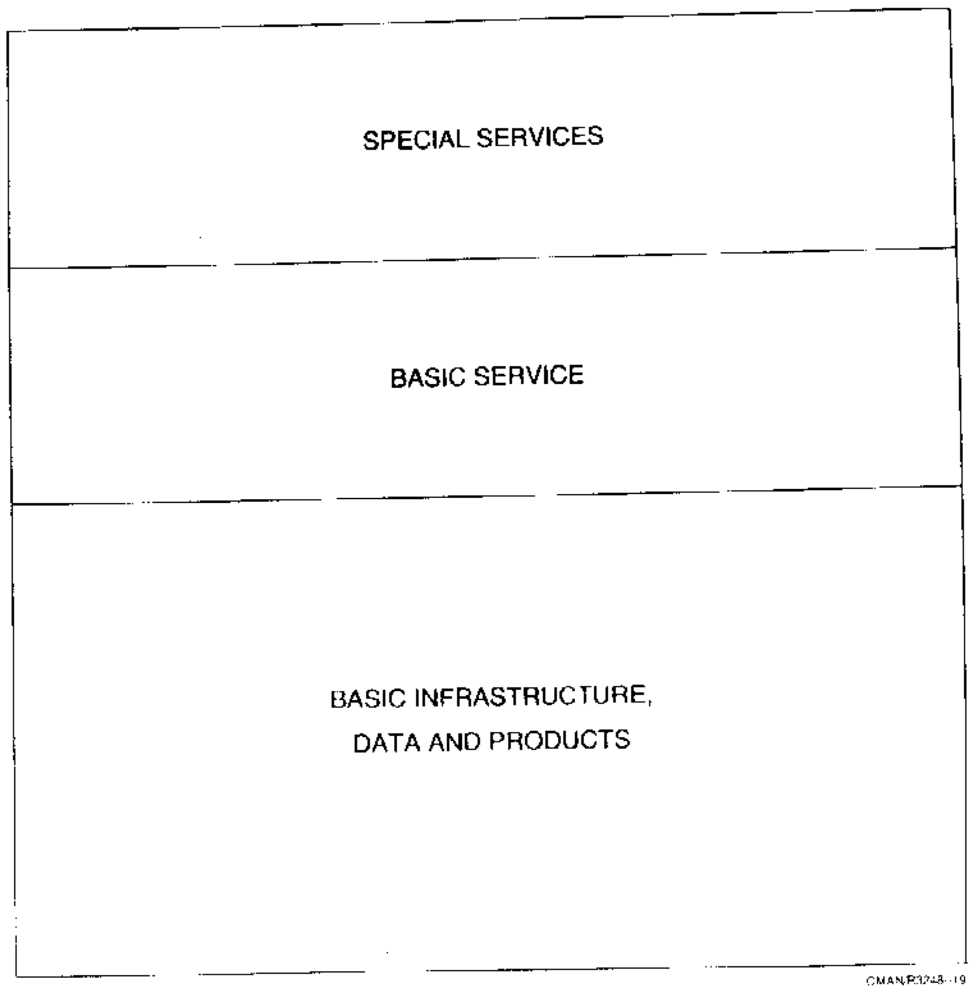

Figure 1. *A schematic representation of the essential components of a national system for provision of meteorological services. The basic infrastructure, data and products (sometimes referred to as 'basic systems') underpin the provision of both the basic service to the community at large and special services to individual users.*

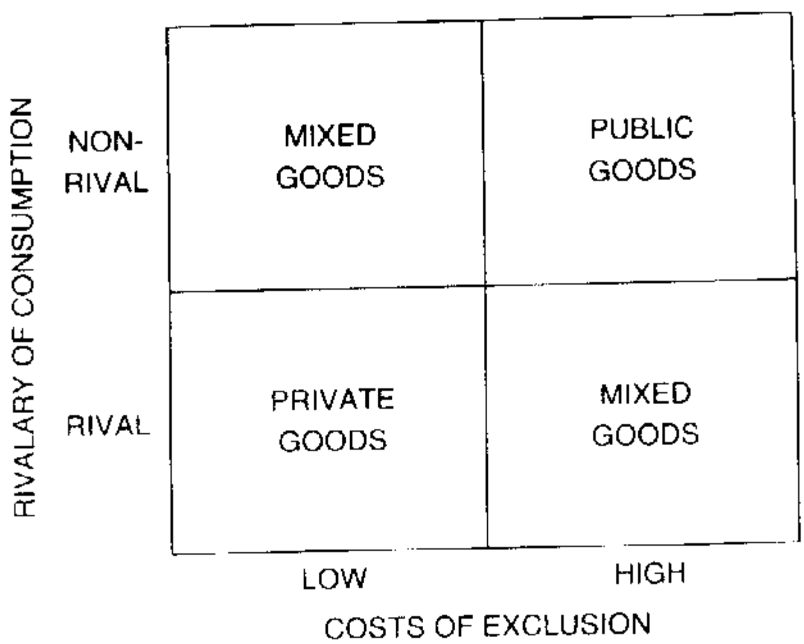

Figure 2. *The categorisation of meteorological services according to rivalry of consumption and costs of exclusion.*

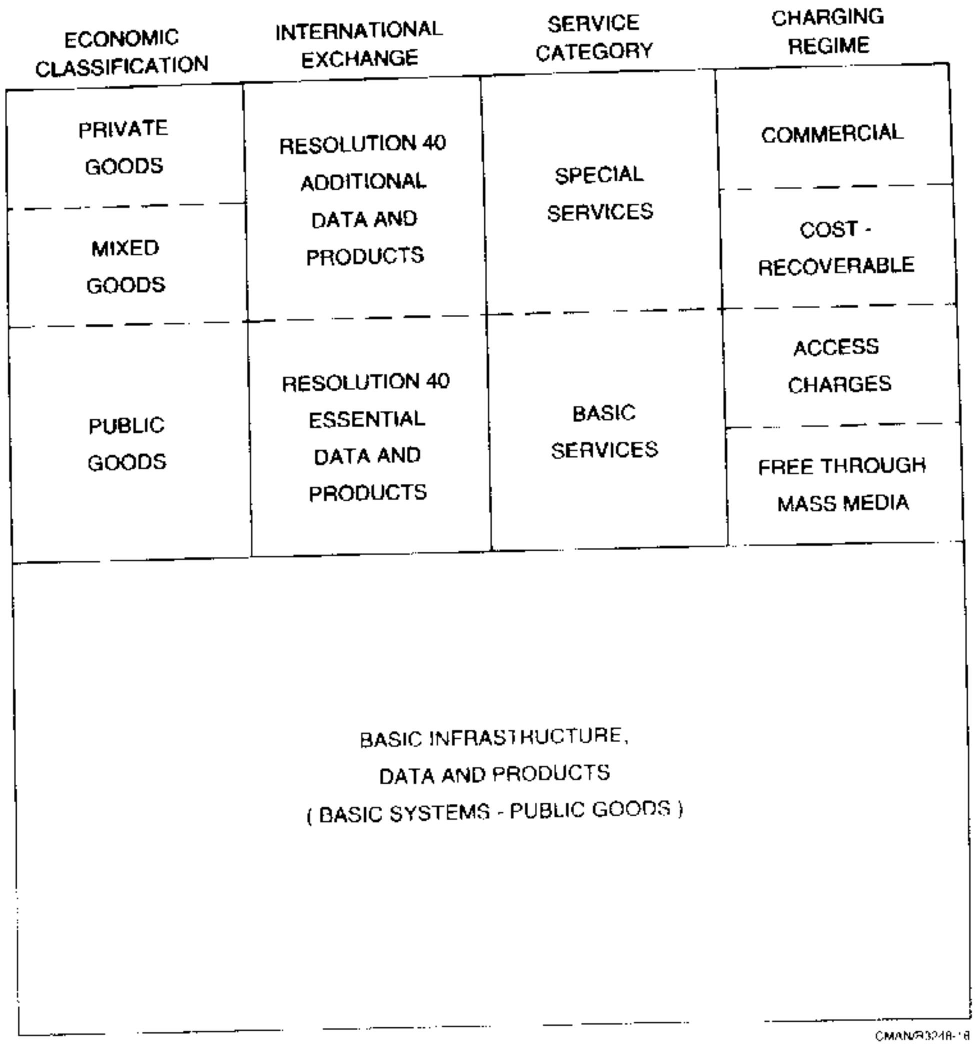

Figure 3. *A schematic representation of the approximate relationships between the basic underpinning national meteorological infrastructure and its various outputs (data, products and services) in terms of their economic classification, the provisions governing their international exchange under Resolution 40 of the Twelfth World Meteorological Congress and possible charging regimes at the national level. It should be noted that the horizontal alignment of boundaries (broken lines) is approximate only, and may vary from case to case and time to time.*

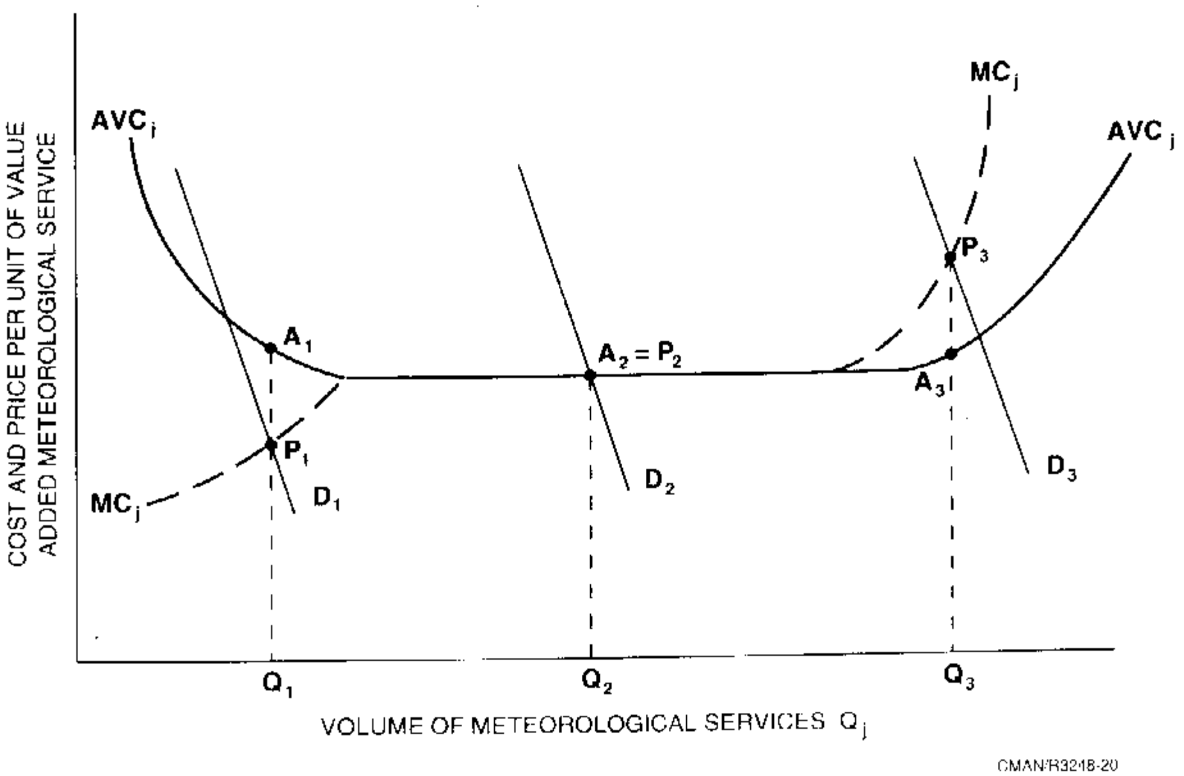

Figure 4. *A schematic representation of the implications of marginal cost pricing of value added meteorological services for three different demand situations D_1, D_2 and D_3. AVC represents the average variable cost of the services and MC the marginal cost.*