METEOROLOGICAL NETWORKS—A SPECIAL APPLICATION OF TRANSBORDER DATA FLOWS

I. Sebestyen

November 1982
WP-82-119

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS
A-2361 Laxenburg, Austria

PREFACE

This working paper is part of the IIASA study "Telecommunication Equipment and Administrative Procedures Relevant to Experimental and Operational East-West Computer Connections," supported by the Control Data Corporation, Minneapolis, USA and the Austrian Ministry for Science and Research, Vienna.

CONTENTS

METEOROLOGICAL NETWORKS—A SPECIAL APPLICATION OF TRANSBORDER DATA FLOWS

0. INTRODUCTION

Meteorological networks are one of the oldest examples of transborder data flow, going back in an organized form for about two centuries. According to [1], [2], and [3], the weather has been a primary concern of mankind since before the dawn of civilization.

This fact is reflected in fragments of the earliest writings and in the existence of numerous ancient deities associated with various weather phenomena. The earliest known systematic treatises on meteorology are the famous *Meteorological* of Aristotle (384-322 B.C.) and the writings of his pupil Theophrastus on winds and on weather signs. During the next 2,000 years the science of meteorology did not progress substantially beyond the point to which it had been carried by Aristotle, in spite of a number of treatises on the subject. The development of the science, like that of the other physical sciences, was forced to await the invention of the instruments by which the primary physical elements could be measured.

The 17th and 18th centuries, in the history of physical science, constitute essentially a period of instrumentation and establishment of the elementary physical laws of gases, liquids, and solids. Especially significant for the development of meteorology were the inventions of the thermometer by Galileo in 1607 and of the barometer by Evangelista Toricelli in 1643, followed by the discovery of Boyle's law in 1659. An explanation of the trade winds, including for the first time the effect of the earth's rotation on atmospheric winds, was attempted by George Hadley in 1735. When the true nature of atmospheric air was determined by Antoine Lavoisier in 1783, and when John Dalton, in 1800 had explained the variations of water vapor in the atmosphere and the relation between the expansion of air and atmospheric condensation, the physical basis of modern meteorology was established.

The development of the science during the 19th century occurred primarily in the field of synoptic meteorology, i.e., in the organization of networks of weather observing stations, in the preparation of daily synoptic charts and in the initiation of modern weather forecasting. The first international compilation of weather observations was made by J.B. Lamarck (with P.S. Laplace, Lavoisier and others) from 1800 to 1815. The earliest weather charts were made well before 1835 by collecting synchronous weather reports by mail. The first telegraphic collection of synoptic reports and mapping thereof for forecasting was accomplished by Urbain J.J. Leverrier following the Crimean War.

Between 1850 and 1875 many nations established meteorological services based on synoptic observations from networks of weather stations. International conferences (Brussels, 1853; Vienna, 1873) established international coordination of these national weather services by arranging for standard observational techniques and for the international exchange of weather observations by telegraph and later by wireless. The practice of weather forecasting increased rapidly during the same period, but progress in the understanding of atmosphere behavior was not rapid before 1900.

From about 1870 the leading nations have published charts each day along with the official forecasts. The basic chart shows the synchronous observations at sea level or surface stations over a more or less extended area, generally at least a large part of a continent and often a whole hemisphere. For each weather station whose observations are taken at internationally standardized synoptic hours--one to four times a day--and received by radio or telegraph at the forecast offices, the values of or symbolic indications of a number of weather elements, are plotted in a model grouping around the circle representing the station on the map. For all stations at least the barometric pressure (usually converted to its value at sea level), the air temperature, the present weather, the wind direction and speed or force, and the sky cover will be reported.

Although meteorology is as old as the other branches of the physical sciences, weather forecasting as a public service is only about 100 years old. It was only after the invention of the electric telegraph (about 1840) that it became possible to establish a communication system suitable for the rapid collection of weather reports. The first systematic experiments in weather telegraphy and forecasting began about 1860 and were conducted by Robert Fitzroy in England, Urbain Jean Joseph Leverrier in France, and the Smithsonian Institution in the United States. A decade later forecasting services had been established in several other countries.

The next advance came from 1900 to 1920 after the invention and development of radiotelegrahpy. As radio became standard equipment on ships it became possible to collect weather reports also from ocean areas. At the same time, and particularly after World War I, aircraft equipped with instruments began to provide information on the state of the atmosphere at higher levels. A major advance was made about 1930. At this time development of the radiosonde permitted soundings of temperature, pressure, and humidity through the troposphere and lower stratosphere. During World War II, the radiosonde was improved to also allow observations of the winds to be made. At the same time radar was developed and used to provide information on clouds and precipitation. After the late 1950s it was much used in locating and tracking thunderstorms, tornadoes and tropical revolving storms.

A major advance of the postwar period was the development of meteorological satellites capable of monitoring the cloud cover and temperature distribution around the world. Another technological advance was the introduction of the electronic computer. Such machines, in a variety of types, have contributed greatly to improvement in the processing of meteorological data, and made it possible to solve many mathematical problems that could not readily be tackled by customary techniques.

The early experiments in weather telegraphy and forecasting were based upon reports from a few land stations observing once or twice a day. The number of observation stations and the frequency of reports grew slowly until about 1920. It was only after the end of World War II that worldwide networks of surface and upper air stations and meteorological telecommunication channels became established. The international network of observing stations and the telecommunication services continued to expand, particularly in the regions that were undergoing rapid technological development. By the late 1950s there were about 10,000 ordinary land stations that provided surface reports, and about 1,000 stations that made soundings of temperature, pressure, humidity, and wind through the troposphere and lower parts of the stratosphere. About 3,000 commercial ships and about 50 specially equipped weather-observing ships provided observations from ocean areas. Several squadrons of aircraft equipped with meteorological instruments and radar engaged in meteorological reconnaissance over ocean areas where ship observations were absent or sparse. Much of the improvement in the forecasting of tropical storms resulted from information provided by meteorological reconnaissance. Commercial aircraft provided much useful information on the cloud and wind systems aloft, and a steadily growing network of radar stations gave detailed reports on severe local weather.

To ensure uniformity in the observations and the reporting procedures throughout the world, sets of definitions, scales, standards and codes were adopted in the 1950s by international agreements under the auspices of the UN World Meteorological Organization (WMO).

Instrumental observations (e.g., pressure and temperature) are reported as numbers, and visual observations (e.g., types of clouds, rain and snow) are translated into numbers according to internationally adopted specifications. The observations are then composed into coded messages and transmitted through established communication networks to all forecasting centers, where the instrumental observations are decoded and plotted as numbers while visual observations are represented by symbols.

The history of East-West relations in the exchange of meteorological observations also goes back as far as the history of organized meteorological observation. In Hungary, for example, the first organized meteorological observation service was launched on November 1, 1781 at the observatory of the University of Buda, which was at this time a member of the so called "Societas Meteorological Palatina", a meteorological network with 36 member stations and its headquarters in Mannheim, Germany.

As mentioned earlier, considerable progress in the development of meteorological networks was made around the 1870s, when the international telegraph networks became well established and were already able to provide the telecommunication backbone needed for the international exchange of meteorological data.

On the order of Emperor Franz Joseph II, the Central Meteorological Institute was founded in Hungary on April 8, 1870 and has since that time been in charge of coordinating and handling the traffic flow of transborder meteorological data. Later, after the beginning of the twentieth century, the radio transmission of morse coded meteorological data became the dominating telecommunication medium for the exchange of meteorological information.

With the growing weight of international telex networks after World War II, 50 baud leased point-to-point telegraph and telex circuits started to take on the daily traffic between national meteorological centers. The map of the European Meteorological Telex Network around the beginning of the 1970s is shown in Figure 1. According to [4], however, this manually switched European telex network, which operated without error detection and correction, became increasingly saturated and overloaded by the growing amount of information. For example, at the beginning of the 1970s the 50 baud Budapest-Moscow telegraph circuit worked for a full 23 hours a day, leading to a delay of 2-3 hours, for example, before the meteorological data of Ukrania were received in Budapest.

By the end of the 1960s it became increasingly obvious that the World Weather Watch program of the WMO had to be reorganized on a new and different basis. This function is now being fulfilled by the new dedicated computer communication network of the WMO, called the Global Telecommunication System (GTS). This system provides the backbone for the WMO Global Observing System (GOS) and the WMO Global Data-Processing System (GDPS).

In the following sections the nature of transborder data flow in the field of meteorology, its traditional trade pattern, and its change due to the emerging new information and telecommunication technologies in particular, within the framework of computer communication networks between East and West will be discussed. It will also be shown that, even in this special field of transborder data flow, which is regarded as rather unproblematic, some new worrying signals of growing difficulties are emerging.

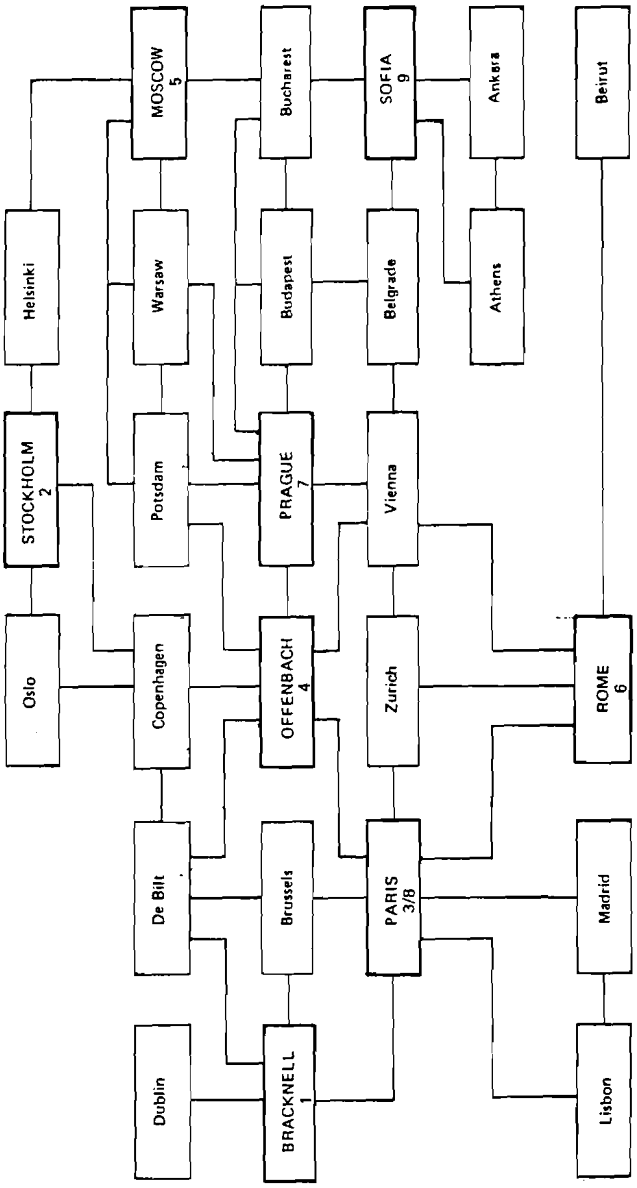


Figure 1. The defunct European meteorological telex network.

1. THE WORLD WEATHER WATCH PROGRAM AND THE GLOBAL TELECOMMUNICATION SYSTEM (GTS) OF THE WMO

1.1. General Description

As already mentioned the Global Telecommunication System (GTS) of the WMO [5], was designed at the end of the 1960s as part of the WMO World Weather Watch (WWW) Program. The GTS is one of the largest international information networks in existence that allows transmission in a store and forward mode of both digital and analogue meteorological information.

According to [13], the WWW is the basic program of the WMO. The WWW was first established by the Fifth World Meteorological Congress (Geneva, 1967).

While the basic approach of the WWW plan remained generally unaltered, important additions have been brought in since the launch of the program, mainly due to two developments. The first is the rapid technological changes and the second is the existing and expected new demand, from several applied fields and programs of other international organizations, on the facilities created under the WWW plan.

Technological change has been rapid in many fields, such as satellite meteorology, where remarkable progress has culminated in a plan for a global system of geostationary and near-polar-orbiting satellites. Continued advances are being made in data-processing techniques, too.

The primary purpose of the WWW is to make available to each of its members, within the limits of the agreed system, meteorological and other related environmental information required in order to enjoy the most efficient and effective meteorological and other related environmental service possible, as regards both applications and research.

The essential elements of the WWW are:

(a) The Global Observing System (GOS), consisting of facilities and arrangements for making observations at stations on land and at sea, from aircraft, meteorological satellites and other platforms;

(b) The Global Data-Processing System (GDPS), consisting of meteorological centers with arrangements for the processing of the required observational data (real-time uses), and for the storage and retrieval of data (non-real-time uses)*;

(c) The Global Telecommunication System (GTS), consisting of telecommunication facilities and arrangements necessary for the rapid and reliable collection and distribution of the required observational data and processed information.

Some of the actual and expected benefits of the WWW are:

(a) Improvements in short- and medium-range meteorological forecasting for general purposes and for many types of special activity, e.g., agriculture, aviation, shipping, fishing, transportation, hydrology, industry, recreation, etc;

(b) Improvements in extended-range meteorological forecasts for the benefit of long-term planning of agriculture, water management, etc.;

---

*Real-time uses in this sense, are operations in which the information must be received and used or processed within, at most, a few hours of being generated. Non-real-time uses are those operations that can be carried out over a more extended time period.

(c) Improvements in the timeliness and accuracy of wanings against natural disasters caused by meteorological phenomena, particularly tropical cyclones;

(d) Provision of observational data and processed information for several types of applications;

(e) Provision of meteorological and other related environmental information for understanding many aspects of environmental pollution and for taking remedial action;

(f) Easier access to stored data and information for all parts of the world for applied as well as basic atmospheric research or related environmental research projects.

1.1.1. The Global Observing System (GOS)

The GOS is the coordinated system of methods, techniques, and facilities for making observations on a world-wide scale within the framework of the WWW.

The GOS consists of two sub-systems, the surface-based sub-system and the space-based (satellite) sub-system. The former is composed of the regional basic synoptic networks, other observational networks of stations on land and at sea, and aircraft meteorological satellites.

The GOS provides observational information that falls broadly into two categories: quantitative information, derived from instrumental measurements, and qualitative (descriptive) information. Examples of quantitative information, which specifies the physical state of the atmosphere, are instrumental measurements of the atmospheric pressure and humidity, air temperature and wind velocity. Examples of qualitative (descriptive) information are observations of of the state of the sky, the forms of clouds, and the types of precipitation.

1.1.2. The Global Processing System (GDPS)

The purpose of the GDPS is to make available to all members processed information, which they require for both real-time and non-real-time applications, with a minimum of duplication, using the most modern computer methods. The GDPS is organized as a three-level system of World Meteorological Centers (WMCs) and Regional Meteorological Centers (RMCs) at the global and regional levels, respectively, and National Meteorological Centers (NMCs), which carry out GDPS functions at the national level. In general, the real-time functions of the system involve pre-processing of data, analysis and prognosis, including derivation of appropriate meteorological parameters. The non-real-time functions include collection, quality control, storage and retrieval as well as cataloguing of data for use in research and special applications.

The WMCs, located in Melbourne, Moscow, and Washington provide products that can be used for general short-, medium-, and long-range forecasting of planetary or large-scale meteorological systems. Melbourne provides products for the southern hemisphere.

The RMCs are: Algiers/Oran, Bracknell, Brasilia, Buenos Aires, Cairo, Dakar, Darwin, Khabarovsk, Lagos, Melbourne, Miami, Montreal, Moscow, Nairobi, New Delhi, Norrkoeping, Novosibirsk, Offenbach, Peking, Rome, Tananarive, Tashkent, Tokyo, Tunis/Casablanca, Wellington. These centers provide regional products that can be used for short- and medium-range forecasting of small-, meso-, and large-scale meteorological systems by NMCs. Products of RMCs have to be presented in such a way that they can be used by members at the national level as input to data-processing procedures that must be performed to provide adequate assistance to users.

Taking into account the requirements for data and forecasting services, the general objectives of the GDPS during the period 1980-1983 are the following:

(a) To facilitate the functioning of short-range weather forecasting and storm-warning services, especially at the regional and national levels;

(b) To improve operational weather forecasts in all time ranges by development and incorporation into operational use of new methods for forecasting, such as models based on stochastic/dynamic techniques, other new modeling techniques and ways of parameterizing atmospheric processes;

(c) To develop and improve methods for presenting and, as necessary, modifying machine-made products for the user, so as to make these products more valuable and more easily applied to operational problems;

(d) To develop and improve methods for processing, storage and retrieval of data for basic meteorological, climatological and other purposes, as appropriate, to meet the needs of other WMO programs in accordance with the requirements stated by the appropriate WMO technical commission (s).

1.1.3. The Global Telecommunication Systems (GTS)

The main functions of the GTS are the following:

(a) To collect observational data provided by the GOS of the WMO;

(b) To distribute the data to so-called National, Regional, and World Meteorological Centers (NMCs, RMCs, and WMCs);

(c) To transmit the resulting processed information--provided by the GDPS of the WMO--to other WMCs, RMCs, and NMCs.

The network organization of the GTS is implemented on a three-level basis, namely:

(a) The so-called Main Trunk Circuit (MTC) and its branches, linking together the WMCs as well as designated so-called Regional Telecommunication Hubs (RTHs);

(b) The regional telecommunication networks; and

(c) The national telecommunication networks.

The basis for the organization of GTS is that it should accommodate the volume of meteorological information and its transmission within the required time limits to meet the needs of the World, Regional, and National Meteorological Centers.

The main concept of GTS is to ensure that every country in the world receives all needed meteorological information, partly in numerical, partly in graphical format. During the middle of the 1970s, the amount of information traveling on GTS per day was approximately 3.5 million characters and 50-70 weather charts. A guiding principle of GTS is that both contribution and consumption of information on the network is free of charge and based on mutual interdependency.

The backbone of the GTS system [5] is a medium-high speed ring network interlinking the main World Meteorological Centers (WMCs) in Washington, Moscow, and Melbourne, with the Regional Telecommunication Hubs (RTHs) in Bracknell, Paris, Offenbach, Prague, Cairo, New Delhi, Tokyo, Nairobi, Peking and Brasilia (Figure 2). All these centers are interlinked with the Main Trunk Circuits (MTCs) and their branches which operate in a segmented "store and forward" mode.

The functions of the Main Trunk Circuit and its branches are the following:

(a) Ensuring the rapid and reliable exchange of observational data required for making analyses and prognosis;
(b) Ensuring the exchange of processed information between the World Meteorological Centers, including data received from meteorological satellites;
(c) Transmitting additional processed information for the purpose of providing Regional Telecommunication Hubs, Regional Meteorological Centers and National Meteorological Centers with the information produced by the WMCs;
(d) Transmitting when feasible, other observational data and processed information required for interregional exchange.

With regard to telecommunications, the World Meteorological Centers and the Regional Telecommunication Hubs are responsible for:

(a) Collecting the observational data originating in their zone of responsibility and transmitting such data in the appropriate form and at the appropriate speed on the Main Trunk Circuit and its branches;
(b) Relaying as internationally agreed, on the Main Trunk Circuit and its branches, in the appropriate form and at the appropriate speed, the meteorological information that they receive from these circuits and/or from RTHs not situated on the Main Trunk circuits;

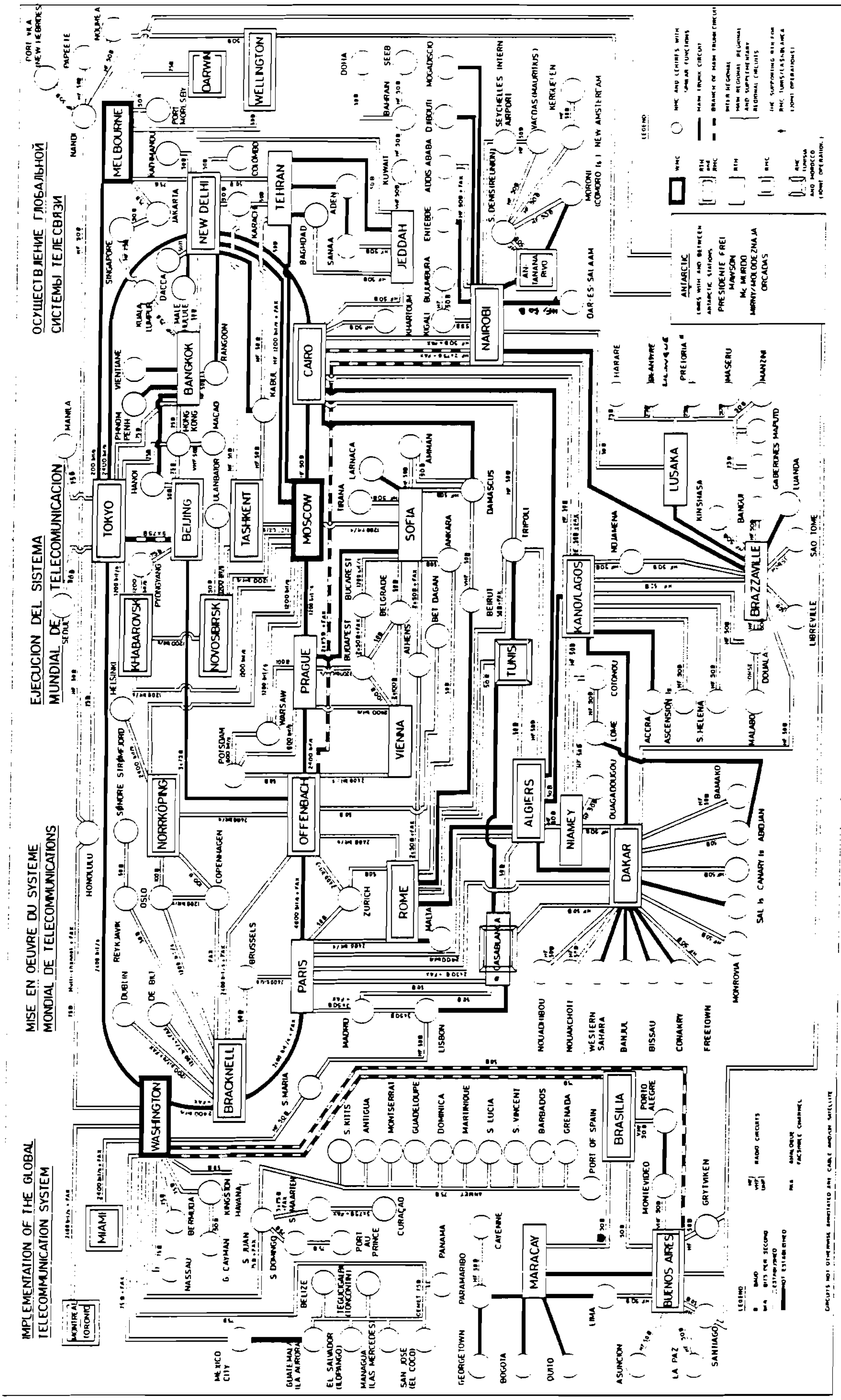


Figure 2. Routing of the main trunk circuit and its branches of the GTS-WMO.

(c) Ensuring, in the appropriate form and at the appropriate speed, the selective distribution of meteorological information to the NMCs and to the RTHs not situated on the Main Trunk Circuit that they serve;

(d) Checking and making corrections in order to maintain standard telecommunication procedures;

(e) Establishing radio broadcasts as required in accordance with regional plans;

(f) Carrying out the monitoring of the operation of the GTS of the WWW.

With regard to telecommunications, the National Meteorological Centers are responsible for:

(a) Collecting observational data from their own territory or that of one or more members according to bilateral agreements, as well as observational data from aircraft and ships received by centers located within the area of responsibility. This collection takes place as soon as possible and is completed within 15 minutes of the observing station's filing time;

(b) Transmitting such data to the associated Regional Telecommunication Hub and World Meteorological Center;

(c) Receiving and distributing for their benefit and that of members who request them, in accordance with bilateral agreements, observational data and processed meteorological information, to meet the requirements of the members concerned;

(d) Checking and making corrections in order to ensure that standard telecommunication procedures are applied;

(e) Carrying out the monitoring of the operation of the GTS of the WWW.

The main engineering principle of GTS is such that the system makes the fullest use of all available telecommunication means (including cable, radio, and satellite circuits) that are reliable and have suitable technical and operational characteristics. For medium- and high-speed data transmissions and for facsimile transmission in digital and analogue forms, standard circuits of the telephone type and radio circuits having similar technical characteristics are used whenever possible for operational and financial reasons.

The circuits provided and the techniques employed have to be adequate to accommodate the volume of meteorological information and its transmission within the required time limits to meet the needs of World, Regional, and National Meteorological Centers.

In the planning of the circuits and transmission schedules, the daily volume of traffic to be passed over any one channel should not exceed 80% of its ultimate capacity. The channels are engineered to ensure the highest possible reliability. The system is based mainly on the interconnection of a number of centers, namely, NMCs, RMCs, RTHs, and WMCs. The WMCs, RMCs, and RTHs are provided with suitable equipment for selection, switching and editing in order to provide NMCs with the data selected to meet their specified needs.

Provision is envisaged for alternative routings, where necessary, to ensure the reliability and efficiency of the system, particularly the reliability and efficiency of the Main Trunk Circuit. The GTS network functions according to a well predefined schedule for alternatively transmitting analogue facsimile weather charts and digital data. Switching between analogue and digital transmission is made automatic by adding special codes to the data to be transmitted. According to their size and resolution a facsimile weather chart takes on average between 9 and 25 minutes to be transmitted over the network, thus at a rather slow speed.

The WMO has defined special transmission protocols for GTS, and a data transmission error protection according to the CCITT V.41 recommendation has been adopted. Some of the WMO protocols are also applied to the upper levels, such as the application level.

1.2. The GTS Regional Telecommunication Network for Europe

The European part of the GTS network is shown in Figure 3 and the status of the individual links of the network and future plans as of June 1980 are shown in Table 1. From the telecommunication point of view, the actual speeds of the network are rather low to medium, but these are more or less adequate for the present traffic load. According to measurements on the 1200 bit/s Budapest-Prague line [4], the daily digital traffic is approximately 2 MByte per day, utilizing the link to about 70%.

Alternative systems for the switching hardware providing the "store and forward" function are used in the different network locations. For example, in the European section of GTS, which was completed between 1970 and 1975, the following computer systems are used:

- dual CDC 1700 in Vienna
- dual Telefunken TR86 in Offenbach
- dual IBM S/7 in Rome and Belgrade
- dual CDC 1700 in Prague
- CII 10070 in Paris
- dual Siemens 4004 in Zurich
- IBM S/7 in Budapest
- dual Marconi Myriad II in Bracknell.

In other European countries CDC and IBM computers are primarily used for switching purposes.

The Eastern and Western European systems are mixed in the sense that error protection is carried out by software in Western Europe and by

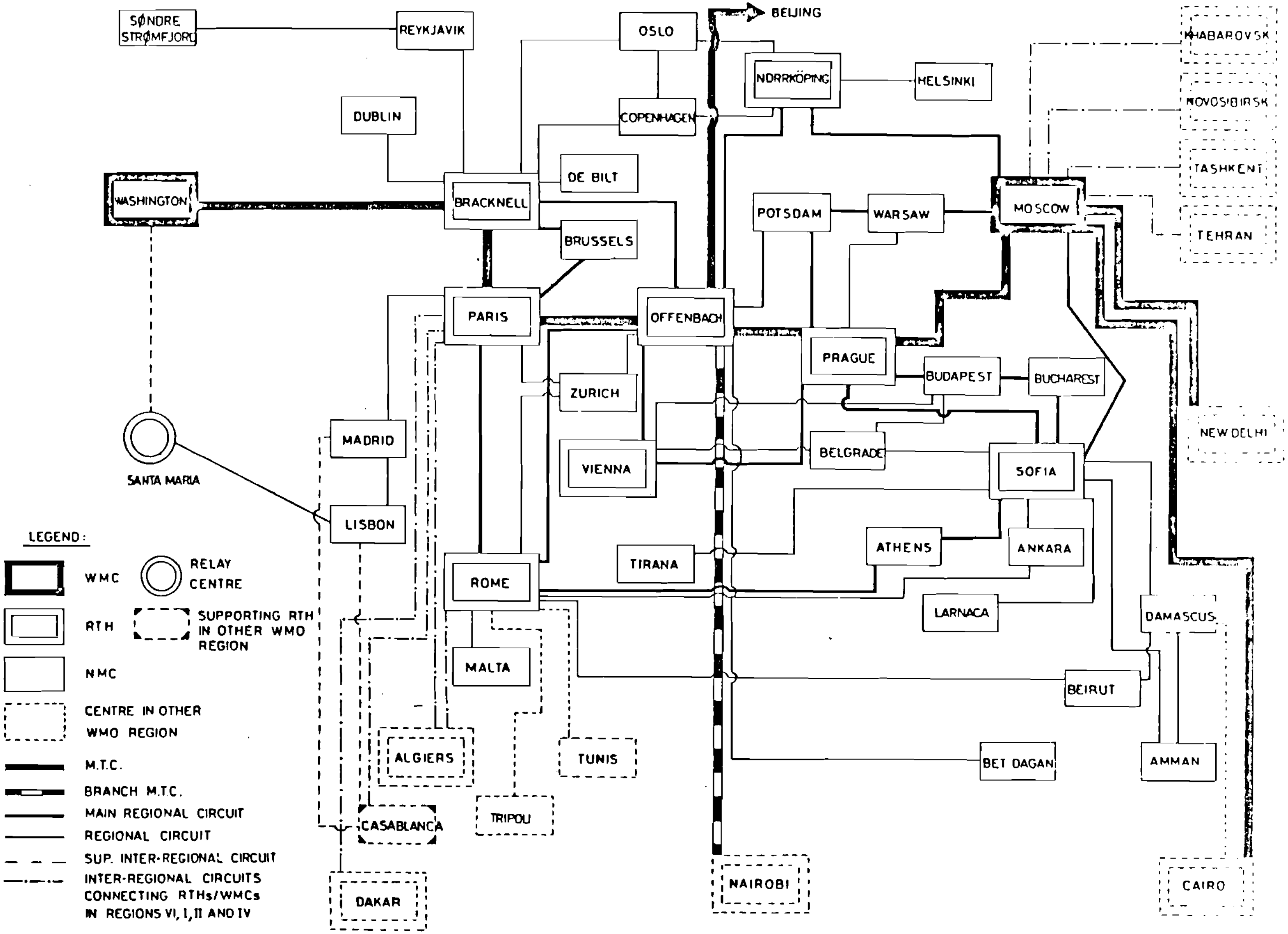


Figure 3. GTS regional telecommunication network for Europe.

Table 1. Present status and future plans for the implementation of the proposed GTS regional meteorological telecommunication network in Europe.

	Present operational status	*Future plans*
1. MTC and its branches		
Moscow–Prague	Cable, 1200 bit/s data, hardware EDC	2400 or 4800 bit/s data/FAX
Prague–Offenbach	Cable, 2400 bit/s data, software EDC	Cable, 2 × 4800 bit/s data + FAX, software EDC
Offenbach–Paris	Cable, 2 × 4800 bit/s data/FAX + FAX, software EDC (1980)	—
Paris–Bracknell	Cable, 2400 bit/s data/FAX, software EDC	Cable, 4800 bit/s data/FAX, software EDC
Bracknell–Washington	Satellite, 2400 bit/s data/FAX, software EDC	Satellite, 4800 bit/s data/FAX, software EDC
Moscow–New Delhi	HF/ISB, 1200 bit/s special EDC + 1 FAX	Satellite, 2400 bit/s (1980)
Moscow–Cairo	HF, 50 bauds ARQ	HF/ISB, 1200 bit/s special EDC + 1 FAX
Offenbach–Nairobi	Satellite, 2 × 50 bauds + 1 FAX	2 × 75 bauds + 1 FAX (to be considered)
2. Main regional circuits		
Bracknell–Offenbach	Cable, 2400 bit/s data/FAX, software EDC	—
Bracknell–Brussels	Cable, 50 bauds	Cable, 2400 bit/s, software EDC (1980)
Brussels–Paris	Cable, 2400 bit/s, software EDC	—
Paris–Rome	Cable, 2400 bit/s data/FAX, software EDC	—
Rome–Offenbach	Cable, 2400 bit/s data, software EDC	—
Offenbach–Vienna	Cable, 2400 bit/s data/FAX, software EDC	Cable, 2 × 4800 bit/s data + FAX, software EDC (1980)
Offenbach–Norrköping	Cable, 2400 bit/s data, software EDC	—
Vienna–Prague	Cable, 2400 bit/s, software EDC	Cable, 2 × 4800 bit/s data + FAX, software EDC
Prague–Budapest	Cable, 1200 bit/s data, hardware EDC	—
Sofia–Prague	—	Cable, 1200 bit/s data (1980)
Budapest–Bucharest	Cable, 2 × 50 bauds + 1 FAX	Cable, 1200 bit/s data/FAX, hardware EDC (1980)
Bucharest–Sofia	Cable, 1200 bit/s data/FAX, hardware EDC	—
Sofia–Moscow	Cable, 1200 bit/s data/FAX, hardware EDC	Cable, 2400 bit/s data/FAX
Prague–Potsdam	Cable, 600 bit/s	Cable, 1200 bit/s data, software EDC
Potsdam–Warsaw	Cable, 600 bit/s	Cable, 1200 bit/s data/FAX, hardware EDC
Warsaw–Moscow	Cable, 1200 bit/s data/FAX, hardware EDC	—

NOTES:
(1) Data/FAX = transmission on a time-sharing basis on the same channel.
(2) Data + FAX = transmission on two separate channels used for data and FAX transmissions respectively.
(3) An entry of "FAX" in this table does not necessarily mean that FAX is transmitted in both directions.

Table 1 continued.

	Present operational status	*Future plans*
2. Main regional circuits (*continued*)		
Moscow–Norrköping	Cable, 1200 bit/s data, hardware EDC	Cable, 2400 bit/s (1980)
Rome–Athens	Cable, 2 × 50 bauds + 1 FAX	Cable, 2400 bit/s data/FAX, software EDC
Sofia–Athens	Cable, 2 × 50 bauds + 1 FAX	Cable, 1200 bit/s and, at a later date, updating to 2400 bit/s data/FAX, software EDC
3. Regional circuits		
Bracknell–Dublin	Cable, 1200 bit/s, software EDC + 1 FAX	—
Bracknell–De Bilt	Cable, 1200 bit/s, software EDC + 1 FAX	—
Bracknell–Reykjavik	Cable, 50 bauds/FAX	Cable, 1200 bit/s data/FAX, software EDC
Reykjavik–Sondre Strømfjord	UHF/cable, 50 bauds	—
Bracknell–Oslo	Cable, 1200 bit/s, software EDC	—
Bracknell–Copenhagen + Oslo	Cable, FAX	—
Oslo–Copenhagen	Cable, 1200 bit/s, software EDC	—
Paris–Madrid	Cable, 3 × 50 bauds + 1 FAX	Cable, 4800 bit/s data/FAX, software EDC (1980)
Madrid–Lisbon	Cable, 3 × 50 bauds	Cable, 2400 bit/s data/FAX, software EDC
Paris–Zurich	Cable, 50 bauds	—
Prague–Warsaw	Cable, 100 bauds	—
Offenbach–Bet Dagan	Cable, 50 bauds	Cable, 100 bauds
Offenbach–Potsdam	Cable, 50 bauds	Cable, 100 bauds
Rome–Zurich	Cable, 50 bauds	—
Vienna–Budapest	Cable, 100 bauds	—
Vienna–Belgrade	Cable, 2 × 100 bauds	Under consideration
Belgrade–Budapest	Cable, 50 bauds	—
Rome–Malta	Cable, 50 bauds (AFTN, unidirectional from Malta to Rome)	—
Rome–Beirut	Cable, 50 bauds (AFTN, unidirectional from Beirut to Rome)	HF/ISB, 75 bauds
Sofia–Larnaca	HF, 50 bauds (unidirectional from Sofia to Larnaca; AFTN, unidirectional from Larnaca to Sofia)	Cable, 100 bauds (1980)
Sofia–Belgrade	Cable, 50 bauds	Cable, 100 bauds
Sofia–Tirana	HF, 50 bauds	—
Sofia–Ankara	Cable, 50 bauds	Cable, 100 bauds (1981/1982)
Sofia–Damascus	HF, 50 bauds	HF, 100 bauds (1981/1982)
Sofia–Amman	HF, 50 bauds	Satellite, 100 bauds (1981/1982)

Table 1 continued.

	Present operational status	*Future plans*
3. Regional circuits (*continued*)		
Damascus–Beirut	VHF, 50 bauds	Cable, 75 bauds
Oslo–Norrköping	Cable, 100 bauds	—
Norrköping–Copenhagen	Cable, 100 bauds	—
Norrköping–Helsinki	Cable, 2400 bit/s, software EDC	—
Offenbach–Zurich	Cable, 2400 bit/s data/FAX, software EDC	—
Rome–Ankara	Cable, 50 bauds	1200 bit/s (1982/1983)
Amman–Damascus	—	Cable, 50 bauds
4. Inter-regional circuits		
Damascus–Cairo	—	HF, 50 bauds
Paris–Algiers	2400 bit/s data/FAX, software EDC	—
Rome–Algiers	—	Not yet determined
Paris–Casablanca	Cable, 50 bauds	2400 bit/s data/FAX, software EDC
Madrid–Casablanca	Cable, 50 bauds	Not yet determined
Lisbon–Casablanca	—	HF, 50 bauds
Paris–Dakar	Satellite, 2 × 50 bauds + 1 FAX	—
Rome–Tunis	Cable, 50 bauds	Cable, 1200 bit/s data/FAX
Rome–Tripoli	—	Cable, 50 bauds (1980)
Moscow–Tehran	HF, 50 bauds	—
Moscow–Novosibirsk	Cable, 1200 bit/s data/FAX, hardware EDC	—
Moscow–Khabarovsk	Cable, 1200 bit/s data/FAX, hardware EDC	—
Moscow–Tashkent	Cable, 1200 bit/s data/FAX, hardware EDC	—
Lisbon–Washington	HF, 50 bauds ARQ	—
5. WMC/RTH radio broadcasts		
Bracknell	1 RTT and 1 FAX	—
Moscow	2 RTT and 2 FAX	—
Norrköping	1 FAX	—
Offenbach	1 FAX	Upgrading to 240 rpm
Paris	1 RTT and 1 FAX	—
Prague	1 FAX	—
Rome	1 RTT and 1 FAX	Combined ISB transmission (end 1980)
Sofia	1 RTT and 1 FAX	—

hardware according to the CCITT recommendation V.41 in Eastern Europe. In most installations in Eastern Europe the telecommunication equipment--modems and terminals--used are domestic made. For example, in Hungary, the Hungarian built modems TAM 600 (ES 8006) and terminals are used, and in the USSR domestic POTOK modems and AKKORD/PL 150 terminals are operated.

The major functions of the "store and forward" switching computers in each network node are the collection and local storage of meteorological data received from the national observation network, and the forwarding of the message package to the regional network node by providing date stamping. Functions such as polling and addressing, sequence checking, disabling/ enabling lines, and message broadcasting are also typical functions. The storage and retrieval of files transmitted from the regional center are most important functions too. Data are--depending on the storage capacity of the computer--usually kept for about one day before they are overwritten by new data. Other daily functions include system and housekeeping functions such as taking system statistics.

As an example of a system configuration, the IBM S/7 system of the Hungarian Meteorological Service has a core capacity of 500 kByte, two disc drives of 80 MByte and handles three 1200 bit/sec leased telephone lines, one each to Prague and Bucharest, and one to the central computer center of the Meteorological Service in Budapest. Connected to each of the two multiplex channels are 16, either local or remote, terminals linked by telegraph circuits. Connection to the national PTT telex network could not be realized because of export license restrictions on the side of the manufacturer. For the same reason, the switching software could also not be supplied. The telecommunication software was therefore written in two years by the inhouse programmers of the Meteorological Service. The system finally went into operation in 1978, and has since worked 24 hours a day with a reliability of over 99%.

The European GTS system allows for fast and reliable transmission of data on the network. Data given by [4] illustrate the use of the network: information from all Hungarian meteorological observation points are in Washington within one hour, and *vice versa* observation data from US ships in the Atlantic are in Budapest within 40 minutes.

As a backup the meteorological service in Budapest has kept their old, traditional, manually switched system. In the event of line failures, as in other centers of the region, they either use spare lines to other centers or receive radio broadcast messages, which are provided for both data and facsimile by some stations (see Table 1). Other meteorological centers also provide appropriate backup systems, according to the guidelines of the WMO, based on additional private data and telex lines, and broadcasting and receiving stations.

2. DATA NETWORK OF THE EUROPEAN CENTER FOR MEDIUM RANGE WEATHER FORECASTS (ECMWF)

The second largest meteorological network with computer links between East and West is the data network--called ECNET--of the European Center for Medium Range Weather Forecasts (ECMWF) (Figure 4) [6, 7]. The ECMWF actually represents a new and interesting trend in the field of meteorological networks and associated special services, which deserves special attention.

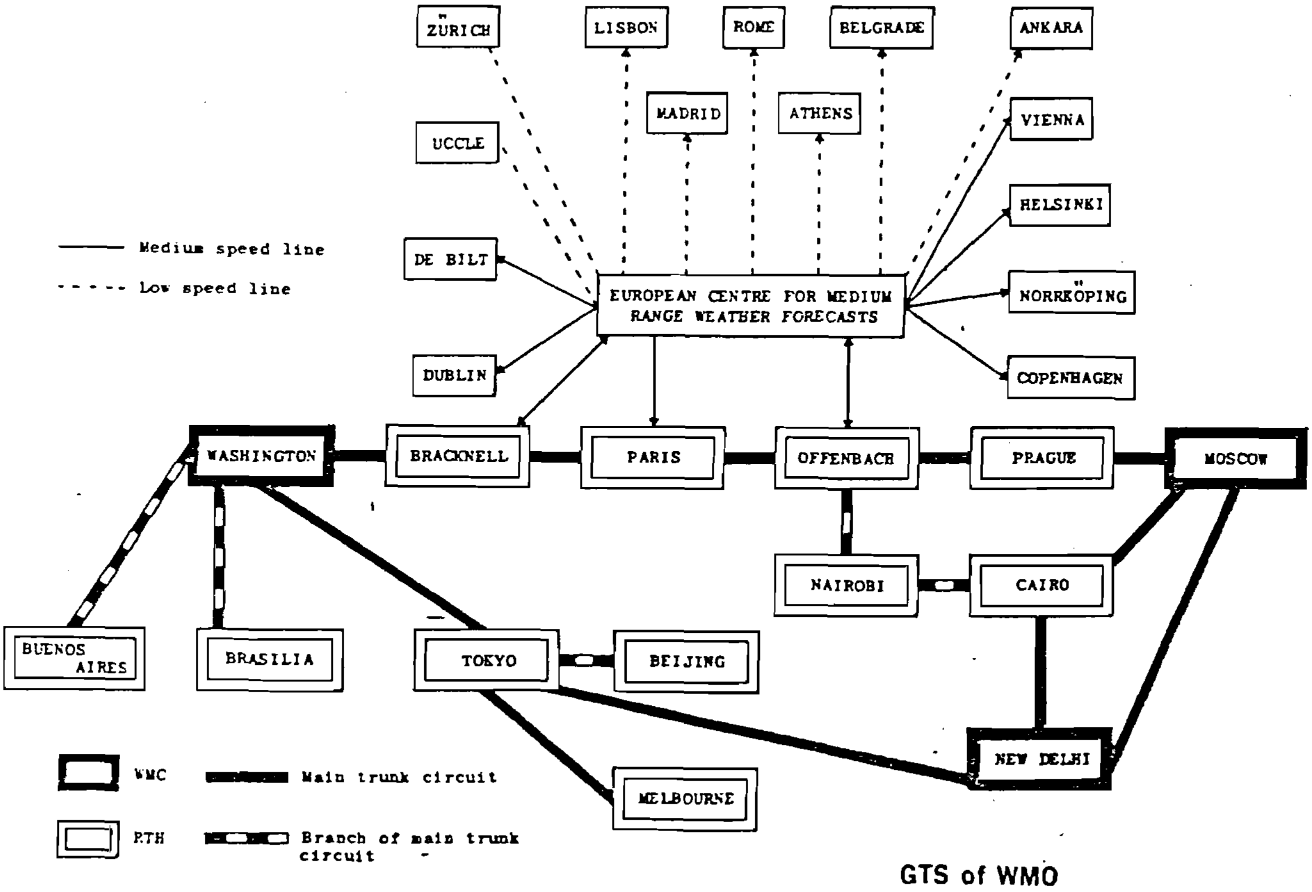


Figure 4. Topology of the ECMWF Network ECNET, October 1981.

In the field of meteorology in general, there are three major steps in handling meteorological data: generation of data by observation, transmission over meteorological networks, and processing for forecasting and statistical purposes, etc. The processed "value added" information can be distributed in many forms, such as printed publications or as data offered through telecommunication networks. According to the general philosophy of the WMO, such data should preferably be fed back into the GTS network and this is accomplished by a number of distinguished meteorological processing centers. These data--in most cases forecasting data--can be received by all meteorological centers within the regular GTS service free of charge. As an example, the Hungarian Meteorological Service uses, among others, the numerical forecasts prepared as a result of model runs on large mainframes of the major WMO centers in Washington, Offenbach, and Moscow for its short term-term forecasting. These forecasting services are at present, and according to meteorology tradition, also free of charge.

There is however a growing conflict in the generation and consumption of these new "value added" services. First of all they are very expensive to set up and run, and thus can only be established by major, more developed countries. The USA, for example, spends about US$50 million per year for the operation and maintenance of their meteorological satellites. The computer configurations used for meteorological forecasting are some of the largest in operation and are also very expensive. Therefore, a new tendency to change to more and more special services of this kind is becoming apparent. This of course, can bring major problems.

First, many meteorologists view with sorrow the gradual disappearance of the intact world of traditional meteorology in which information was exchanged solely on the basis of mutual interdependence. Second, with the introduction and use of new technologies such as meteorological and remote sensing satellites, the predominant role of domestic local observation is diminishing. More and more data can now be gathered from the sky with automated observation devices without having to rely on the data provided by other countries. In this sense, the more developed countries who can afford to operate these new technologies rely increasingly less on international cooperation. On the other hand, the less developed or smaller countries will continue to depend on data (raw and processed) originating from these large developed countries. As the primary reasons for this trend are technical and economical there are thus no good major reasons to halt the process, even though it may produce as a side effect negative impacts on mutual international cooperation which has always been regarded as a positive example in the world.

As mentioned earlier these new systems are very expensive and for this reason can only be built by either the richest countries, or by a group of countries as a result of international cooperation. However, since very large investments are required, some return will be necessary. Either fees will have to be charged for the consumption of services, or only those organizations that contributed financially to the development and operation of these services can benefit from them. There are already several systems in Europe that belong to this category. The system ARGOS, which provides data base information from sea buoys on the oceans, charges according to its use.

Another large system of this kind is the ECMWF system that charges its member countries subscription fees in proportion to their Gross National Product; a total of £7 million per year (1982)[14]. The center, with its headquarters in Shinfield Park near Reading in the UK, operates one of the world's largest computer installations used for meteorological medium-range forecasting [8] (Figure 5). The ECMWF with its huge CDC and Cray mainframes is a nice example of how a group of nations can cooperate and share expensive resources. However, it is also an example of how other countries that do not have sufficient resources to enable them to participate are unintentionally "excluded", although a fraction of the generated results is fed back into the GTS network of the WMO.

The main tasks of the Center are the following:

- Joint development of dynamical atmospheric models for medium-range weather forecasting by means of numerical methods.
- Regular generation of data suitable for medium-range forecasting.
- Cooperation in science and research to improve the quality of medium-range forecasting.
- Collection and storage of meteorological data.
- Dissemination of medium-range forecasts and research results to member states.

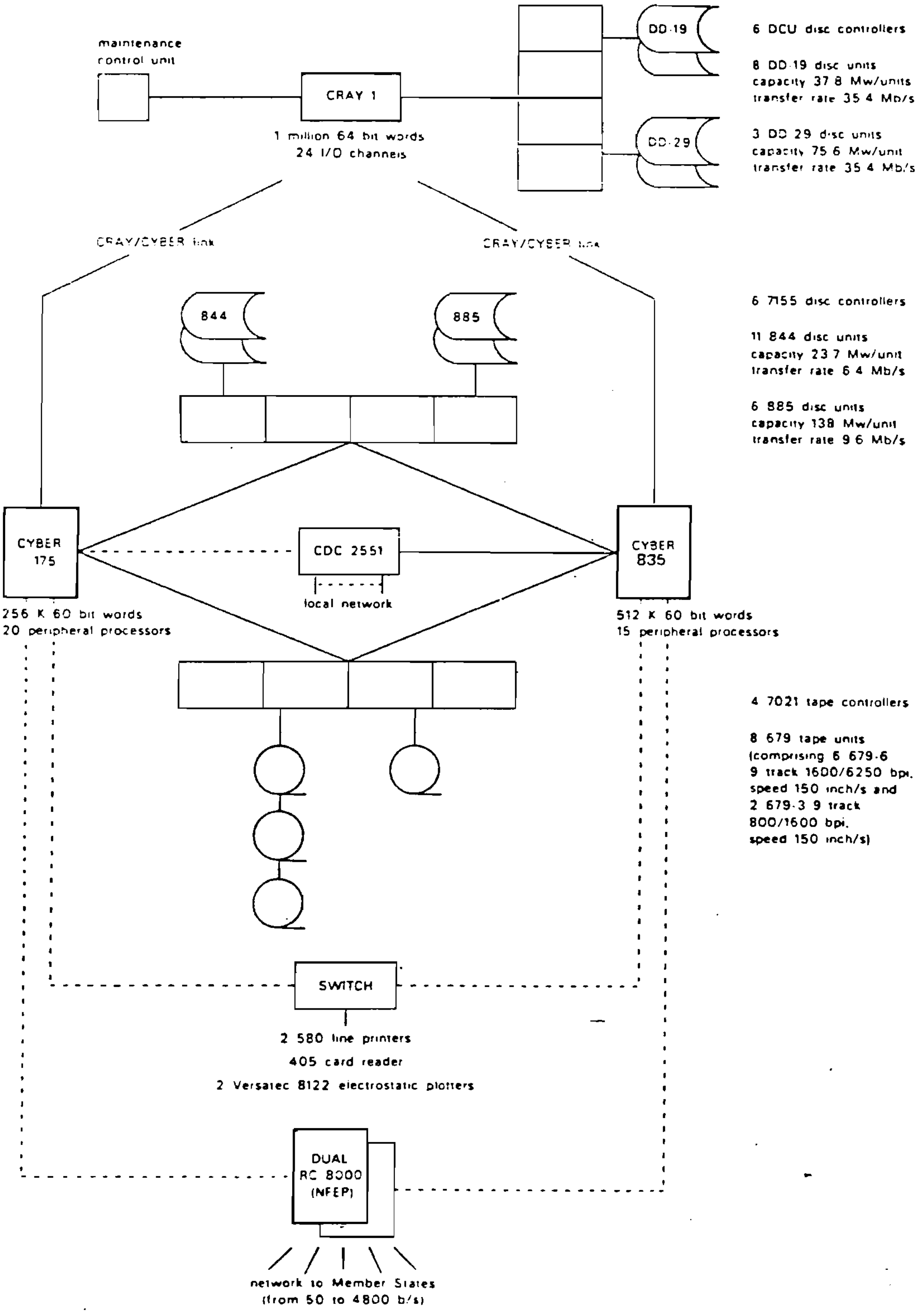


Figure 5 The European Center for Medium Range Weather Forecasts (ECMWF).

- Collaboration with the WMO in fulfilling meteorological programs.
- Training member countries in meteorological forecasting.

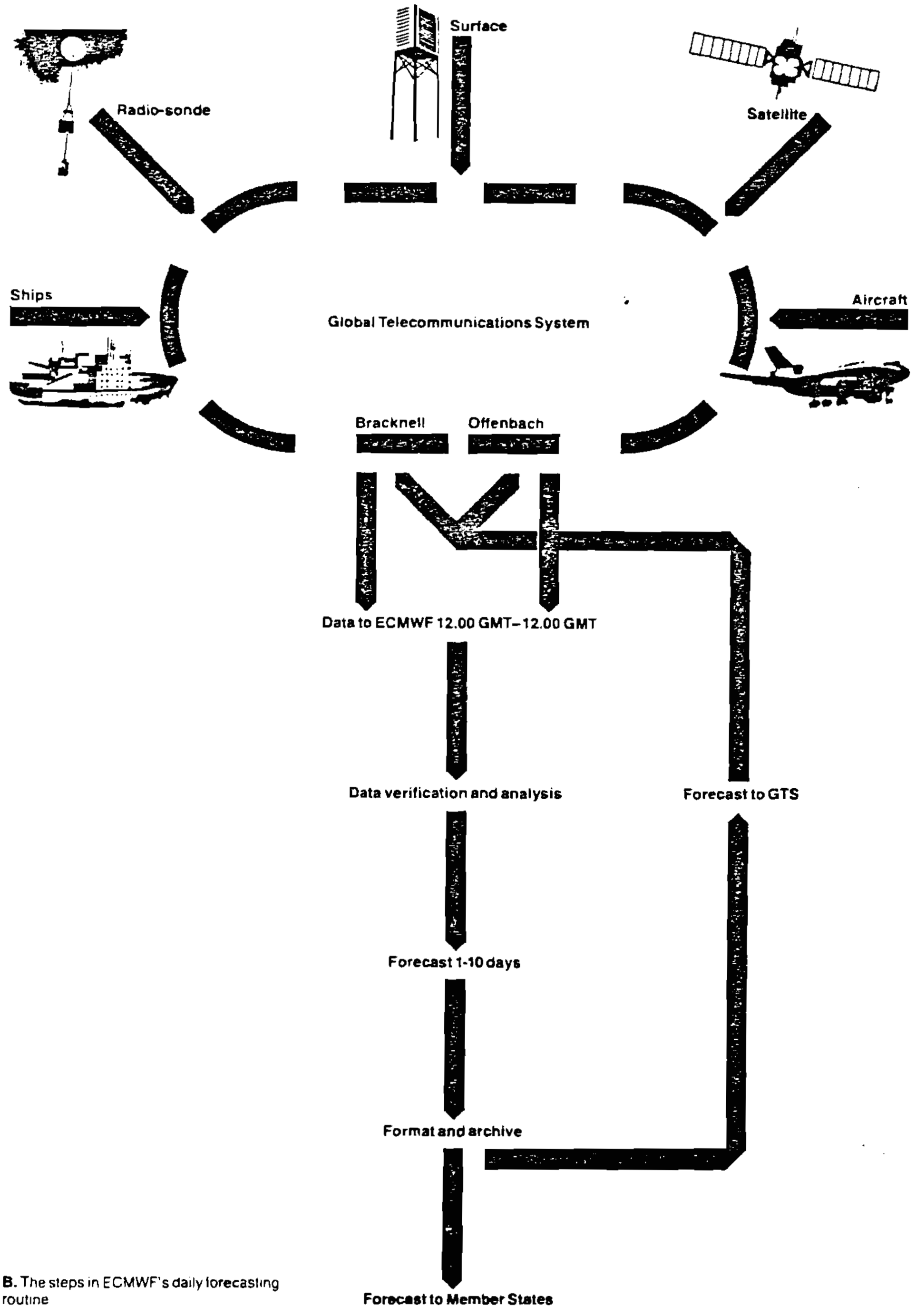
As can be seen in Figure 4, the ECMWF network is separate from the GTS network of the WMO, and its topology reflects the above main functions of the center. It is primarily used for the dissemination of medium-range forecasting data to the member countries and for remote working on the large mainframes of the Reading Computer Center. For example, the local CYBER 171 system of the Austrian Weather Service in Vienna is connected to the Reading center as a Remote Job Entry device, where models are run on the CRAY computer and output for dispatch is prepared on the CYBERS of the center. The line between Vienna and Reading is a point-to-point connection with 2400 bit/sec, using the X.25 protocol of CCITT on lower levels.

The main, regular service of the ECMWF network is to provide forecasts for up to 7-10 days in advance. Observational meteorological data are acquired through the Global Telecommunications System (GTS) of the World Meteorological Organization. Figure 4 shows that ECMWF has two links with the GTS, one via Bracknell, the other via Offenbach, each link acting as a back-up for the other. The 10-day forecast, taking about 3 1/2 hours elapsed time on the Cray computer, starts at 21.30 and is completed at around 01.00. As a measure of the reliability of the daily operation, a record is kept of the termination times of the forecasts on the Cray. Approximately 45% of the forecasts terminate within 15 minutes of the scheduled time of 01.00, while 90% terminate within one hour. Less than one forecast in 20 is delayed more than 2 hours, the usual reason for long delays being computer malfunction. Post-processing, including transforming the parameters from the mode coordinate system to one more suitable for users of the forecasts, is carried out as the operational run proceeds. Figure 4 also shows the ECMWF network for dissemination of its products; this will be considered further below. The major steps in ECMWF's daily forecasting routine are shown in Figure 6.

Since ECMWF has a global analysis system, all available observational data from the entire global domain are required, including surface observations from land and sea (SYNOP), radiosonde reports from instrumental balloons (TEMP), weather reports from commercial aircraft (AIREP), atmospheric temperature measurements from polar-orbiting satellites (SATEM), wind observations from geostationary satellites (SATOB), and reports from drifting buoys or oceanographic reports (SEA). Each day, around 35,000 separate weather reports are received at ECMWF. After reception, the reports are checked, some are corrected and the reports are stored in the ECMWF Reports Data Base.

3. METEOROLOGICAL DATA FROM SATELLITES

Information received from earth observation satellites represents a special category of transborder data flow. In this regime, a satellite owned by a given country can make observations of just its country of origin and/or other countries from an extraterritorial orbit and beam data back to earth. In this sense the transborder data flow takes place between neutral territory and one or more places in one or more countries. The data transmission path to earth may either be in a broadcast



B. The steps in ECMWF's daily forecasting routine

Figure 6. The steps in ECMWF's daily forecasting routine.

mode, allowing access to the data by any observation station on earth equipped with the appropriate dishes, receivers, and other instruments required, or in a point-to-point mode addressed to only one or a few recipients. Most meteorological satellites belong to the first category, i.e., their observation data is free to all stations; having the appropriate receiving equipment is the only criteria for receiving data.

In the second category of satellites, the majority belong to the so-called sensing satellites type, but there are also a few low orbit meteorological satellites. The information flow in these systems is triggered off by terrestrial command when the satellite is in the best position to transmit its high speed data to the earth. To share this type of data with other nations, a second step in transborder data flow cooperation-- now between national territories--has to be taken. For some meteorological satellites this is actually the case; data collected by a designated earth station is fed into the GTS network of the WMO for worldwide distribution. GTS, however, also carries image and numerical satellite data of the first category, enabling those countries and meteorological stations without their own earth stations or with smaller dishes and limited capability (e.g., for analogue weather facsimile data only) to receive the full spectrum of observations, such as digital data for high resolution in weather facsimiles. In the following we describe the two main categories of satellites, i.e., the meteorological satellites and the remote sensing satellites.

3.1. Weather Satellites

In the category of earth observation satellites, the first and still most frequently used are weather satellites. From far above the earth's surface, cameras and other sensors provide meteorologists with broader pictures of weather movements. Combined with the analysis from high-speed computers, meteorological satellites have made weather forecasting much less of a guessing game: today's 24-hour forecasts have the same accuracy--84%--as 12-hour forecasts did 15 years ago. With better prediction of severe storms, such as hurricanes and typhoons, evacuation warnings can be issued and lives saved. Since satellites began keeping track of hurricanes in the mid-sixties, no one has died because of deficient warning. Hurricane Camille, the worst storm of the century, caused minimal loss of life in 1969, whereas 1,500 people died in hurricanes in Mexico in 1959 and 5,000 in Texas in 1900. A cooperative typhoon-warning system being set up in East Asia should reduce the area's yearly storm damage of more than US$3 billion. The Philippines, annually hit by four or five typhoons boiling suddenly off the Pacific, will be a major beneficiary. Within 15 years, global satellite imagery should enable meteorologists to make five-day forecasts that are as accurate as 24-hour ones today, which would translate into US$5.5 billion of savings in agriculture and aviation in the United States alone [9].

Meteorological satellites are generally divided into two groups, according to their type of orbit, being described as either polar-orbiting or geostationary [10].

The polar orbiters are at an altitude typically between 800 km and 1,000 km and they pass near both North and South Poles in the course of a single orbit, that is to say their orbit is roughly at right angles to the equitorial plane of the earth. They take about 105 minutes to circle the earth and because of the earth's rotation, each orbit crosses the equator about 25° of longitude farther west than the previous one. With instruments that are able to scan from side to side, a particular location on the earth can be viewed at least twice every 24 hours; once when the satellite is traveling roughly from north to south and again when it is traveling from south to north. The possibility of viewing the specified location more than twice in 24 hours arises from the fact that many instruments view sufficiently far to the side of the satellite track for there to be an overlap on consecutive orbits. This occurs particularly at high latitudes, where consecutive orbits come much closer together than near the equator.

One item normally carried on polar-orbiting satellites is a tape recorder. The satellite is within view of its main ground station for only a short time during an orbit and may be out of view altogether for several orbits. If this station is to recover the global coverage of observations made during these periods, data must be recorded to await a suitable opportunity for transmission.

A geostationary satellite (sometimes called a geosynchronous satellite) remains stationary relative to the earth and so always views the same area of the earth's surface. This is achieved by putting it into orbit above the equator at a height such that it takes precisely 24 hours to complete one orbit and so matches exactly the rotation rate of the earth. The necessary height is very nearly 36,000 km (approximately 23,000 miles)--many times greater than the heights at which polar-orbiting satellites operate. From its high vantage point a single geostationary spacecraft can view a circular area representing more than one quarter of the earth's surface. The problem of being often out of sight of the controlling ground station does not arise in the case of geostationary satellites, so normal operations do not require a data-recording facility on board.

The characteristics of polar and geostationary orbits offer different advantages to the meteorologist so the two types of satellite complement each other. In particular, a polar-orbiting satellite can provide complete global coverage every 12 hours while a geostationary satellite, although never achieving global coverage, can monitor a substantial part of the earth's surface almost continuously.

3.1.1. Current Operational Polar-Orbiting Meteorological Satellites

There are two series of satellites in this category, the TIROS-N series and the METEOR-2 series, which are operated by the USA and the USSR, respectively.

TIROS-N is the third generation of operational polar-orbiting satellites from the USA. The first of the series was launched on 13 October, 1978; the program was declared fully operational on 16 July, 1979 (following the launch of the second satellite) and it is planned to be continued into the 1990s. There are normally two spacecraft operating together, traveling in orbits approximately at right angles to each other. In this way, they pass alternatively across any part of the earth's surface at intervals of between five and eight hours. Their heights are about 850 kms above the earth and each orbit takes about 101 minutes, so that in the course of 24 hours they complete over 14 orbits. The orbits are said to be "sun-synchronous", which means that they cross the equator at the same local time (solar time) on each orbit, thus ensuring consistent illumination for visible imagery from day to day. Every spacecraft is designed to have an operational life of at least two years and replacements are launched at suitable intervals to maintain the twin system.

Four primary instrument packages are carried: one provides visible and infra-red pictures of cloud cover (or, in the absence of clouds, the earth's surface); one is an atmospheric sounder; another monitors solar activity; and the fourth is for data collection and platform location. Picture resolution, i.e., the size of the distinct elements of which it is composed, is slightly more than 1 km. It is interesting to note that the TIROS-N series has a somewhat international character with part of the sounding package (the Stratospheric Sounding Unit), which provides data for levels high in the atmosphere, being provided by the United Kingdom and the package for data collection and platform location (named ARGOS--one of the charged services in Europe) being provided by France.

Data are relayed to ground stations via three separate direct broadcasts. One of them, the Automatic Picture Transmission (APT) service, transmits medium-resolution (4 kms) images continuously as they are acquired by the satellite. They appear as an ever-extending strip whose width represents a distance of about 2,600 kms, and the picture ends when the spacecraft disappears below the horizon of the receiving station. Equipment needed for reception of this particular broadcast is relatively simple and inexpensive, enabling many sections of the meteorological community with only modest resources to enjoy the benefits of direct reception of images of their own region.

The USSR METEOR-2 satellites, of the METEOR-2 improved operational meteorological satellite system, were first brought into operation in the mid-1970s. They followed an earlier METEOR series and will continue until at least 1985, with one or two satellites being launched each year throughout that time. Their primary task is the acquisition of visible and infra-red images, although world-wide temperature soundings are being made on an experimental basis. Like the TIROS-N series, they carry an APT facility that broadcasts reduced-resolution images. Orbital height is 900 kms and the time taken to complete one orbit is about 102 minutes. Images are obtained from three different instruments on each spacecraft: a radiometer is used for the infra-red; there is television-type scanning equipment for the high-resolution visible, and the APT service relays images from a device called a scanning telephotometer.

3.1.2. Current Operational Geostationary Meteorological Satellites

Geostationary meteorological satellites are operated by the USA, Japan, and the European Space Agency (ESA). They have much in common with each other and there is a good deal of collaboration between the operators. Working through an international group called the Co-ordination of Geostationary Meteorological Satellites (CGMS), the operators have achieved a compatibility between data-collection systems and, to a lesser extent, between data-dissemination services. The former ensures that transmission from a mobile DCP (for instance, one on board an aircraft), will be received without interruption as it passes from one spacecraft coverage area to another. The satellites all provide two direct broadcast services, one of which--WEFAX (Weather Facsimile)--has characteristics similar to the APT transmissions of polar-orbiting satellites. By adding just one or two extra pieces of equipment, an APT station can be modified to receive WEFAX as well.

The USA satellites are known as Geostationary Operation Environmental Satellites (GOES). The two main ones are located at 75°W and 135°W and are known simply as GOES-East and GOES-West, respectively. GOES-East monitors the weather over the eastern half of North America, all of Central and South America and much of the Atlantic, while GOES-West monitors western North America and a substantial part of the eastern Pacific. They both provide frequent visible and infra-red images of the whole of the areas (or discs) viewed. The normal interval between images is 30 minutes but this can be reduced to as little as three minutes if coverage is restricted to a small part of the disc. This operation mode is used to make detailed observations of a weather feature that is rapidly changing or developing. Environmental data can be collected from as many as 10,000 DCPs every six hours. The two most recently launched GOES spacecraft carry experimental instrumentation for making atmospheric soundings of both temperature and humidity and are the first geostationary satellites to have this capability. First results have been extremely encouraging but operational soundings are not expected to become available for some time, particularly since soundings and image cannot yet be obtained simultaneously. A Space Environment Monitor on each GOES includes sensors for measuring solar activity and magnetic field.

The European satellite is named METEOSAT. It is located above the equator on the prime meridian from where it can observe the whole continent of Africa, much of Europe and the Atlantic and part of South America. The first in the series, METEOSAT-1, was launched in November 1977 and METEOSAT-2 in June 1981. Primary missions are imaging, data collection and dissemination, and services broadly similar to those of GOES are provided. The imagery available includes, in addition to the usual visible and infra-red, what are called "water-vapor images". These depict the average humidity in the part of the atmosphere between about 5 kms and 10 kms above the earth's surface. Moist areas appear in the pictures as relatively light shades and dry areas as very dark. The tops of some of the highest clouds can also be seen, showing up as intense white patches. Water-vapor images often reveal quite dramatically the broad, sweeping character of major features of the global atmospheric circulation, which cannot be observed directly by any other technique.

Japan's Geostationary Meteorological Satellite (GMS) (also called Himawari) is located at 140°E and views a large part of eastern Asia, the whole of Australasia and a vast area of the western Pacific. The original spacecraft was launched in July 1977 and its replacement, GMS-2, in August 1981. The principal meteorological payload is again a radiometer for high-quality images and like GOES (but not METEOSAT), there is instrumentation for monitoring solar activity and the space environment. Routine full-disc images are produced every three hours but special observations may be made at intermediate times for research purposes or when, for example, a severe storm or typhoon is under surveillance.

Two more geostationary satellites are expected to complement the geostationary meteorological satellite network: GOMS (Geostationary Operational Meteorological Satellite) to be placed over the Indian Ocean by the USSR, and INSAT (the Indian National Satellite) to be placed over the same region.

In addition to these "meteorological service" satellites, there are worldwide some special research oriented programs using dedicated "research" satellites, such as the NIMBUS program of the USA or the METEOR program of the USSR. A recent research satellite, which represented an exciting step forward in the applications of satellites to environmental sciences, was the USA satellite SEASAT-A, or ocean dynamics satellite. Its particular significance was that its instrument payload was concerned primarily with measurements of the ocean surface using microwave techniques. SEASAT was launched into a polar orbit approximately 850 kms high, on 26 June 1978. Unfortunately, its life was not as long as had been hoped, for it suffered a major power failure on 10 October of the same year. However, during its time in orbit, more than 90 days of data were collected from its microwave instruments, giving the data-analysis teams plenty to work on to establish accuracies, capabilities, and limitations.

All the instrument sensors on SEASAT were evolved from predecessors that had been flown successfully on spacecraft or aircraft. They included a radar altimeter, to measure average wave height and sea-surface topography; a device called a scatterometer for determining wind speed and direction at the sea surface; radar to observe wave patterns and ice distribution; and a microwave radiometer to measure sea-surface temperature. SEASAT was described as a "proof-of-concept" mission. Evaluations of its achievements and the quality of its observations have clearly demonstrated the feasibility and potential usefulness of a satellite dedicated to ocean purposes.

3.2. Remote Sensing Satellites

Beyond weather satellites, a wide array of remote sensing satellites [9] stand poised to move from the research and development phase to routine daily use. Beginning in the early 1970s, the USA and the USSR put into orbit general purpose remote sensing satellites. France and Japan are expected to orbit civilian remote sensing systems within the next five years. Known as LANDSATS, these satellites have proved useful to farmers, foresters, shippers, highway builders, coastal zone managers, and mapmakers. LANDSATS work in a polar orbit and on each pass scan a 185 kms wide strip of the earth's surface, much less than the meteorological orbiters. The result is that 18 days are therefore required for complete global coverage, making it unsuitable for most meteorological applications.

Remote sensing of living systems--crops, forests, grasslands, plankton and fisheries--could provide solid trend information on a truly global scale as well as having many uses in day-to-day resource management. The US Department of Agriculture has used LANDSAT images of foodgrowing regions to improve crop harvests. It was estimated in 1979 that the direct economic benefits of satellite crop forecasting have been about US$325 million a year, far exceeding the US$80 million cost of the program. In the United States, forest-products firms with large landholdings have found that satellite images provide not only broader coverage than ground-based assessments, but also a more accurate view of tree health than direct visual inspection. Thus far these systems are of value only over areas with large fields and low crop variety.

Mineral and petroleum explorers have also benefited from remote sensing. By studying satellite images of known mineral deposits and then looking for similar formations elsewhere, geologists have been able to locate commercially valuable deposits. Most notable thus far has been the discovery of copper deposits in a remote region of Pakistan. How widespread such discoveries are likely to be is a matter of controversy among geologists. The oil companies have made extensive use of LANDSAT data, but the impact this has had on oil discoveries is hard to assess because firms maintain a tight lid of proprietary secrecy on exploration techniques. Another useful application of remote sensing will be to monitor the reclamation of strip-mined land.

The prospects for greater routine use of LANDSAT-type satellites for resource management are today clouded by a series of institutional, political, and financial problems. Because the data obtained by remote sensing satellites have commercial use, developing countries fear that multinational corporations geared to use the information will gain greater leverage on their economies and enhanced control over their resources. Several Third World countries, led by Indonesia, believe that no remote sensing data of a country should be acquired or released without the observed country's explicit permission.

The United States, supported by most of the other OECD members, maintains a policy of "open access" by selling LANDSAT photographs to anyone willing to pay the price without even asking for the purchaser's identity. A compromise position advanced by the Soviet Union would require the sensed nation to give prior consent for dissemination of images with greater than 50 meters resolution. The current US LANDSAT satellites have a resolution of 80 meters, but a US experimental system has a 30 meter resolution and the new French commercial system (SPOT) will go down to 10 or 20 meters. Stopping at 50 meters would eliminate some potentially valuable applications, such as detecting specific pollution sources, but going to 10 or 20 meters would generate information of military significance.

According to [11], for example, forecasting of crop yields would require the best possible resolution. A resolution of 10 meters would be necessary in redefined categories of inventory and mapping of land use, and mapping of vegetation types. For most other types of applications a resolution below 50 meters would be ideal. From the technological point of view, a remote sensing satellite resolution of 10 meters or less will be feasible. As already mentioned, the French SPOT satellite to be launched in 1984, will provide images with 20 and 10 meters resolution, and limited stereo capability. The French system is an exception, however, since unfortunately these resolution areas are in the category of military applications, and thus access to these technologies by civilian scientists is limited.

According to [9], for example, maps of the moon are better than those of the earth because military authorities allow lunar orbiters to carry more advanced cameras than those on civilian spacecraft that orbit the earth. Much of the early earth-sensing technology was pioneered by the military and transferred to civilian uses later. But the military is less open about the use of key sensing technologies by civilian groups. Thus the US military advised the SEASAT system to carry radar systems considerably below the state of the art, much to the dismay of some scientists whose experiments could have benefited from the more advanced radars. Point-source pollution monitoring will also suffer without the use of high resolution sensors now primarily used by the military.

As already mentioned the dissemination of remote sensing data is done on a purely commercial basis, and this has become a source of many problems and conflicts between nations; should weather access to remote sensing data be free or not, and if not, who should pay for it and how much, and last but not least, how can these data be best utilized?

After examining the use of satellites for earth observation it becomes apparent at this point that although these new technologies have brought about many advances and benefits for mankind, they are, at the same time, a source of new conflicts.

4. PROBLEMS AND CONFLICTS IN TRANSBORDER FLOW OF METEOROLOGICAL DATA

As has been shown, the developments in meteorological observation, information exchange, and processing over the last hundred years, and in particular the last 20 years, has brought about dramatic technological changes and advances. However, the new, more powerful, but more expensive, systems have also resulted in some negative effects which were not experienced earlier when the "intact world" of traditional meteorology was still in order. In the "good old days" it was meteorology that was often cited as being a beautiful example of international cooperation based on mutual dependency. Now, this "world" is only just intact as a result of the efforts made by international organizations, such as the WMO, and some governments. However, the number of discouraging signs is growing, such as the increasing gap between the meteorological services of developed and developing countries, the increasing number of charged services, the decreasing dependency of the biggest countries on the rest of the world, and the increasing dependency of the rest of the world on them. Without exaggerating these signs (which can be compared to the tip of an iceberg), we will describe and analyze some of the problems that are disturbing to the present practice of meteorological services, and that may badly affect future cooperation.

4.1. The Increasing Overload of Meteorological Data and the High Costs of Processing

As a result of new observation, telecommunication, and processing technologies, the amount of meteorological data obtained per day is exploding. It is estimated that a single weather satellite generates 10^{12} new data points each day, which have to be delivered to the user and these, of course, are expensive and difficult to handle. Although the cost of installation and operation of observation systems is extremely high, many of these systems still generate observational data--due to the "generosity" of the more developed countries--free of charge. The tragedy is that although the data are made available through massive international efforts and financial investment, many countries still lack the financial and intellectual resources to complete the chain. Thus, although the information is there and crosses borders to become available in other territories, some countries cannot take advantage of it.

This is often the case for GTS's services too. Although, for example, digital data of satellite images are regularly put on the network, less developed and poorer countries do not have the necessary computer systems or means to store and process these data for their own needs. Thus, for them, much of this valuable information is simply lost. The more developed countries, on the other hand, can cope much more easily with the increased demand for computer power. Even though it means major investments they are in a better situation to install powerful computers linked to their local GTS node. They are able to build up meteorological archives on these computers, run complicated forecasting models and utilize effectively the data available. Often, as a result of these model runs, they generously feed some of their results back into the GTS network. However, due to the high investment and operating costs only a part of this service is free of charge. The results of these--free or not--model runs would, in principle, be of great help to the meteorological centers in all countries. There is, unfortunately, still a number of countries that do not have the necessary means to utilize even those goods that are free.

Another problem is that poorer countries often do not have the means to even archive the observational data of their own country, observational information that they originally fed into the GTS network.

The richer countries, on the other hand, who have better means for absorbing and processing the vast amount of information on the network, can easily archive all data, including those from countries who do not have their national data archived in machine readable format. However, when the poorer countries need their own historical data at some later date, they have to buy it back, a situation that creates another area of conflict between the developed and developing countries. This new conflict is also brought about by the increased costs of meteorological technologies and new technological advances in this complex field. In the "good old days" the data would neither have been collected nor transmitted, and it definitely would not have been stored. It would simply have been lost and forgotten for ever. However, with present technology this data can be and is archived and retrieved; but someone has to pay for it.

As previously mentioned, the same is true whenever the observed information is processed, for example, for medium-term forecasting. The resources involved in such services are extremely high and again someone has to pay for them. For these reasons it appears that it will be very difficult to keep up the practice of mutual and free exchange of observations and the meteorological data derived from them. This classic principle was easy to keep in the "good old days" when observational tools and techniques were similar and data were mainly manually collected, and where all concerned were fully dependent on the effective exchange of such data.

4.2. Polarization of Dependencies

As already mentioned the mutual dependency between countries in the transborder flow of meteorological data is diminishing. Major developed countries who find it much easier to accumulate the necessary resources required for the provision of complicated observation stations, such as meteorological satellites, and for large data processing centers, are more and more in a better position to generate and transmit a larger share of all the data and to archive and process meteorological information and to rely less and less on the traditional meteorological observations that were the basis for exchange and interdependency between nations. Due to technological progress less developed countries are increasingly more dependent on the data and services provided by developed countries as the former are less likely to be able to afford the high costs associated with the introduction of these new technologies. However, with more concentrated regional cooperation among these countries, and maybe eventually external support, the situation might improve.

The growing tendency for the richest countries to build up and maintain global meteorological observational and forecasting systems by themselves is basically supported by the growing weight of military systems. It is a well known fact that in military operations the exclusive knowledge of an exact weather forecast can be decisive. For example, during World War II all major military operations were planned on meteorological advice, and the launchings were timed on the basis of weather forecasts. Of major importance were the highly specialized forecasts prepared for massive air operations in darkness, amphibious operations, etc. The largest of all operations, namely, the assault on the continent of Europe by the Allied forces in June 1944, was successfully postponed for 24 hours on the basis of weather forecasts, which had to satisfy a number of operational specifications. The importance of military weather forecasting has increased greatly with the increase in military technology, and forecasting services have become integral parts of the military establishments [8]. In the United States, for example, the U.S. Department of Defence operates separate so-called DMSP (Defence Meteorological Satellite Program) satellites for its exclusive use [12].

4.3. Polarization in Data Use

Technological developments in meteorology progress at a rapid rate and only developed countries and transnational corporations have any chance of keeping pace with this process and thus utilizing its advantages. It is certainly true, both in absolute and relative terms, that less developed countries also benefit greatly from these advances in general, and the development in each individual developing country is remarkable. However, the development pattern and especially pace of development in these countries is at considerably different stages. Differences in the quality of meteorological observation and in the exchange and use of data have always existed but with the technological advances made in the last 20 years these differences have, in absolute terms, grown. If the individual development stages in meteorology are regarded as "learning curves" then we believe that the last major learning curve--introduced by the new information, observation and telecommunication technologies--which occurred in most developed countries about 20 years ago, will only now start to take place in the less developed countries. This general pattern is shown in Figure 7, which we believe reflects the nature of the qualitative changes in the meteorological services that we are witnessing.

As a result of this technological explosion, a polarization can be observed in the use of meteorological data, which might be the source of future conflicts. Most developed countries and transnational corporations are in a better position to master the problem of information overflow of meteorological data. They will also be in a far better position to utilize these data to make decisions on problems that developing countries cannot react upon due to their lack of information. It is well known that many less developed countries feel uneasy because the more developed countries know more about their past, present, and future weather conditions and the impacts this could have on a given developing country, than the country themselves. A major point of conflict is that the generation of this information is tied to large investments, which only some countries can afford. In the case of a large transnational corporation this investment may bring returns, but this often results in the new generated data being handled as the property of the corporation. On the other hand, if these investments were not made no new information would be generated and a lot of observational data would probably be lost. How to find the solution to this problem is a complicated and difficult question, but it needs to be answered soon.

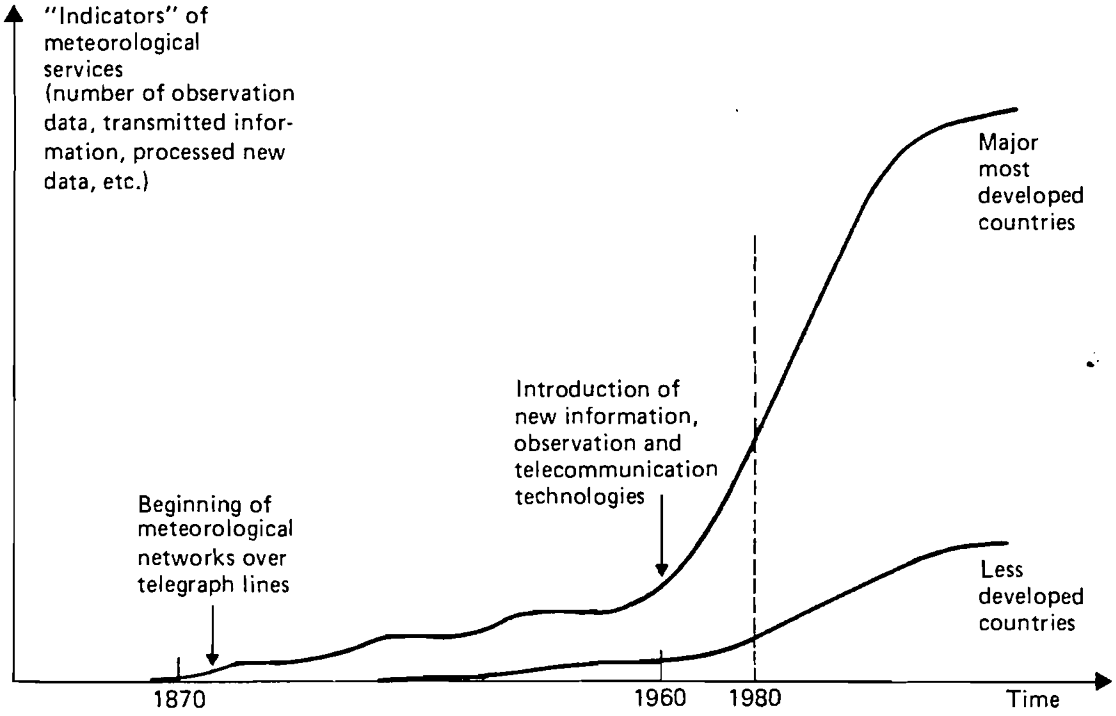

"Indicators" of meteorological services (number of observation data, transmitted information, processed new data, etc.)
Major most developed countries
Introduction of new information, observation and telecommunication technologies
Beginning of meteorological networks over telegraph lines
Less developed countries
1870
1960
1980
Time

Figure 7.

4.4. Export and Import Restrictions on Equipment

Last, but not least, the growing problem of export and import restrictions on equipment used for meteorological purposes should be mentioned. In an area where, traditionally, interdependency and cooperation were guiding principles, the growing "technologization" of meteorology raises the issue of export and import restrictions linked to the general trade of high technology. As more and more new technology moves into the field of meteorology it brings with it an increasing fear of the undesired transfer of this technology or export/import discrimination. It also raises again the problem that some components of meteorological systems (especially in observation technology) come close inside the "neighborhood" of military systems, and this cannot be overlooked.

A concrete example of an import restriction case was reported by [4]. When the Hungarian Meteorological Service wanted to import the IBM S/7 switching computer no export license was granted for the IBM "store and forward" software CCAP. In addition no permission was granted to provide the IBM S/7 with telex ports. As a result, an inhouse team of the Hungarian Meteorological Service had to independently develop an appropriate switching software. This meant that the computer was delayed for two-years before it could provide a regular service and higher costs were incurred due to the duplication of effort. It also, however, meant a loss of revenue for IBM because the deal did not go through as planned.

On a more general note, it would seem worthwhile to investigate the advantages and disadvantages of export/import restrictions, which until now have not been properly understood. The above example of not granting an export license did not serve for the good of IBM and forced the Hungarians to develop this system by themselves, which, in the long run, put them in a better position with regard to the level of knowledge for this particular application and thus makes them less dependent on foreign technology. The impact of export restrictions on the creation of new jobs in foreign countries is another interesting and most timely issue to look at.

5. SUMMARY AND CONCLUSIONS

Meteorological networks are one of the oldest and classic applications of transborder data flow, which existed well before the emergence of computer communication networks. During the last 20 years with the appearance of new observation, telecommunication, and information technologies, the amount and complexity of data crossing borders has increased dramatically. In East-West relations, the flow of meteorological data is one of the best established applications known that works without any major problems according to the standards developed and introduced by the WMO. The backbone of transborder meteorological data traffic between East and West is the GTS network of the WMO. In addition, data from Western meteorological satellites is received and processed in the Socialist countries and data from Soviet meteorological satellites by Western and Third World countries. As a backup system to the GTS network between East and West, meteorological data are broadcast across borders in a manner defined and coordinated by the WMO.

International cooperation in the exchange of meteorological data has traditionally been good. The exchange of observational and processed data was based on interdependency and no cost. With the introduction of new and expensive observation, telecommunication, and information technologies this favorable situation is about to change. Although the guiding principles of interdependency and the free exchange of information still dominate, there is a growing tendency to introduce certain cost recovery policies due to the high investment and operating costs of new systems.

The new technological developments have brought considerable advances and benefit to mankind, however, and probably inherently, it has also triggered off some negative impacts, such as

- an increase in the overload of meteorological data for less advanced meteorological services
- an increase in the cost of forecasting and processing data
- a growing dependency by others on a few major developed countries coupled with the growing independency of these major countries on the rest of the world
- a polarization of countries with regard to their capability to utilize meteorological data, and
- an increase in trade restrictions in this classical field of cooperation.

REFERENCES

[1] *Encyclopedia Britannica*, Vol. 15, p. 28. Encyclopedia Britannica, Inc., William Benton Publisher, London.

[2] *Encyclopedia Britannica*, Vol. 21, p. 567.

[3] *Encyclopedia Britannica*, Vol. 23, p. 333.

[4] Mezoesi, M., S. Olasz, T. Csikely, Hungarian Meteorological Service, Budapest. Personal discussion, 1982.

[5] World Meteorological Organization (1981) *Manual on the Global Telecommunication System*. WMO Publication No. 386. Geneva, Switzerland.

[6] Wihl, G., Zentralanstalt fuer Meteorologie und Geodynamik, Vienna. Personal discussion, 1982.

[7] European Center for Medium Range Weather Forecast (1981) *ECMWF Newsletter* No. 2, p. 2. Reading, United Kingdom.

[8] European Center for Medium Range Weather Forecast (1982) *ECMWF Newsletter* No. 15, p. 1. Reading, United Kingdom.

[9] Deudney, D. (1982) *Space: The High Frontier in Perspective*. Worldwatch Paper No. 50. Worldwatch Institute, Washington, D.C.

[10] World Meteorological Organization Secretariat (1982) *Satellites in Meteorology, Oceanography and Hydrology*. WMO-No. 585. Geneva, Switzerland.

[11] European Space Agency (1978) *Applications of Earth Resources Satellite Data to Development Aid Programmes*. ESA SP-1010. Remote Sensing Working Group Experts, European Space Agency, Paris, France.

[12] Barrett, E.C. (1979) Crop Environment Monitoring: The Remote Sensing Systems. In the Proceedings of an International Training Course organized by the ESA and the FAO on *Satellite Remote Sensing Applications in Agroclimatology and Agrometeorology*, Rome, October 1978. ESA-SP-1020. European Space Agency, Paris France.

[13] Secretariat of the WMO (1979) *World Weather Watch, The Plan and Implementation Programme 1980- 1983*. WMO No. 535. WMO, Geneva, Switzerland.

[14] Knighting, E. (1982) The European Centre for Medium-Range Weaher Forecasts, ECMWF, Reading, United Kingdom.