WORLD METEOROLOGICAL ORGANIZATION

WORLD WEATHER WATCH

Planning Report No. 36

THE ROLE OF SATELLITES IN WMO PROGRAMMES IN THE 1980s

by

D. S. Johnson and I. P. Vetlov

WMO - No. 494

Secretariat of the World Meteorological Organization - Geneva - Switzerland

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NOTE

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FOREWORD

The data provided by meteorological satellites operating as part of the World Weather Watch (WWW) Programme are now recognized as constituting an extremely valuable addition to the observations obtained from surface-based stations. Increasing use is also being made of satellites for collecting and relaying meteorological observational data from other observing stations. The whole satellite field is in fact still developing rapidly and it is therefore important, when planning further improvements in the WWW Programme, to keep in mind the possible future role of satellites.

It was with this in mind that the Seventh World Meteorological Congress in 1975 requested the Executive Committee to arrange for the development of suitable plans for meteorological satellite systems for operation in the 1980s and to submit a detailed report to Eighth Congress. This task was undertaken by the Executive Committee Panel of Experts on Satellites.

The present report, prepared by two members of the panel, Mr. D. S. Johnson (U.S.A.) and Dr I. P. Vetlov (U.S.S.R.), is based on the results of operational and research work in the field of meteorological satellites which was carried out in their respective countries. The report summarizes the present status of satellite technology and describes the type of satellite observing system which might be expected in the 1980s.

As recommended by the twenty-ninth session (1977) of the Executive Committee, Member countries of WMO will be invited to take this report into account in the development of long-range national plans in this field. The WMO constituent bodies concerned will also be invited to take the report into account when considering their respective future programmes.

I should like to take this opportunity of expressing the sincere thanks of the World Meteorological Organization to Mr. Johnson and Dr. Vetlov, and their colleagues, for the vast amount of work done in producing this valuable publication which will doubtless be of great interest and use to all the countries of the world.

D. A. Davies
Secretary-General

SUMMARY

This publication contains an analysis of the present state of facilities available for space techniques and an attempt is made to assess the future role of meteorological satellites in WMO programmes in the 1980s.

The introductory chapter contains an historical account of the development of satellites and the WWW, and enumerates the main advances in the field of the interpretation and use of satellite data. It concludes with a statement of the aim of the publication.

The second chapter lists the hydrometeorological and geophysical parameters which could be determined by means of satellites in the 1980s. A general assessment is given of the possibilities for meeting the requirements of the various WMO programmes by means of satellite observations.

Chapter 3 is devoted to a description of the future WMO satellite system. The merits and drawbacks of each type of satellite are discussed and the function of the satellites of the future system is described, including their use as a means for collecting and relaying routine observational data.

In Chapter 4 the aims and principles of processing satellite data at three levels – global, regional and national – are formulated. A general scheme is given for routine satellite data from immediately after a measurement has been made until it becomes available for operational and research purposes.

In Chapter 5 examples are given of the use of satellite data and an assessment is made of the possibility of further uses of the information for analysis and issuing weather forecasts for hydrological, marine meteorological and aeronautical meteorological interests and other fields of operational and scientific activities.

The principles of remote sensing of geophysical parameters from satellites and the existing requirements for measurements of these parameters (accuracy, resolution and frequency of observation) are described in Annexes I and II. An assessment is given of the possibility of meeting these requirements by means of the satellite system in the 1980s.

ABBREVIATIONS USED

APT	Automatic Picture Transmission
CAgM	Commission for Agricultural Meteorology (WMO)
CBS	Commission for Basic Systems (WMO)
CMM	Commission for Marine Meteorology (WMO)
DCP	Data-collection Platform
FGGE	First GARP Global Experiment
GARP	Global Atmospheric Research Programme (WMO/ICSU)
GDPS	Global Data-processing System
GOS	Global Observing System
GTS	Global Telecommunication System
ICSU	International Council of Scientific Unions
IGOSS	Integrated Global Ocean Station System
IOC	Intergovernmental Oceanographic Commission (Unesco)
IR	Infra-red
NIR	Near Infra-red Ranges
NMC	National Meteorological Centre
NOAA	National Oceanic and Atmospheric Administration (U.S.A.)
RMC	Regional Meteorological Centre
SHF	Super High Frequency
UHF	Ultra High Frequency
Unesco	United Nations Educational, Scientific and Cultural Organization
UV	Ultra-violet
VHRR	Very High Resolution Radiometer
WMC	World Meteorological Centre
WMO	World Meteorological Organization
WWW	World Weather Watch (WMO)

CHAPTER 1

INTRODUCTION

Meteorologists were among the first to appreciate the possibilities opened up by the launching of the first artificial Earth satellites. In 1961, two leading meteorologists, V. A. Bugaev and H. Wexler, proposed the World Weather Watch (WWW), in which satellites would play a key role. This proposal formed the basis of the well-known First Report on the Use of Outer Space for the Development of the Atmospheric Sciences, prepared by WMO in response to United Nations Resolution No. 1721 (XVI), calling for international co-operation in the use of outer space for peaceful purposes.

Until quite recently this early planning for WWW served as a useful guide for the development of a global satellite observing system. However, satellites will soon play a far greater role than was originally anticipated in 1961. Satellites will play an increasingly important role not only in obtaining observational data, but also in providing a capacity for the collection and distribution of information in support of various WMO programmes.

Indeed, satellites are indispensable for the success of the World Weather Watch,* the Global Atmospheric Research Programme (GARP), the First GARP Global Experiment (FGGE) and climate modelling, the weather-modification programme, the Tropical Cyclone Project, the Integrated Global Ocean Station System (IGOSS), the Operational Hydrology Programme and water resources development programme, and also in support of various other WMO activities. It is particularly gratifying to know that satellite data are now being more widely used for the various applications of meteorology and hydrology, in particular in providing services for transport (air, sea and land), agriculture, food production and recreation.

Satellite pictures are extensively used in the operational work of most Members. A number of countries have now also begun to use operationally quantitative data from satellites (e.g. upper-air winds, vertical temperature distribution and sea-surface temperature). Apart from the U.S.S.R. and the U.S.A., through whose efforts the global satellite system of today was largely created, a number of other countries will, by the end of this decade, be making very substantial contributions to that system.

All these factors taken together point to the need, at the present time, to summarize the current status of satellite technology, examine the future role of satellites in WMO programmes, and outline the satellite system which might be expected in the 'eighties (the types of observation, use for data relay, and the processing, interpretation and dissemination of information). Such a prognosis will of course be of a general nature, since there is always uncertainty in predicting technological developments 10 to 15 years in the future and in estimating national programmes which will be implemented in that time period.

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* The current WWW plan and implementation programme for the period 1976-1979, as adopted by Seventh Congress (WMO Publication No. 418, paragraphs 71-82), calls for polar-orbiting satellites and five geostationary satellites to provide full coverage around the globe.

CHAPTER 2

BASIC REQUIREMENTS OF WMO PROGRAMMES AND THE ROLE OF SATELLITES

The last 10 or 15 years have seen the introduction of satellite observations into many phases of hydrometeorological research and operations. The information on the atmosphere and the Earth's surface, obtained from operational meteorological satellites of the U.S.A. and the U.S.S.R., has significantly supplemented the mass of hydrometeorological observations obtained by traditional methods, improved our understanding of atmospheric processes and, thus, is improving weather analysis and forecasting. The possibilities of using satellites both for the making of hydrometeorological observations by means of instruments installed in them and for the collection and dissemination of data have been demonstrated.

Theoretical studies and instrument developments now in progress in many countries have shown the possibility, in principle, of using space methods to obtain a wide variety of information concerning the state of the atmosphere and the Earth's surface. For example, recent satellite experiments have shown that measurements in the microwave portion of the spectrum make it possible to determine, in most weather conditions, the vertical distribution of temperature and water vapour, the temperature of the ocean surface, areas of precipitation with an estimate of intensity, etc. This progress leads us to expect to be able, in the near future, to obtain from satellites a whole range of parameters describing the state of the atmosphere and the oceans' surface necessary for improving weather forecasting as well as the support rendered to hydrology and other WMO programmes. Other experiments, although many have not advanced as far as those referred to above, have indicated how instruments can be constructed, the use of which could contribute to meeting a large number of observational requirements of WMO programmes.

The current status of development of satellite meteorology and technology and an assessment of future trends in this development lead to the expectation that the following parameters can be obtained by means of satellites in the 'eighties. The physical bases of the methods of determining the parameters listed below are given in Annex I.

Hydrometeorological and geophysical parameters which can be determined from satellite observations

Atmosphere

Mean temperatures of isobaric layers*
Total water-vapour content and its distribution by layers*
Total ozone content and its distribution by layers
Characteristics of aerosols
Components of the radiation balance at the top of the atmosphere*
Wind speed and direction in the troposphere (at two or three levels)*

Clouds

Spatial distribution of cloud and its structure*
Height and temperature of the cloud tops*
Phase composition (droplets, ice particles or mixed) of the upper cloud layer
Total water content of clouds
Location of precipitation areas and their approximate intensity*

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* It can be assumed that these parameters will be available on an operational basis by the middle of the 'eighties. The remainder should be available at least on an experimental basis.

Ocean surface

Temperature of the ocean surface *
Location of the major ocean-surface currents*
Degree of roughness of the ocean (e.g. waves) and the related surface wind fields
Ice conditions *
Location of polluted areas (of certain types) on the ocean surface

Land surface

Temperature of the land surface *
Degree of soil moisture
Distribution of snow cover *
Characteristics of the soil and plant cover
Location of areas of melting snow and ice *

Significant progress will undoubtedly be achieved in the 1980s not only in obtaining new types of information by means of satellites (as clearly illustrated by the preceding list of parameters) but also in improving the quality of information currently derived from satellite data. Most satellite information will be quantitative in nature, and the accuracy and time-and-space resolution of the measurements will be improved. Thus, satellite systems will improve the global data coverage required for analysis and forecasting of large- and planetary-scale phenomena. At the same time, they will contribute to meeting the requirements for information needed for the analysis and forecasting of meso- and small-scale phenomena.

The need to improve the services which are provided in support of various fields of economic activity (and especially to improve the quality of hydrometeorological warnings and forecasts) is an important stimulus for the continued development of satellite systems.

The wide variations in weather analysis and forecasting techniques, and in the types of service performed in support of aviation, hydrology, agriculture, marine activities, etc., lead to large differences in observational requirements. Although the observational requirements have not yet been fully developed for all WMO programmes, the following broad principles generally prevail:

(a) For weather analysis and forecasting, and for many applications programmes, the information should be available regularly and promptly and be both comprehensive and complete. This results from the rapid changeability of many phenomena, especially in the atmosphere, and the need for the timely detection of these phenomena and their evolution;

(b) The area from which information must be obtained is determined largely by the scale of the phenomenon being monitored and by the period for which predictions are needed;

(c) The accuracy, density and frequency of observations are determined, above all, by the scale of the phenomenon or process to be monitored, the variability of the physical parameters which describe the phenomenon and the sensitivity of analysis and prediction methods to observational errors.

Observational requirements for large- and planetary-scale phenomena are more refined in the WWW and in the First GARP Global Experiment (see Annex II) than in most other WMO programmes, although no doubt these requirements will be modified and extended as continued research, especially under the GARP, increases our knowledge. In other areas, the requirements will be developed in the coming years by the interaction between those concerned with practical operations in a particular field, research to increase our knowledge and understanding of the relevant phenomena and processes, and the development of a feasible and applicable technology for observations

* It can be assumed that these parameters will be available on an operational basis by the middle of the 'eighties. The remainder should be available at least on an experimental basis.

and data processing. This is the process being followed in the World Weather Watch and the Global Atmospheric Research Programme. Annex II also includes lists of data requirements which may serve as a basis for further studies by the relevant WMO bodies, such as the Commissions for Hydrology, Marine Meteorology and Agricultural Meteorology.

It is seen that satellites will make a major contribution to the World Weather Watch and the First GARP Global Experiment (FGGE). All of the requirements for the horizontal density of observations can be met. The vertical resolution of temperature and humidity observations can also be obtained; however, upper-air winds can be determined reliably only over oceans and where clouds of certain types exist. Thus, winds generally can be obtained at only two, and sometimes three, levels in the troposphere by tracking cloud motions. Satellites can track constant-level balloons drifting in the stratosphere to increase the observational coverage.

In the 1980s it is expected that upper-air temperatures of layers will be determined with an accuracy of about 1.5-2°C, compared with the stated requirement of 1.0°C. This will be feasible even in areas of extensive cloud cover, except in regions of heavy precipitation.* The theoretical limit for the accuracy of such satellite measurements appears to be about 1.0°C; however, practical limitations may never permit this limit to be reached. The accuracy requirements for upper-air winds (± 3 m s^{-1}) and relative humidity (± 30 per cent) can be met now. By the time of FGGE, sea-surface temperatures will be measured with an absolute accuracy of about ± 1.5°C and gradients to about 1.0°C. This is expected to improve to about 1.0°C and 0.5°C respectively by the end of the 1980s. The latter meet the accuracy requirements for the WWW. It is not possible to measure surface pressure with useful accuracy by means of remote measurement from satellites. However, satellites will play an important role in collecting surface observations from ships, buoys and isolated land stations needed to define the reference level from which the satellite sounding data can be integrated to obtain the mass field.

The preceding requirements are primarily oriented to support of analysis and prediction on the large and planetary scales.** The WWW plan includes within its scope the need for analyses and predictions on the small- and mesoscales. Especially important is the need of national services to detect and continuously monitor severe weather events such as tropical storms, severe convective phenomena, gust fronts, squall lines, and other phenomena which can cause extensive damage and loss of life.

While specific requirements have not yet been stated by WMO, recent experience with geostationary satellites indicates that images from these satellites will have a major impact on weather services in the tropics and mid latitudes by providing a "continuous weather watch" with high horizontal resolution. By the end of the 1980s we can also expect temperature and humidity soundings from geostationary satellites, with a horizontal resolution in the order of 10-100 km, depending on the cloud cover, and a frequency of about once per hour, over regions in the order of 5-10 000 km^2. Similar imaging and sounding data will be available in the polar regions every one and a half to two hours from the set of satellites in polar orbits. While these data are very important for synoptic meteorology, the high frequency of sounding data should be particularly useful in improving our understanding of small- and mesoscale phenomena, and the extension of numerical prediction techniques into this range (so-called limited fine mesh and mesoscale models).

With the advent of geostationary satellites covering the entire tropics and mid latitudes, a special effort should be made by WMO to ensure that its Members receive the major initial benefit which can be achieved from a "continuous weather watch", especially of violent weather.

Of course, the data for WWW and FGGE are also essential for various WMO research programmes. There are additional requirements for satellite data in support of these atmospheric research programmes. In particular, satellite

* This statement, as well as the figures in the following text, are assessments or predictions based on the latest results of satellite research experiments and additional improvements expected during the next several years.

** Scales used here are as defined in the World Weather Watch plan for the period 1976-1979, WMO Publication No. 418, paragraph 42.

measurements will be effective in monitoring the planetary radiation budget at the top of the atmosphere, cloud albedo, ice, snow and cloud cover, ozone distribution, total aerosol loading, etc.

The requirements for the WMO programme in climate dynamics are in a formative stage, as is the study of improved satellite sensors which may meet some of these requirements.* Although very high precision is required, it appears that satellite techniques could be devised to monitor usefully the incoming solar radiation, the planetary radiation budget, ice and snow cover, sea-surface temperature and most of the cloud parameters. Satellite data will undoubtedly contribute in other ways as well, but further definition will require extensive joint study by scientific specialists and technologists.

High-resolution (one kilometre or better) satellite images already fulfil hydrological requirements for determining the horizontal extent of snow cover. In-situ observations must also be available, however, in order to estimate total available water. Satellite data will be available operationally to detect the onset of snow- and ice-surface melting. Areal extent of surface water, ice on rivers and lakes, and other surface features can be determined with useful accuracy, although it is best to use extremely high resolution data (about 0.1 km) of the Landsat type. Although a number of stations for the direct reception of Landsat data are now being established in many countries it is not yet clear what frequency of observations (now once every nine days) will prevail in the 1980s. These, and possibly still higher resolution multispectral data, show promise in contributing to ground-water detection, certain aspects of water-quality monitoring and geomorphology.

It will always be necessary to have in-situ observations in hydrology. Satellites will play an increasingly important role in relaying these data rapidly to decision points, such as to warn of floods or to control water resources and hydroelectric generation. Hydrological parameters which appear to be likely candidates for satellite-data relay from remote sites include snow depth and density, river or lake stage, cumulative precipitation, aquifer water level, water-quality data and soil moisture and temperature.

Remote sensing from satellites in support of oceanographic programmes is much less well developed than in meteorology. Therefore the data requirements are also in a preliminary state. It must be recognized that remote sensing from satellites can only provide data on the surface of the oceans, except to a depth of several metres in the visible portion of the spectrum. However, as in hydrology, satellites will provide a practical means of collecting in-situ observations from ship and buoy platforms over the world's oceans. Satellites can also locate drifting buoys at appropriate intervals and, from these, ocean currents at the drogue level can be determined. Furthermore, a novel method for obtaining ocean vertical "soundings" has been proposed (Mintz and Suomi). If such a method proves feasible, it could provide the temperature, density, etc. from the surface to the bottom of the mixed layer. These data would be relayed via satellite.

As indicated previously, sea-surface temperatures are already derived from satellite observations; an accuracy of about 1.0°C absolute and 0.5°C relative appears to be the maximum attainable. Ocean surface "fronts", and thus major ocean currents and regions of upwelling, can be detected with a temperature difference of less than 1°C, and located with an accuracy of a few kilometres. Ice fields can be monitored routinely with one-kilometre-resolution satellite images. Where specially needed, extremely high resolution images (in the order of 0.1 km) may be available for detailed surveys of leads, etc. Microwave observations will probably provide "all-weather" capability, but at lower resolution, and also give some indication of the age and thickness of the ice.

A number of major satellite experiments related to oceanography will be conducted in the 1978-1980 time period. These include ocean colour measurements (for clorophyl, sediment, surface pollution), improved surface-temperature measurement, surface roughness and wind determination by microwave techniques, etc. It can be expected that those techniques whose validity and utility are demonstrated in the experimental phase may become operational before the end of the 1980s. If these satellite experiments demonstrate the validity and utility of new techniques, they may become operational before the end of the 1980s.

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* See JOC-XII, paragraph 4.4.2.

CHAPTER 3

POSSIBLE CONSTELLATION OF SATELLITES

At the present time it appears that the satellite requirements of the World Weather Watch and other WMO programmes will best be satisfied by a system consisting of three to four satellites in quasi-polar orbits and four to five geostationary satellites in equatorial orbits. This configuration will be utilized during the First GARP Global Experiment in 1978-1979.

Satellites in polar and geostationary orbits are complementary in the frequency and area of coverage of observations, collection and relay of in-situ observations, and dissemination of data by direct broadcast. With four or five geostationary satellites around the Equator, imaging of clouds and storms in the tropics and mid latitudes (up to about 60°) can be obtained at least once an hour. Atmospheric soundings with the same frequency over limited areas of the Earth for use in mesoscale analysis should be possible from geostationary satellites by the end of the 1980s.

Three to four satellites in quasi-polar orbit will provide full global coverage every six hours close to the synoptic times for global, large- and planetary-scale analysis and prediction. The convergence of these orbits near the poles provides more frequent coverage for regional and local use at high latitudes, complementary to the nearly continuous coverage by the geostationary satellites equatorwards of about 60° latitude.

Polar and geostationary orbits are also complementary in providing frequent collection of in-situ observations from automatic or remote (e.g. ship, island) observing stations. These data-collection systems will be fully operational in the 1980s and should play an important role in collecting observations from remote areas as a part of the Global Telecommunication System (GTS) and in meeting many specialized regional needs (e.g. for hydrology). Examples of such observations are additional winds in the troposphere and stratosphere, surface observations of pressure, snow density and precipitation, and subsurface ocean temperatures and salinity. Both polar and geostationary satellites are already being used experimentally to relay observations from manual and automatic stations at remote locations on land, and from ship, buoy, balloon and aircraft platforms. In most cases, the use of satellite data relay offers the only realistic way to acquire, in a timely fashion, many observations needed for warnings and predictions.

In view of the above, it is important that WMO Members continue the geostationary satellite systems being provided for the FGGE in order to supply the routine operational support to the WWW and applications programmes. Those Members operating satellites in polar orbits should be encouraged to establish co-ordinated, complementary orbits for optimum frequency of observational coverage.

Other orbits may need to be considered in the future. Should the monitoring of climate require a very accurate knowledge of the Earth's planetary radiation balance (e.g. space and time variability of cloudiness), sensors on spacecraft in special orbits (in addition to polar and geostationary) may be needed.

The observational requirements and the role of satellites in meeting these requirements have been summarized in the preceding section. From a system point of view, the polar-orbiting satellites will have a primary role in providing global sounding data and high-resolution surface observations, especially those required for specialized applications programmes. The spacecraft in geostationary orbit will be used primarily for continuous monitoring of clouds for short-period and mesoscale forecasting and storm warnings, and to obtain winds at two or three levels in the troposphere.

While the broad concept of the satellite configuration of the 1980s seems quite clear, the detailed configuration remains to be defined and measurement and interpretation techniques refined. The results of experimental programmes now in progress and the experience to be gained from the continuing and expanding application of satellite information in WMO programmes will assist in this definition and refinement.

CHAPTER 4

PROCESSING, INTERPRETATION, DISSEMINATION AND STORAGE OF SATELLITE DATA

The satellite system is not just an observing sub-system of WWW/Global Observing System (GOS); it must also include data processing, interpretation and the subsequent dissemination of the resulting information. The effectiveness of the satellite system depends, therefore, on the degree to which all of its constituent parts are perfected. In the WWW system, it has been planned to perform the reception, processing and interpretation of both conventional and satellite data at three levels:

(a) World Meteorological Centres, whose primary job is to provide the products required for the analysis and forecasting of large- and planetary-scale processes (scales are as defined in the WWW Plan and Implementation Programme for 1976-1979, WMO Publication No. 418, paragraph 42);

(b) Regional Meteorological Centres, which primarily provide the products required for the analysis and forecasting of large-, meso- and, to some extent, small-scale processes;

(c) National Meteorological Centres, which process data at the national level, using the products of the WMCs and RMCs, in conjunction with data which may be received directly from satellites.

In the past, the major role of satellites in the WWW has been primarily to meet data requirements for the analysis and forecasting of large- and planetary-scale processes. This has led to the establishment of a system of data flow to WMCs and the subsequent transmission of low-resolution* products on a hemispheric or global scale. At the same time, the use of the Automatic Picture Transmission (APT) system has partially met regional and national needs for medium-resolution* satellite images.

The advent of new satellite techniques, which are increasing the types, frequency and resolution of satellite observations, unquestionably calls for an improvement in the means of receiving, processing, interpreting and disseminating satellite data at all three levels. Particular efforts in this respect should be directed towards meeting regional and national requirements for satellite data.

Images of vast areas of the Earth's surface and cloud cover with resolutions from one to ten kilometres will be available at least every 30 to 60 minutes from geostationary satellites. Observations from polar-orbiting satellites of surface features, with resolution in the order of 100 to 1000 metres in the visible and infra-red, and of tens of kilometres in the microwave portion of the spectrum, will be available for use in marine applications, hydrology and other environmental fields. Microwave and infra-red atmospheric sounding data with a horizontal resolution from 10 to 100 km will be available at least every six hours and up to once an hour in some regions. But with their existing capacity, the GTS and GDPS are unable to satisfy expected regional and national requirements for these additional satellite data, nor can World Centres be expected to receive and process all of them. It is therefore desirable to expand the capabilities for the direct reception and processing of full-resolution information from both geostationary and polar-orbiting satellites at the regional and national level.

While it is desirable that each Regional Meteorological Centre (RMC) and even a number of National Meteorological Centres (NMCs) should have a specialized satellite facility** of the type discussed here, it is recognized that this may not be feasible in a number of cases. It also may not be required where a number of centres exist in close

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* Resolution of satellite images as used here is: low ~ 10 km, medium ~ 3-5 km, high ~ 1 km, extremely high ~ 0.1 km. It is necessary to define the limit of resolution of images required for a number of WMO programmes, especially hydrology and oceanography.

** The question of the use of specialized satellite facilities in the framework of the current WWW requires further consideration.

proximity. Therefore, it might be desirable that Regional Associations examine in detail the role of the specialized satellite facility in meeting requirements within the Region and the possible existing or planned satellite facilities which might be utilized. Then appropriate steps could be taken to arrange for the required information output of such facilities to be made available on a timely basis to the RMCs and NMCs within each Region. In this regard, the Commission for Basic Systems (CBS), and other relevant Commissions, may wish to develop general guidance on the roles of such specialized satellite facilities in Regional and National Meteorological Centres and applications programmes.

A specialized satellite facility should ultimately be capable of receiving full-resolution images from the appropriate geostationary satellite, as well as high-resolution images and sounding data by direct broadcast from the satellites in polar orbit. It may also be desirable to receive those data-collection signals for the region which are being relayed by both the geostationary and polar-orbiting spacecraft, rather than waiting for their transmission from the WMC.

The equipment mentioned above must be more sophisticated than that required for the APT system. In particular, a mini-computer and a photographic laboratory, in addition to receivers and recording equipment, are necessary for the processing and interpretation of high-resolution pictures. Extensive computer capability is needed if quantitative data, such as upper-air wind and temperature/humidity sounding data, are to be derived from satellite observations. The interpretation of these satellite data should be carried out by highly qualified meteorologists, hydrologists and oceanographers who have received specialized training. Programmers, electronic technicians, photographers, etc. will also be required to operate the specialized equipment. The exact types of personnel will be determined by the regional requirements.

The products to be supplied by the specialized satellite facility should be determined by regional and national requirements and by available communication facilities. As a minimum, alphanumeric messages should be issued, giving the location and intensity of storms, warnings concerning their occurrence and development, snow-pack assessment in different river basins, the location of significant sea-surface temperature gradients, etc.

It might be desirable that, in preparing mesoscale forecasts, Regional Meteorological Centres should make use of the higher resolution sounding data received directly from satellites and regional wind data derived from sequences of high-resolution images received from geostationary satellites by direct broadcast. These wind and sounding data can be available regionally several hours sooner than through the WMCs and the GTS, and with the higher space and time resolution required for meso-to-synoptic-scale short-term forecasting.

An optimum system for the dissemination of data from the specialized satellite facilities would include the transmission to NMCs (and to RMCs if not co-located) of high-resolution limited-area pictures and other graphic products. This, however, is not yet feasible in many parts of the world. As a minimum, provision should be made for APT and WEFAX reception at the national level as well as at those RMCs not yet equipped with the more sophisticated facility described here. These images will be extremely helpful in using the information from the specialized satellite facility and storm warnings received from RMCs. Thus, the output of the specialized facilities will depend on national requirements and the available communication, reception and display facilities. The output will unquestionably vary from region to region and within each region.

As implied earlier, the future development of space techniques raises the question of the need to strengthen the role of NMCs. The time may come when they must receive high-frequency, high-resolution satellite information in order to maintain a continuous "weather watch" and to support small-scale analysis or prediction.

WMCs should receive the data required for global analysis and forecasting from WMO Member countries possessing satellite systems. The data in question should reach the WMCs as quickly as possible, enabling them to prepare, in good time, analyses and forecasts of large- and planetary-scale processes. The growth in the volume of global satellite data may call for improved communication facilities for these transmissions. Improvement of communications may also be needed to meet regional and national requirements for transmission of processed satellite data from the WMCs.

Most satellite data should be archived for subsequent use in research. In this field, WMO is presently using the experience of the U.S.A. and the U.S.S.R., the two countries operating satellite systems on a routine basis. In view of the increasing role of satellite systems and the participation of additional countries in their establishment and operation, WMO should prepare a detailed plan for the archiving of the satellite data expected in the 1980s. The archiving of large volumes of satellite data is a fairly complicated matter. To preserve the full accuracy and resolution of satellite data, they must be stored in digital form. With existing techniques, however, this is not fully possible. Another difficulty is that the possibilities of storing data on board satellites are limited. At the moment, the NOAA series of satellites, operated by the U.S.A., can record only about ten per cent of VHRR (Very High Resolution Radiometer) data for subsequent transmission when the satellite comes within view of one of the two data-receiving stations. While this coverage will increase to perhaps 40 per cent with the next generation TIROS-N series, the complete storage of these data will be possible only on a regional basis. Similar archiving problems exist in connexion with the high-resolution multi-spectral measurement data from the satellites expected to be in operation before 1990.

Thus the archiving of data at two levels appears to be desirable. The Moscow and Washington WMCs should archive the medium- and low-resolution polar orbit data for the entire globe in both digital form on magnetic tape and in the form of cloud pictures on film. They should also archive U.S.A. and U.S.S.R. geostationary satellite data. The resolution and format of geostationary satellite image archiving will depend on the development and introduction of high-frequency digital recording devices. Other geostationary satellite operators should assume responsibility for archiving similar data produced by their satellites. Regional Associations should establish suitable arrangements for the second level of archiving, i.e. the storing of high-resolution (in space and time) data, which are largely of Regional interest and which it is not feasible to handle on a global basis.

Since it is not possible, at the present time, to estimate accurately the effectiveness of many of the future types of satellite observation, the system we have described for collecting, processing, interpreting and disseminating satellite data for the purposes of WWW and other WMO programmes should be regarded as provisional. The satellites to be operated during the FGGE, and experimental satellites to be launched during the next few years, will play an important role in elaborating and improving on the outline given here.

CHAPTER 5

THE USE OF SATELLITE DATA

It is already clear that satellite data can be applied in the most varied fields of hydrometeorology (weather forecasting, oceanography, hydrology, climatology, etc.). The extent and effectiveness of the use of satellite data depend on the nature and quality of the observations, on the status of the interpretation of satellite measurements and on the level of our scientific understanding of the fields of application. Thus it is to be expected that satellite measurements in the 'eighties, depending on the state of development of the measurement programme, will be directly applied in operational work, while some of the satellite measurements will be used in research, including providing the basis for the construction of different types of mathematical model for describing the processes occurring in the atmospheric-oceanic-hydrospheric system. The latter will lead, later on, to improved operations and services.

Use of satellite data in operational work

Satellite data were used successfully in meteorological operations almost as soon as the first satellite cloud pictures appeared. At the present time, significant advances have been made in the interpretation of satellite cloud data for the purposes of synoptic analysis and forecasting, thanks to which satellite cloud photos are successfully used by forecasting units in many countries. With their aid, the position, stage of development and direction of movement of tropical and extra-tropical cyclones, the position and strength of atmospheric fronts, inter-tropical convergence areas, jet streams, etc. can be reliably determined. It is also possible to estimate the stability of the atmosphere, the development of convection therein, and the distribution of precipitation areas. In addition, the effects of topography and surface temperature on the type and distribution of clouds can be detected. The successful use of satellite cloud pictures in synoptic weather analysis and forecasting led to the introduction, in 1967, of the Automatic Picture Transmission (APT) programme.

More complete and accurate satellite data, expected to be available in the 1980s, will significantly improve the use of satellite information in synoptic and numerical analysis and forecasting of atmospheric processes of various scales, and in hydrology, oceanography, etc.

The system of four to five geostationary satellites and three to four polar-orbiting satellites, which is expected to be in operation during that period, will make it possible to monitor weather conditions continuously over the whole globe. In this way, ships, aircraft, industry, agriculture, the populace, etc. can be given timely advice and warnings of dangerous weather. For example, adjustments to routes for shipping and aircraft can be recommended. The more extensive use of frequent high-resolution pictures and the increase in the range of observations included in the system of direct transmissions from these satellites will significantly increase the value of this information, including the possibility of their use in large- and meso-scale weather forecasts.

The success of numerical methods of forecasting various meteorological parameters depends largely on the degree of accuracy of numerical analysis of the parameters upon which the numerical forecast is based. Until only recently it was impossible to conduct such analyses with the required degree of accuracy over most ocean areas or other inaccessible or sparsely populated regions. Now, as a result of the experiments conducted by the U.S.A. and the U.S.S.R., one can obtain satellite data from these regions which permit the determination of the temperature of atmospheric layers. Such measurements have been made operationally aboard NOAA satellites since 1972.

However, since many satellite measurements are not available simultaneously over the entire globe, they should not always be used in the traditional manner of conventional observations. Optimum methods must be developed for properly including satellite data in numerical analysis and in a manner which utilizes the unique properties of these data. These "four-dimensional" or "space-time" numerical analysis methods are being intensively developed at the present time. As a result, it is expected that, in the 'eighties, the quantitative information obtained from meteorological satellites (temperature, humidity, wind) will be widely applied in global and regional systems of numerical analysis and forecasting. Experience now being obtained in this field indicates that the use of new quantitative satellite data in improved analysis and prediction models will increase the quality of numerical weather forecasts and that satellite data will improve the quality of numerical weather forecasts on the large scale. Frequent and high-resolution satellite soundings are also expected to contribute to the development and application of numerical forecast techniques of mesoscale and small-scale phenomena.

Methods of using satellite information are less developed in hydrology than in meteorology. Nevertheless, satellite pictures of the land surface are already being successfully used for the solution of certain hydrological problems. These include, in the first place, contributing to the calculation of the water equivalent of snow and assessment of ice conditions on large lakes. Satellite pictures can be used to determine the distribution of snow cover. In conjunction with surface bench-mark measurements of snow, such information can be used for forecasting spring floods.

Figure 1 is a satellite picture of the snow-covered surface of the south-eastern part of the U.S.A. The largest bright area on the right of the picture is the Piedmont plateau and the lowland part of the Atlantic coast (State of South Carolina). The large number of dark patches on the western side of the snow-covered territory indicate the uneveness of the snow cover on the plateau. The picture clearly shows that the snow has already melted in the river valleys, so that they stand out very clearly against the light background. Figure 2 shows the isopleths of the depth of snow cover based on ground observations plus interpretation of the variations in brightness in the satellite picture.

Figures 3 and 4 illustrate the possibility of using satellite pictures for estimating ice conditions on large lakes. Figure 3 shows a series of pictures of Lake Ladoga in the U.S.S.R. The parts free from ice (dark colour) can be clearly distinguished from the ice-covered parts (light colour); it is also possible to estimate the ice concentration and discern snow-covered ice. Successive pictures of the area make it possible to follow the trend of the ice melt, the displacement of the edge of the ice floe, and the speed of movement of large ice floes, and thereby make a more reliable forecast of the date of the complete freeing of the lake from ice.

Figure 4 compares the ice analysis for Lake Ladoga on 22 April 1974, based on satellite pictures, with that based on aircraft survey data. There is good agreement between the two analyses.

The future use of satellites for snow and ice monitoring, detecting snow and ice melt, collecting and relaying in-situ observations, and possibly providing useful estimates of precipitation and soil moisture and surface temperature in the 'eighties may enable hydrologists to improve the reliability of long- and short-term forecasts of spring floods, the inflow of water into reservoirs, high-water forecasts and flood warnings, etc. Such improvements would be of considerable economic importance and affect the safety of populations.

Various maritime operations, such as shipping, open-sea mining, oil drilling and fishing, require detailed information about the state of the oceans and accurate sea and weather forecasts. The steadily growing fraction of the population living in coastal regions increases the need for improved forecasting and storm-warning services. But the previous lack of observations over the vast ocean expanses has hitherto prevented the creation of an effective system of ocean monitoring and prediction. Satellites offer the potential of substantially contributing to such a monitoring system.

Satellite measurements make it possible to study only the two-dimensional fields, i.e. surface, of oceanographic parameters. But that limitation is not such a handicap as may appear at first sight, since the combined use of satellite data and in-situ measurements opens up the possibility of observing the oceans in three dimensions on an economically feasible basis. Moreover, detailed information about the two-dimensional structure at the ocean surface is useful in itself, if only because the majority of man's activities are confined to the sea surface.

Satellite measurements of radiation in atmospheric "windows" make it possible to produce charts of surface-water temperatures for all ocean areas which are necessary to establish the lower boundary conditions for numerical weather-forecasting models and for determining the heat reserves of the water when making ice forecasts.

Main ocean-surface currents and regions of upwelling can be detected from sea-surface temperature gradients detected by satellites. The latter fact is of particular interest because cold sub-surface water contains a high percentage of nutritive substances which provide favourable conditions for the growth of the fish population.

Information concerning the degree of roughness of the ocean surface (waves) and of ice conditions is of direct value in ensuring the safety of shipping and fishing vessels, recommending optimum routes for shipping, and for other purposes connected with maritime activities.

The provision of data on an operational basis concerning pollution in ocean areas will make it possible to organize effective control and to take measures to combat it.

Figures 5-13 illustrate some of the possibilities of using satellite information in oceanography. Figure 5 shows the western part of the North Atlantic as viewed by satellite in the 11 μm thermal infra-red atmospheric "window". Figure 6 is a map-diagram of the same region drawn by interpreting the picture. The thermal structure of the ocean surface in that region is clearly shown. The position of the west wall of the Gulf Stream can be confidently identified, as can the location of shelf waters, i.e. the waters of the continental slope. Eddies formed along the Gulf Stream are also identifiable. These satellite data can also be used quantitatively to determine absolute temperatures with useful accuracy.

Figures 7-13 show visible and infra-red images of sea ice from NOAA and Meteor satellites, and also the map-diagrams corresponding to some of the pictures. The pictures contain information about the position of the ice edge, about ice movements, the limits between ice bodies of differing concentrations, about polynias and other characteristics of ice conditions of interest to oceanographers. These data are already used operationally to assist in safe ship routeing.

Use of satellite data in research

As was shown in Chapter 2, many of these data will be obtainable from satellites in the 'eighties. The satellite data will make a significant contribution to: the creation of a numerical theory of the general air/sea circulation, development of mathematical models of climate, and improving hydrothermodynamic methods of long-term weather forecasting. According to present ideas, the solution of these fundamental problems requires, in the first place, the study of the processes of heat-radiation fluxes in the atmosphere, the processes of energy exchange between air and ocean (land surface), and the mechanism of the interaction between circulation and radiation processes in air and sea.

New global satellite measurements to be obtained in the 1980s of such parameters as ozone content, the quantity of atmospheric aerosols, the components of the radiation balance at the upper limit of the atmosphere, etc. will allow progress to be made in the studies of radiation-flux processes as they govern atmospheric energetics.

The study of the extremely complex process of sea/air energy exchange also requires the knowledge of a whole set of parameters characterizing the state of the atmosphere and ocean on the planetary scale. Satellite information about water temperatures, ocean currents, sea waves, ice conditions, air temperature and humidity, and wind (to be obtained in the 1980s) will be widely used in the improvement of the mathematical models and processing systems by which these complex processes are described.

Cloudiness is one of the main factors governing the interaction between circulation and radiation processes in the atmosphere. Qualitatively, this role of cloudiness has long been known, but the numerical details of its interaction with the radiation and circulation processes have not yet been studied with the necessary accuracy and completeness. To solve this difficult problem, quantitative data of the required accuracy must be available concerning the whole set of parameters which determine the formation and evolution of clouds and their effect on radiation. In the 'eighties, many of these parameters will be obtainable by means of satellites, thus contributing to the solution of the complicated problem concerning the interaction of atmospheric circulation and radiation processes.

This publication certainly does not cover all the aspects of the potential uses of the expected satellite information in routine operations and in research. However, it seems obvious that the increasing role of satellites in WWW and other WMO programmes can hardly be overestimated.

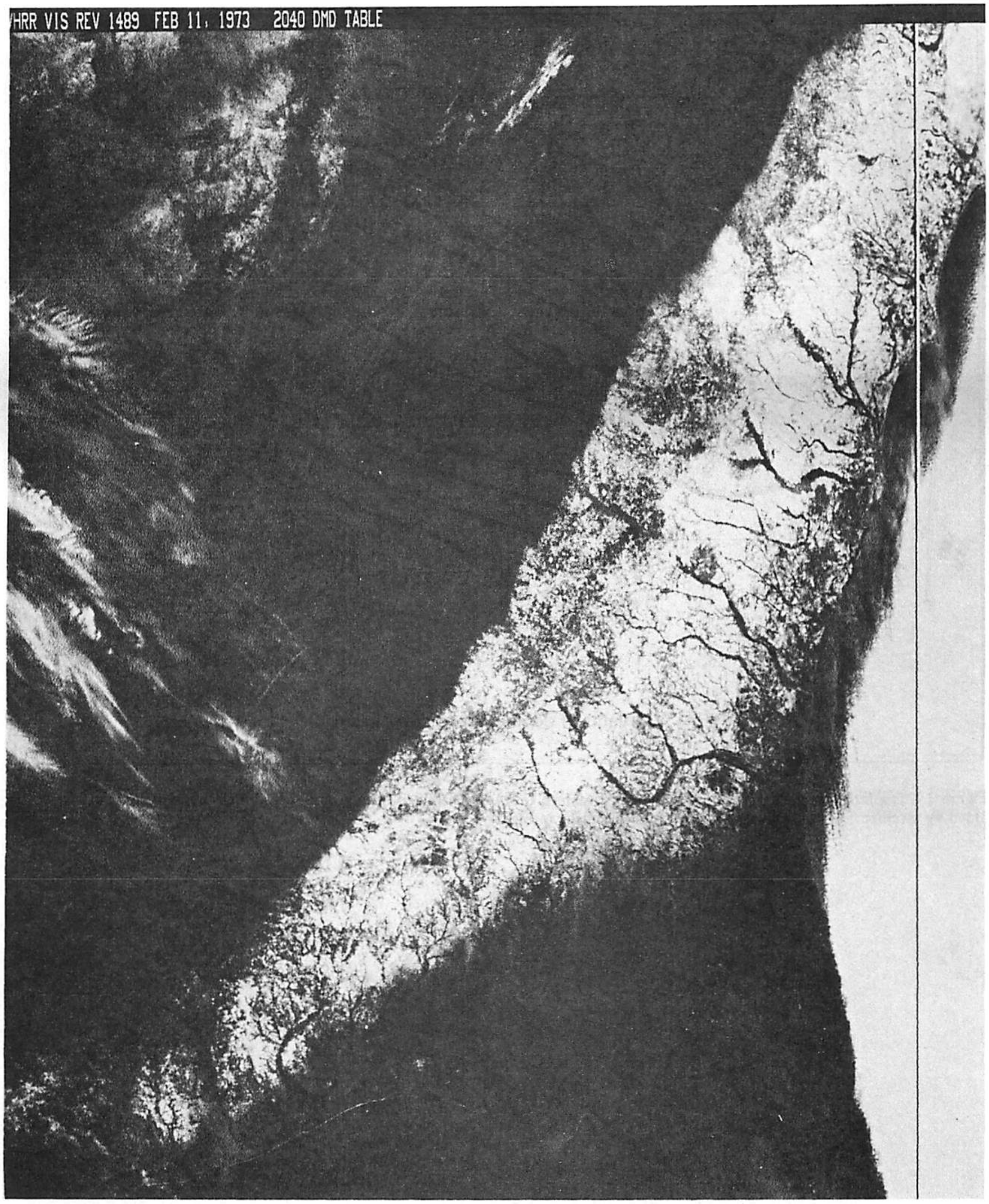


Figure 1 – Satellite photo of snow-covered territory in the visible part of the spectrum. South-eastern U.S.A., 11 February 1973, NOAA 3 satellite

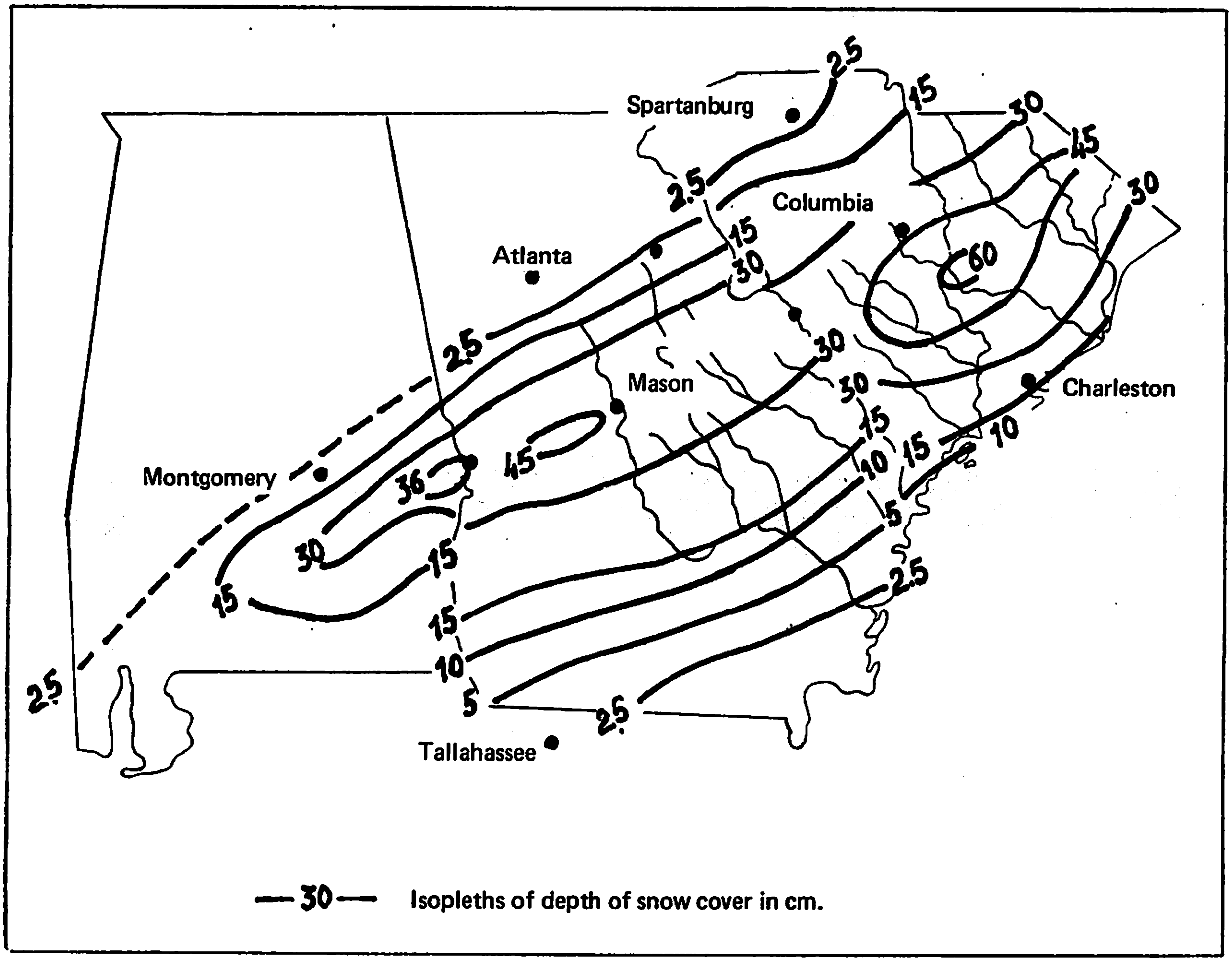
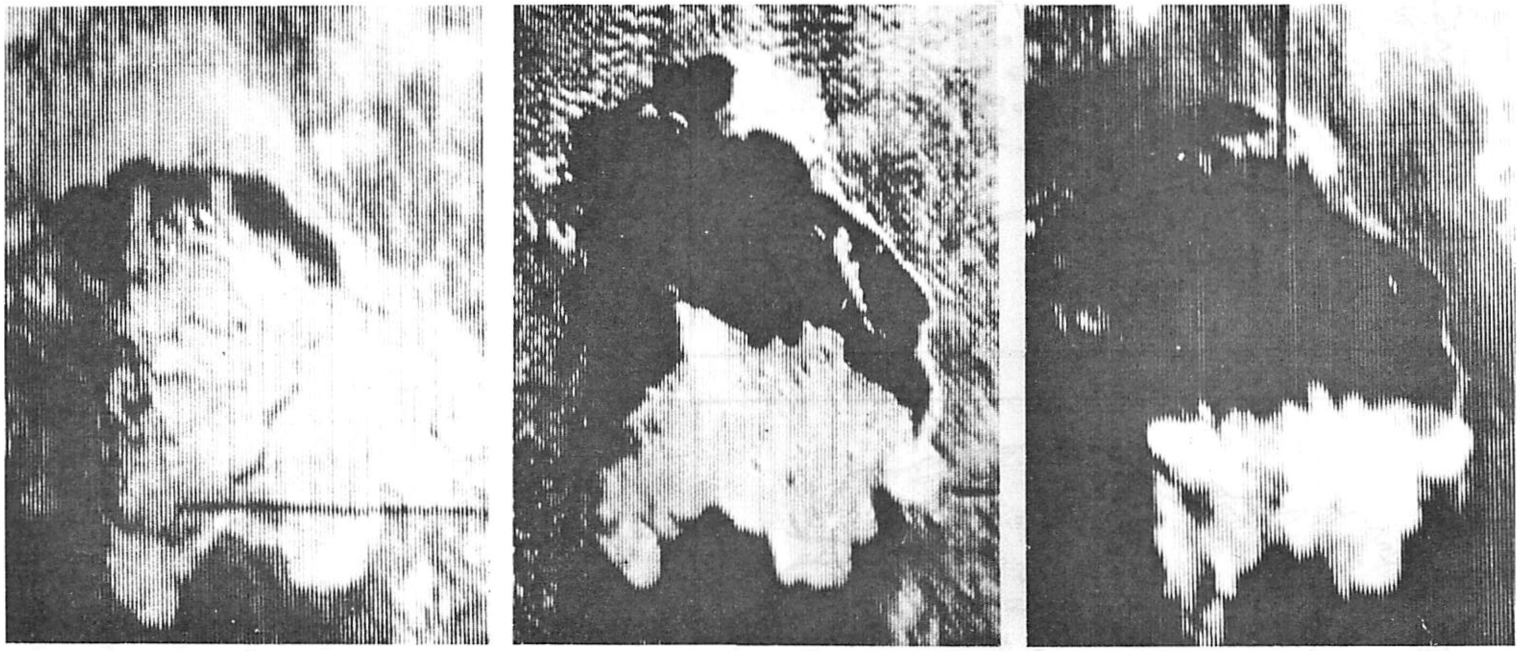


Figure 2 – Isopleths of depth of snow cover in south-eastern U.S.A., determined from ground-based measurements with interpolation aided by satellite brightness measurements from the image in Figure 1



3 April 22 April 3 May

Figure 3 – Changes in ice cover on Lake Ladoga observed from 3 April to 3 May 1976 by "METEOR 13" satellite

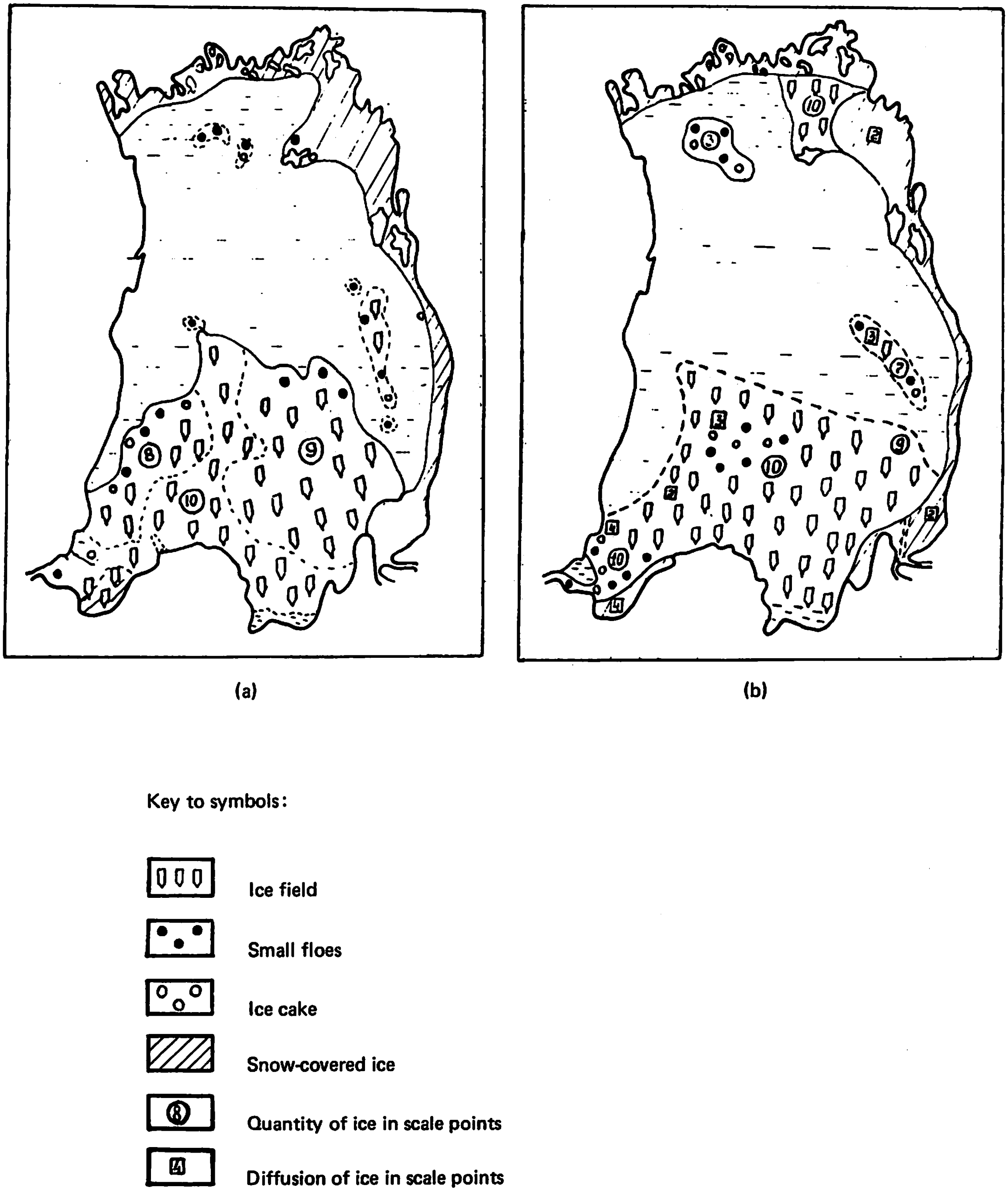


Figure 4 – Map-diagram of ice conditions on 22 April 1974, (a) according to satellite picture, and (b) according to aircraft survey data

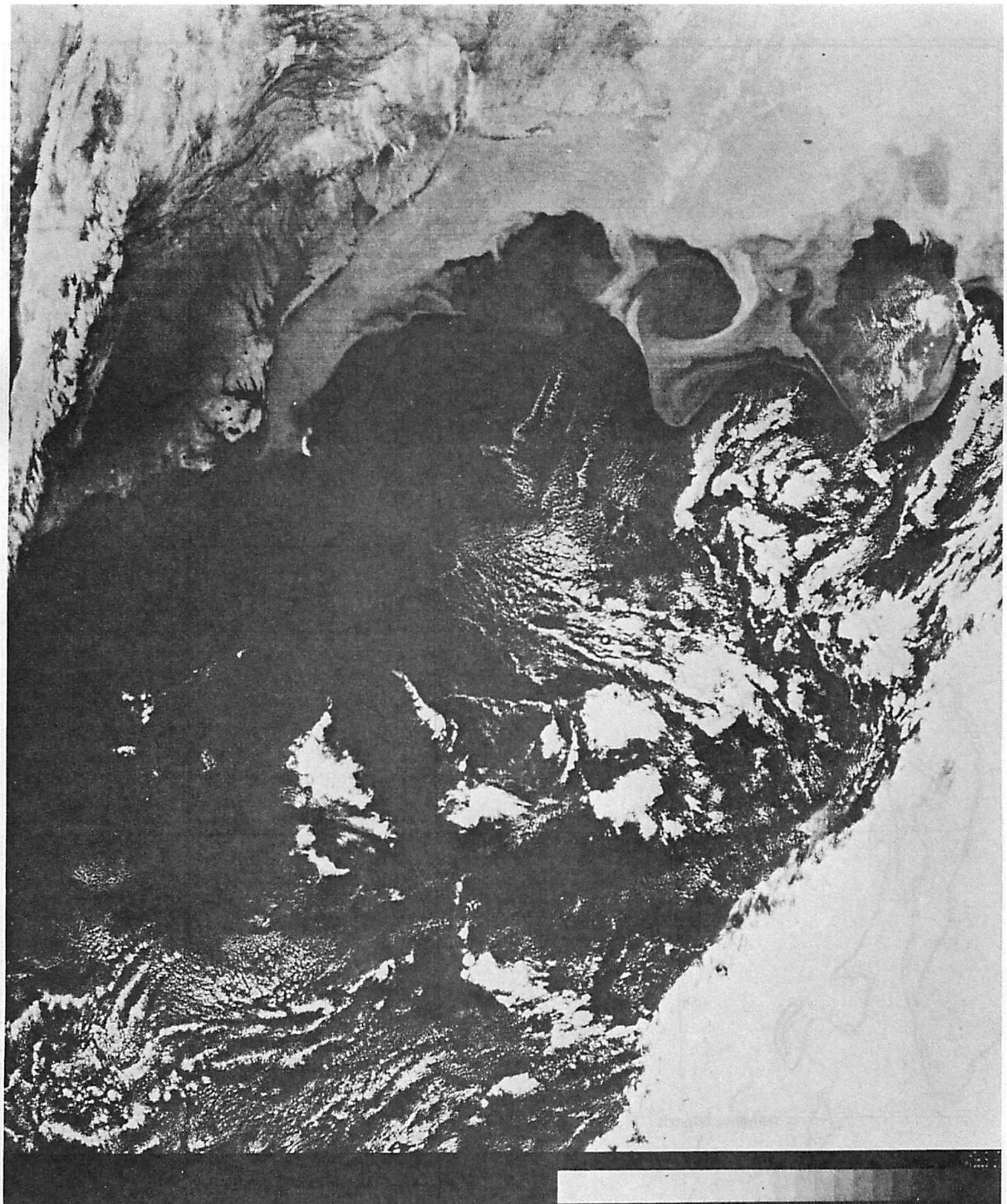


Figure 5 – IR picture of the western part of the North Atlantic, 28 April 1973, NOAA 3 satellite, showing sea-surface temperature gradients

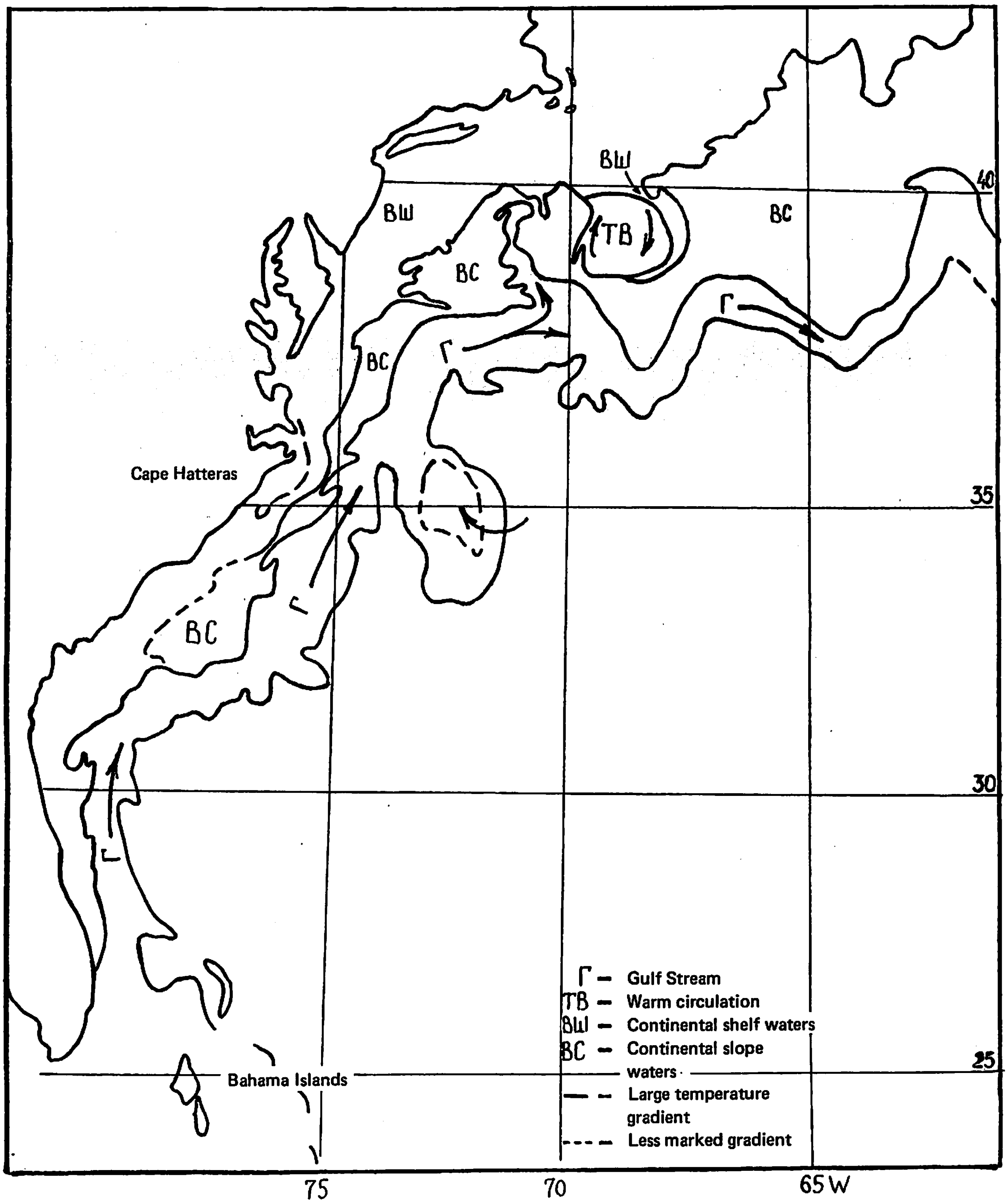


Figure 6 – Experimental analysis of the Gulf Stream from the IR picture shown in Figure 5 (Mercator's projection)

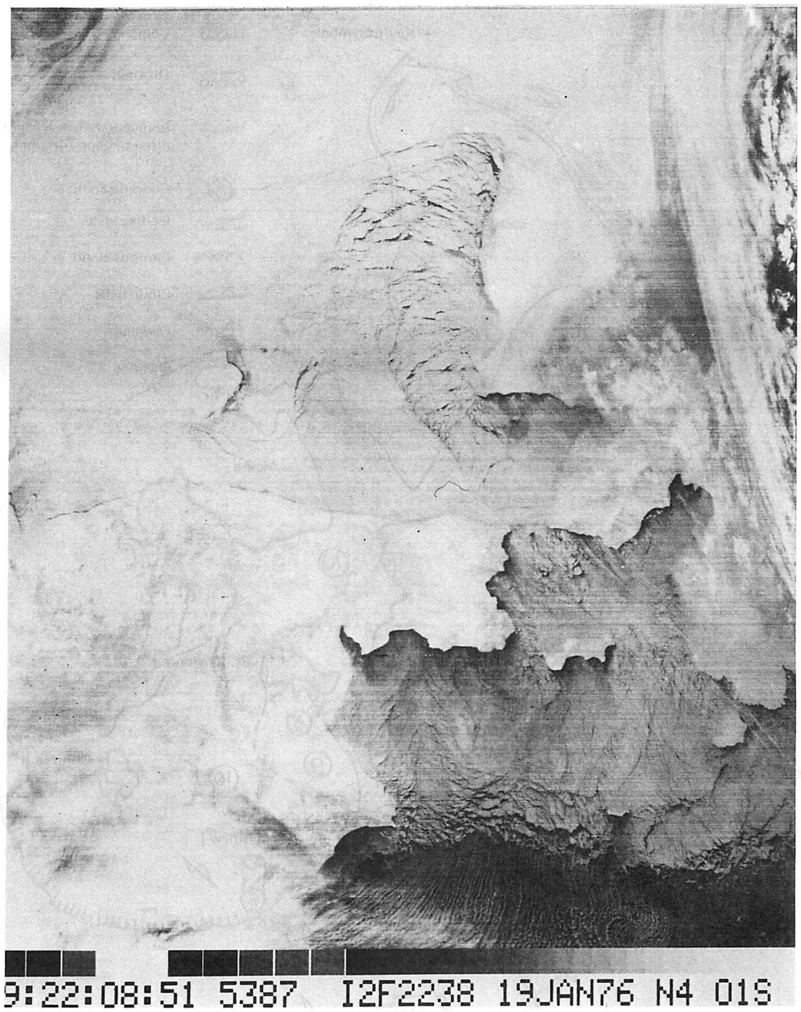


Figure 7 – Ice conditions in the Chukotsk and Bering Seas, as observed in the infra-red on 19 January 1976 by the NOAA 4 satellite

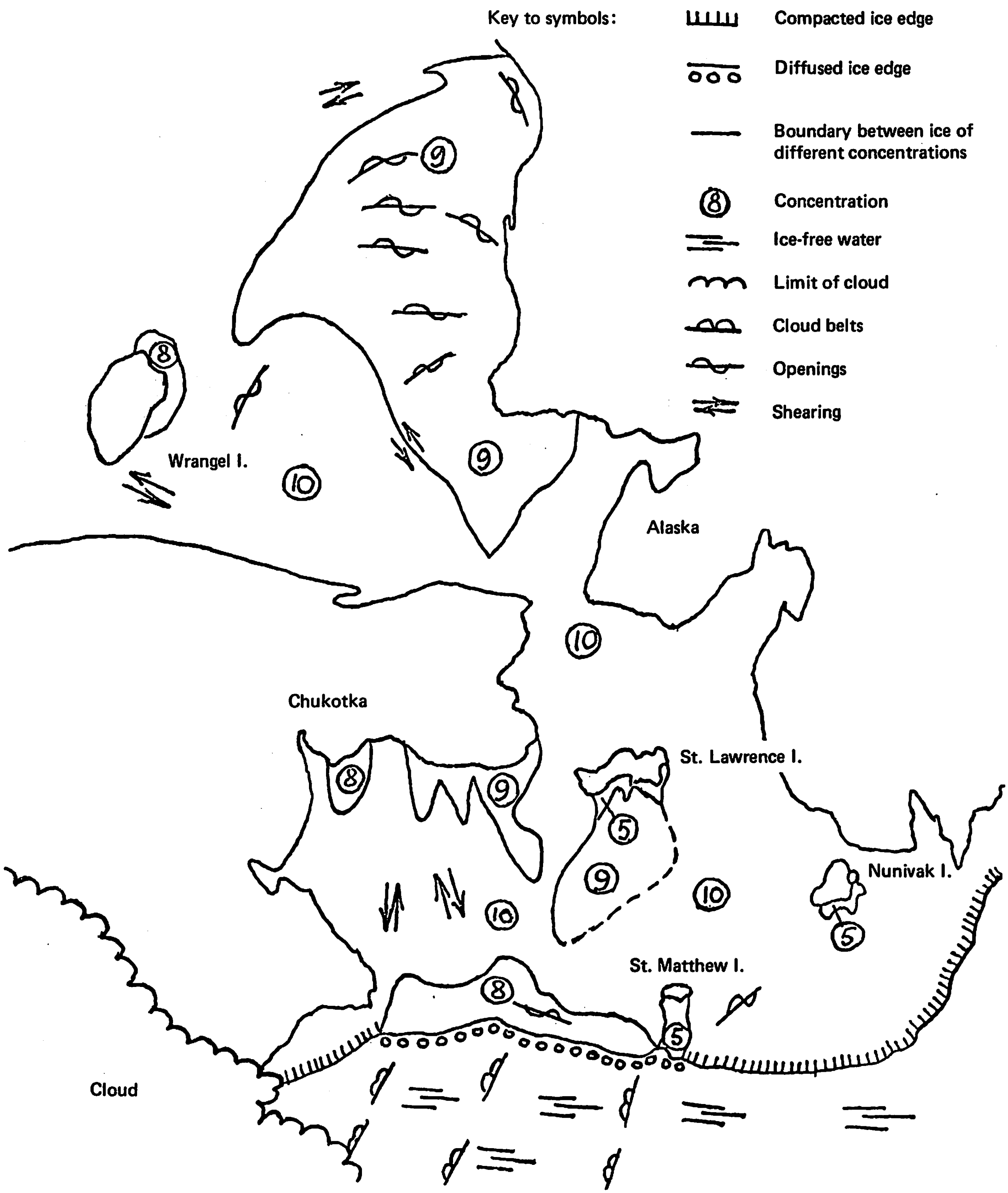


Figure 8 – Map-diagram of ice conditions on the Chukotsk and Bering Seas, corresponding to Figure 7

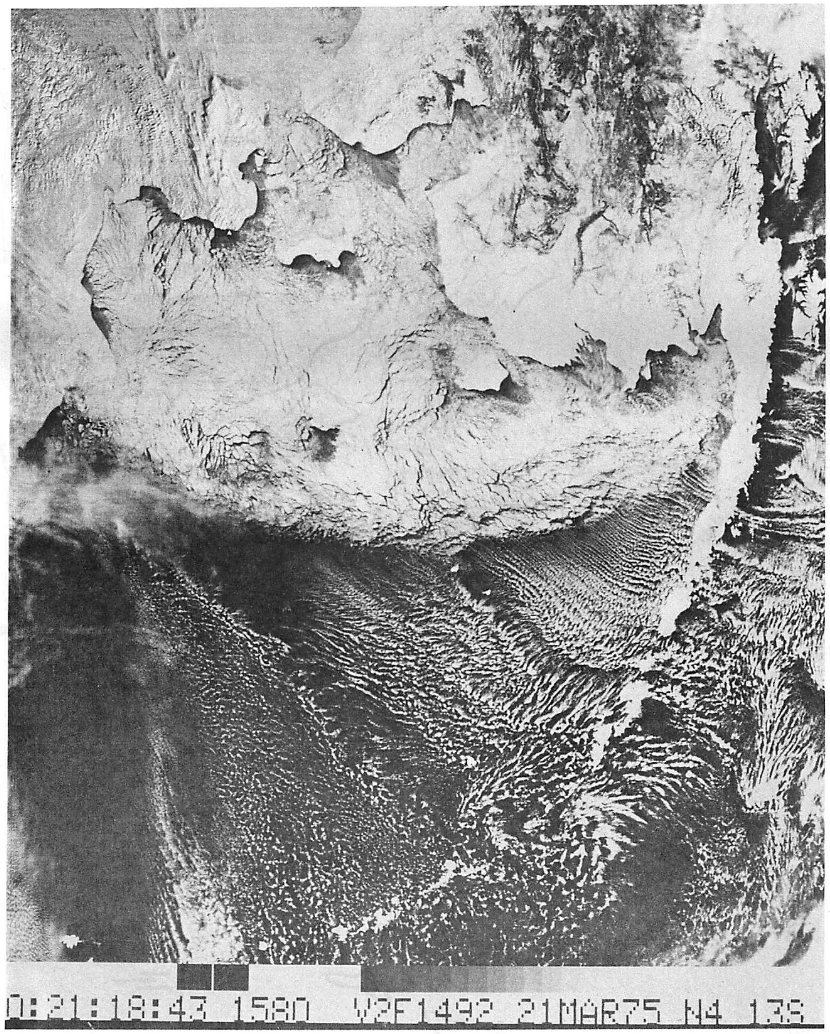


Figure 9 – Ice conditions in the Bering Sea, observed in the visible on 21 March 1975 by the NOAA 4 satellite

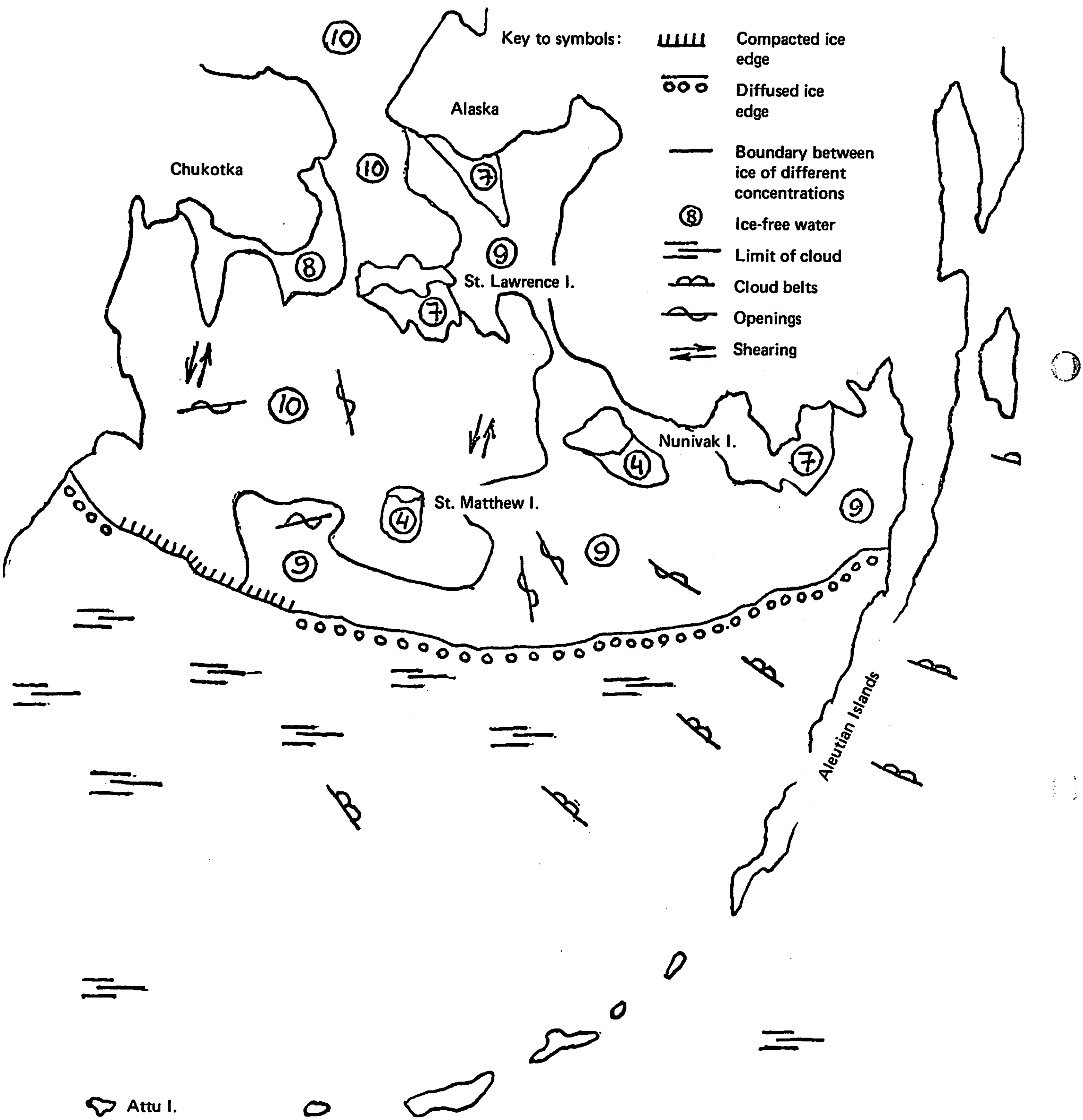


Figure 10 – Map-diagram of ice conditions in the Bering Sea, corresponding to Figure 9

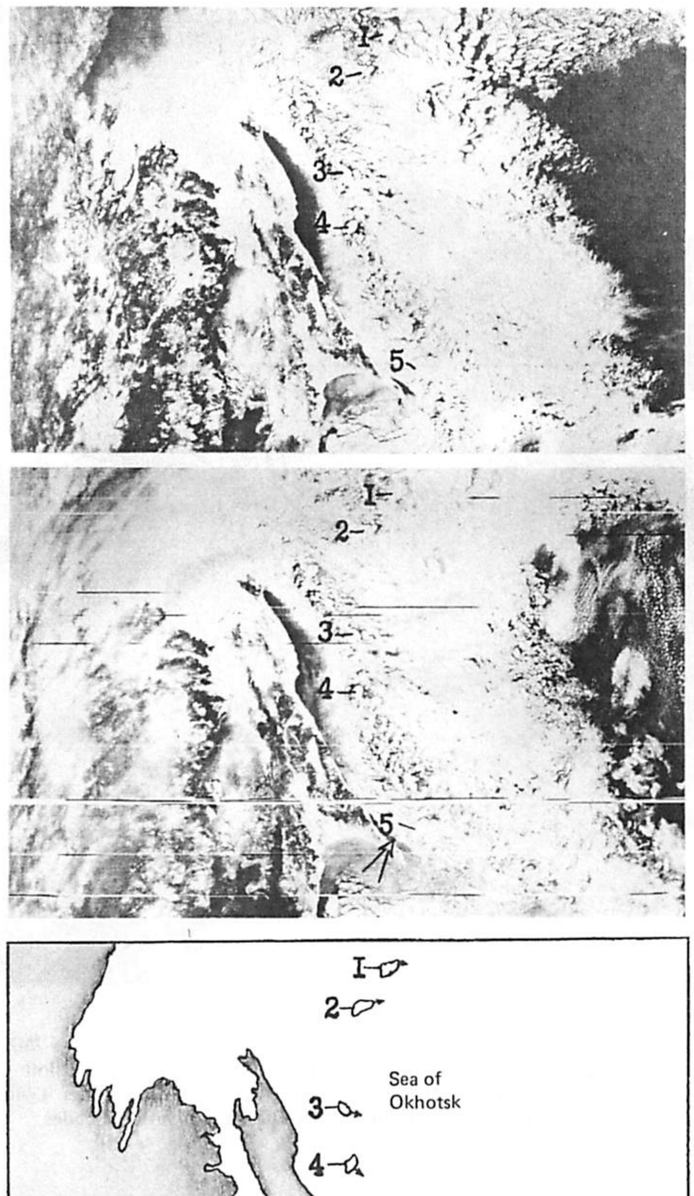


Figure 11 – Ice drift in the Sea of Okhotsk from (a) 12 to (b) 14 March 1975 according to data from "METEOR 18" satellite, and (c) map-diagram. The pictures show the drift of distinct ice formations (in all three pictures they are marked with numbers from 1 to 5). Below the Terpeniye peninsula, in the course of the two days, a coastal polynia formed about 150 km long and up to 30 km wide (shown by a double arrow on picture (b))

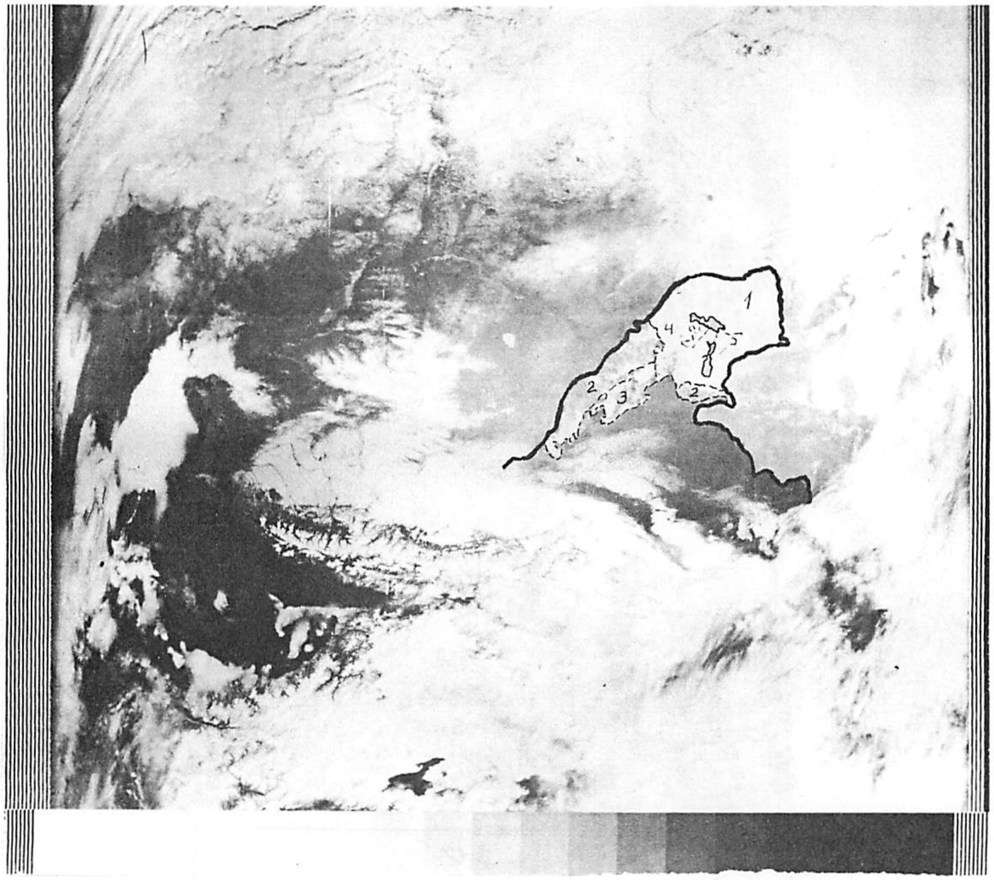


Figure 12 – Ice conditions in the Caspian Sea on 25 February 1976, as observed by the "METEOR" satellite. North-eastern part of the sea is covered with sea ice (I), concentration of 7-10 bright white colour, level ice. The rest of the ice cover has a concentration from 4-6 to 7-8 (2 and 3), having grey and white colours. Leads, polynias and fracture zones (4 and 5) are shown by dark winding lines and isolated dark patches of various shades

Figure 13 – Ice conditions in the Kara Sea (upper part) observed on 24 May 1976 by the "METEOR" satellite

ANNEX I

PHYSICAL BASIS OF REMOTE METHODS OF DETERMINING HYDROMETEOROLOGICAL AND GEOPHYSICAL PARAMETERS

1. Introduction

Measurements from space of the characteristics of the Earth's outgoing radiation in different parts of the spectrum (for example *(a)* reflected solar radiation in the ultra-violet (UV), the visual and near infra-red (NIR) ranges; *(b)* emission in the infra-red (IR) and microwave ranges (SHF)) can provide us with practically all the necessary information on the physical processes in the atmosphere and the ocean. Additional information on the composition of the atmosphere could be obtained from measurements of the solar radiation passing through the atmosphere and from artificial radiation sources (for example, radar, lasers) reflecting off the Earth's surface or the atmosphere. To obtain data on the atmosphere and the ocean from these measurements, the inverse problems have to be solved, i.e. to determine the quantitative physical parameters of the atmosphere, cloud and ocean or to obtain qualitative assessments of the state of these systems on the basis of radiation and transmissivity characteristics.

The outgoing radiation measured by satellites is generated by the whole "air/sea/land" system.

The complex dependence of the outgoing radiation characteristics measured by satellites on the underlying "air/surface" system, which, in turn, is a reflection of the integrated effect of a large number of physical parameters, calls for a many-sided approach in obtaining satellite measurements to be used in determining those parameters. This approach includes:

(a) The choice of the optimum spectrum intervals for measuring the radiation characteristics appropriate to the determination of the required physical parameters of the atmosphere or ocean;

(b) Determination of the optimum design of the measuring apparatus required to obtain the basic information to a degree of accuracy and in a quantity accurate for the solution of the problem;

(c) Determination of the conditions under which satellite and *in situ* measurements are made so as to provide an unambiguous estimate of the accuracy of remote satellite measurements and to reveal the specific peculiarities of satellite data as compared with the results of direct observation;

(d) Development of optimum methods of processing and interpreting the satellite measurements, including the storage and initial processing of the raw data.

The construction of numerical models of information systems applicable to actual conditions plays a significant role in the optimization of experiments. The principle for the construction of such models consists essentially in the following: Given a variety of models of the physical state of the atmosphere and the underlying surface which approach the actual situation, one calculates those characteristics of the radiation field which would be measured by the instruments installed on board the satellite. This permits on a preliminary basis:

(a) Estimation of the range of changes of radiation characteristics which are to be measured;

(b) Determination of the sensitivity of the measured characteristics to various parameters of the atmosphere and the underlying surface;

(c) Definition of the optimum number of spectral intervals in different spectral bands in which the characteristics of outgoing radiation are to be measured;

(d) Checking of various methods of solving the inverse problems and the estimate of the degree of error in the remote determination of physical parameters of the air and sea (land).

2. Basic physical problems

The use of satellite methods for measuring the parameters of the main factors in the information of weather processes, the atmosphere, cloud, the ocean and land surface is justified by the results of research into the complex dependence of radiation characteristics on various physical parameters of the air and sea. When determining the extent of the investigations required, the following important features of the formation processes of the radiation field in the "air/sea/land" system must be considered:

(a) Solar radiation in the UV, visible, and near IR regions of the spectrum (wavelength up to 3 μm), and also the emittance of the planet in the middle IR range (3 to 50 μm), is severely affected by the atmosphere and, in particular, by clouds;

(b) Irradiation properties of the ocean surface in the IR range are fairly stable and differ little from the irradiation properties of an absolute black body. The coefficient of reflection (albedo) of solar radiation from the ocean surface is normally 1-3 per cent (except when the sun's rays fall from a high zenith angle), depending on the type and concentration of hydrosols in the ocean;

(c) Emission from the ocean surface in the microwave range (λ = 1 mm to 10 cm) is, on the contrary, scarcely attenuated in the atmosphere (except in the absorption bands of atmospheric gases, in water clouds, and in areas of precipitation (rain));

(d) The irradiation characteristics of the ocean surface in the microwave range are strongly influenced by the state of the surface and this effect cannot always be distinguished from the effect of cloud.

The varied nature of these influences suggests that the reliable determination of air and sea parameters requires the choice of an optimum set of spectral intervals within which the measurement of radiation enables one to calculate the contribution of the various factors affecting the structure of the radiation field and to determine each of the physical parameters, wherever possible, by two independent methods.

For the purpose of the specific physical problems set forth above, it is desirable to define research procedures appropriate to each of the basic systems concerned: the atmosphere, cloud, sea and land surfaces, despite the fact that these are closely linked one with another.

In the following sections the principles of various classes of satellite measurements are stated briefly and an assessment given of the quality, accuracy and scope expected for each parameter. In some cases, it is based on the latest results of satellite research experiments. Thus, the assessments are predictions of what may be expected by the end of the 1980s rather than an evaluation of the status of measurements from current operational satellite systems.

2.1 DETERMINATION OF PHYSICAL PARAMETERS OF THE ATMOSPHERE

2.1.1 *Mean temperatures of isobaric layers*

The mean temperature of isobaric layers is determined by measuring the radiation in different parts of the absorption bands of atmospheric gases whose concentrations are known and vary little in time and space. A physical prerequisite for such a measurement is the fact that outgoing radiation in the centre of the band is generated at great heights, whereas in the intermediate parts of the band and in the wings it is mainly formed in the middle and lower layers of the atmosphere.

Spectrometers designed for all types of thermal probing are provided in the experimental "NIMBUS" and "METEOR" satellites, as well as in the NOAA operational satellites. Spectral measurements are conducted in the carbon dioxide absorption bands, with centres at 15 or 4.3 μm in the infra-red region of the spectrum, and also in the oxygen absorption band, with a centre of 0.5 cm in the EHF range. In the first case, the method of determining the temperature is based on an assumption of the constancy of CO_2 concentrations in the atmosphere; in the second case, on an assumption of the constancy of atmospheric O_2 concentrations.

Data on spectral measurements obtained by satellites show that it is possible, in principle, to solve problems of thermal soundings. But the accuracy with which temperatures are determined is still insufficient as judged by comparison with radiosonde observations (the mean square error in the troposphere is 2-3 K and it is 4-5 K in the neighbourhood of the tropopause). The upper limit for these soundings appears to be 30-35 km.

To reduce errors in the determination of temperature, it is extremely important to increase the accuracy of the calculated atmospheric spectral transmission functions, which vary widely in real conditions. Therefore, it is necessary when working in the IR range to calculate the effects of clouds' aerosol attenuation at the wings of the CO_2 and water vapour absorption bands (the lines of the latter overlap with the CO_2 band) and, when using the microwave range, to correct for the water content of water clouds and the emittance properties of the underlying surface. It is possible to estimate these factors by means of appropriate additional radiation measurements by satellites. Where these conditions are fulfilled, it may be expected that the maximum altitude of soundings can be raised to a height of about 40-50 km, with a mean square error of determining the temperature of 1-2 K in the troposphere and 2-3 K in the stratosphere.

In addition to thermal sounding methods based on spectral measurements of outgoing radiation, measured by the satellite close to the nadir, methods have been developed in recent years based on the measurement of the heat radiation of the atmosphere on a oblique path. In this case, by using the spectral angle dependence of measured radiation, it is possible to increase considerably the height of sounding and to cover by satellite measurements the part of the atmosphere up to 60-80 km, which, at present, is covered only by an extremely sparse network of rocket probes. Preliminary estimates show that oblique sounding can be as accurate as direct rocket temperature measurements.

2.1.2 *Total water-vapour content and its distribution in layers*

The total content of water vapour is determined by measuring the outgoing radiation in the absorption bands and in the neighbouring "atmospheric windows". This method of determining the total content of water vapour in the atmosphere has now been demonstrated to be acceptable. Water vapour has several absorption bands in the near, middle and far regions of the IR spectrum and some individual absorption lines in the SHF range.

The accuracy with which the moisture content can be determined by measuring the reflected solar radiation in the absorption bands in the near IR range of the spectrum is still indeterminate because methods have to be worked out to compensate or correct aerosol attenuation in cloudless conditions and the additional effects of partial cloudiness, plus scattering of the sun's rays in the upper layers of the atmosphere, leading to the "narrowing" of the absorption bands. Sufficient accuracy may be obtained in cloudless conditions in measuring emission in the absorption bands in the middle and far IR ranges of the spectrum, but as the opacity of the atmosphere increases, there will be an increasing number of errors due to aerosol effects. In cloudy conditions, the moisture content can be determined by means of the IR range only in the atmospheric layer above the clouds.

When using the measurement of heat radiation in the SHF range, the role of aerosol attenuation and ice clouds is negligible. Water clouds, however, have a significant influence on the accuracy with which the moisture content is determined, but this influence may be reduced by additional measurements in the SHF range. The use of the SHF range also involves difficulties connected with allowance for variations in the emittance of the land surface. Water has a high reflectivity so that large variations in emittance are observed between dry and wet soils.

Experiments have been carried out in the U.S.S.R. and the U.S.A. to determine the total water vapour content using absorption bands in the IR and SHF ranges. These experiments show that the total moisture content can be determined with acceptable accuracy, especially from measurements in the SHF range (errors of measurement in the SHF range amounted to 0.2 g/cm^3; with measurements in the IR range, they were 0.2-0.3 g/cm^3 in cloudless conditions).

It is possible to increase the accuracy of determining total moisture content by using a complex set of measurements which will permit a large number of effects to be taken into account when deriving the moisture content. In practice, both the vertical profiles of temperature and humidity, and the total moisture content, should be determined as a single set. With an integrated approach, the total moisture content can be obtained by integrating the vertical moisture distribution by height.

In recent research on estimating the capability of remote methods for determination of the distribution of water vapour in the atmosphere by layers, use was made of spectral measurements in the 6.3 and 20-50 μm water vapour absorption bands in the IR range and of individual absorption lines with a wavelength of 1.35 cm in the SHF range. Satellite experiments have been conducted in the U.S.A. in all three ranges and in the U.S.S.R. in the SHF range. The spectral measurement results made it possible to determine the relative humidity in the middle and upper troposphere with an accuracy of about 20 per cent and, in the lower troposphere, with an accuracy of 30-40 per cent.

The basic difficulties in solving the problem of humidity determination are similar to those encountered in the determination of temperature, with the principal effort concentrated on obtaining greater accuracy. According to the latest theories, errors in determining humidity can be reduced if spectral measurements of outgoing radiation are made simultaneously in the IR range (preferably in the region of 20-50 μm) and in the SHF range (near the 1.35 cm band). This is due both to the apparently more complex form of the corresponding integral equations (IR measurements provide little information about moisture content in the lower layers of the atmosphere) and to the greater ability of SHF radiation to penetrate cloud. The accuracy of determining water vapour concentrations in the troposphere (up to a height of 10 km) may be increased by 10 per cent by:

(a) Reducing errors of measurement in the IR and microwave ranges;

(b) Optimum selection of the number and position of spectral intervals in which measurements are to be made;

(c) Making additional radiation measurements in the "atmospheric windows" in the IR range adjoining the water vapour absorption bands to account for aerosol absorption;

(d) Making additional measurements of the brightness temperature in the SHF range to allow for the effects of water clouds (large amounts of water result in errors which are difficult to remove).

Measurements of the IR and SHF spectra of the Earth's radiation in a zenithal direction permit sounding up to a height of 10 km; to determine water vapour in the stratosphere, the powerful 1.64 cm resonance may be used. The bandwidth of the SHF radiometer can be made sufficiently narrow so that only radiation from a single line in the band is observed and this results in a "sharper" weighting function of the integral equation.

The results of current research have also shown that, to obtain information about the moisture content of the upper layers of the atmosphere (and, in particular, the stratosphere), it is desirable to consider the possibility of applying the method of oblique sounding, i.e. the method based on the use of the angular dependence of outgoing heat (long-wave) radiation. In that case, information on humidity can be obtained to heights of 30-40 km with accuracy of 20-40 per cent.

2.1.3 *Total ozone content and distribution by layers*

It is suggested that, for the best results, measurements should be made of outgoing heat radiation in the IR range in the ozone absorption band of 9.6 μm (i.e., exactly the same methods as are used in solving the problem of the concentration of water vapour), as well as of the reflected and scattered radiation in the UV range of the spectrum.

Results of satellite experiments in the 9.6 μm absorption band, carried out in the U.S.A., have shown that the method of determining ozone concentrations by measuring the spectra of outgoing heat radiation in the 9.6 μm band has limited possibilities.

Probably the most effective method would be to measure:

(a) The reflected and scattered solar radiation in the UV range of the spectrum;

(b) The transparency of the atmosphere in that range over an oblique path.

2.1.4 *Characteristics of aerosols*

The characteristics of aerosols (the optical thickness, vertical distribution of the coefficient of scattering, particle size distribution) have been obtained in a series of space experiments by measuring certain parameters of the Earth's radiation field by satellites:

(a) By means of photographs of the Earth's horizon taken from "Vostok" and "Soyuz" spacecraft, the vertical distributions of the coefficient of aerosol attenuation were determined for a range of heights between 15 and 60 km;

(b) By measuring the angular distribution of reflected solar radiation at various intervals of the visible spectral range – 0.72 and 0.74 μm – obtained by means of a "KOSMOS 149" satellite, the magnitude of the optical thickness of the atmosphere was determined above cloudless ocean areas and other weakly reflecting surfaces.

These experiments, and also the theoretical research on the correlations between reflected solar radiation and aerosol characteristics, have demonstrated the possibility of determining the following parameters:

(a) The optical thickness of the atmosphere at certain intervals of the visual and near IR range (0.55; 0.74; 1.0; 2.2 μm) by measuring the angular distribution of reflected solar radiation (the error of determination is of the order of 20 per cent with threefold or fourfold changes in the optical thickness). The method of obtaining the raw data consists in measuring the brightness temperature above a sufficiently homogeneous and weakly reflecting ocean surface with a photometer, scanning along the satellite's trajectory in planes near to the sun's vertical plane;

(b) Vertical distribution of the coefficient of aerosol attenuation in selected portions of the spectrum in which the absorption bands of gases in constant relative concentrations (oxygen, carbon dioxide) are situated. As raw information, one uses measurements of solar radiation in various portions of selected absorption bands, which enables the attenuation to be determined at various levels in the atmospheric layer up to 10-15 km. Because of the nature of the equation, the measurements of absolute brightness temperature must be made with an error of 1 per cent or less if the desired magnitudes are to be obtained with an acceptable accuracy (of the order of 20 per cent). Such accuracies are fully obtainable when the sun is used as a standard source of radiation;

(c) The spectrum of aerosol particles from the spectral distribution of the coefficient of aerosol attenuation at different levels, obtained when solving the above problem. Since the accuracy of the raw information (the coefficient of aerosol attenuation) will be low, the basic methodological problem here is to seek for additional information which will reduce the error in determining the spectrum of the particles. It is, in particular, necessary to work out a method of determining an indicatrice of scattering from the reflected solar radiation measurements. This problem has also an interest of its own, because the indicatrice is one of the most important characteristics of atmospheric opacity, used in many applied problems. However, satellite methods of determining the characteristics of aerosol opacity of the atmosphere cannot be regarded as fully developed. In particular, the accuracy of these methods has not yet been estimated from independent data.

The above-mentioned methods of measuring aerosol characteristics from satellites are applied only on the sunlit part of the Earth. In view, therefore, of the importance of calculating these characteristics in solving inverse problems of remote sounding of the atmosphere and the underlying surface, the possibility must be considered in the future of using laser measurements of opacity.

2.1.5 *Components of the radiation balance at the upper boundary of the atmosphere*

A number of Soviet and American satellites have been instrumented for measuring the integral fluxes of reflected solar radiation and emittance for the purpose of studying the radiation balance of the earth/air system and its components. Although this problem looks comparatively simple, the direct measurement of the fluxes nevertheless encounters a number of practical difficulties. As a result, the measurements obtained are used only in climatological research.

The main difficulties in the direct determination of radiation fluxes by measurement from satellites are as follows:

(a) Wide-angle measurements lack the angular resolution to observe mesoscale phenomena;

(b) Narrow-angle measurements must be integrated and extrapolated to the whole hemisphere and this process is a potential source of errors;

(c) The use of medium-resolution instruments also fails to solve the problem because their measurements contain undetermined physical magnitudes. This uncertainty is connected with the fact that various arrangements of parts of clouds or other surface bodies (objects) fall within the field of view of the instrument thus strongly influencing the fluxes being measured.

In the selection of the most reliable method of determining fluxes, the effects of the above-mentioned uncertainties must be estimated and, above all, the measured fluxes must be compared with the calculations carried out on the basis of simultaneous measurements of the vertical temperature and humidity profiles, cloud characteristics and other parameters required for determining radiation fluxes.

2.1.6 *Wind speed and direction at heights*

Prior to the advent of geostationary meteorological satellites, wind direction or speed could be inferred only by analysis of cloud type, distribution and patterns, using pictures from polar-orbiting satellites. Such characteristics as Lee wave cloud patterns, cloud "street" and bands, and cirrus cloud "blow-off" from thunderstorms are used. However, these analysis techniques often give only an indication of wind direction and divergence or the broad features of the large-scale air flow.

Numerical prediction models, in particular, require wind speed and direction observations in several layers in the atmosphere with a vector accuracy of $\pm 3 \text{ m s}^{-1}$ (see Annex II – Observational requirements for WMO programmes). Where geostationary satellite images are available, this accuracy is being achieved in those regions where suitable clouds prevail. Generally excellent wind observations are obtained at about 850 mb over most ocean areas by measuring the displacement of cumulus clouds over a period ranging from 30 minutes to two hours. In the same manner, many types of cirrus cloud over oceans and over some land areas can be used to obtain wind vectors in the altitude range 200-400 mb. The altitude of the clouds and thus of the wind value is roughly estimated by measurement of their equivalent black body temperature using the infra-red channel, estimates of cloud emittances and analysis of cloud type. Winds obtained from geostationary satellite image data have been compared with aircraft and balloon data and show excellent agreement, within the stated requirement for accuracy. The large number of cloud tracers available in many regions permit detailed analyses of the deformation field with very high horizontal resolution not previously attainable. This is proving particularly important in the tropics.

No remote sensing technique has been developed to obtain wind observations in clear air. Satellite data-collection systems are available to relay data from aircraft and drifting balloons and to locate the latter. However, the realization of such systems presents a number of practical difficulties.

2.2 DETERMINATION OF THE PHYSICAL PARAMETERS OF CLOUDS

2.2.1 *Spatial distribution and structure of cloud*

Experience in the operation of meteorological satellite systems shows that the basic method for determining the spatial distribution and structure of cloud is to photograph clouds in the visible and infra-red parts of the spectrum. There is no question that, in the future, satellite pictures will be the basic source for determining these cloud characteristics. The possibility of improving the determination of these characteristics is obviously linked to the development of methods for the numerical interpretation of multispectral satellite pictures.

2.2.2 *Height and temperature of the cloud top*

In recent years, much attention has been given to the determination of the height and temperature of the cloud top. These cloud characteristics are determined by outgoing radiation measurements by "TIROS", "METEOR" and "KOSMOS" satellites. Efforts to solve these problems show that the height of cloud tops may be determined by the following methods:

(a) The photometric method based on measuring the intensity of reflected solar radiation in the oxygen absorption band ($\lambda = 0.76\ \mu m$) and in the "atmospheric window" ($\lambda = 0.74\ \mu m$);

(b) Radiometric method, based on an analysis of the radiation temperature of clouds obtained by measuring their emission in the "atmospheric window" in the IR range (10-12 μm).

Trials of the photometric method were carried out, from the "KOSMOS 320" satellite, which showed that the mean square error of the determination of cloud top height was of the order of 1 km. Tests were also carried out from the "Gemini V" spacecraft and from high-altitude aircraft which showed that the accuracy depended strongly on the opacity of the cloud and the "sharpness" of the top. Dense clouds with well-defined top edges yield good results. Thin clouds, particularly cirrus, show large errors.

To increase the accuracy of determination of cloud top height additional information is necessary, enabling corrections for the following factors to be obtained:

(a) The absorption of solar radiation when it is scattered by cloud (this process leads to the effective reduction of the photometric height of the cloud, as compared with the real height);

(b) The back scattering of the atmospheric layer above the clouds, which produces an effective increase of the photometric height as compared with the real height;

(c) Back scattering from the Earth's surface or low clouds below the one being observed. This leads to a reduction in the photometric height.

The absorption of radiation in cloud can be calculated from data of the absolute luminance of clouds in the "window" at 0.74 μm, permitting determination of the optical thickness of the effectively reflecting cloud layer, and from the results of measurements of the water content of the clouds, which permit determination of the coefficient of scattering of solar radiation by the cloud particles. The possibility of calculating the effect of the scattering of solar radiation by the atmospheric layer above the clouds depends on the possibility of determining the vertical distribution of the coefficient of aerosol attenuation or, at least, the optical thickness of the layer above the clouds.

This effect is of particular importance when an optically rather dense layer of aerosols exists above the clouds which merges with the layer of semi-transparent cloud. In this latter case, the photometric height of such multi-layer cloud is situated between the upper and the lower layers; and the very concept of the "cloud top" needs to be clarified. The drawback of the method described above is that it cannot be applied on the dark (night) side of the Earth.

The measurement of the Earth's emission in the "atmospheric window" in the IR range has been an integral part of the meteorological satellite programme ever since such satellites went into operation. Measurements in this "window" are used to produce images of cloud and the Earth's surface, and to determine the radiation temperature of the underlying surface and cloud tops. Where the vertical temperature profile of the atmosphere is known, data concerning the radiation temperature of the cloud tops make it possible to estimate their height. Errors in the radiometric method may be due to the following factors:

(a) The use of climatic temperature profiles where, for any reason, the real profile at the time of measurement is not available;

(b) Variations in the radiation properties (emissivity) of the clouds;

(c) The effect of the atmospheric layer above the clouds which distorts the emission from the clouds.

The effects listed above result in non-controlled errors, which reveal the need for a many-sided approach to the question of interpreting cloud radiation temperature measurements. Since these questions are closely connected with the problem of measuring the temperature of the Earth's surface, they will be considered in greater detail below. In this way, the problem of determining the height and temperature of clouds should be solved together with that of determining the thermal state of the atmosphere and the underlying surface, the phase state and water content of clouds using measurements in the SHF range, and of the moisture and aerosol content components of the atmosphere.

The second approach to determining cloud top heights is laser sounding of the atmosphere from satellites. The principles of this method are sufficiently clear, but the interpretation of the corresponding measurements, though promising, is not a simple matter.

One of the most interesting problems is that of determining the height of the middle cloud layer, i.e. the level of the horizontal layer which divides the cloud into upper and lower parts with different water content. To determine this height, SHF radiometric measurements are made of the middle cloud layer temperature and of the temperature of the ocean surface.

The temperature of the ocean surface can be determined by the SHF radiometric method, by measuring the radiation in the 10-cm range (accuracy of measurement: 1-2 K).

The temperature of the middle cloud layer is estimated from multi-channel measurement data using channels in the EHF/SHF bands, for example, the 0.4, 0.8 and 1.35 cm waves, which makes it possible to distinguish the component radiation from the humidity in the form of vapour and to obtain data on the emissivity and the absorption in the small droplet cloud layer. The amount of absorption in the cloud is a function of the effective temperature and the moisture content. The radiation spectrum of the cloud atmosphere, taking into account the temperature dependence of the dielectric permeability of water, makes it possible to estimate the effective temperature of the cloud. In the case of single-layer cloud with a thickness of up to 2 km, the difference between the effective temperature and the temperature of the middle cloud layer does not exceed 1-2 K. The calculations show that, with an optimum choice of spectral intervals and a 10 per cent accuracy of measurement of the relative absorption, the error in determining the temperature of the middle cloud layer is 2-3 K. In these conditions, the expected error in the determination of the height of the middle layers should be 0.5-1 km.

SHF radiometric measurements are most effective for measuring the height of low-level cloud. With a multi-level cloud structure, combined measurements in the SHF and IR channels enable one to obtain separate estimates of the height of high- and low-level clouds.

2.2.3 *The phase composition of clouds*

In principle, the basis for the solution of this problem consists in comparing measurements of the brightness temperature of the clouds in the 0.8 cm liquid water absorption band with the radiation temperature in the 10-12 μm "atmospheric window" above the ocean. In the case of water clouds, the brightness temperature attains a peak and the radiation temperature is comparatively high (over 273 K). In the case of ice-clouds, the brightness temperature does not change, but the radiation temperature is always below 273 K, the value of the latter depending on the height of the cloud top. The problem under discussion is thus linked with that of determining the cloud-top height. Experiments in determining the phase composition of clouds by radiation measurements in the 0.8 cm band and in the 10-12 μm "window" by "KOSMOS 243" and "KOSMOS 348" satellites have shown that, where the water content is sufficiently great, a reliable separation of water clouds can be obtained. Cases are observed, however, of comparatively low peaks of the brightness of temperature, with values of the radiation temperature approaching 273 K. In these cases, the cloud layers may be confused. For reliable identification, both in these cases and with pure water (liquid) and pure ice clouds, another set of measurements may be used, including measurements of the radiation temperature in the 10-12 μm "window" and measurements of reflected solar radiation in 0.95 μm band for water vapour and the 1.03 μm band for ice. Such measurements taken from a "KOSMOS 320" satellite show that they enable a well-defined separation to be made between water (liquid) and ice clouds and groups of mixed clouds.

The combination of both sets of measurements referred to above increases the reliability of identifying all three groups of cloud. Water and ice clouds can also be separated by measurements of the polarization characteristics of reflected solar radiation in the visible and near IR range of the spectrum. The method of interpreting such measurements, especially in the case of mixed clouds, has not yet been sufficiently developed.

Water and ice clouds may be distinguished by the combined analysis of cloud pictures in the 8-12 μm "window" in the IR range and of polarization measurement data of radiation in the 0.8 cm band. This set of observations is being carried out by the "METEOR 18" satellite.

2.2.4 *Total water content of clouds*

This problem may be solved by measuring the brightness temperature of clouds in the SHF range of the spectrum on the 8-12, 3.5-2.5, 1.6, 0.8 and 0.4 cm wavebands. Measurements in a limited range on the 8.5, 3.4 and 0.8 cm wavebands, carried out by a "KOSMOS 243" satellite, made it possible to distinguish five gradations of water content of clouds and areas of moderate and heavy precipitation.

The main difficulty in determining the water content of clouds is the non-homogeneity of the temperature structure of the main mass of droplets in the cloud and the variation in the radiation properties of the water surface related to the formation of foam and spray. The influence of the latter factor can be excluded by using additional information enabling a reliable distinction to be made between the cloud-covered and cloudless sea. Such information can be obtained by simultaneous measurements of radiation in the IR "windows" and the visible range of the spectrum.

2.2.5 *Location of precipitation areas and their intensity*

Rainfall areas can be tracked and their intensity estimated by measuring radiation in the SHF range, because the brightness temperature in that range of clouds from which rain is falling is quite different from the outgoing radiation in cloudless conditions. Apart from that, one of the distinguishing features of SHF radiation in the atmosphere when rain is falling (in comparison with colloidally stable clouds) is the polarization effect. But when making space observations to determine the polarization components of SHF radiation, it is necessary to exclude the influence of the underlying surface, which may have a determinant effect on radiation measurements on two or more specially selected frequencies, chosen so as to differ significantly according to the brightness temperatures of cloud and negligibly according to the radiation properties of the surface. For example, for the separate detection, above the ocean surface, of dense cloud and rain of an intensity exceeding 2 mm/hour, the 3- and 10-cm wavebands can be recommended. Calculations show that rain can cause a difference in the brightness temperatures of the air, in vertical and horizontal polarizations, of the order of 10-15 K, while with 10-cm waves, it does not exceed 1 K. Several gradations of rainfall intensity and of the moisture content of water clouds can be separately estimated according to the magnitude of the brightness temperature on two polarizations perpendicular to one another. In addition to this method, which can only be applied over water surfaces, precipitation areas can be determined by simultaneous measurements of the luminance of clouds in the visible and IR ranges. The numerical evaluation of the accuracy of this method, however, requires further development.

2.3 DETERMINATION OF PHYSICAL PARAMETERS OF THE OCEAN SURFACE

2.3.1 *Ocean-surface temperature*

Satellites can determine the temperature of a water surface by measuring the intensity of the heat radiation in the "atmospheric windows" in the IR and SHF ranges of the spectrum.

In the measurement of water-surface temperatures, it is advisable to use thermal radiation in the 5- to 10-cm waveband, where there is a marked dependence of the brightness temperature on the actual temperature variations. In the case of observations of calm waters the temperature may be estimated with an accuracy of 0.5 to 1.5 K. Data are available from experiments concerning the effectiveness of the SHF radiometric method in which measurements were made from aircraft and from the "KOSMOS 243" satellite.

The basic advantage of the infra-red part of the spectrum lies in the fact that the degree of blackness of a water surface is near to 1 and varies within narrow limits so that the average difference between the radiation and the kinetic temperatures of the ocean surface is 0.5 K. In addition, a sufficiently high-range resolution (1-2 km) can be obtained in the IR range of the spectrum. A drawback of the IR range is the strong atmospheric distortion of ocean radiation due to the considerable absorption and emission of the atmosphere which, even in cloudless conditions, may lead to errors of the order of 5-10 K in determining the ocean temperature. In cloudy conditions, the IR range can only determine the radiation temperature of the cloud tops.

The basic advantage of microwave radiation is the virtual absence of any attenuation due to the atmosphere and cloud, except for clouds with a high water content and precipitation. The disadvantage of the microwave range is connected with the fact that the emissivity of the ocean in this range varies considerably, depending on the state of the surface. This leads to the change of the ocean brightness temperature in a manner similar to the changes caused by water clouds and precipitation. For the reliable determination of ocean temperature it is therefore necessary to use radiation measurements in both spectral ranges simultaneously. This makes it possible to separate the surface and the cloud effects, to check the state of the surface where there is no cloud cover and to increase the accuracy of determination of the surface temperature.

To obtain accuracy to within 1 K in determining surface water temperature it is necessary to:

(a) Increase considerably the sensitivity of radiometric apparatus (it must be brought to 0.1 K);

(b) Carry out accurate measurements of the dielectric characteristics of the ocean;

(c) Conduct complex measurements in the SHF range enabling corrections to be made for agitation and salinity.

2.3.2 *Location of main ocean currents*

To determine the positions of currents by the topographic characteristics of the ocean surface, the satellite's orbit (in relation to the centre of the Earth) must be determined with great accuracy, and the position of the mean sea level must be very well known, as well as the distance of the satellite from the sea surface. The exact position of the stationary ocean geoid (allowing for gravitational anomalies) can, of course, be obtained as a result of a long process of averaging, if care is taken to exclude stationary deviations caused by ocean currents and other quasi-stationary factors. Here simultaneous observations from satellites and from ships are necessary.

There are several methods of determining topographic details of the ocean surface:

(a) Measurement of the scattering of radio waves reflected from the ocean surface when the transmitter is located on a ship and the receiver on a satellite;

(b) Use of a short-pulse radar altimeter (the wavelength should be significantly smaller than the magnitude of the vertical measurement being made);

(c) Obtaining a radar picture by means of a radar scanner.

At the present time, radio-altimeters in the SHF band with a signal pulse of 5-20 seconds enable surface measurements to be made from heights of 100 to 500 km with an accuracy of 3 to 5 m and the position of depressions and the features of the marine geoid to be determined. "Skylab", for example, in the course of its radio-altimeter experiment on ocean topography, obtained profiles of the Puerto Rico depression and revealed a number of other anomalies.

It may be expected that, in future, the accuracy of radio-altimeter measurements of the level of the ocean surface will be improved to values of 0.3 to 3 m, which will make it possible to measure the tidal fluctuations, the variations of level resulting from changes in atmospheric pressure and mesoscale eddies.

The maximum accuracy of radio-altimeters for studying ocean topography is limited by a number of factors, including the accuracy of the orbit tracking and the precision of the altitude stability of the carrier, variations in the propagation speeds of the radio signals with changing atmospheric conditions, and the state of the ocean surface.

2.3.3 *Wave and wind at the ocean surface*

Measurements of wind speed vectors, of parameters of the gravitational wave and of the intensity of foaming are made with the aid of the characteristics of scattering and the SHF radiation properties of the water surface.

The amplitude of the capillary waves, which depends on the speed of the surface wind, can be estimated by measuring the intensity of the back scattering in the SHF range with oblique sounding. The dependence of the intensity of scattering on the azimuthal angle between the wind direction and the line of sight can be used for determining wind direction. The methods described enable the wind velocity in the range of 0 to 3 m s^{-1} to be estimated with an accuracy no worse than 10 per cent.

An experimental test of the radar method of estimating the surface wind speed from a "Skylab" spacecraft showed that the divergence between the wind speed estimated made from satellite and surface data does not exceed 10 per cent, except in cases of intense precipitation. The height of the gravitational wave in the ocean may be determined by means of vertical radar sounding with wideband signals with a range resolution no worse than 1 m. It is also possible to take soundings with two (or more) frequencies and then to correlate the results (using the correlation of the inter-channel correlation coefficients of the echo-signals with the distribution of height variations of the water surface).

An independent method of estimating wave height is to measure the spectrum expansion of the echo-signal produced by the difference in direction of the orbital particles movement at the crest and troughs of the ocean waves. The characteristics of the spatial structure of the wave field at the sea surface (length of waves, direction of movement) can be obtained by radar pictures with a spatial resolution not worse than 10-20 m. Radar observations with high-resolution capacity are accompanied by time-modulation effects of the echo-signals which enable the period of wave movement and the effective wave height to be estimated.

Measurements of variations in the intensity of long-wave radiation from the ocean in the SHF range make it possible to identify the degree of surface agitation. The effect of changes in the polarization and emission depending on the state of the sea surface can be used to indicate ocean-surface gradients.

2.3.4 *Characteristics of ice conditions*

The contrast of the brightness temperatures in a field of sea ice in the SHF range does not exceed 100°K, so that measurements of the emission of polar seas make it possible to determine sea-ice concentration. Measurements on several wavelengths (for example 8.3 and 0.8 cm) enable one to distinguish the obstacles produced by possible scattering by non-uniformities of the ice structure. The possibility of using the SHF range for studying ice conditions has been confirmed by experiments with "KOSMOS 243" and "KOSMOS 384" satellites.

With ice thicknesses of several decimetres, the thickness of ice fields in process of growth can be detected and estimated from emission measurements in the IR and SHF parts of the spectrum.

Ice-field drift can be estimated by measurements on radar pictures. The inadequate spatial resolution of SHF apparatus, however, seriously limits the possibilities of the detailed study of ice conditions.

2.3.5 *Salinity and the location of pollution areas*

Estimates of variations in the salinity of sea water may be made by active radar soundings at angles near the vertical and by UHF radiometric measurements. Salinity variations manifest themselves in the form of variations in conductivity, leading to changes in the reflectivity of sea water in this waveband. Calculations show that the radiometric sensitivity is 0.3 to 0.6 K per g/l; the change in the reflectivity is 0.4 to 0.8 per cent per g/l in the UHF range.

Radiometric measurements from aircraft show that the radiometric sensitivity to changes in salinity increases in proportion to wavelength. However, the use of wavelengths above 40 to 60 cm may result in increasing effects of interference from cosmic rays and in a deterioration of the spatial resolution.

When estimating salinity by the radar sounding method, it is advisable to use the VHF waveband where the sensitivity is 0.4 to 1 dB per g/l.

The possibility of detecting oil and petrol on the water surface is related to the effects of the damping of the capillary waves and the diminution of the reflectivity of the water surface due to the presence of a transition layer in the form of a film of oil or petrol.

In cloudless conditions, information about the pollution of the sea surface may be obtained from measurements of the reflected solar radiation spectra and their polarization characteristics in the visible and near IR ranges. When interpreting these measurements, however, it is important to take account of variations in the luminance of the atmosphere, which, in these ranges, make a significant contribution to the radiation of the "sea/air" system; aerosols constitute an important factor in such variations. This means that the problem of the determination of a polluted ocean surface must be solved in combination with the problem of determining aerosol content.

2.3.6 *Ocean admixtures*

In studying ocean admixtures, measurements of reflected solar radiation spectra in the visible range can be used. The most important admixture in ocean water is the chlorophyll contained in plankton. The study of the global distribution and variations of plankton is one of the most important problems of space ecology and the study of the natural resources of the ocean. Chlorophyll has two clearly distinguished absorption bands in the visual range of the spectrum. One of these (the stronger) lies in the violet-blue portion of the spectrum (0.43-0.46 μm) and the other in the red band (0.66-0.70 μm). The chlorophyll content can be estimated by measuring the radiation reflected by the ocean in the range $\lambda = 0.430\ \mu$m (the chlorophyll absorption band). A comparison of such measurement data with standard methods of determining chlorophyll reveals a good coincidence. If we assume that the concentration of chlorophyll is proportional to the plankton content, we obtain a method of estimating the plankton content of sea water. In order to develop this method, it will be necessary to study the effects, on the reflection spectra, of the state of the plants, the time of year, the role of other pigments contained in the plants and the transmission function of sea water and the atmosphere. A promising method of obtaining some idea of the vertical structure of chlorophyll (and plankton) is active location by means of lasers.

2.4 DETERMINATION OF THE PHYSICAL PARAMETERS OF THE LAND SURFACE

2.4.1 *Land-surface temperature*

In addition to their purely meteorological significance, data concerning land- (soil-)surface temperatures are extremely important for agrometeorological purposes. The same methods for obtaining such data from satellites can be used as in the case of determining water-surface temperatures, i.e. radiation measurements in the "atmospheric windows" of the IR and SHF ranges. While the basic problem of interpreting these measurements are common to the ocean and to the land, there are certain specific differences. For example, the use of the SHF range is less effective in the case of the land surface than in that of water surfaces, because for water surfaces the atmosphere has a negligible effect in that range. In the case of land surfaces, such measurements are significantly affected by a large number of factors, including moisture and variations in the reflectivity of land objects in both the SHF and the IR ranges of the spectrum. However, radiation measurements in certain parts of the IR and SHF ranges can give a fairly high reliability in determining soil temperature and humidity.

2.4.2 *Soil-moisture content*

In recent years, a number of satellite methods have been suggested for the remote sensing of soil moisture and plant cover. In solving this problem, it has been proposed that use should be made of the dependence of the following characteristics of soil types and cover on the moisture content:

(a) Reflectivity in the near IR range;

(b) The extent of polarization of the solar radiation reflected from the soil in the visible part of the spectrum;

(c) The properties of emission in the SHF range.

The use of active radar methods is also recommended.

In view of the fact that the reflection and emission properties of land-cover areas depend not only on temperature and humidity but on other factors, it is possible to obtain a reliable estimate of the humidity only for selected areas where the state of the plant cover is known or for areas having standard analogies. For example, the roughness of the surface, the angle of observation and the type of plant cover have a significant effect on reflectivity in the near-IR range.

To reveal the real possibilities of applying the proposed methods to the estimation of humidity, the methods must be thoroughly tested on the basis of experimental data with a view to selecting the optimum method and to collecting material for establishing relations between moisture and radiation characteristics.

ANNEX II

OBSERVATIONAL REQUIREMENTS FOR WMO PROGRAMMES

The tables in this annex summarize the observational requirements for WMO programmes (requirements which are often formulated in terms of conventional observing systems) and show the possibility of meeting these with data from meteorological satellites in the 1980s. Undoubtedly, these tables will need revision as the relevant bodies of WMO continue their examination of satellite technology and consider the role of satellite data in WMO programmes. The sources of these requirements are listed below.

1. Observational requirements for WWW (and FGGE) and further observational requirements for research activities in addition to the WWW requirements (Tables I and II)

These have been extracted from the following publications:

(a) WMO Publication No. 49 - Technical Regulations;

(b) WMO Publication No. 418 - World Weather Watch - The Plan and Implementation Programme 1976-1979;

(c) The Physical Basis of Climate and Climate Modelling, 1975, GARP Publication Series No. 16;

(d) First GARP Global Experiment - Objectives and Plans, 1973, GARP Publication Series No. 11.

2. Observational data requirements in hydrology (Table III)

2.1 An Informal Planning Meeting on Satellite Applications in Hydrology (Geneva, 1976) compiled a list of data requirements which may serve as a basis for further studies by the competent WMO bodies, particularly the Commission for Hydrology. For ease of reference, this list is summarized in the Tables in which the desired resolution, accuracy and frequency for each element have been indicated from the operational view point and which might also meet the needs for specific research projects. The observational requirements for hydrology listed in Table III have been taken from the report of the above-mentioned Informal Planning Meeting.

2.2 It is difficult to establish definite requirements in terms of spatial resolution, accuracy and frequency of observation for the measurement of hydrological elements. Operational and experimental hydrological programmes normally deal with specific drainage basins. In some countries, such as Switzerland, basins less than 100 km^2 are of considerable operational importance. In other countries, such as Canada and the U.S.S.R., basins involved in operational programmes may be as large as, or larger than, 10 000 km^2. Thus, the resolution requirements must be tailored to the size of the drainage basin (or lake, glacier, etc.), involved. In Table III, figures are given for the following sizes of drainage basin: A - less than 100 km^2; B - between 100 and 1000 km^2; C - more than 1000 km^2.

2.3 It is also difficult to generalize hydrological data requirements because, in different countries, many different levels of research and operational activities exist. The requirements for operational programmes in developed countries generally differ from those in developing countries. The data requirements listed in Table III represent compromises between these different needs. They may be considered for many operational and experimental or research projects which are directed towards eventual application to operational programmes. Many other research projects, and perhaps some operational programmes, will require very different values of resolution, accuracy, or frequency. The accuracy and frequency requirements given in brackets in Table III are the values recommended by the Informal Planning Meeting mentioned earlier. Those not in brackets are the requirements given in relevant WMO Guides and in the Technical Regulations.

2.4 Spatial resolution is an exceedingly complex subject. Obviously, satellite image resolution should be matched to the map detail, expressed as resolution, which is required by the users. At least three aspects of spatial resolution are of interest to hydrologists:

(a) Image resolution (which may be expressed in several different ways);

(b) Accuracy of locating surface features (such as a flooded area or a sediment plume) on a map;

(c) The high degree of resolution which may be required to detect a hydrological element (such as snow in openings between trees) even though such a fine degree of resolution is not specifically required for hydrological application.

The distinction between (a) and (b) is as follows: although image resolution may be high enough to delineate a major thunderstorm system, the location accuracy may not be good enough to show, by the assessment of successive images, whether or not the thunderstorm system is stationary over a stream basin. The resolution required also depends to some extent on the information content of the remote sensing system and the method of processing the data. In Table III, the order of magnitude of resolution is estimated, based on the hydrological application required. However, the values given must be considered as approximate and preliminary.

2.5 The legal aspects of dissemination of very high resolution images of the Earth from space are under consideration by the United Nations Outer Space Committee.

2.6 Accuracy and frequency of observational requirements have been estimated for most of the hydrological elements considered. It must be noted that when dangerous or extreme phenomena, such as major floods or large mudflows occur, more frequent observations may be required. More frequent or more accurate observations may also be needed for research purposes. On the other hand, less frequent and less accurate observations may suffice for some routine purposes.

3. Observational requirements for marine activities, including oceanography (Table IV)

3.1 The following statements of satellite observing requirements have been taken from the report of the Informal Planning Meeting on the Satellite Applications in Marine Activities, including Oceanography (Geneva, 6-9 September 1976). Satellite information is being used for the observation of sea ice in a number of oceanographic research programmes and in support of marine forecasting. The formal statements of specific user requirements contained in the WMO Marine Science Affairs Report No. 4 - Requirements for Marine Meteorological Services - WMO Publication No. 288, although not specifically directed to satellite observations, have been taken into consideration in the following tables. Applications of marine, atmospheric and ocean parameters are manyfold and vary from one area to another as a function of the scales of the phenomena to be investigated. Satellite, surface-based and aircraft observations should form one integrated system, with due appreciation of the advantages of each type of observation. Ultimately, marine observational requirements should therefore be expressed in terms of the various possible types of observation and this calls for a combined effort from both the user and the instrumental engineering communities.

3.2 As a basis for further work, Table IV lists the satellite information which has been stated to be required and provides, where possible, further detailed information about the resolutions, frequencies and accuracies needed.

3.3 Arrangements for further study have been made both by the WMO Commission for Marine Meteorology (CMM) and the Intergovernmental Oceanographic Commission (IOC). A report on past, present and future capabilities of satellites in support of oceanography is being prepared by an IOC rapporteur. CMM has recently nominated a Rapporteur on the Study of Satellite Data Requirements for Marine Meteorological Services (Resolution 3, CMM-VII).

4. Observational requirements for agrometeorology (Table V)

The observational requirements listed for agrometeorology have been compiled by the WMO Secretariat in consultation with the president of the WMO Commission for Agricultural Meteorology (CAgM). This list sets out the satellite data which would be useful in agrometeorology and may serve as the basis for the further studies in the formulation of observational requirements in this field.

TABLE I

Observational requirements for WWW (and FGGE)

Parameter	Requirements			Available from satellites	
	Horizontal resolution	Vertical resolution	Accuracy	Expected 1980s	Remarks
Mid and high latitudes					
Temperature	500 km	4 levels in troposphere 3 levels in stratosphere	± 1°C	Possible ± 1.5°C - 2°C	± 1.5°C expected after 1985
Wind	500 km	4 levels in troposphere	$\pm 3\ m\ s^{-1}$	Possible 2 levels in troposphere	Where suitable clouds exist over oceans, but not at high latitudes
Relative humidity	500 km	2 degrees of freedom in troposphere	± 30%	Possible	
Sea-surface temperature	500 km	-	± 1°C (FGGE ± 0.5°C)	Possible ± 1.0°C to 1.5°C	Perhaps ± 1.0°C after 1985; ± 0.5 to 1.0°C relative accuracy possible for horizontal gradients
Pressure	500 km	-	± 0.3%	Not possible	
Tropics					
Temperature	500 km over land 1000 km over oceanic areas (FGGE 500 km)	4 levels in troposphere 3 levels in stratosphere	± 1°C	Possible ± 1.5 - 2°C	± 1.5°C expected after 1985

TABLE I (contd.)

Observational requirements for WWW (and FGGE)

Parameter	Requirements			Available from satellites	
	Horizontal resolution	Vertical resolution	Accuracy	Expected 1980s	Remarks
Wind	500 km over land 1000 km over oceanic areas (FGGE: stratosphere 4000 km troposphere active regions 350-500 km inactive regions 500-700 km)	4 levels in troposphere (FGGE 5 levels) 3 levels in stratosphere	± 2 m s^{-1}	Possible ± 3 m s^{-1} 2 levels in troposphere	Where suitable clouds exist over oceans, but not at high latitudes
Relative humidity	500 km over land 1000 km over oceanic areas (FGGE 500 km)	2 degrees of freedom in troposphere	$\pm$ 30%	Possible	
Sea-surface temperature	1000 km (FGGE 500 km)		$\pm 1^{\circ}$C (FGGE $\pm 0.5^{\circ}$C)	Possible $\pm 1.0^{\circ}$C to 1.5°C	Perhaps $\pm 1.0^{\circ}$C after 1985; $\pm$ 0.5 to 1.0°C relative accuracy possible for horizontal gradients

TABLE II

Further satellite observational requirements for research activities in addition to the WWW requirements

Parameter	Requirements			Available from satellites	
	Horizontal resolution	Frequency of observation	Relative accuracy	Expected 1980s	Remarks
Planetary radiation budget (at top of atmosphere)					
(a) Longwave flux	300 km	4 times daily	5%	Possible	
(b) Reflected shortwave flux	300 km	2 times daily	5%	Possible	
(c) Solar fluxes (total and spectral intervals)		Weekly	1%	Possible	
Clouds (imagery) (infrared and visible)	1 - 8 km	Every ½ hour over full disk of geostationary satellite; 2 to 4 times daily or more in areas poleward of geo-stationary coverage		Possible	Half-hour images only available from geostationary satellites
		Every 5-15 minutes for mesoscale problems		Possible	Only from the geostationary satellites
Cloud (top) height and amount	300 km (FGGE 100 km)	4 times daily	Height: 50-100 mb Amount: 20% (FGGE 5%)	Experimental	May become operational after 1985
Cloud albedo	300 km	2 times or more daily	15% (of albedo percentage)	Possible	
Surface temperature (land, snow, ice)	50 - 300 km	4 times or more daily	1-2°C over land 0.5°C over snow and ice	Possible ± 2 to 3°C	Possible, about ± 2°C after 1985 (The emissivity of the surface must be determined.)

TABLE II (contd.)

Further satellite observational requirements for research activities in addition to the WWW requirements

Parameter	Requirements			Available from satellites	
	Horizontal resolution	Frequency of observation	Relative accuracy	Expected 1980s	Remarks
Surface albedo	300 km (FGGE 100 km)	2 times daily	10% (of albedo percentage) (FGGE 0.01-0.03)	Possible	
Wind stress at sea surface	300 km	2 or more times daily	-	Experimental	
Ocean currents (principally location and direction)	10 - 50 km	Weekly	-	Possible	Only major surface currents
Snow cover	4 km	Weekly	-	Possible	
Ice (a) Sea ice (b) Polar ice sheets (c) Glaciers	1 - 4 km	Daily to weekly	-	Possible	Daily over cloud-free areas only
Ozone concentration	300 km	Daily	10%	Experimental	May become operational after 1985
Precipitation	300 km	4 or more times daily	10%	Experimental	May become operational after 1985, but only rough estimates over oceans
Liquid water content	50 km	4 or more times daily	10%	Experimental	May become operational after 1985, but only rough estimates
Aerosols	50 - 300 km	Daily		Experimental	
Atmospheric chemical constituents	50 - 300 km	Daily		Experimental	

TABLE III

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
SNOW ON THE LAND						
Snowline: line separating a region of less than 50% snow cover from a region with more than 50% snow cover	A	30 m	(Daily)	-	Possible (but not daily) over limited areas only	
	B	100 m	(Daily)	-	Possible (but not daily) over limited areas only	Current experimental: horizontal resolution 100 m for limited areas. Frequency twice per 18 days for cloud-free areas.
	C	1000 m	(Daily)	-	Possible over limited areas only	In 1980s horizontal resolution expected 30-40 m. Coverage will remain twice per 18 days.
Snow cover: percentage of a basin or other specific area, in horizontal projection, covered by snow	A	300 m	(Daily)	(± 5% of snow area)	Possible for cloud-free areas	
	B	1000 m	(Daily)	(± 5% of snow area)	Possible for cloud-free areas	
	C	10000 m	(Daily)	(± 5% of snow area)	Possible for cloud-free areas	
Water equivalent: depth of water that would result if a vertical column of the snow-pack of unit cross-section were melted	A	100 m	Daily	± 2 mm if < 2 cm ± 10% if > 2 cm	Not possible	There are no presently known techniques. In-situ measurements can be made and collected via satellite data-collection systems, either continuously within the regions covered by geostationary satellites, or up to four times per day from any location on the earth.
Free water content: equivalent depth of all the water in the liquid phase contained in a vertical column of the snow-pack of unit cross-section	B	300 m	Daily	± 2 mm if < 2 cm ± 10% if > 2 cm	Not possible	

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
(contd.)	C	1000 m	Daily	± 2 mm if < 2 cm ± 10% if > 2 cm	Not possible	Future outlook: micro-wave radiometers (active and/or passive) may permit observation of free water content and possibly water equivalent, but at coarse resolution (10s of km).
Snow-surface temperature: equivalent radiating temperature of the top surface of the snowpack	A	100 m	(6-hourly)	± 1°C	Possible (but not daily) ± 2 to 3°C over limited areas only	Current operational. The horizontal resolution for mapping gradients is 10 km or better. The frequency of observation is variable from 2/day (1km resolution) to 48/day (10km resolution) depending on location. Measurements are limited by the presence of clouds.
	B	300 m	(6-hourly)	± 1°C	Possible (but not daily) ± 2 to 3°C over limited areas only	
	C	1000 m	(6-hourly)	± 1°C	Possible ± 2 to 3°C over limited areas only	Future outlook: experiments will soon be conducted to determine surface temperatures from satellite measurements of micro-wave emission. If this can be done satisfactorily, it would eliminate the cloud interference problem which exists with infra-red devices; however, the resolution will be very low. Note: The expected 1980s values would be higher for radiation temperature. These values assume errors in estimating emissivity.

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Surface albedo: ratio of the energy reflected to the amount of energy incident over a specified range of wavelengths of the electromagnetic spectrum (e.g. the visible band)	A	100 m	(6-hourly)	(5%)	Possible over limited areas only	The requirements can be met, if albedo is defined as the ratio of outward bound radiation to inbound radiation in the wavelength regions in which the sensors are sensitive.
	B	300 m	(6-hourly)	(5%)	" "	
	C	1000 m	(6-hourly)	(5%)	" "	
LAKE AND RIVER ICE						
Ice line: boundary between a continuous land-fast ice-cover and water	A	30 m	(Daily)	-	Possible (but not daily) over limited areas only	Same as Snowline above
	B	100 m	(Daily)	-	Possible (but not daily) over limited areas only	
	C	1000 m	(Daily)	-	Possible over limited areas	
Continuous ice cover: percentage of a lake or river area covered by continuous land-fast ice	A	300 m	(Daily)	(± 2%)	Possible over limited areas only	Same as Snow cover above
	B	1000 m	(Daily)	(± 2%)	Possible over limited areas only	
	C	10000 m	(Daily)	(± 2%)	Possible over limited areas only	

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Ice concentration: fraction of an area within a lake or river that is covered by free-floating ice	A	10 m (1)	(Daily) (2)	-	Not possible	The resolution of foreseeable operational satellite sensors is not great enough to provide useful measurements, at least until after 1984. Can be done every 9 days in cloud-free areas on an experimental basis.
	B	30 m (1)	(Daily) (2)	-	Not possible	
	C	300 m (1)	(Daily) (2)	-	Not possible	
Ice movement: changes in position with time of individual free-floating ice elements or of the ice line	A	10 m	(Daily)	-	Not possible	Current operational: movement of large area ice (dimensions of several kms or larger). Frequency of coverage 2/day to 24/day depending on location. Limited by cloud coverage.
	B	30 m	(Daily)	-	Possible (but not daily) over limited areas only	
	C	300 m	(Daily)	-	Possible over limited areas only	Current experimental: movement of ice with areal extent of hundreds of metres in selected areas. Frequency of coverage 2/18 days. Limited by cloud coverage. Future outlook: movement of ice with areal extent of somewhat less than 100 metres in selected areas. Frequency of coverage 2/18 days. Limited by cloud coverage.

(1) Mean concentration values averaged over larger areas are useful.

(2) During melt season only

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Type or strength: international classification of ice types, which are associated with ice strength and other physical characteristics	A	30 m	(Daily)	-	Not possible	Qualitative determination from interpretation of 100 m resolution imagery is possible on an experimental basis for limited regions. Frequency of coverage 2/18 days in cloud-free regions.
	B	100 m	(Daily)	-	Possible (but not daily) over limited areas only	
	C	1000 m	(Daily)	-	Possible over limited areas only	Experimental microwave data will be available for evaluation by 1980 with low resolution (10s of km).
Thickness: vertical depth of ice which may include snow cover on the ice	A	30 m	Daily	± 2 cm if < 20 cm ± 10% if > 20 cm	Not possible	
	B	100 m	Daily		Not possible	
	C	1000 m	Daily		Not possible	
Ice surface temperature: effective radiating temperature of the ice or snow cover on the ice	A	30 m	(Daily)	(± 1°C)	Not possible	Same as Snow-surface temperature above
	B	100 m	(Daily)	(± 1°C)	Possible (but not daily) ± 2 to 3°C over limited areas only	
	C	1000 m	(Daily)	(± 1°C)	Possible ± 2 to 3°C over limited areas only	

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
GLACIERS						
Inventory: information on glacier sizes, shapes, volumes and settings is required for their hydrological importance	A	30 m	(10 years)	(5%)	Possible	Possible within the limitations of imaging resolutions of 100 m (present) and 40 m (1977) and 30 m (beyond 1980).
	B	100 m	(10 years)	(5%)	Possible	
	C	300 m	(10 years)	(5%)	Possible	
Snow-covered area: ratio of snow-covered area to total area (also called the accumulation area ratio, AAR)	A	100 m	(Weekly)(2)	(5%)	Possible over limited areas only	Same as Inventory above
	B	300 m	(Weekly)(2)	(5%)	Possible	
	C	1000 m	(Weekly)(2)	(5%)	Possible	
Variations of length: refers to the advance or retreat of the terminus, an element of climatic-hydrological importance	A	10 m	(Yearly)	(± one resolution element)	-	Same as Inventory above
	B	30 m	(Yearly)		Possible	
	C	100 m	(Yearly)		Possible	
Mass balance: difference between accumulation and ablation expressed as water-equivalent, provides information on the seasonal meteorological régime, the changing frozen water storage in the glacier, and the hydrological character of the glacier runoff	A	100 m	(Seasonally)	(± 5%)	Not possible	
	B	300 m	(Seasonally)	(± 5%)	Not possible	
	C	1000 m	(Seasonally)	(± 5%)	Not possible	

(2) During melt season only

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Monitoring surges: certain glaciers may periodically flow very rapidly (metres per hour), then revert to a normal or quiescent régime	A	30 m	(Monthly)	(± 20%)	Possible	Same as Inventory above
	B	100 m	(Monthly)	(± 20%)	Possible	
	C	300 m	(Monthly)	(± 20%)	Possible	
SURFACE WATER						
Areal extent: surface of the open water when it represents a minor portion of the surface water of the basin	A	10 m	(Daily)(3)	(5%)	-	Same as Snowline above
	B	30 m	(Daily)(3)	(5%)	Possible (but not daily) over limited areas only	
	C	100 m	(4 days)(3)	(5%)	Possible over limited areas only	
Saturated soil area: surface of soil not capable of significant infiltration or percolation	A	10 m	(Daily)(3)	(5%)	-	An inventory of soil type can be taken by satellite imaging devices within the limitations of horizontal resolution of 100 m (present), 40 m (1977), and 30 m (beyond 1980).
	B	30 m	(Daily)(3)	(5%)	May be possible (but not daily) over limited areas only	
	C	100 m	(4 days)(3)	(5%)	May be possible over limited areas only	

(3) Time interval between measurements

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Flood extent: surface covered by water during flood	A	10 m	(1 hour)[3,4]	(5%)	-	Same as Snowline above
	B	30 m	(12 hours)[3,4]	(5%)	Possible (but not daily) over limited areas only	
	C	100 m	(1 day)[3,4]	(5%)	Possible over limited areas	
Flood plain boundaries: lines which separate flood-prone from non-flood-prone areas	A	10 m	(5 years[3] and after every major flood)	(5%)		(May be mapped with horizontal resolution of 100 m (present), 40 m (1977), and 30 m (beyond 1980.)
	B	10 m		(5%)		
	C	10 m		(5%)		
Lake or river stage: elevation of the water surface of a lake or a river relative to a datum	A	-	(10')[3]; (30')[5]	± 1 cm	Not possible	In-situ measurement with satellite data collection provides the only way of meeting the requirement in the foreseeable future.
	B	-	(15')[3]; (1 hr)[5]	± 1 cm	Not possible	
	C	-	(1 hr)[3]; (4 hrs)[5]	± 1 cm	Not possible	

(3) Time interval between measurements

(4) During a flood event only

(5) Time interval for transmission by DCP

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Waves, set-up, seiches[(6)]: disturbance in the body of water propagated at a constant or varying speed, often of an oscillatory nature, accompanied by alternate rise and fall of surface fluid particles	A	-	-	-	Not possible	Direct measurements at a small number of points on major bodies of water, with geostationary satellite data collection, can provide useful measurements at the present time, dependent on the deployment of appropriate platforms and sensors. Indirect determination of surface roughness for large water bodies may be possible on an experimental basis in the 1980s. No operational capability is expected in the foreseeable future.
	B	-	-	-	Not possible	
	C	-	-	-	Not possible	
Mud flows and landslides[(6)]: flow of water so heavily charged with earth and debris that the flowing mass is thick or viscous	A	-	-	-	Possible on large scale	Very large events (dimensions of 100s of metres) are detectable by satellite. No major improvement expected in the foreseeable future.
	B	-	-	-		
	C	-	-	-		
GROUNDWATER AND SOIL						
Aquifer mapping: indication of the area where groundwater is found	A	100 m	(5 years)	-	Not possible	No remote sensing techniques are known at present. In-situ measurements of some of the desired parameters can be made via satellite data-collection.
	B	100 m	(5 years)	-	Not possible	
	C	100 m	(5 years)	-	Not possible	

(6) No resolution, accuracy or frequency requirements could be established by the Informal Planning Meeting. However, the participants at the meeting recognize the importance of regular observation of these hydrological elements and hope that specific requirements can be established at a later date.

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Location of discharge to rivers: indication of existence of groundwater	A	30 m	(Weekly)	-	Not possible	
	B	30 m	(Weekly)	-	Not possible	
	C	30 m	(Weekly)	-	Not possible	
Location of discharge to lakes: same as Discharge to rivers	A	100 m	(Weekly)	-	Not possible	
	B	100 m	(Weekly)	-	Not possible	
	C	100 m	(Weekly)	-	Not possible	
Location of springs: same as Discharge to rivers	A	30 m	(5 years)	-	Not possible	
	B	30 m	(5 years)	-	Not possible	
	C	30 m	(5 years)	-	Not possible	
Groundwater level: elevation, at a certain location and time, of the piezometric surface of an aquifer	A	300 m	(Daily)	(1 cm)	Not possible	
	B	1000 m	(Daily)	(1 cm)	Not possible	
	C	1000 m	(Daily)	(1 cm)	Not possible	
Soil type: classification of loose deposits on Earth's surface	A	100 m	(5 years)	-	Possible over limited areas only	An inventory of soil type can be made by satellite imaging devices within the limitations of horizontal resolution of 100 m (present), 40 m (1977), and 30 m (beyond 1980).
	B	1000 m	(5 years)	-		
	C	1000 m	(5 years)	-		

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Moisture content profile(7):	A	100 m	(Daily)		Not possible	
	B	300 m	(Daily)	10% of field capacity	Not possible	
	C	1000 m	(Daily)		Not possible	
Temperature profile(7):	A	100 m	(Daily)	(0.5°C)	Not possible	
	B	300 m	(Daily)	(0.5°C)	Not possible	
	C	1000 m	(Daily)	(0.5°C)	Not possible	
Infiltration: flow of water from the soil surface into the soil	A	100 m	(Daily)	(10%)	Not possible	
	B	300 m	(Daily)	(10%)	Not possible	
	C	1000 m	(Daily)	(10%)	Not possible	
Percolation: flow of water through a porous medium, mainly downward gravity flow	A	100 m	(Daily)	(10%)	Not possible	
	B	300 m	(Daily)	(10%)	Not possible	
	C	1000 m	(Daily)	(10%)	Not possible	
Depth of seasonal frost: distance from the ground surface to the freezing level (0°C)	A	100 m	(Weekly)	(10%)	Not possible	
	B	300 m	(Weekly)	(10%)	Not possible	
	C	1000 m	(Weekly)	(10%)	Not possible	

(7) At depths of 5, 10, 20, 50 and 100 cm

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Detection of permafrost: indication of areas where the ground is frozen all the year	A	100 m	(5 years)	-	Not possible	
	B	300 m	(5 years)	-	Not possible	
	C	1000 m	(5 years)	-	Not possible	
WATER QUALITY						
Turbidity: condition of a liquid due to fine visible material in suspension which impedes the passage of light through the liquid	A	30 m	(Daily)	(± 0.5 FTU)*	Not possible	Some information about turbidity can be derived from multi-spectral imaging such as those obtained experimentally from "LANDSAT" and "METEOR" and expected from the Coastal Zone Colour Scanner to be flown on Nimbus-G.
	B	100 m	(Daily)	(± 0.5 FTU)*	Not possible	
	C	1000 m	(Daily)	(± 0.5 FTU)*	Possible over limited areas only	
Suspended sediment: sediment which remains in suspension in flowing water for a long time without settling on the streambed	A	30 m	(Daily)	(± 10 ppm)	Not possible	Same as Turbidity above
	B	100 m	(Daily)	(± 10 ppm)	Not possible	
	C	1000 m	(Daily)	(± 10 ppm)	Possible over limited areas only	
Colour: deviation from the aspect of pure transparent water	A	30 m	(Daily)(8)	(± 10 mg Pt/l)**	Not possible	Same as Turbidity above
	B	100 m	(Daily)(8)	(± 10 mg Pt/l)**	Not possible	
	C	1000 m	(Daily)(8)	(± 10 mg Pt/l)**	Possible over limited areas only	

(8) Six hours for pollution monitoring for rivers and small lakes

* Range of measurements is 0.0025 - 5.0 FTU; (FTU = (FORMAZIN TURBIDITY UNIT) = 400 JTU (JACKSON TURBIDITY UNIT)); i.e., accuracy listed in the Table corresponds to 20% of the range.

** Range of measurements is 1-50mg Pt/l; (mg Pt/l = mg og Platinum per litre), i.e., accuracy listed in the Table corresponds to 20% of the range.

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Algae bloom: a large number of a particular algae species, often amounting to 0.5 to 1 million cells per litre	A	30 m	(2-3 days)	-	Not possible	Same as Turbidity above
	B	100 m	(2-3 days)	-	Not possible	
	C	1000 m	(2-3 days)	-	Possible over limited areas only	
Surface film: layer of oil or another fluid distinct from water spread over an area of the water and having molecular dimension	A	30 m	(Daily)(8)	-	Not possible	Limited capability has been demonstrated experimentally using multi-spectral high-resolution sensors. Operationally useful systems not yet assured.
	B	100 m	(Daily)(8)	-	Not possible	
	C	1000 m	(Daily)(8)	-	Not possible	
Surface water temperature: temperature of the water in the top mm layer	A	30 m	(6 hours)	(± 0.03°C in 0-1° range, ± 0.1°C in 1-4° range otherwise ± 1°C)	Not possible	1 to 1.5°C absolute and 0.5°C relative temperature accuracy can be achieved. 0.03 to 0.1°C not feasible.
	B	100 m	(6 hours)		Not possible	
	C	1000 m	(6 hours)		Not possible	
Temperature profile: temperature variation in depth	A	-	(2-3 days)	(± 0.25°C)	Not possible	Cannot be measured by satellite in the foreseeable future, but could be transmitted using satellite data-collection system.
	B	1000 m	(2-3 days)	(± 0.25°C)	Not possible	
	C	10000 m	(2-3 days)	(± 0.25°C)	Not possible	
DRAINAGE BASIN CHARACTERISTICS						
Drainage area: whole area having a common outlet for its surface runoff	A, B	30 m	(Every 10 years)	(± 1% of watershed area)	Possible	
	C	100 m				

(8) Six hours for pollution monitoring for rivers and small lakes

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Channel dimensions and patterns: length, number, order and pattern of stream-channel net-works must be outlined, even into the headwater reaches, to define the channel pattern. Channel order or number values can then be assigned to channel branches according to a variety of geomorphic quantification techniques	A, B C	30 m 100 m	(Every 5 years or after major flood event)	(± 5% of length)	Possible	
Overland flow length: average horizontal distance that water must flow over the ground before it enters a definite channel	A, B C	30 m 100 m	(Every 5 years)	(± 5% of length)	Possible	
Surface slope: the average slope between a divide and the stream channel over which water must run to reach the stream channel	A, B C	30 m 100 m	(Every 5 years)	(± 5% hor. ± 5 cm vert.)	Not possible	
Land cover type: natural vegetation or soil or arti-ficial surface, expressed as a percentage of watershed area	A,B,C	100 m	(Every year)	(± 1% of watershed area)	Possible	Can be met on a limited area basis at present. Requires large-scale digital processing.

TABLE III (contd.)

<u>Observational requirements for hydrology</u>

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
<u>Albedo</u>: ratio of the amount of energy reflected to the amount of energy incident over a specified range of wavelengths of the electromagnetic spectrum (e.g. the visible band)	A	100 m	(6 hourly)[9]	(5%)		Same as <u>Surface albedo</u> above
	B	300 m	(6 hourly)[9]	(5%)		
	C	1000 m	(6 hourly)[9]	(5%)	Possible over cloud-free areas	
PRECIPITATION AND EVAPOTRANSPIRATION FOR OPERATIONAL PURPOSES						
<u>Precipitation</u>: liquid or solid products of the condensation of water vapour falling from clouds or deposited from air on the ground	A	100 m	(6-hourly)[10]	± 2 mm if < 40 mm ± 5% if > 40 mm	Experimental	In-situ measurement with geostationary satellite data collection is currently operational in a few locations in the western hemisphere. Coverage can be greatly expanded in the western hemisphere as rapidly as platforms can be put in place, and can be extended to the rest of the world in 1978-1980. Precipitation measurement by satellite with useful accuracy may be possible on an experimental basis before 1985. The prospects for operational measurements over land areas are not promising for the foreseeable future. Stated resolution cannot be met.
	B	1000 m	(6-hourly)[10]	± 2 mm if < 40 mm ± 5% if > 40 mm	Experimental	
	C	5000 m	(6-hourly)[10]	± 2 mm if < 40 mm ± 5% if > 40 mm	Experimental	

(9) Less frequent observations may be acceptable.

(10) The Informal Planning Meeting recommended the following: precipitation should be measured during 5-minute intervals for basins of sizes A and B, and during 30-minute intervals for basins of size C; these measurements should be transmitted by a data-collection system at intervals of 1 hour for basins of size A, 2 hours for size B, and 6 hours for size C.

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Evaporation: quantity of water evaporated from an open water surface or from ground	A	100 m	Daily	± 0.5 mm	Not possible	No potential for the direct measurement of this parameter by satellite exists at the present time. Related variables can be measured. These will exist in computations.
	B	1000 m	Daily	± 0.5 mm	Not possible	
	C	5000 m	Daily	± 0.5 mm	Not possible	
Evapotranspiration: amount of water transferred from the soil to the atmosphere by evaporation and plant transpiration	A	100 m	Daily	± 0.5 mm	Not possible	Same as Evaporation above
	B	1000 m	Daily	± 0.5 mm	Not possible	
	C	5000 m	Daily	± 0.5 mm	Not possible	
LARGE-SCALE ATMOSPHERIC WATER BALANCE						
Precipitation: (see precipitation above)	-	100 km	6-hourly	± 2 mm if < 40 mm ± 5% if > 40 mm	Experimental	Same as Precipitation above
Evaporation: (see evaporation above)	-	100 km	(6-hourly)	(± 5%)	Not possible	Same as Evaporation above
Evapotranspiration: (see evapotranspiration above)	-	100 km	(6-hourly)	(± 5%)	Not possible	Same as Evapotranspiration above

TABLE III (contd.)

Observational requirements for hydrology

Parameter and its definition	Requirement				Available from satellites	
	Scale	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Atmospheric moisture storage: amount of water substances stored in the atmospheric column above a given region	-	100 km	(6-hourly)	(± 5%)	Experimental	Future satellite systems may be able to provide useful data for computations based on satellite-sensed profiles of moisture and wind, plus the capability for collecting in-situ data from conventional radiosondes and constant-level balloons.
Atmospheric moisture flux divergence: net quasi-horizontal rate of outflow of water substance from atmospheric column above a given region	-	100 km	(6-hourly)	(± 5%)	Experimental	Same as Atmospheric moisture storage above

TABLE IV

Satellite observational requirements for marine activities including oceanography

Parameter	Requirements			Available from satellites	
	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Sea-surface temperature (SST)	300 km[2]	6 hours	± 0.5°C	Possible ± 1 to 1.5°C	
Horizontal SST gradient[1]	Depends on detail to be investigated	Once or twice a day	Near the temperature critical for fish catch, accuracy of ± 0.5°C	Possible	
Horizontal gradient of water colour[1]		Once or twice a day		Experi-mental	Horizontal resolution will be 0.8 km with observations being obtained over a swath 700 km wide beneath the satellite track.
Horizontal gradient of water transparency[1]		Once or twice a day		Experi-mental	Extremely high resolution visible images with special processing can contribute here. Coverage will be limited in space and time.
Surface current	Depends on detail to be investigated	12 hours	Speed: 0.3 m s^{-1} Direction: 20 degrees	Possible	Satellites can be used to track drifting buoys equipped with drogues to determine this parameter at the depth of drogue. The accuracy will depend on the length of time between observations of the position of the buoy.

(1) For use in the analysis of ocean surface currents and water masses
(2) WMO Technical Regulations [A.1.1] 3.1.6(1)

TABLE IV (contd.)

<u>Satellite observational requirements for marine activities including oceanography</u>

Parameter	Requirements			Available from satellites	
	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Chlorophyl content				Experi-mental	Same as horizontal gradient of water colour above.
Ocean waves	300 km(1)	Intervals not exceeding 6 hours	Height: 0.5 m Period: 0.5 s Direction: 10 degrees (swell in particular)	Experi-mental	On board synthetic aperture radar will give the surface wave power spectrum for significant wave height for all wave lengths over 50 m and can give the predominant direction of one, and perhaps two, wave trains with an angular accuracy of about 10°.
Sea ice: Concentration; Age and thickness; Ridging; hummocks; Ice edge; Leads; Icebergs	Greatest possible Sufficiently high to enable detection and location (Ice edge; Leads; Icebergs)	At least once daily	10 per cent	Experi-mental* " " "	*Except for concentration and major leads, which are now determined operationally in certain areas.
Surface wind	300 km(1) in areas of concentrated marine activities (e.g. offshore) as great as possible	Intervals not exceeding 6 hours	Speed: 1 m s^{-1} Direction: 10 degrees	Experi-mental	Microwave techniques will soon be tested on research satellites.
Fog	Sufficiently high to enable detection and location	Intervals not exceeding 6 hours	Boundaries of fog areas as sharp as possible	Oper-ational	Easily detected in geostationary and polar satellite images, but limited to fog areas larger than about 10 km.

(1) WMO Technical Regulations /A.1.1/ 3.1.6(1)

TABLE IV (contd.)

Satellite observational requirements for marine activities including oceanography

Parameter	Requirements			Available from satellites	
	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Tropical cyclones and other areas of severe weather	Sufficiently high to enable detection and location	As frequent as possible		Possible	
Marine pollution: Oil slicks, as distinct from natural slicks	Sufficiently high to enable detection and location			Experi-mental	Only very preliminary work has been done on satellite technique for the detection of oil slicks and other marine pollution on the ocean surface. There are also laboratory and aircraft projects examining physical principles and techniques for possible pollution monitoring. Some techniques undoubtedly will be tested on research spacecraft during the next decade.
Pollutants, other than hydrocarbons in the micro-surface layer of the oceans				"	

TABLE V

Observational requirements for agrometeorology

Parameter	Requirements			Available from satellites	
	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Surface temperature	10 ha (0.1 km^2)	Hourly	± 1.0°C	Possible (but not daily) ± 2 to 3°C over limited areas only	Must know or estimate surface emissivity. Stated resolution and frequency not expected operationally in the 1980s.
Soil moisture*	10 ha (0.1 km^2)	Daily	± 10% of field	Not possible	See section GROUNDWATER in Table III.
Precipitation at surface	10 ha (0.1 km^2)	Daily	± 5%	Experimental	See Precipitation in Table III. Stated resolution cannot be met.
Radiation balance at surface or top of vegetation layer	10 ha (0.1 km^2)	4 times daily	± 5%	Possible over limited areas only	
Flux of water vapour from 0-10 m above ground or surface of vegetation	10 ha (0.1 km^2)	Hourly	± 10%	Not possible	See Evaporation in Table III.
Surface albedo	10 ha (0.1 km^2)	Twice daily	± 5%	Possible over limited areas only	The requirements can be met, if albedo is defined as the ratio of outward bound radiation to inbound radiation in the wavelength regions in which the sensors are sensitive.
CO_2 concentration from 0-10 m above ground or surface of vegetation	10 ha (0.1 km^2)	Hourly	± 10%		

* Every 20 cm to 1 m depth

TABLE V (contd.)

Observational requirements for agrometeorology

Parameter	Requirements			Available from satellites	
	Resolution	Frequency	Accuracy	Expected 1980s	Remarks
Snow cover area	1 ha (0.01 km^2)	Daily	± 5%	Possible (but not daily) over limited areas only	See section SNOW ON THE LAND in Table III.
Snow depth	1 ha (0.01 km^2)	Daily	2 cm below 20 cm ± 10% above 20 cm	Not possible	Same as above.
Water equivalent of snow	1 ha (0.01 km^2)	Daily	2 mm below 20 cm ± 10% above 20 cm	Not possible	Same as above.
Soil temperature*	10 ha (0.1 km^2)	Hourly	± 1.0°C	Not possible	

* Every 5 cm to 20 cm, every 20 cm to 20-100 cm

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Note on World Weather Watch Planning Reports

[illegible] of World Weather Watch Planning Reports [illegible] in 1966 as a means of informing all concerned about the planning work for the World Weather Watch (WWW) and with a view to stimulating further discussions about this work. The first stage in the planning effort culminated in the adoption by Fifth Congress in April 1967 of the WWW plan for 1968–1971. Sixth Congress, in April 1971, subsequently adopted the WWW plan for 1972–1975. This plan calls for periodic reviews of the component systems of WWW in order to tailor them to the latest technological developments so that new techniques may be introduced as soon as they have been proved to be sufficiently accurate, reliable and economical. It has, accordingly, been decided to continue the series of WWW Planning Reports.

These publications are reports of work in progress and the proposals contained therein do not necessarily have any official WMO status.

Note concernant les Rapports sur la planification de la Veille météorologique mondiale

La série des Rapports sur la planification de la Veille météorologique mondiale a été lancée en 1966 pour tenir tous les intéressés au courant des travaux de planification de la Veille météorologique mondiale (VMM) et également pour susciter de nouvelles discussions concernant ces travaux. A la fin de la première phase des activités de planification, le Cinquième Congrès a adopté, en avril 1967, le plan de la VMM pour 1968–1971. Le Sixième Congrès a adopté par la suite, en avril 1971, le plan de la VMM pour 1972–1975. Ce plan prévoit la révision périodique des systèmes composant la VMM pour les adapter aux progrès les plus récents de la technique, de manière que de nouveaux procédés puissent être utilisés dès qu'ils se seront révélés suffisamment exacts, sûrs et rentables. Il a donc été décidé de continuer à faire paraître des Rapports sur la planification de la VMM.

Ces publications sont des rapports sur les travaux en cours et les propositions qu'elles contiennent n'ont pas nécessairement un caractère officiel au sein de l'OMM.

Примечание к докладам по планированию Всемирной службы погоды

Серия докладов по планированию Всемирной службы погоды была начата в 1966 году для информации всех заинтересованных о работе по планированию Всемирной службы погоды (ВСП) и с целью дальнейшего стимулирования обсуждения этой работы. Первый этап работы по планированию завершился принятием на Пятом конгрессе плана ВСП на 1968–1971 гг. Затем Шестой конгресс в апреле 1971 г. принял план ВСП на 1972–1975 гг. Этот план предусматривает периодический пересмотр составных элементов системы ВСП для того, чтобы приводить их в соответствие с последними техническими достижениями, с тем чтобы быстрейшим путем могла внедряться новая техника, после того как она станет достаточно точной, надежной и экономичной. В соответствии с этим было решено продолжить серию докладов по планированию ВСП.

Эти публикации представляют собой доклады об осуществляемой работе, и содержащиеся в них предложения не обязательно имеют какой-либо официальный статус ВМО.

Nota sobre los Informes de planificación de la Vigilancia Meteorológica Mundial

La serie de Informes de planificación de la Vigilancia Meteorológica Mundial se inició en 1966 para tener al corriente a todos los interesados de las actividades de planificación de la Vigilancia Meteorológica Mundial (VMM) y también con el fin de estimular la ulterior discusión de dichos trabajos. La primera fase de las actividades de planificación culminó con la adopción por el Quinto Congreso, en abril de 1967, del plan de la VMM para el período 1968–1971. Posteriormente, el Sexto Congreso adoptó, en abril de 1971, el plan de la VMM para 1972–1975. Este plan requiere la revisión periódica de los sistemas que componen la VMM con el fin de adaptarlos a los progresos más recientes de la técnica de manera que se puedan utilizar nuevos procedimientos cuando se haya demostrado que son lo suficientemente precisos, seguros y económicos. En consecuencia, se decidió que continuara la publicación de la serie de Informes de planificación de la VMM.

Estas publicaciones constituyen informes de las actividades en curso y las propuestas que en ellas se especifican no tienen necesariamente carácter oficial dentro de la OMM.