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SATELLITES FOR MONITORING CLIMATE CHANGE: THE EMERGING SCENARIO

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Although in the last few years, large-scale utilisation of satellite data has become possible for climate studies, there is also an increasing realisation of the limitations of the processes by which information from meteorological satellites is being converted to a climate-scale data base. This has led meteorologists and satellite planners to think very seriously about using modified or totally new wavelength channels, increasing the number of channels of radiometers, improving the resolutions, trying new orbits, etc. Some of these plans are very ambitious and if brought into reality, they are likely to completely alter the satellite scenario by the turn of the century. This paper first reviews the current status of various on-going programmes and efforts and then describes the new possibilities that are opening up, based upon the plan projections of various countries available presently.

Key Words: Satellites; Monitoring Climate Change; Wavelength Channel; Temperature Retrievals; Earth Radiation Budget; Ozone Hole; Vegetation; Snow Cover; Microwave Remote Sensing

Introduction

The primary objective of the operational weather satellite programmes of various countries has been to augment the conventional inputs available to weather forecasters. Satellites like INSAT, GOES, METEOSAT or TIROS have all carried high-resolution radiometers designed to measure infrared radiances from cloud tops or the earth's surface in spectral windows which have minimal absorption. The main products from these measurements are cloud imagery and sea surface temperature/cloud top temperature information, with cloud motion vectors derived as a useful by-product. METEOSAT was the first satellite to provide water vapour channel imagery, while the U.S. polar-orbiting satellites introduced the capability of radiance measurements in 20 different wavelength channels for sounding purposes.

Over the years, and in the last decade in particular, many efforts have been launched to make use of meteorological satellite data in a manner aiming far beyond the immediate requirements of weather analysis and forecasting. Large-scale precipitation is being derived from infrared channel temperature histograms under the Global Precipitation Climatology Project (GPCP), while cloud climatologies on different scales are being generated under the International Satellite Cloud Climatology Project (ISCCP). Outgoing Longwave Radiation (OLR) derivations from meteorological satellites are finding an important place in earth radiation budget studies.

The derived products like OLR, precipitation, moisture, etc. are being used in validating atmosphere-ocean models, in climate simulation experiments and for diagnostic studies of the climate system. Although the record lengths of these products are much shorter (10-20 years) than conventional climatological data, and there are problems like sensor degradation, calibration errors, etc. the extensive coverage in space and time provided by satellite products enhances their usefulness.

Although in the last few years, large-scale utilization of satellite data has become possible for climate studies, there is also an increasing realisation of the limitations of the processes by which information from meteorological satellites is being converted to a climate-scale data base. This has led meteorologists and satellite planners to think very seriously about using modified or totally new wavelength channels, increasing the number of channels of radiometers, improving the resolutions, trying new orbits, etc. Some of these plans are very ambitious and if brought into reality, they are likely to completely alter the satellite scenario by the turn of the century. This paper first reviews the current status of various on-going programmes and efforts and then describes the new possibilities that are opening up, based upon the plan projections of various countries available presently.

Climate Monitoring through Weather Satellites

This section gives a description of past and current efforts to construct long-term data sets of parameters crucial to climate monitoring, using data available from meteorological satellites.

Precipitation Measurements from Satellites

Under the World Climate Research Programme (WCRP), the World Meteorological Organization (WMO) has established the Global Precipitation Climatology Project (GPCP) whose objective is to prepare a climatology of precipitation over the globe in order to achieve a better understanding of the hydrological cycle and energy budget of the atmosphere. The importance of the GPCP programme lies in the fact that a large fraction of the energy input from the earth's surface to the atmosphere is in the form of latent heat of water vapour and its subsequent release by condensation in the atmosphere. Moreover, the global patterns of precipitation constitute the most significant manifestation of climate and are the most sensitive indicators of climate change.

The GPCP Project started in 1986 and is to run upto 1995. It plans to use both geostationary and polar-orbiting satellite data during this 10-year period in conjunction with surface data in order to prepare the precipitation climatology. The satellite precipitation retrieval method uses 16-class temperature histograms, prepared daily and accumulated over 5-day periods[1].

Computations of precipitation on a $2.5° \times 2.5°$ scale over the Indian and Indian Ocean region have been made with INSAT data regularly over the last few years. Such estimates have proved to be useful in studying the interannual variability of monsoon rainfall[2].

Ferraro[3] has indicated that for the purposes of climate studies, precipitation measurements from satellites are required on a 50×50km scale with an accuracy of 1mm/day or 10%, whichever is smaller. However, monthly totals with spatial resolutions of $2.5° \times 2.5°$ are also needed for studies of interannual variability. Researchers are also seeking an improvement to 25 × 25km, 6 hourly and 10% accuracy as desirable goals.

In the GPCP-type algorithms, estimates of tropical rainfall based upon the IR temperature threshold technique are useful, but significant biases have been found particularly those associated with non-raining cirrus and rain from warm clouds[4]. To correct for these biases, locally applicable calibrations would have to be developed. In general, microwave channel algorithms have produced instantaneous rainfall estimates which are superior to those of the IR-based algorithms.

Hybrid alogirthms using both infrared and microwave brightness temperature have been found to have smaller sampling errors and improved estimates of precipitation for both weather and climate applications[5].

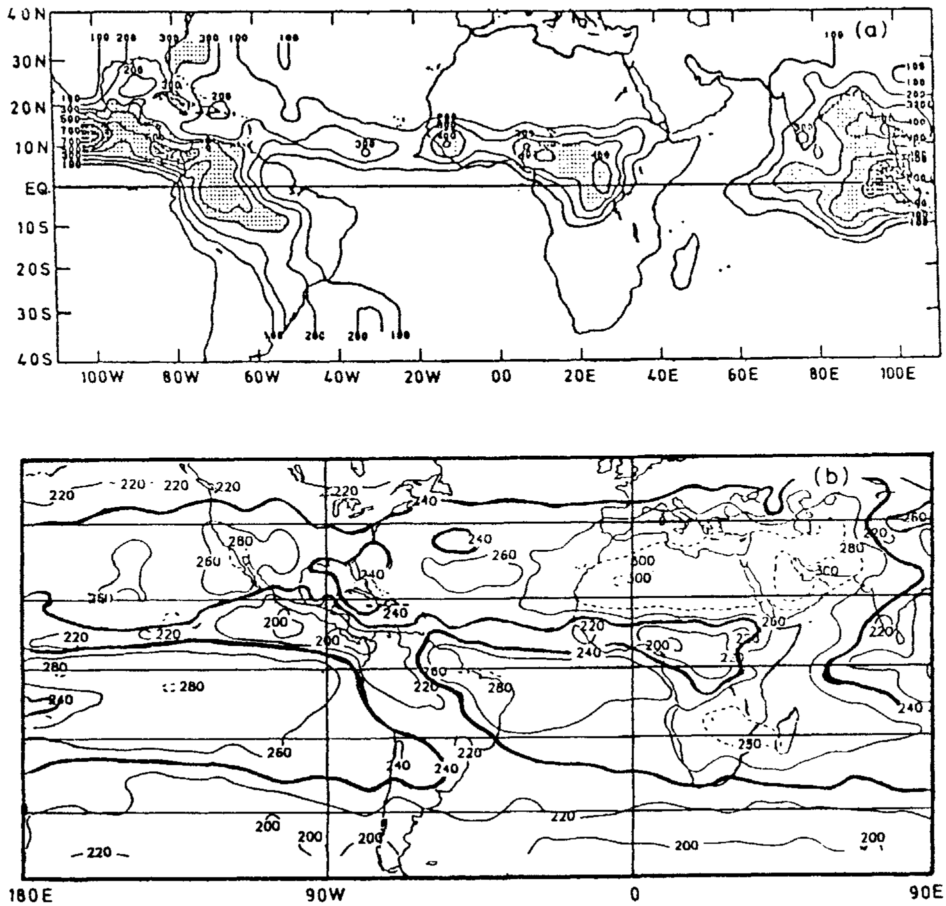

Fig 1 Monthly mean (*a*) Precipitation and (*b*) OLR derived from NOAA-11 AVHRR for September 1992. (*Source*: *Climate Diagnostic Bulletin*, NOAA/CAC).

Earth Radiation Budget

Since the early years of the weather satellite programme, there has been sufficient interest in the measurement of the earth's radiation budget components[6]. However, the quality of the derived data has been compromised by changes in satellites, orbits and sensors as well as the algorithms for correlating narrow band radiances to broad band values. In India also, derivations of Outgoing Longwave Radiation (OLR) are being routinely made from INSAT thermal infra-red data since 1986, on a 2.5°×2.5° grid over daily, weekly and monthly time scales. INSAT OLR is of potential value for studies of seasonal and inter-annual variations over the Indian Ocean region[2] as it is well-correlated with convective and precipitating regimes. Fig. 1 shows that there is good correspondence between OLR and large-scale precipitation on a monthly scale. It is seen that the 240w/m^2 OLR isopleth generally separates the raining areas from the non-raining ones.

The Earth Radiation Budget Experiment (ERBE) of the U.S. is a coordinated effort to use data from identical instruments on-board different satellites to measure the broad-band components of the earth's radiation budget to a high degree of accuracy with diurnal resolution[7]. The ERBE project involves three satellites, NOAA-9, NOAA-10 and ERBS (Earth Radiation Budget Satellite). ERBS is in a 57° inclined orbit at 600km altitude, which precesses through all hours of the day at the equator once every 36 days, thus providing a complete diurnal sampling. The ERBE scanning radiometers provide broad-band measurements in both shortwave (0.2-5.0 μ) and longwave (5-50 μ) regions at 30km resolution. These are distinctly superior to the indirect OLR derivations from the 10.5-12.5 μ window measurements. The ERBE data collection began in 1985 and continued till Feb. 1990.

The NIMBUS-7 research satellite launched in 1978, in a local noon/local midnight orbit, has produced several long-term data sets. NIMBUS-7 had a Temperature Humidity Infrared Radiometer (THIR) and Wide Field of View Radiometer (WFOVR) measuring shortwave (0.2-3.8 μ) and total longwave (0.2-50 μ) radiation. NIMBUS-7 ERB data has coarse resolution, lower calibration accuracy, and a systematic degradation of the sensor with time. Its advantage lies in the consistent viewpoint and the longer period of data availability. Hurrel and Campbell[8] have shown various comparisons of OLR obtained from ERBE, NOAA and NIMBUS-7. One such comparison of the three OLR patterns for the month of July 1985 is reproduced in Fig. 2. The NIMBUS-7 pattern is seen to be smoother because of the large field of view of the sensor. Although the general spatial distributions agree, there are noticeable differences in the magnitudes as may be expected.

Ozone Hole

Ozone measurements through satellites are of three categories: (1) total ozone measurements by TOMS (Total Ozone Mapping Spectrometer) on the NIMBUS-7 satellite, (2) total ozone retrievals from TOVS (TIROS Operational Vertical Sounder) on NOAA satellites, and (3) Ozone profile measurements in 25-55km altitudes by SBUV (Solar Backscatter Ultraviolet Technique) instrument on NOAA and NIMBUS Satellites. The three data sets are available

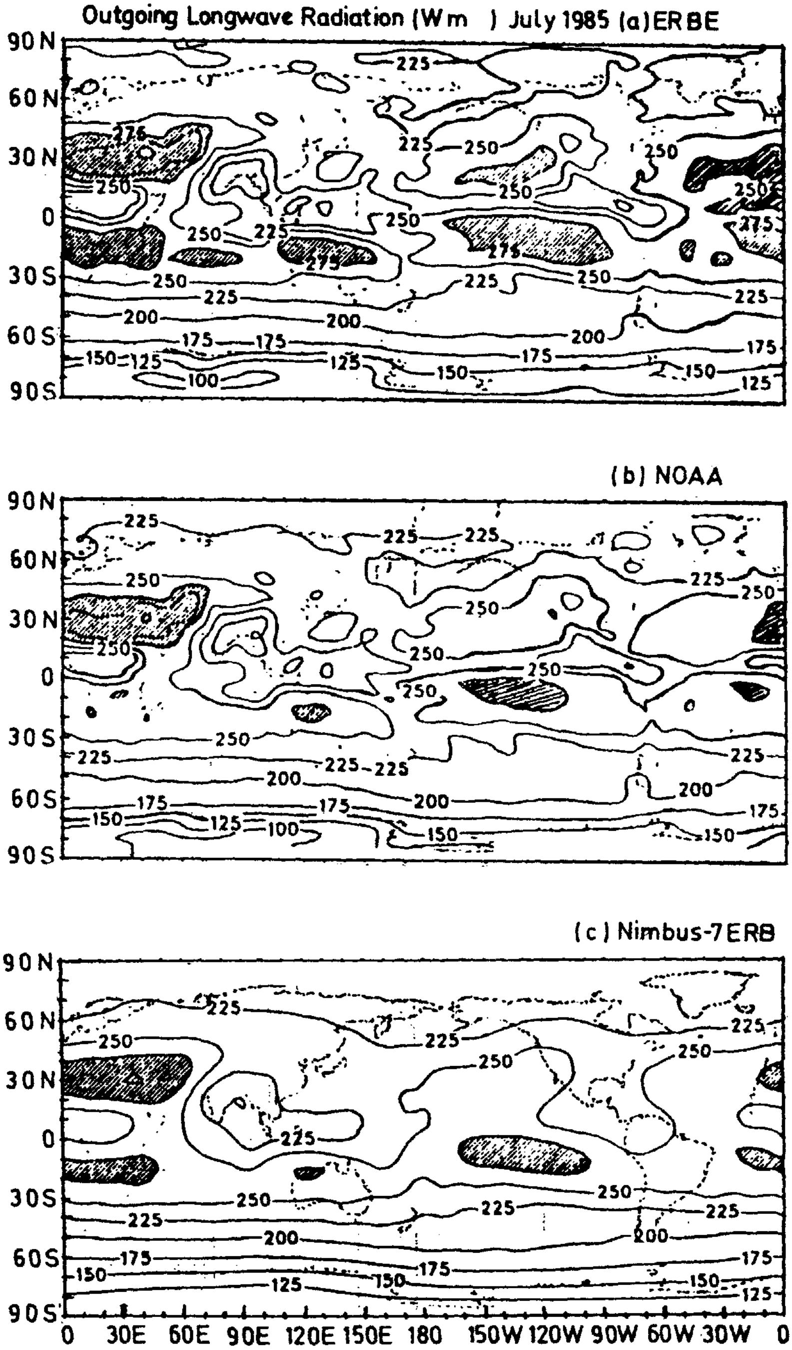

Fig 2 Outgoing longwave radiation in W m^{-2} for July 1985 from (*a*) ERBE, (*b*) NOAA and (*c*) Nimbus-7 ERB. Values less than 225 W m^{-2} are indicated by stippling and values greater than 275 W m^{-2} are hatched. The contour increment is 25 W m^{-2}.

from 1978, 1979 and 1985 respectively. The TOMS instrument uses differential absorption of reflected solar ultra-violet radiation to estimte total ozone, while TOVS brightness temperature in the 9.7 μ band is used for total ozone retrievals. The SBUV operates on the principle of detecting the spectral distribution of backscattered solar ultraviolet radiation. The horizontal resolution of TOVS is 17km, that of SBUV is 200km and TOMS is 100km. Each of these three ozone data sets thus have their own strengths and weaknesses.

Recent observations of ozone have indicated that there is a significant depletion of ozone in the vertical column during the spring season of the Southern Hemisphere (Sept-Oct) over the Antarctic region. This phenomenon, which has come to be known as the "ozone hole", has become a subject of intense study and investigation. Both the depth and area of the hole are now being monitored regularly through measurements made by TOVS. Fig. 3 taken from Halpert *et al.*[9] shows the time series of the area over which TOVS derived total ozone had a value of less than 212 Dobson Units (DU). Total ozone values of such low magnitude are not generally observed outside the southern polar regions. Even over the polar regions, they were never so low before the eighties. The threshold of 212 DU therefore is a convenient mark for delineating the ozone hole boundary. From late September to early October 1992, the ozone hole was seen to have its greatest areal extent so far, perhaps due to the presence of aerosols from the Mt. Pinatubo volcanic eruption of June 1991. A further gradual depletion of ozone is expected to occur in years to come as the concentration of stratospheric chlorine and bromine would increase.

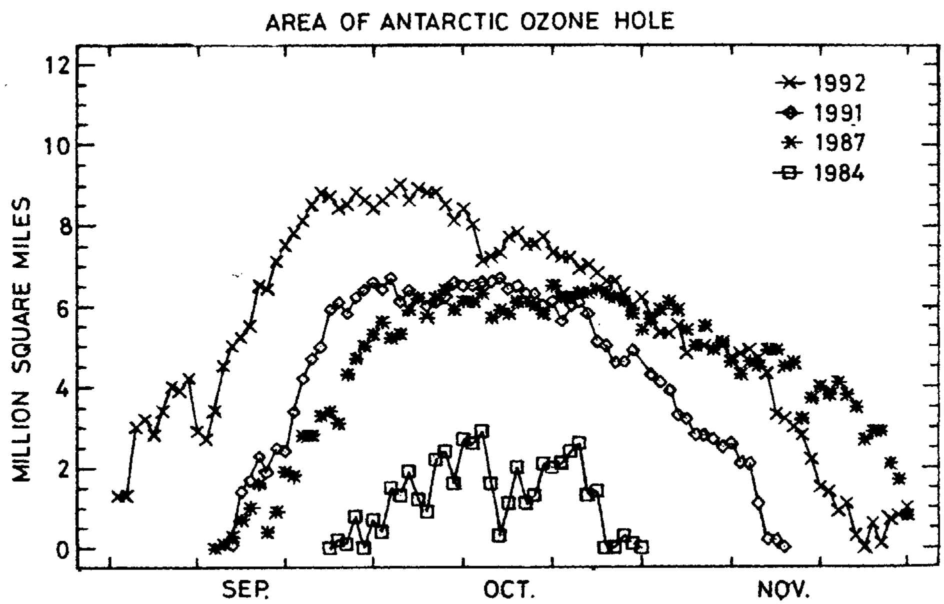

Fig 3 Time series of the area (million square miles) over which TOVS total ozone was measured to be less than 212 Dobson Units for the September-December period for 1984, 1987 1991 and 1992

Aerosols

The volcanic eruptions of El Chichon in March 1982 and Mt. Pinatubo in June 1991 have had effects which could be noticed in satellite imagery and satellite-derived temperature products. In such events, sulphur dioxide gets injected into the stratosphere where it slowly combines with water vapour to form sulphuric acid. This in turn leads to more solar radiation being reflected to space. The Aerosol Optical Thickness (AOT), which controls the reflection of solar radiation back to space, is typically less than 0.1, except in areas having dust, smoke, haze, industrial waste products, etc. However, following Mt. Pinatubo's eruption, AOT has been found to exceed the value of 0.1 over a large part of the earth's surface. An increase in AOT by 0.1 corresponds to a 1% increase in the earth's albedo. This is an indirect measure of the cooling effect on the earth's climate by factors such as stratospheric loading by volcanic particles. Since 1987, NOAA/AVHRR Channel 1 radiance measurements are being used to derive AOT and time series of departures of AOT from mean values provide an insight into the transport of aerosols within the earth's atmosphere and its impact on climate[10]

Vegetation and Snow Cover

In 1982, NOAA began producing weekly global vegetation index maps primarily as a data source for assessment of global agricultural production. Normalised Difference Vegetation Index (NDVI) is also being computed on a finer local scale over the Indian Region by the National Remote Sensing Agency[11]. Since recently, vegetation indices are finding use in climate monitoring, and also as boundary conditions in climate prediction models. However, the usefulness of an NDVI climatology is uncertain because of biases introduced by cloud contamination and scan angle differences in the short term and orbital drift and sensor degradation in the long term. These problems need to be eliminated before interannual variability of NDVI can be gainfully used in climate studies.

Since 1966, NOAA has been bringing out Northern Hemisphere Weekly Snow and Ice Cover Charts based upon manual analysis of satellite visible imagery. This effort has resulted in the compilation of a long-term data set[12] which is useful for monitoring the continental snow cover and for deriving snow cover anomalies. Satellite-derived fields of snow depth are also available in areas which are not heavily vegetated. According to current thinking, cryospheric variations of the higher latitudes will have a key role to play in future climate and global change and such parameters therefore need to be incorporated with precision in climate prediction models. The Eurasian snow cover is also an important parameter used operationally in the long-range forecasting of the Southwest monsoon rainfall[13].

Temperature Retrievals

The three channels of the Microwave Sounding Unit (MSU) of NOAA satellites measure a vertically averaged thermal emission by molecular oxygen in the 60GHz band. Oxygen is uniformly mixed in the atmosphere and its concentration is very stable in time. The MSU temperatures are, therefore, suitable for monitoring intra-seasonal and inter-annual temperature variations of the troposphere and stratosphere[14].

The MSU Channel 2 peaks near 500hpa and is dominated by the tropospheric temperature signal, while channel 4 which peaks at 70hpa is representative of stratospheric temperatures. The MSU brightness temperatures have been carefully calibrated over more than 13 years and because of their interconsistency, it is possible to compute anomaly fields. The anomalies have been found to reflect the effects of volcanic eruption in the lower straqtosphere and ENSO events on the tropospheric temperatures.

Although the retrieval of sea surface temperature from the thermal window radiances measured by satellites is a simple process, the accuracy of the retrieval is utilised by the effects of the atmospheric absorption which cannot be parameterised and therefore not accounted for. The best way is to eliminate them from the considerations of the retrieval by using multi-channel measurements. The adoption of the Multi-Channel Sea Surface Temperature (MCSST) algorithm by NOAA in 1981 resulted in greatly improved SST retrievals, comparing within 0.4°C of drifting buoy matchups. However, the algorithms need to be constantly fine-tuned and there are other problems like paucity of *in situ* data over southern hemispheric oceans and the inability of satellite techniques to retrieve SST in cloudy areas, which is a big constraint over the monsoon regime.

Future Possibilities

Microwave Remote Sensing

After over 25 years of meteorological remote sensing in the solar and infrared channels, there has been a sudden upsurge of interest in the exploitation of the microwave frequencies for meteorological purposes. The Defence Meteorological Satellite Programme of the U.S. (DMSP) launched in 1987, a polar-orbiting low altitude satellite having the Special Sensor Microwave Imager (SSM/I). This very successful mission has been followed up by more microwave instruments in the DMSP programme. Moreover, the utility of the data has been greatly enhanced because the sharing of the data with civilian users in the U.S. was permitted, thus opening up a new field of applications[15].

The SSM/I is a passive system measuring microwave radiation in the 19, 22, 37 and 85GHz bands with resolutions ranging from 69 × 43 to 15 × 13km. The SSM/T instrument (Special Sensor Microwave/Temperature) is a cross-track scanning radiometer with seven channels in the 50-60GHz region peaking at various heights from the surface to 30km. For water vapour soundings, a different version of SSM/T, called SSM/T2 will fly on future DMSP Satellites. This will be followed by SSM/IS (Special Sensor Microwave/Imager Sounder), a conical scanner, incorporating the channels of all the three instruments, SSM/T, SSM/T2 and SSM/I.

The NOAA K-N satellites will carry an Advanced Microwave Sounding Unit, AMSU/A, which will be a 15-channel radiometer capable of providing temperature soundings from the surface to 3hPa with a 50km nadir resolution.

AMSU/B will be a 5-channel radiometer with 15km resolution, for derivation of water vapour profiles.

The data from the SSM's and AMSU's will help in the estimation of global precipitation over land and water, global cloud liquid water content over water, and water vapour and atmospheric temperature profiles. Studies indicate that for climate monitoring, the best results are obtained when data from different channels like visible, infrared and microwave are used in conjunction, so that the shortcomings of one are largely overcome by the advantages offered by the others. This is particularly so in the case of global precipitation, where infrared-plus-microwave algorithms have yielded promising results. Here the twice a day microwave data are matched with 8 times a day infrared data from geostationary satellites, while the physically-based microwave rainfall estimates are used to calibrate or fine-tune the indirect infrared estimates.

Tropical Rainfall Measuring Mission (TRMM)

The Tropical Rainfall Measuring Mission (TRMM) is a joint project of the U.S. and Japan for making extensive and accurate measurements of tropical rainfall[16]. The TRMM satellite, which will be launched in 1997 is envisaged to be in a 35° inclination orbit. It will be non-sun-synchronous, so as to provide sampling at different times of the day with a repeat cycle of about 3 days. It will have a low altitude of about 350km.

TRMM will combine the advantages of (*a*) an AVHRR type instrument viewing in the solar and thermal infrared channels for indirect precipitation estimation, (*b*) a microwave imager of the SSM/I type operating at 19, 22, 37 and 85 GHz to provide physical rainfall retrievals, (*c*) a scanning microwave radiometer at 19GHz, and (*d*) a precipitation radar working at a frequency of 14GHz with a footprint of 5km. This combination of data from both active and passive microwave instruments with simultaneously available visible and infrared measurements is expected to lead to a quantum jump in precipitation monitoring over the tropics.

Geostationary Satellites

A major design change in the next-generation U.S. geostationary weather satellites of the GOES I-M Series will be that they will be three-axis stabilised spacecraft similar to INSAT[17]. With a spinning satellite in geostationary orbit, the sensor sees the earth for less than 5% of the time. In a three-axis stabilised configuration, it can be designed to view the earth for upto 75% of the time, thus improving greatly the radiometric efficiency.

GOES I-M will have a 5-channel imager (1 visible and 4 *i-r*) scanning the earth's disc in 30 minutes[18]. The resolution at the subsatellite point will be 1km for visible, 4km for *i-r* and 8km for the water vapour channels (Table I) They will also have a 19-channel sounder (1 visible and 18 *i-r*) comparable in performance to the present NOAA TOVS with resolution of 8km and a repeat time of 42 mintues (Table II).

In the GOES-N system, which will follows GOES I-M, there is a proposal to have two imaging instruments working parallely, one seeing the full disc and another for faster scanning of small sectors. GOES-N may also have 5 new channels at 4km resolution, and the resolution of the GOES I-M channels may be improved by a factor of two. The sounder accuracy and resolution are also planned to be improved.

Table I

GOES I-M Imager channels

Channel Number	Wavelength Range (μ)	Band	Resolution (km)	Application
1	0.55-0.75	Vis	1	Daytime cloud cover
2	3.80-4.0	*i-r*	4	Night-time cloud cover
3	6.50-7.0	*i-r*	8	Water vapour imaging
4	10.20-11.20	*i-r*	4	Surface temperature
5	11.50-12.50	*i-r*	4	SST, water vapour

Table II

GOES I-M sounder channels

Channel Number	Central Wavelength (μ)	Resolution (km)	Application
1	14.71		Temperature sounding
2	14.37	8km for all channels	,,
3	14.06		,,
4	13.96		,,
5	13.37		,,
6	12.66		,,
7	12.02		Surface temperature
8	11.03		,,
9	9.71		Total ozone
10	7.43		Moisture sounding
11	7.02		,,
12	6.51		,,
13	4.57		Temperature sounding
14	4.52		,,
15	4.45		,,
16	4.13		,,
17	3.98		Surface temperature
18	3.74		,,
19	0.70		Cloud imaging

Table III

MSG SEVIRI channels

Band	Wavelength Range (μ)	Resolution (km)	Application
High-resolution visible	0.50-0.90	1	High-resolution imaging
Visible	0.56-0.71	3	Basic imaging
,,	0.71-0.95	3	,,
Infrared	1.44-1.79	3	,,
,,	3.40-4.20	3	,,
,,	8.30-9.10	3	,,
,,	9.80-11.80	3	,,
,,	11.00-13.00	3	,,
Water vapour	5.35-7.15	3	Air mass monitoring
,,	6.85-7.85	3	,,
Ozone	9.46-9.94	3	,,
Carbon dioxide	13.04-13.76	3	,,

The current European meteorological satellites were initially designed in the early seventies and have been used in orbit since 1977. These are planned to be replaced by the Meteosat Second Generation (MSG) satellites by the year 2000. The MSG mission, besides providing continuity of present services, envisages support to climate and environmental monitoring as well as to earth resources management. The basic instrument to be carried by MSG is the Spinning Enhanced Visible and Infra-Red Imager (SEVIRI), consisting of a 7-channel imaging radiometer, a 4-channel air mass monitor and a single-channel high resolution visible imager (Table III). The air-mass monitor will have two channels in the water vapour absorption band and one each in the carbon dioxide and ozone bands. All these channels of SEVIRI will have a resolution of 3km at the sub-satellite print and a scanning cycle of 15 minutes for the full disc, except the high resolution visible channel which will have a better resolution of 1km at the sub-satellite point with a 15 min. scan time[19].

Japan proposes to launch its geostationary meteorological satellite GMS-5 in 1994 which will be same as earlier GMS satellites excepting that a water vapour channel is proposed to be added. The Indian geostationary satellite, INSAT which is a multi-user system, will not have meteorological payloads in the INSAT-2C and INSAT-2D spacecrafts. The meteorological component will be restored in INSAT-2E which will be the last satellite of the INSAT-2 series.

U.S./European Polar Orbiting Satellites

As a replacement of the currently operational NOAA-11 and NOAA-12 polar orbiting satellites, the U.S. plans to launch what has been termed as the NOAA K-N series[18]. In these satellites, the AVHRR will be upgraded with the addition of a sixth channel at 1.6 μ to provide better discrimination of snow and ice from clouds. The MSU and SSU will be replaced by the Advanced Microwave Sounding Unit (AMSU) which would have 20 microwave channels at 45km nadir resolution.

A further significant departure from what has been the operational policy of the U.S. for a long time, the U.S. proposes to have only one (in place of two) polar orbiting satellite at a time, starting from NOAA-O. This will provide coverage at local afternoon (1330) in the ascending node. For the coverage at local morning (0730) in the descending node, the U.S. has sought the partnership of Eumetsat to provide an identical satellite, which has been termed as the Eumetsat Polar System[20]. The complementary system of NOAA and EPS is expected to become operational by the year 2001. Both the satellites are likely to have a 7-channel, 1.1km-resolution imager and more advanced infrared and microwave sounders, in addition to a host of other instruments like SBUV, TOMS, altimeter and scattermeter, etc.

The sophistication planned to be introduced in these new polar-orbiting satellites will lead to the availability of measurements of a wide range of atmospheric as well as oceanographic variables such as precipitation rates over ocean and land, cloud water and vapour content, snow/ice cover, radiation budget components and all-weather retrievals of temperature profiles, SST, ocean surface winds, wave heights, vegetation, trace gas concentrations, etc.

Continued Measurements of Total Ozone

The Total Ozone Mapping Spectrometer (TOMS) on-board NIMBUS-7 has provided total column ozone over the globe every day since 1978. Later in this decade, the TOMS instrument will fly on other satellite systems, first on the Russian METEOR-3, then on Japan's ADEOS and after that on the Earth Probes Programme of the U.S.

This cooperation and coordinated activity of three different countries will ensure continued availability of total ozone data to meet the needs of climate change monitoring beyond the life of NIMBUS-7.

The Upper Atmospheric Research Satellite (UARS) launched by the U.S. is also providing data on variations in global ozone and the dynamics of the upper atmosphere.

Other Satellites and Instruments

The European Remote Sensing Satellite ERS-1, launched in 1992, and the other satellites of this type which will be launched by Japan (JERS), are primarily earth resources satellites. However, the ERS carries the Synthetic Aperture Radar (SAR) which is capable of measuring ocean surface topography and deriving ocean surface winds. The repeat cycle of ERS-1 is 3 days for ocean surface wind measurements. Such measurements are not possible from geostationary satellites by the cloud displacement technique below 900hPa level.

Japan[21] is also planning the Advanced Earth Observation Satellite (ADEOS), which will have an Ocean Column and Temperature Scanner (OCTS) with 6 visible channels and 6 *i-r* channels at a surface resolution of 0.7km. It will also have an Advanced Visible and Near Infra-red Radiometer

(AVNIR) with 3 visible channels, 1 near *i-r* channel and a panchromatic channel. Besides these, ADEOS is expected to have several specialised payloads. Among these will be a NASA Scatterometer (NSCAT) for measurement of ocean surface wind speed ($\pm$ 2m/s) and direction ($\pm$ 20°) over the globe. It will also have an Interferometric Monitor for Greenhouse Gases (IMG) for measurements of the concentration of CO_2, N_2O, CH_4, etc.) and a Retroreflector in Space (RIS) for measurement of Ozone, CFC's, CO_2, etc. by laser beam absorption technique, transmitted by a ground station and reflected back by ADEOS.

Mission to Planet Earth

The U.S. Mission to Planet Earth is a programme which is based on the realisation that the earth faces the prospects of accelerated environmental change including climate warming, rising sea levels, deforestation, desertification, ozone depletion, acid rain and reduction in biodiversity. It is also felt that present means for monitoring these changes are inadequate. The U.S. therefore proposes to have a comprehensive programme of global and climate change monitoring based upon sophisticated, Earth Observing System (EOS) satellites to be launched by U.S. in the years 2000 and beyond and supported by international satellite programmes during this decade itself. The existing programmes include UARS, TOPEX/Poseidon, NSCAT, ERBE, TOMS, etc. whereas the future missions planned are the NASA Earth Probes and Geostationary Platforms. The latter will include various payloads to monitor the hydrological, biogeochemical, climatic and geophysical processes within the total earth system. Much of the Mission to Planet Earth is currently in the stage of conceptual evolution[22] and the precise shape that it will take in the coming years remains to be seen.

Turn-of-the-Century Scenario

Although the availability of financial resources is the major limiting factor in the growth of space programmes, it is certain from the current enthusiasm that the environmental satellite scenario in the years 2000 and beyond will be totally different from what it was in the 1980's or 1990's. Besides satellites in geostationary and polar orbits, there would be satellites orbiting over the tropical belt and satellites in non-sun-synchronous orbits to provide total diurnal sampling. Cooperative arrangements amongst nations will result in identical instruments being flown by different countries (e.g., TOMS). The polar orbiting meteorological satellites will no longer be the sole responsibility of the U.S. but Europe will share half the burden. Microwave imagers and sounders will perhaps outnumber the conventional visible/infrared radiometers which themselves will undergo a distinct improvement. Retrieval algorithms will almost certainly make use of data from both infrared and microwave channels to improve the accuracy and temporal sampling. New parameters like concentration of greenhouse gases and CFC's will be monitored, while continuity will be provided for the present measurements of ozone, atmospheric temperatures, radiation balance components, etc. Measurements of sea surface temperature, surface vegetation cover, snow cover, etc. may no longer be restricted to non-cloudy conditions.

By all means, the turn-of-the-century satellite scenario holds out of prospect that will excite anyone. And it is also reassuring to know that the earth and space science community is geared to meet the challenges of global and climate changes, the consequences of which are sometimes made out to be so awesome.

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