PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Global Habitability and Earth Remote Sensing [and Discussion]

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Global Habitability and Earth remote sensing

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[Plate 1]

This paper discusses current techniques developed by N.A.S.A. for observation of the atmosphere, oceans and land from satellites. N.A.S.A. has developed a new concept called 'Global Habitability' to provide a framework for an interdisciplinary, global scientific research programme. Its aims are discussed together with future projects for Earth remote sensing.

In 1960 N.A.S.A. launched the Tiros satellite into polar orbit to study the atmosphere of the Earth. Later in the 1960s, hand-held cameras on the first manned flights gave us additional new and exciting glimpses of the Earth. In the early 1970s N.A.S.A. flew sensors optimized for observing the oceans on the Skylab mission, and the launch of the Earth Resources Technology Satellite (ERTS-1) in 1972 gave us the means of studying the land masses. So, by the early 1970s we had demonstrated the ability to observe the atmosphere, oceans and land areas over practically the entire Earth.

Data acquired from space are now being used on a regular basis for research in agriculture, land use, hydrology and geology, and the value of these data has been fully demonstrated. We can now make land cover inventories, locate, classify and measure major forest types, identify shoreline changes, salinity zones and flood plain boundaries, and identify water impoundments greater than two acres (8084 m^2). The knowledge gained from these studies has been used to forecast commodity production for wheat and to identify crop stress areas. These capabilities can be used to assist in determining global biomass changes and in conjunction with a global biology programme can begin to determine the process by which changes in biomass occur.

Perhaps the most dramatic example of the use of space-based data has been for atmospheric physics. Research instruments and techniques developed by N.A.S.A. to obtain global measurements of tropospheric parameters such as temperature, humidity and winds have led to a substantial improvement in our knowledge of the troposphere. The same techniques have been incorporated into National Weather Service models to improve the quality of long-term forecasts. Data from recent N.A.S.A. satellites are being used to update forecasting techniques so that we may approach the goal of a reliable seven day forecast. N.A.S.A. satellites have also measured the distribution of the ozone and other important species in the stratosphere. These data have improved our basic understanding of the stratosphere and of the role that man-made pollutants might have on the ozone content. An experiment carried on the Shuttle has demonstrated a capability to measure a tropospheric trace species (carbon monoxide) from space.

It is now possible to measure both sea surface winds and wave heights, and to determine the circulation patterns in the oceans by using satellite techniques. Measurements of the chlorophyll content of the sea can now be made routinely and have been used to determine the probability of fish harvests off the West coast of the United States. Improved algorithms have been developed to determine global skin surface temperatures (figure 1, plate 1) from the current operational NOAA polar orbiting satellites.

Each step that has been taken forward in specific disciplines in remote sensing has provided another piece of a very large puzzle that is the Earth system. It is now time to assemble the separate pieces into a coherent whole. Over the past year, N.A.S.A. has been working with other organizations to develop a concept called 'global habitability', to provide a framework for an interdisciplinary, global, scientific research programme.

The objective of the programme is to investigate long-term physical, chemical, and biological trends and changes in the Earth's environment, including its atmosphere, land masses, and oceans. The programme will specifically investigate the effects of natural and human activities on the Earth's environment by measuring and modelling important physical, chemical, and biological processes and their interactions, and will estimate the future effects on biological productivity and habitability of the Earth by man, by other species, and the effects on natural causes. The programme will involve the acquisition and analysis of space and sub-orbital observation, land and sea-based measurements, modelling and laboratory research, and supporting data management technologies over a ten year or longer period of time. The programme will, of necessity, involve major international participation and will be coordinated as far as possible with national research programmes and those of international agencies. The aim of the N.A.S.A. global habitability concept is to obtain a solid body of knowledge from which policy decisions can be made and which will address the questions of change, either natural or of human origin, effecting the habitability of the Earth.

A primary challenge of the 1980s is to improve upon the quality and usefulness of remote

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Description of plate 1

Figure 1, plate 1, is the first global map ever made of Earth's mean skin surface temperature. It was derived from multispectral data measured by satellites. The ocean and land temperature values have been averaged spatially over a grid 2.5° latitude by 3° longitude and correspond to the month of January 1979. The mean temperature values for this month clearly show several cold regions, such as Siberia and northern Canada, during winter in the Northern Hemisphere and a hot Australian continent during summer in the Southern Hemisphere. Mountainous areas are clearly visible in Asia, Africa and South America. The horizontal gradients of surface temperature are displayed on the map in colour contour (density of grey here) at intervals of 2 K and show some of the major features of ocean surface temperature, such as the Gulf Stream, the Kuroshio Current and the local temperature minimum in the eastern tropical Pacific Ocean. The sea surface temperatures derived by satellite are in very good agreement with ship and buoy measurements.

Surface temperature data are important for weather predictions and climate studies. Since the cold polar regions cover a small area of the globe relative to the warm equatorial regions, the mean surface temperature is dominated by its value in the tropics. The resulting mean skin surface temperature during January 1979 is calculated to be: global, 14.14 °C (57.46 °F); N. Hemisphere, 11.94 °C (53.49 °F); S. Hemisphere, 16.35 °C (61.43 °F). Currently, climate scientists are testing the accuracy of using surface temperature anomalies in the Pacific Ocean as potential predictors, on seasonal timescales, of weather conditions over parts of North America. In addition, day and night variations in the surface temperature can be used to study soil moisture.

The image was obtained by a team of N.A.S.A. scientists from the Jet Propulsion Laboratory in Pasadena, California, and the Goddard Space Flight Center in Greenbelt, Maryland. The satellite data were acquired by the high resolution infrared sounder and the microwave sounding unit, both instruments flying on board the National Oceanic and Atmospheric Administration (NOAA) weather satellites. The surface temperature was derived from the 3.7 μm window channels in combination with additional microwave and infrared data from the two sounders. The combined data sets were computer processed, by using a data analysis method that removed the effects of clouds, atmosphere, and reflection of solar radiation.

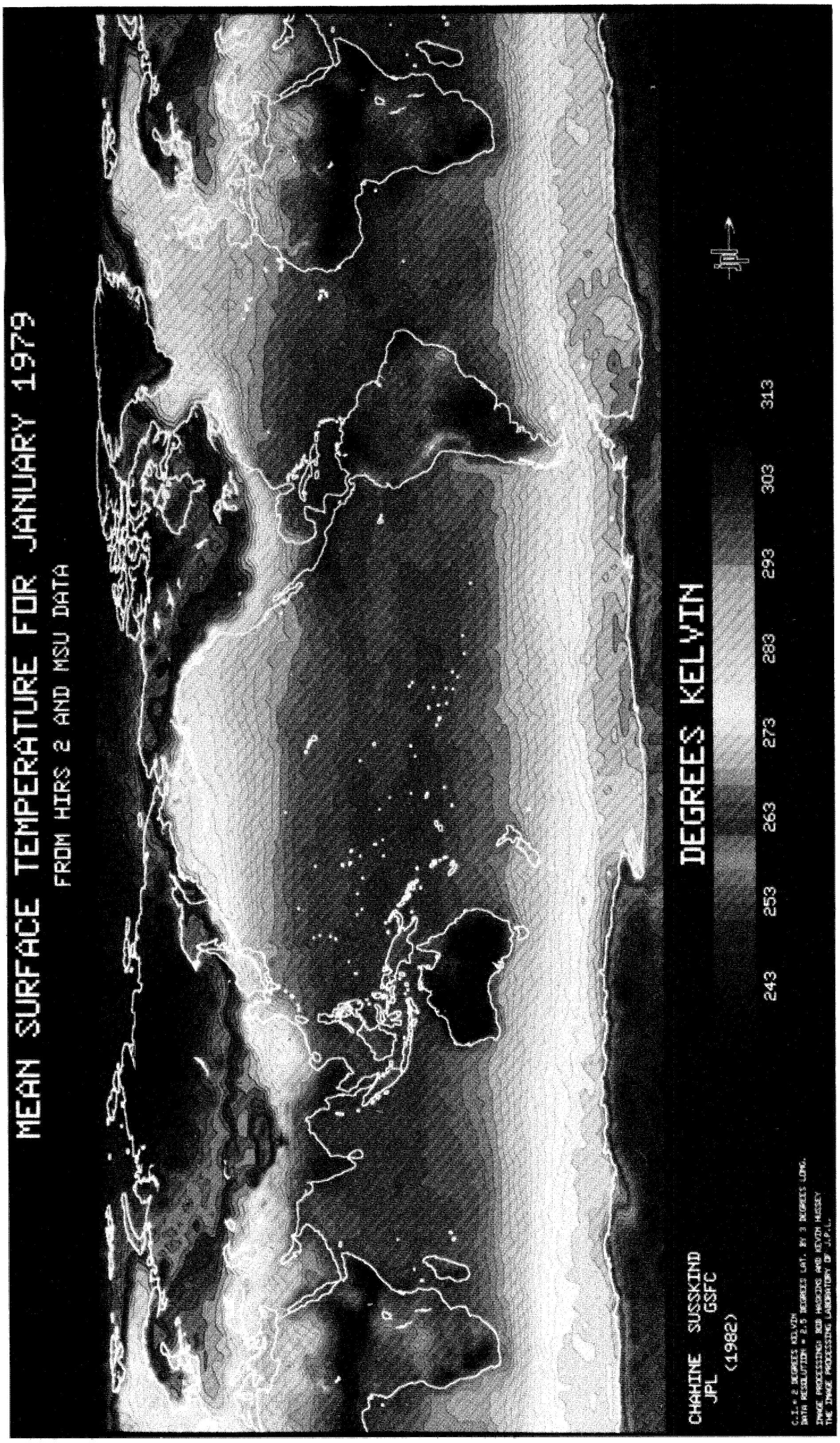

FIGURE 1. Global mean monthly skin surface temperature. For full description see opposite.

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sensing information. Landsat-4, launched in July 1982, represents a major step forward in meeting this challenge. The improved spatial, spectral, and radiometric characteristics of the thermatic mapper have already contributed to improved analysis of data from agricultural, wetlands, and geological test sites. The Space Shuttle is also providing exciting new possibilities in Earth observation. The Shuttle Imaging Radar (SIR-A) acquired more than ten million square kilometres of surface imagery during a two day mission in November 1981. An L-band Synthetic Aperture Radar (SAR) obtained imagery of many arid and tropical areas of the world for the first time. The Shuttle also carried SMIRR (Shuttle Multispectral Infrared Radiometer), which has already provided information leading to the discovery of an area of potential metallic mineralization in Mexico. In addition to these recent accomplishments, we are planning more Shuttle-based remote sensing experiments in the 1980s. These include the large format camera in early 1984; the Shuttle imaging radar-B in the summer of 1984; and the multispectral linear array in the late 1980s.

N.A.S.A. is also improving its capability for global studies of the atmosphere and the oceans. The Upper Atmosphere Research Satellite (UARS) will provide scientific understanding of the complex physical and chemical interactions that maintain the ozone layer in the Earth's stratosphere. We are also planning the Ocean Topography Mission (TOPEX) to improve our understanding of the circulation of the ocean. We are developing an advanced radar scatterometer (SCATT) for more accurate sea surface wind measurement, and an Ocean Colour Imager (OCI) for improved primary ocean productivity measurements.

Observations from the Nimbus-6 and Nimbus-7 Earth Radiation Budget (ERB) instruments and operational NOAA satellites are being used as a foundation for developing a continuing series of Earth radiation budget (solar constant) data sets. The data sets formed from these observations will serve as a continuing resource for climate research. These data sets will be continued and augmented by launch of the Earth Radiation Budget Experiment (ERBE) scheduled for 1984. Recent evidence from the Nimbus-7 and SMM satellite observations confirm natural variations in the total solar output of several tenths of 1% for periods of up to about two weeks. To determine the impact of such variations on the climate systems as well as to monitor their long-term trend, several instruments including the Active Cavity Radiometer (ACR) have been designed for Shuttle operations. In addition, instruments such as the Atmospheric Observations from Shuttle (ATMOS) infrared spectrometer have been developed to measure stratospheric and mesospheric trace species. We eventually plan to combine these instruments in a single payload known as the Earth Observations Module.

N.A.S.A. has come a long way in the twenty-three years since the first Tiros. We now have the capability to take the next great step. Building upon the remote sensing advances of the past twenty years, we can now study Earth as an interlocking system of complex global processes. The potential for progress in this next step will be limited only by our imagination and perseverence. We in N.A.S.A. intend to do our part in making the next twenty years in remote sensing as exciting and successful as the past twenty years have been.

Discussion

J. R. PAGE (19 *Kingsland Road*, *Alton*, *U.K.*). The limited resolution of currently available visual data from N.A.S.A. satellites for civilian use limits the scientific disciplines that can benefit from remote Earth sensing. Does Dr Tilford think, therefore, that there is a possibility of improving the quality of data in the future?

S. G. Tilford. I think that the spectral resolution will increase by orders of magnitude with the instrumentation that we now have planned for the 1990s within the Earth Science and Applications Programme, i.e. we expect to fly the Shuttle Imaging Spectrometer Experiment (SISEX) with over a hundred spectral bands at approximately ten nanometre resolution. With respect to spatial resolution, I do not believe that we will develop, in our programmes, footprints with resolutions less than about 15–20 m. With spatial resolutions less than these values, we could have problems with full global distribution and use of these data.

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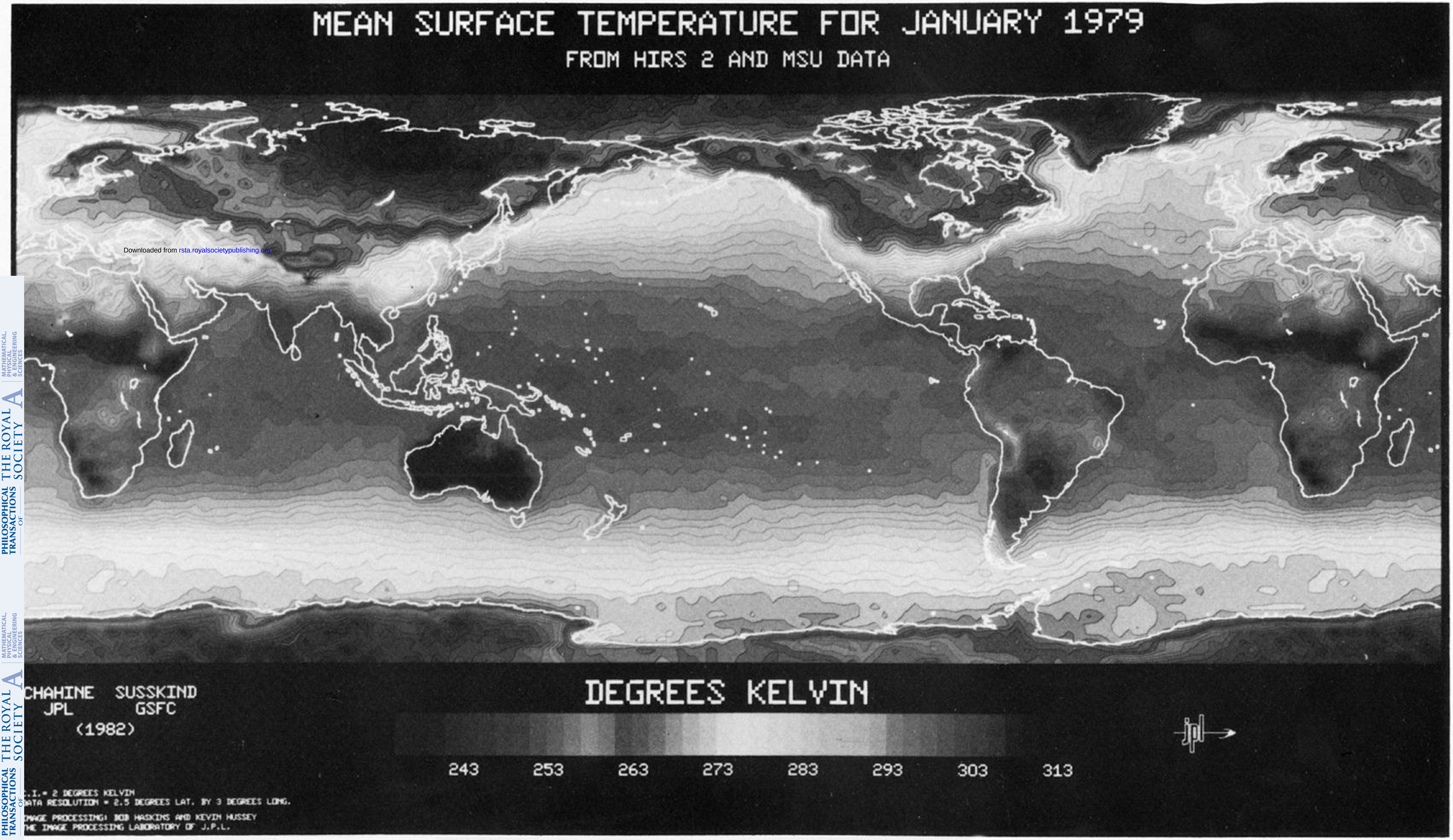

FIGURE 1. Global mean monthly skin surface temperature.