JOHN E. HARRIES*

Chemistry and physics of the atmosphere

1 INTRODUCTION

The advent of space techniques has had a profound effect on how mankind views the place of the Earth and of the human race in the universe. To see the planet Earth, in images taken from orbiting spacecraft such as the Space Shuttle, or from greater distances (as in the case of those famous images of the Earth from the surface of the Moon) tells us something about the fragility of the planet, and the importance of caring for our environment. Scientists were quick to recognise that this new perspective could be turned to great advantage in the drive to understand how the physical, chemical and indeed biological, systems of the Earth worked. From about 1960, a series of space missions began, aimed not outwards towards the stars, but inwards towards our atmosphere, oceans and land. In this chapter, we will follow the story of how space techniques have been applied in the 20th century to studies of:

- The meteorology and physics of the atmosphere and climate;
- The chemistry of the atmosphere.

We will also describe some of the scientific ideas that have been tested from space, as well as the satellites and instruments that have been developed: we will also mention some of the people involved in this exciting enterprise. It will be seen from this review that space has had a profound effect not only on mankind's perspective of the planet Earth, but also on the scientific understanding of the processes at work in the atmosphere and climate on the Earth. NASA captured just the right phrase when it created its "Mission to Planet Earth"[1] and ESA brought in the biological and anthropogenic aspects when it called the Earth science envelope programme "Living Earth."

* Imperial College, London, United Kingdom

[1] Despite subsequently changing this to the more prosaic "Earth Science Enterprise".

John E. Harries, The Century of Space Science, 1653–1668

2 HISTORICAL PERSPECTIVE

April Fool's day, 1960, was perhaps not the best choice of date for the launch of the World's great adventure in monitoring how the atmosphere of our planet Earth works, from a space platform. Nevertheless, on that date, the United States of America, acting through the new National Aeronautics and Space Administration (NASA), launched the TIROS 1 (the Television and InfraRed Observation Satellite).

The satellite was basically a cylinder with 18 flattened sides to mount solar power cells. The satellite was approximately 1.07 m in diameter, 0.56 m high (including the projecting television camera lens), and had a launch weight of approximately 128.4 kg, including fuel for small solid rockets to control the satellite's spin over time. (For comparison, the latest generation of Earth observing satellites often reach 4 m in length, and weigh several metric tonnes!). TIROS I ceased operating in mid-June 1960 due to an electrical failure. During the 77 days it operated, the satellite sent back 19,389 usable pictures that were used in weather operations. TIROS II was launched on November 23, 1960.

The main sensors that provided the cloud pictures were television cameras. The TIROS cameras were slow-scan devices that took snapshots of the scene below; one "snapshot" was taken every ten seconds. These were rugged, lightweight devices weighing only about 2 kg, including the camera lens. TIROS I was equipped with two cameras, wide angle and narrow angle. Progress since these simple early experiments has been enormous, as we shall see later.

NASA had been formed from the National Advisory Committee for Aeronautics (NACA) on October 1, 1958, and achieved many startling successes across the whole range of space activities, not only in studies of the Earth. Nevertheless, Earth observation was clearly one of the most important applications of the new space technology and systems that were being developed. In recognition of this, the National Oceanographic and Atmospheric Administration (NOAA) was formed, to become a major partner to NASA (primarily a technology agency) in the exploitation of the new observations. These two agencies between them would go on to dominate the observation, study and monitoring of planet Earth from space for the remainder of the century.

Elsewhere, other countries were quick to recognise the importance of Earth observation from space for studies of the environment. In Europe, the European Space Agency (ESA) was formed in 1975, and quickly developed the Meteosat series of spinning satellites, the first of which was launched in 1977 into an equatorial geostationary orbit at the Greenwich meridian position. This was just two years after the first NASA GOES (Geostationary Operational Environmental Satellite: a 3-axis stabilised spacecraft) had been placed into geostationary orbit over the Indian Ocean. ESA went on to develop the ERS-1 and -2 polar orbiting satellites, which carried a variety of visible, infrared and microwave instrumentation. Within Europe, 1986 saw the creation of what is in some ways a European equivalent of NOAA, the EUMETSAT (European Meteorological Satellite organisation), to exploit the new observations for meteorology and later for climate studies.

Across the world, other countries were becoming involved, including Japan, which through NASDA (National Aeronautics and Space Development Agency), and with the involvement of other national agencies, has developed a series of polar and geostationary satellites. Also, India, Brazil, Australia and other nations have set up national agencies and become active.

Now, at the beginning of the 21st century, a wide variety of observations of the Earth's atmosphere from space are available, including operational observations, made regularly, with good sampling over long periods; and also dedicated, more specific missions, designed to address specific issues. Progress has been enormous in just 40 years. Our understanding of the Earth and its atmosphere has advanced amazingly, often helped greatly by the new, global observations from space. In one way, this advent of global observations has come just in time as far as present worries over climate change are concerned: it is already the case that researchers are able to go back over much of those 40 years and study how planet Earth has actually developed, based on satellite observations. In another way, perhaps we have become more sensitive to global variations, partly by having more data available. Either way, space has made a major impact.

In the rest of this chapter we have been faced with a choice. We might either attempt to provide an absolutely comprehensive listing of all the missions that have occurred, along with relevant technical details; or to be more selective, and try only to illustrate the range of observations, and to pick out a few highlights of scientific advance that has come about, perhaps mentioning one or two individuals along the way, in an attempt to provide a little more colour to our story. Despite the fact that this latter approach will not be comprehensive, and will leave gaps (for which the author apologises right away), we have decided on the latter course. What is about to be served up is a subjective view of the highlights of efforts to study the atmosphere from space in the latter part of the 20th century.

3 THE METEOROLOGY AND PHYSICS OF THE ATMOSPHERE AND CLIMATE

3.1 Background

The measurement of basic atmospheric parameters, such as temperature and humidity, by instruments on the meteorological satellites flown by several agencies has been of great value in two ways. First, by providing images of cloud patterns and their developments, or by providing vertical profiles of temperature and humidity in the atmosphere, these data have had a direct and immediate impact on the accuracy of weather forecasts and extreme weather events. A second, extremely powerful use of the data has only more recently been appreciated, however. This is that, by providing a long term series of accurate, well intercalibrated measurements, extending over several decades, these missions have provided data on the state of the atmosphere which is absolutely vital in studies of how the climate might be varying. Data from one-off dedicated "scientific" missions are of limited value in this sense, since they have very limited duration (with a few exceptions, such as UARS – see below). There is huge scientific value in this longevity and continuity of observation. The exceptional value of operational meteorological satellites in providing the basic, long term description of the state of the atmosphere necessary for a wide range of atmospheric problems has become apparent in the closing decades of the 20th century. In addition, the activities of other agencies such as NASA that have funded long-term observations by instruments measuring simple, but important physical parameters like the Earth Radiation Budget, have also been most important.

Geostationary satellites provide a continuous view of the earth disc from an apparently stationary position in space. The instruments on polar orbiting satellites, flying at a much lower altitude, provide higher resolution details about atmospheric temperature and moisture profiles, ozone amounts and radiation budget, although with a less frequent global coverage. The combination of the two types of measurement has proven to be very powerful.

We have already heard how TIROS-1 was put into orbit on April 1, 1960. There followed a rush of satellites and new developments of instruments, too numerous to account for fully here. Between 1960 and 1973, the ESSA series (first operational TIROS) was developed and flown; the Improved TIROS Operational System (ITOS) began in January 1970, carrying a second generation of visible and IR sensors; later in 1970, NOAA-1/ITOS-A heralded the first in the long series of NOAA satellites that operates up to the present day; and in 1973 the NOAA-3 spacecraft was the first satellite which provided direct broadcast VTPR (Vertical Temperature Profile Radiometer) data. The NOAA series has operated up to the end of the century, carrying instruments which have been gradually improved and developed. Then, in 1975 GOES-1 heralded the beginning of geostationary observations, joined by Meteosat-1 in 1977. Let us look a little more closely at some of these developments.

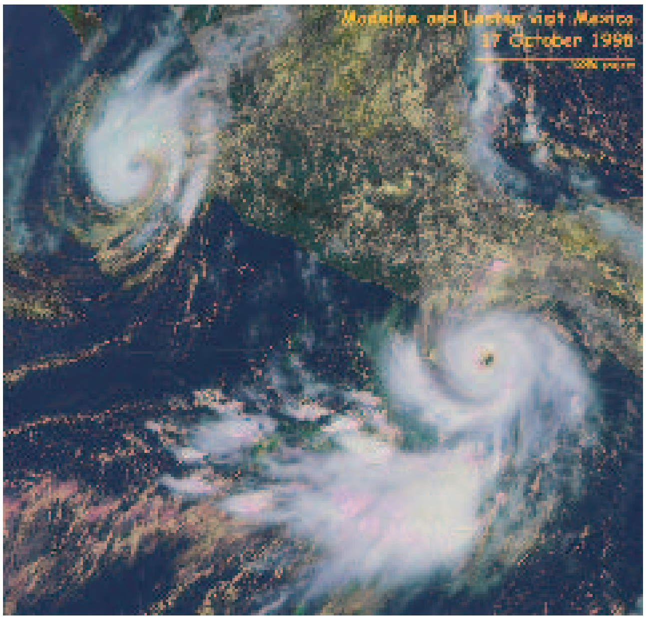

Figure 1 GOES visible image of Hurricanes Madeline and Lester, off the coast of Mexico, October 1998. (Courtesy of NASA–Goddard Space Flight Center, data from NOAA GOES.)

3.2 NOAA's geostationary weather satellites[2]

The idea of using the geostationary orbit generally has been ascribed to the science fiction writer, Arthur C Clarke, but the power of the geostationary orbit for meteorology, equipped with a variety of visible and infrared imagers and sounders was advocated strongly by Professor Verner Suomi[3] of the University of Wisconsin. His vision led to the enormous application that we see every day of geostationary observations to weather and climate research (Suomi and Vonder Haar 1969).

GOES satellites provide the kind of continuous monitoring necessary for intensive data analysis. They circle the Earth in a geosynchronous orbit, which means they orbit in the equatorial plane of the Earth at a speed matching the Earth's rotation. This allows them to remain over one position on the surface. The geosynchronous orbit is about 35,800 km above the Earth, high enough to allow the satellites a full-disc view of the Earth. Because they stay above a fixed spot on the surface, they provide a constant vigil for the atmospheric "triggers" for severe weather conditions such as tornadoes, flash floods, hail storms, and hurricanes. When these conditions develop, the GOES satellites are able to monitor storm development and track their movements.

GOES satellite imagery is also used to estimate rainfall during the thunderstorms and hurricanes for flash flood warnings, as well as to estimate snowfall accumulations and overall extent of snow cover. Such data help meteorologists issue severe weather warnings. Figure 1 shows a GOES image of hurricanes Lester and Madeline, off the coast of Mexico on October 17, 1998, illustrating the use of geostationary observations for one of these purposes, tracking storms.

The United States normally operates two meteorological satellites in geostationary orbit over the equator. Each satellite views almost a third of the Earth's surface: one monitors North and South America and most of the Atlantic Ocean, the other North America and the Pacific Ocean basin. GOES-8 (or GOES-East) is positioned at 75°W longitude and the equator, while GOES-10 (or GOES-West) is positioned at 135°W longitude and the equator. Coverage extends approximately from 20°W longitude to 165°E longitude.

The main mission is carried out by the primary instruments, the Imager and the Sounder. The imager is a multichannel instrument that senses radiant energy and reflected solar energy from the Earth's surface and atmosphere. The Sounder provides data to determine the vertical temperature and moisture profile of the atmosphere, surface and cloud top temperatures, and ozone distribution.

Other instruments on board the spacecraft include a Search and Rescue transponder, a data collection and relay system for ground-based data platforms, and a space environment monitor. The latter consists of a magnetometer, an X-ray sensor, a high energy proton and alpha detector, and an energetic particles sensor. All are used for monitoring the near-Earth space environment or solar "weather."

[2]For more information about NOAA geostationary and polar orbiting satellites, see: http:\\www.noaa.gov.

[3]For more about the life and work of Verner Suomi, see: http://profhorn.meteor.wisc.edu/wxwise/museum/a1main.html

Table 1 GOES-10 characteristics

Main body	2.0 m by 2.1 m by 2.3 m
Solar array	4.8 m by 2.7 m
Weight at liftoff	2105 kg
Launch vehicle	Atlas I
Launch date	April 25, 1997, Cape Canaveral Air Station, FL
Orbital information	Type: Geosynchronous Altitude: 35,786 km Period: 1,436 minutes Inclination: 0.41 degrees
Sensors	Imager Sounder Space Environment Monitor (SEM) Data Collection System (DCS) Search and Rescue (S&R) transponder

Some typical characteristics of the GOES spacecraft are shown in Table 1.

Data from GOES satellites aid forecasters in providing better advanced warnings of thunderstorms, flash floods, hurricanes, and other severe weather. The GOES-I series provide meteorologists and hydrologists with detailed weather measurements, more frequent imagery, and new types of atmospheric soundings. The data gathered by the GOES satellites, combined with that from new Doppler radars and sophisticated communications systems make for improved forecasts and weather warnings.

3.3 NOAA's polar orbiting weather satellites

Complementing the geostationary satellites are two polar-orbiting satellites, constantly circling the Earth in an almost north–south orbit, passing close to both poles. The orbits are circular and sun synchronous, with an altitude between 830 (morning orbit) and 870 (afternoon orbit) km. One satellite crosses the equator at 7:30 a.m. local time, the other at 1:40 p.m. local time. The circular orbit permits uniform data acquisition by the satellite and efficient control of the satellite by the NOAA Command and Data Acquisition (CDA) stations located near Fairbanks, Alaska and Wallops Island, Virginia. Operating as pair, these satellites ensure that data for any region of the Earth are no more than six hours old.

A suite of instruments is able to measure many parameters of the Earth's atmosphere, its surface, cloud cover, incoming solar protons, positive ions, electron-flux density, and the energy spectrum at the satellite altitude. As a part of the mission, the satellites can receive, process and retransmit data from Search and Rescue beacon transmitters, and automatic data collection platforms on land, ocean buoys, or aboard free-floating balloons. The primary instrument aboard the satellite is the Advanced Very High Resolution Radiometer or AVHRR.

Table 2 NOAA-15 characteristics

Main body	4.2 m long, 1.88 m diameter
Solar array	2.73 m by 6.14 m
Weight at liftoff	2231.7 kg including 756.7 kg of expendable fuel
Launch vehicle	Lockheed Martin Titan II
Launch date	May 13, 1998, Vandenburg Air Force Base, CA
Orbital information	Type: sun synchronous Altitude: 833 km Period: 101.2 minutes Inclination: 98.70 degrees
Sensors	Advanced Very High Resolution Radiometer (AVHRR/3) Advanced Microwave Sounding Unit-A (AMSU-A) Advanced Microwave Sounding Unit-B (AMSU-B) High Resolution Infrared Radiation Sounder (HIRS/3) Space Environment Monitor (SEM/2) Search and Rescue (S&R) Repeater and Processor Data Collection System (DCS/2)

Data from all the satellite sensors are transmitted to the ground via a broadcast called the High Resolution Picture Transmission (HRPT). A second data transmission consists of only image data from two of the AVHRR channels, called Automatic Picture Transmission (APT). For users who want to establish their own direct readout receiving station, low resolution imagery data in the APT service can be received with inexpensive equipment, while the highest resolution data transmitted in the HRPT service utilises a more complex receiver.

Table 2 contains some characteristics of the NOAA-15 satellite.

The polar orbiters are able to monitor the entire Earth, tracking atmospheric variables and providing atmospheric data and cloud images. The satellites provide visible and infrared radiometer data that are used for imaging purposes, radiation measurements, and temperature profiles. The polar orbiters' ultraviolet sensors also provide ozone levels in the atmosphere and are able to detect the "ozone hole" over Antarctica during mid-September to mid-November. These satellites send more than 16,000 global measurements daily via NOAA's CDA station to NOAA computers, adding valuable information for forecasting models, especially for remote ocean areas, where conventional data are lacking.

Springer
http://www.springer.com/978-0-7923-7196-0

The Century of Space Science
Bleeker, J.A.; Geiss, J.; Huber, M. (Eds.)
2001, XLIX, 1846 p., Hardcover
ISBN: 978-0-7923-7196-0