A multi-tiered ballistic-missile defense system that must react in a flash and without problems to an attack involving thousands of missiles would require flawless, unjammable, high-capacity communications and automatic signal and data processing under extremely stressful conditions both in space and in links between space and ground. For this reason development of C^3I technologies for boost-phase and midcourse-phase target surveillance, acquisition, tracking, and kill assessment (called SATKA) has received the lion's share of attention and funding in the SDI program. SDI officials acknowledge that the required SATKA technologies are presently embryonic at best. Included among them are millimeter-wave and laser space communications; multinode space, air, and terrestrial communications networks; and completely reliable interactions between human operators and space-based and ground-based weapons. Implicit in all this are fault-free or highly fault-tolerant microcomputers and software of unprecedented sophistication, embodying exceptionally "smart" algorithms, or problem-solving procedures. Designing and building such a system would be difficult enough; testing it prior to deployment, or even afterward, may indeed be impossible.

In conjunction with SDI the Pentagon is assembling a program called Strategic Defense Architecture (SDA) 2000. Its ambitious goal is to integrate space defense, ballistic missile defense, and air defense by the 21st century. Such integration would be a function of C^3I and would demand a great deal both of it and from it. In other words, C^3I is being called upon not only to ensure that the U.S. can deter and detect a nuclear strike, and retaliate effectively with nuclear weapons, but also to become the central nervous system of an all-embracing and highly demanding nonnuclear defensive strategic posture as well—a very tall order.

Offensive operations. Space is the key environment for U.S. military operations. It harbors the communications, early-warning, surveillance, photoreconnaissance, navigation, and weather satellites on which U.S. strategic and tactical forces by now almost utterly depend. Defending those satellites against Soviet hunter-killer satellites or lasers is the purpose of the U.S. Air Force's ASAT program. That program, described in the *U.S. Air Force Space Plan* promulgated in 1983, lays the doctrinal groundwork for the Air Force to make space a combat arena. In that respect the plan also discusses "force application," foreshadowing the development of manned spacecraft capable of offensive as well as defensive operations in and from space.

Such machines would be a far cry from the space shuttle, which is launched vertically on boosters and is intended mostly for such benign missions as deploying and repairing satellites. One variant of a combat spacecraft is the transatmospheric vehicle (TAV) being designed by the Air Force and five aerospace companies: Boeing, General Dynamics, Lockheed, McDonnell Douglas, and Rockwell. It is shaping up as a revolutionary, multimission machine capable of taking off from ordinary airfields under its own power, flying into space, and then reentering the atmosphere to carry out strategic or even tactical missions anywhere in the world. The transatmospheric vehicle and other Air Force "advanced aerospace vehicle" concepts and technologies are now being pursued under a newly consolidated military aerospace plane (MAP) program at the Air Force Systems Command.

President Reagan's message to the U.S. military to begin preparing to take the "high ground" in space actually predates his origination of the SDI program in 1983. On July 4, 1982, at the landing of the fourth flight of the space shuttle, Reagan declared what none of his predecessors ever had, that the most important goal of the U.S. space program is to strengthen national security, and he served notice in effect that, unless the U.S. and the Soviet Union can come to terms, the arms race would indeed be extended to space.

—James W. Canan

Earth sciences

Increased international cooperation was a notable feature of the past year in the Earth sciences. The United States, Soviet Union, and many other countries participated in experiments together and also exchanged information gained in their own studies. Geologists continued to analyze catastrophic events of the past in an effort to determine their role in influencing changes of the Earth's surface and among its plants and animals. Hydrologists focused on the widespread and severe drought in Africa and performed follow-up research on the El Niño event of 1982–83.

Atmospheric sciences

During the past year four areas of the atmospheric sciences achieved notable advances. These areas were concerned with the development of specialized monitoring capabilities, the planning and performance of observational field programs, the implementation of new forecasting techniques, and the investigation of inadvertent climatic change.

Monitoring the weather. As in previous years there was continued development of capabilities to monitor the atmosphere. These observational systems included surface-based as well as Earth-orbiting instruments. On Oct. 5, 1984, the Earth Radiation

Budget Satellite of the U.S. National Aeronautics and Space Administration (NASA) was launched by the space shuttle "Challenger." Designed to monitor the Sun's radiation reflected back from the Earth and also the radiation emitted by the Earth, this satellite became a vital component in the system of monitoring climatic change. The increasing frequency of shuttle launches was expected to enhance this capability in the coming years.

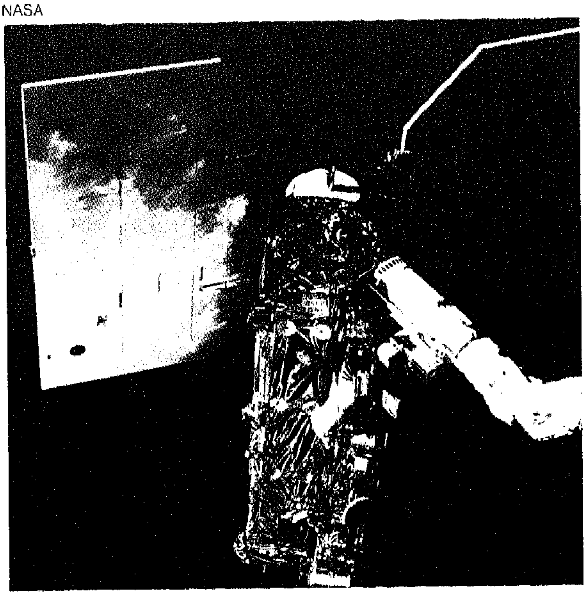
Surface-based measurement systems were taking advantage of the Earth-orbiting satellites. Wind, temperature, humidity, and other meteorological and hydrological variables could be sampled in remote locations, after which the data would be transmitted to satellites and then telemetered back to ground stations on the Earth. This could be accomplished in real time so that weather changes near the ground in isolated locations could be closely monitored. The size and shape of the surface-based systems varied considerably, but in general, apart from the small antenna that was necessary, their size was no larger than an average suitcase, with a weight of no more than 50 kg (110 lb).

The monitoring of thunderstorms can also be achieved by using ground-based observational systems called lightning locators. Until recently satellite and radar observations were the chief tools used to track thunderstorm activity. Lightning locators represent a new technique to monitor lightning. At least two types were developed to detect cloud-to-ground lightning strikes. Both record time, location, flash polarity, and stroke count of the strikes. Lightning locator systems were being installed in order to provide continuous monitoring of thunderstorms in many parts of the world.

The value of other types of remote sensing tools continued to be demonstrated. The pulsed carbon dioxide infrared Doppler lidar, as applied by the U.S. National Oceanic and Atmospheric Administration (NOAA) Wave Propagation Laboratory, was being used to monitor a wide range of atmospheric properties, including the thickness of volcanic dust layers in the stratosphere, the prevalence of cirrus clouds, and the spatial and temporal variations in the wind near the ground over distances of a few kilometers. This information was obtained by monitoring the backscatter from coherent electromagnetic radiation having a wavelength of 10.6 micrometers. This is one of the primary tools used to continue to observe the quantity and spatial distribution of residual aerosols in the stratosphere remaining from the El Chichón volcanic eruption of 1982.

The launching of lidar systems on future space shuttle flights was under consideration. Referred to as wind sensing coherent infrared radars, these systems were intended to provide a global mapping of winds as a function of height for use as input to global circulation numerical models. The information contained in the laser radiation that was backscattered from atmospheric aerosols such as water droplets and dust particles is used to determine the winds.

NASA



Earth Radiation Budget Satellite of NASA, shown here just before its release into orbit, monitors the Sun's radiation reflected back from the Earth and also the radiation emitted by the Earth.

The Doppler radar demonstrated its versatility by observing a wide range of meteorological phenomena, including wind shears dangerous to aircraft, tornadoes, and the wind flow in the vicinity of weather fronts. Employing electromagnetic wavelengths ranging from three centimeters to ten centimeters, scientists used the backscattering of the radar beam from water droplets and aerosols to estimate velocity in the direction of the beam. By using two radars with the same region of coverage (referred to as dual Dopplers), they could obtain a complete description of the three-dimensional wind velocity. These radars can be flown on an aircraft, such as those of the U.S. National Center for Atmospheric Research (NCAR) Research Aviation Facility, or moved around in trailers. In several countries, including the United States and Sweden, Doppler radars were being implemented as part of routine weather forecasting.

Observation programs. In order to enhance the understanding of atmospheric processes a wide range of measurement experiments was performed during the year, and additional research was planned for the future. The Genesis of Atlantic Lows Experiment, planned for January to March 1986, is designed to improve knowledge concerning the mechanisms of winter storm development along the east coast of the United States. During the winter such storms often develop considerable intensity, producing high winds and rain along the coast from Cape Hatteras, N.C., northward and heavy snow inland.

In the summer of 1984 scientists from NOAA and Colorado State University participated in a field experiment to monitor large organized areas of thunderstorms, referred to as mesoscale convective systems, which form east of the Rocky Mountains at night. Flash floods and other severe weather are often associated with these systems, which can cover areas as large as 100,000 sq km (40,000 sq mi). The program was designed in anticipation of a much more ambitious project, known as STORM-Central (Storm-scale Operational and Research Meteorology program in the central United States), which is being planned for the central Great Plains in the late 1980s.

Lightning associated with thunderstorms was the focus of a field program in the late summer of 1984 centered at the New Mexico Institute of Mining and Technology's Irving Langmuir Laboratory. In addition to such observation equipment as aircraft, radars, and balloons, small rockets trailing grounded wires were launched to trigger lightning when conditions were right.

Safe aircraft landings and takeoffs were the focus of the Joint Airport Weather Studies program in 1984. Rapidly sinking air near the ground associated with evaporating precipitation from cumulus clouds, referred to as downbursts, and resultant large wind shears can catastrophically influence aircraft operations through the loss of lift. In Denver, Colo., during the summer of 1984 forecasts of suspected downbursts were transmitted to pilots. A crash almost occurred in Denver during the late spring of 1984, when a commercial pilot ignored the guidance of the forecasters concerning the presence of a downburst in the vicinity of the airport.

Improving the understanding of the fundamental processes by which trace atmospheric constituents are transferred between the troposphere and the stratosphere was the goal of NASA's stratospheric-tropospheric exchange project. During five major missions scheduled to take place from 1984 to 1987, high-altitude aircraft are to measure a range of atmospheric components including ozone, carbon monoxide, water vapor, liquid water, ice crystals, and aerosols. Knowledge of aerosol exchange from the troposphere into the stratosphere is critically important to climate. In contrast to the troposphere, where materials are usually flushed out by precipitation within a few days or weeks, aerosols have a much larger residence time in the stratosphere. An increase in concentration at that height can act to cause cooling at the Earth's surface by reflecting more sunlight back into space.

An international program to determine the effect of clouds on the atmospheric circulation of the Earth was the format of the five-year Project FIRE (First International Satellite Cloud Climatology Program Regional Experiment), begun in late 1984. Separate missions to study cirrus clouds over the midcontinental U.S. and marine stratocumulus clouds off the southwest coast of California were scheduled to be performed in both 1986 and 1988. Knowledge of cloud properties and how they influence the radiation budget of the Earth is essential if an adequate understanding of climate and climate change is to be achieved.

The Tropical Ocean and Global Atmosphere (TOGA) research program is a ten-year international project that began in 1985 as a joint project of the Joint Scientific Committee of the World Climate Research Program and the Committee on Climatic Changes and Ocean. It was designed to investigate the ways in which oceanographic and atmospheric changes in the tropics influence climate worldwide and includes a joint air-sea interaction study in the western Pacific planned by China and the U.S. The project involves two consecutive five-year expeditions, for which China is to provide research vessels and the U.S. instruments and equipment. As many as 36 nations are expected to participate in TOGA.

Forecasting techniques. Improved prediction of weather and climate requires better forecasting techniques. In 1984 significant advances were obtained in both very short-range predictions and in forecasts of significant long-term climate. Over the longer time frame J. J. O'Brien of Florida State University introduced a procedure that permits the prediction of the El Niño four to eight months before it occurs. (The term El Niño refers to a major warming of the water along the South American Pacific coast associated with the reduction or elimination of large-scale wind flow parallel to the coast. Climatologists have concluded that this warming causes major weather disruptions from normal weather patterns throughout the world.) In 1983 the El Niño was blamed for such climatic anomalies as record-setting rains in Peru and Ecuador as well as drought in Australia, Indonesia, Africa, India, and Spain. Using a statistical model, O'Brien forecasts the El Niño by certain early distinctive anomalies in the surface wind stress over the Pacific.

On the shorter time scale NOAA continued to expand its capabilities to forecast hurricane storm surges along the Atlantic and Gulf coasts of the U.S. Potential storm surge impacts on Buzzards Bay in Massachusetts, Narragansett Bay in Rhode Island, Delaware Bay in Delaware and New Jersey, and Matagorda Bay and Lower Laguna Bay on the central and south Texas coast were completed in 1984. Storm surge, the coastal flooding that occurs before the arrival of a tropical cyclone, is the leading cause of deaths in such storms throughout the world.

A new procedure to alert the public to health risks during heat waves was introduced in 1984. A heat index defined by NOAA measured the contribution made by high humidity in association with abnormally high temperatures in reducing the body's ability to cool itself. This index can be considered the "apparent temperature" that the average person feels for various combinations of high temperature and humidity. With an actual air temperature of 38° C (100° F) and a relative humidity of 50%, for example, the apparent temperature would be 49° C (120° F). Sunstrokes and heat exhaustion are likely when the heat index reaches that level.

During the 1984 Olympic Games, held in Los Angeles, this index and a wide range of other weather information were prepared for use by Olympic officials and participants. The most sophisticated weather monitoring and forecasting system ever assembled in support of the Olympics was made available during the events. Solar-powered, automated weather stations were located at each of the outdoor game sites. An Olympic Weather Center was established at the National Weather Service Forecast Office in Los Angeles, with a special weather facility at Long Beach Harbor to support the yachting races. Meteorologists from the Canadian and French national meteorological services participated in preparing the Olympic event forecasts.

The capability of meteorologists to analyze current weather conditions and to provide very short-range forecasts continued to improve in 1984. This scale of weather description and short-period forecasting is referred to as nowcasting. In September 1984 the International Association of Meteorology and Atmospheric Physics, the World Meteorology Organization, the European Space Agency, and the Swedish Meteorological and Hydrological Institute sponsored the second International Symposium on Nowcasting in Norrköping, Sweden. Major advances in nowcasting were reported at that symposium including the United Kingdom Meteorological Office Mesoscale Forecasting System. This system included the first operational prediction model in the world capable of representing the effect of local hills, islands, and different land use patterns on local weather. These small-scale variations are often critical in determining weather conditions observed at a specific location. The French national meteorological service was developing a similar model.

Inadvertent weather modification. A major finding released during the past year by the Illinois State Weather Survey was that frequencies of thunderstorms over areas that are as large as the North American continent show major long-term trends. From 1901 to 1945 there was a general increase of about 15% followed by a general 10% decrease from 1945 to 1980.

Concern continued with respect to the potential impact on climate of the increase of carbon dioxide in the atmosphere. Additions of carbon dioxide to the atmosphere as a result of the combustion of fossil fuel can retard radiational cooling to space, thereby causing a net warming at the Earth's surface. Unless mitigated by other results of human activities, such as reduced sunlight at the ground due to additions of aerosols to the upper atmosphere, this warming could result in major changes in climate patterns. In 1984, as part of the continued study of this phenomenon, NOAA used aircraft to estimate how much carbon dioxide is transferred from the atmosphere into the North Atlantic during winter storms when the cold ocean waters are most efficient in absorbing carbon dioxide.

Acid deposition research also continued to receive considerable attention during 1984. Such deposition, which can fall either in precipitation (acid rain) or be deposited in dry air, has been attributed both to industrial and automotive emissions. NCAR and other groups were attempting to develop models that would identify the source of the acid and the physical and chemical mechanisms by which it is transported to other locations. Despite the lack of complete understanding of the acid deposition problem, specific political measures were enacted. In 1984 the state of New York passed a law that would reduce its sulfur dioxide and nitrogen oxide emissions, the main precursors of acid deposition, by as much as 30% by 1991. In December 1984 seven northeastern states filed a lawsuit against the U.S. Environmental Protection Agency, charging it with failure to curb acid rain.

Heightened interest and concern continued in 1984 regarding the climatic impact of a major nuclear exchange between the superpowers. It was postulated that the enormous volumes of soot and smoke that would be ejected into the upper troposphere and stratosphere by surface thermonuclear releases and by the huge fires following such an exchange would darken the sky for an extended period. Sunlight reaching the ground would be reduced, possibly resulting in subfreezing temperatures at the surface throughout a substantial portion of the world, even during the summer. Considerable uncertainty remained as to the climatic impact of such a catastrophic event, however, and intensive research was expected to continue into 1985 and beyond.

—Roger A. Pielke

Geological sciences

Among the major developments in the geological sciences was the use of seismic waves generated by earthquakes to study processes taking place in the Earth's interior. An earthquake that took place in