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Informal Report

**MASTER**

**Outer Geosciences**

University of California



**LOS ALAMOS SCIENTIFIC LABORATORY**

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## **Outer Geosciences**

**Richard L. Blake**

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## **OUTER GEOSCIENCES**

by

**Richard L. Blake**

### **ABSTRACT**

**This report presents an objective discussion of the importance of the atmospheric/solar-terrestrial system to national energy programs. A brief sketch is given of the solar-terrestrial environment, extending from the earth's surface to the sun. Processes in this natural system influence several energy activities directly or indirectly, and some present and potential energy activities can influence the natural system. It is not yet possible to assess the two-way interactions quantitatively or to evaluate the economic impact. We suggest that an investment by the Department of Energy (DOE) in a long-range basic research program is an important part of the department's mission. Existing programs by other agencies in this area of research are reviewed and a compatible DOE program is outlined.**

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### **I. SUMMARY**

When new technologies are developed, questions inevitably arise whose answers depend upon the state of understanding in the fundamental sciences behind the technologies. The sciences relevant to demand, sources, and production of energy on earth surely include the solar system sciences—how the sun and earth evolve and how their components interact. We demonstrate herein that appropriate activities by the Department of Energy (DOE) will include support for basic research on the atmospheric/solar-terrestrial system, which we have labelled the "Outer Geosciences" and in which are included the sun, interplanetary medium, magnetosphere, ionosphere, and upper atmosphere. By acting now with foresight to augment the knowledge base of the atmospheric/solar-terrestrial system we may well preclude future misfortune from

unpredicted interactions between energy technologies and the environment.

At a time when this nation has become keenly aware of the adverse effects of energy and technology on the environment, DOE has been given the task of developing the technologies of energy supply. To carry out its task for the good of mankind, DOE has a three-phase assessment program in the areas of environment, technology, and resources. When such assessments are attempted, it immediately becomes clear that the "environment" is not just the atmosphere and solid earth volume near an energy installation but rather the totality of solid earth, water systems, biological and chemical systems, and the atmosphere—all parts of a complex, interacting global system sometimes called the biosphere. The need to consider the global aspects of this system has become clear in recent years and has prompted this report.

Our national energy, transportation, and industrial sectors will necessarily be with us throughout our future and will have significant influence on the worldwide environmental system, as we have learned from radioactivity, smog, and ozone hazards.

In recent years we have learned that important variations in the earth's biosphere arise from interactions of the near-surface components with a far larger system extending to the sun and also arise from man-produced factors. Not only does solar radiation drive the circulation of the lower atmosphere with its weather patterns, but the short-wavelength (ultraviolet or uv) portion and particles are largely responsible for conditions in the higher atmosphere well above the weather-dominated layer. These higher portions contain trace constituents whose importance far exceeds their fractional concentration; a prime example is ozone. The concentrations and changes in these trace constituents caused by fluctuations in solar radiations must be assessed as a base line to compare with changes caused by energy-related technologies and other man-made injections.

Solar emissions related to the 11-year solar activity cycle cause major changes in the earth's magnetic field, plasmasphere, ionosphere, and atmosphere. In turn, these changes induce effects at earth's surface with significant socioeconomic consequences. Examples (some of which are illustrated in Fig. 1) include

- (a) interruptions in long-distance power transmission owing to geomagnetic induction,
- (b) interference in oil and gas pipeline monitors,
- (c) disruption of long-distance radio and telephone communications,
- (d) severe interference with magnetometer signals obtained for geophysical exploration for minerals and petroleum, and
- (e) modulation of both climate and weather.

Recently, evidence for the last example has become stronger. In particular, drought conditions in the U.S. high plains and other parts of the world have occurred in association with the 22-year double solar activity cycle regularly since the mid 1800's and with longer term solar activity minima for the past 5000 years (where comparison has been possible). Changes in average rainfall and average pressure track the solar activity in different ways at different geographic locations.

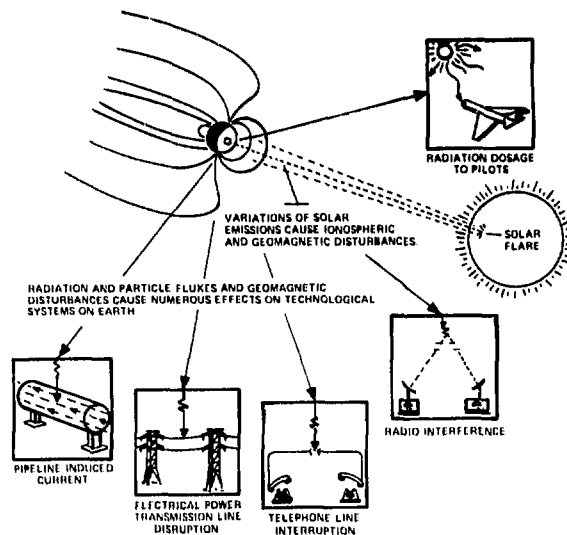
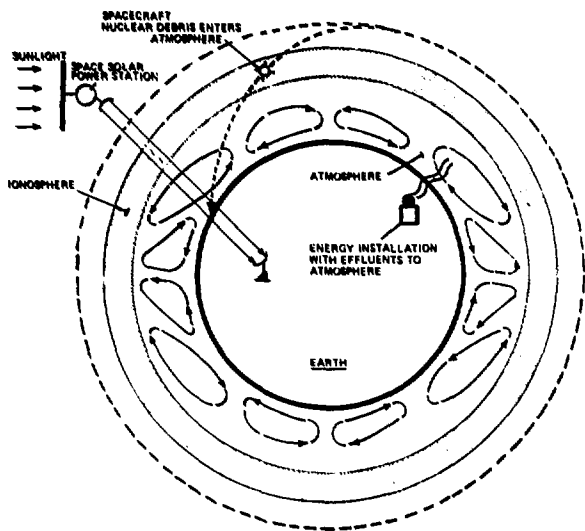


Fig. 1.

*A sketch to illustrate how solar activity causes variations in the earth's outer environment, which in turn cause undesirable effects near the earth's surface. More examples are given in the text, including effects on weather and climate.*

Man-produced factors known to affect the natural solar-terrestrial system include the following.

- (a) Harmonics of 60- and 50-Hz power systems may be a dominant cause of electron losses from the magnetosphere into the ionosphere.
- (b) Increasing carbon dioxide levels from fossil fuel consumption cause atmosphere warming and climate changes.
- (c) Injections of chemical or radioactive species into the atmosphere from weapons tests, industrial processes, energy technologies, transportation, and other human activities may alter not only the total radiation balance that controls climate directly but also the radiation balance in nonvisible spectral regions, such as the uv, producing human medical consequences. In addition, the atmospheric electrical state may be altered with possible meteorological consequences.
- (d) The space power systems discussed so far can significantly modify the ionosphere locally and, when used for long periods and in large numbers, globally.



**Fig. 2.**

*A sketch of the earth's atmosphere and ionosphere (not to scale) to illustrate the global scale of a few activities relevant to DOE. The figure depicts how activities both at the surface and in space can influence the global environment of earth. Space power systems and nuclear debris from spacecraft reactors or weapons tests in the upper atmosphere are potential future problems whose consequences can only be deduced from knowledge of the Outer Geosciences environment.*

Figure 2 indicates very generally the global nature of the atmosphere and ionosphere. Vertical and horizontal transport can occur in several ways, with the result that perturbations in the atmosphere or ionosphere do not always remain localized.

At present there is insufficient basic knowledge of climate, the atmosphere, magnetosphere, and sun as an interacting system to permit definitive conclusions on cause-effect relationships. Therefore, part of DOE's responsibilities must be support of basic scientific research to expand the knowledge base about this total system, so that realistic assessments can be made about consequences to the natural environment from man's energy systems and vice versa.

The goals of the Outer Geosciences Program suggested here are

- (1) to provide detailed characterization of the structure, natural variability, and dynamics

of the atmospheric/solar-terrestrial system and

- (2) to provide a basis for reliable prediction and assessment of the effects of energy and national security activities on that system and vice versa.

Because we are concerned about basic research, the support activity logically belongs in the Division of Basic Energy Sciences (BES), where it will complement existing applied research projects in other DOE divisions. In BES the basic research in atmospheric/solar-terrestrial areas can be implemented by expansion of the Geosciences to include more outer atmospheric and solar-terrestrial studies (that is, the Outer Geosciences).

Other agencies that have been contacted have extended considerable encouragement for DOE to emphasize basic research to improve our base-line knowledge in specific areas including

- (a) sun-climate relations,
- (b) sun-weather relations,
- (c) upper atmosphere physics and chemistry,
- (d) magnetospheric physics (especially coupling to the ionosphere and atmosphere), and
- (e) solar physics (especially the activity cycle and radiative output).

More understanding is needed in these areas before the effects noted above can be assessed adequately. Only when the important variables have been isolated and their interrelations defined can realistic assessments be made. A consensus on the need for fundamental research on components of the sun-earth system in all its varieties of interactions and a consensus that modeling of parts as well as the whole system should be encouraged to keep up with observational developments were readily apparent.

Coordination with the National Atmospheric Sciences Program and the National Climate Program would follow naturally because DOE is already engaged in the former and it has been involved in planning the latter.

## II. INTRODUCTION

As DOE's responsibility in recent years has shifted from purely nuclear matters in the AEC to the entire spectrum of energy systems, the interactions between energy systems and the environment have taken on increasing importance. At present we are

far too ignorant of the natural environment to anticipate accurately the long-term global consequences of most energy technologies. What we do know is that "environment" certainly includes more than the immediate surroundings of an energy installation. Existing programs in DOE that are geared to this "local" concept of the biosphere are essential to DOE's mission, but we believe they are not sufficient. Our reasons will be outlined in this report.

There are projects under way in DOE to improve our knowledge of the local system at the interface of earth and atmosphere. The Division of Biomedical and Environmental Research has numerous research projects in this area and other divisions contribute to them. Surface geophysical sciences have been included in the basic research program of the Division of Physical Research for a decade. A Geosciences Working Group (GSWG) with members from all DOE divisions has been effective in coordinating geosciences-related research. GSWG recently has become aware of the need for improved knowledge of the extended atmosphere and sun-earth phenomena. The natural environment is being viewed increasingly on a global scale as an evolving set of interacting components including the solid earth, water systems, biological and chemical systems, the atmosphere, the geomagnetic field, and incident solar radiation and particle fluxes.

This report responds to the question, raised within the GSWG and by outside scientists and personnel in other agencies, of why DOE has not become more active in support of research in the Outer Geosciences including the outer atmosphere, magnetosphere, interplanetary medium, and the sun. A small but very productive activity in this area has been supported by the Geosciences Program and the Division of Military Application (DMA), but the long-term socioeconomic importance seems so great that more coordinated support seems appropriate and timely. In what follows we review the reasons why the Outer Geosciences are relevant to DOE's mission, the existing programs in all agencies, and the significant areas that should be supported by modest expansion of the present Geosciences Program.

Outer Geosciences will be our shorthand to describe the totality of the atmosphere, ionosphere, magnetosphere, interplanetary medium, and the

sun—all parts of an interacting system with direct present and future influence on mankind.

### III. ATMOSPHERIC/SOLAR-TERRESTRIAL SYSTEM

Our earth is part of the solar system and inextricably bound to participate in the system's evolution. We are concerned here with several facts about the sun's energy output and its effects on earth. Over eons the solar output has been responsible for the existence of fossil fuels. On a daily basis the sun's visible radiation output is the driving force for earth's atmospheric circulation, which is what we call weather after including the interaction of this atmospheric circulation with land masses, oceans, polar ice, and other influences. Intermediate between these extremes are many earth responses to solar outputs other than visible light. The effects of these earth responses on human endeavors are often indirect and subtle; nevertheless they are important. In this section, we illustrate the general features of the system with emphasis on intermediate interactions, which we lump together in a broadly defined discipline called atmospheric/solar-terrestrial processes or Outer Geosciences. We present the descriptive information working inward from the sun to the earth's surface.

#### A. The Sun

As innocent and constant as the sun appears in our daily lives, the nonscientist often thinks of it as immutable, a fixed object in the heavens to be admired for its beauty and life-giving power. When we inquire as to the source of its energy, we learn that nuclear reactions going on in the solar interior over billions of years have created the energy that diffuses outward to the solar surface and is emitted into space. Most of the energy from our sun is emitted as visible light (Fig. 3).

Solar processes are linked by the nature of the sun's structure from the deep interior to the outer atmosphere. The earth's climate and environment, extending from surface phenomena through the atmosphere and into the ionosphere and magnetosphere, are determined by the evolution of



*Fig. 3.*

*An image of a portion of the solar photosphere in visible light, which contains most of the energy output of the sun and drives the circulation of the earth's atmosphere. Here, the appearance of a large group of dark sunspots breaks the symmetry and uniformity that have led people for centuries to think of the sun as a constant and "perfect" sphere of hot gas. Solar activity is concentrated around these sunspots, which usually cover only a small fraction of the sun's surface (Sac Peak-AURA photograph).*

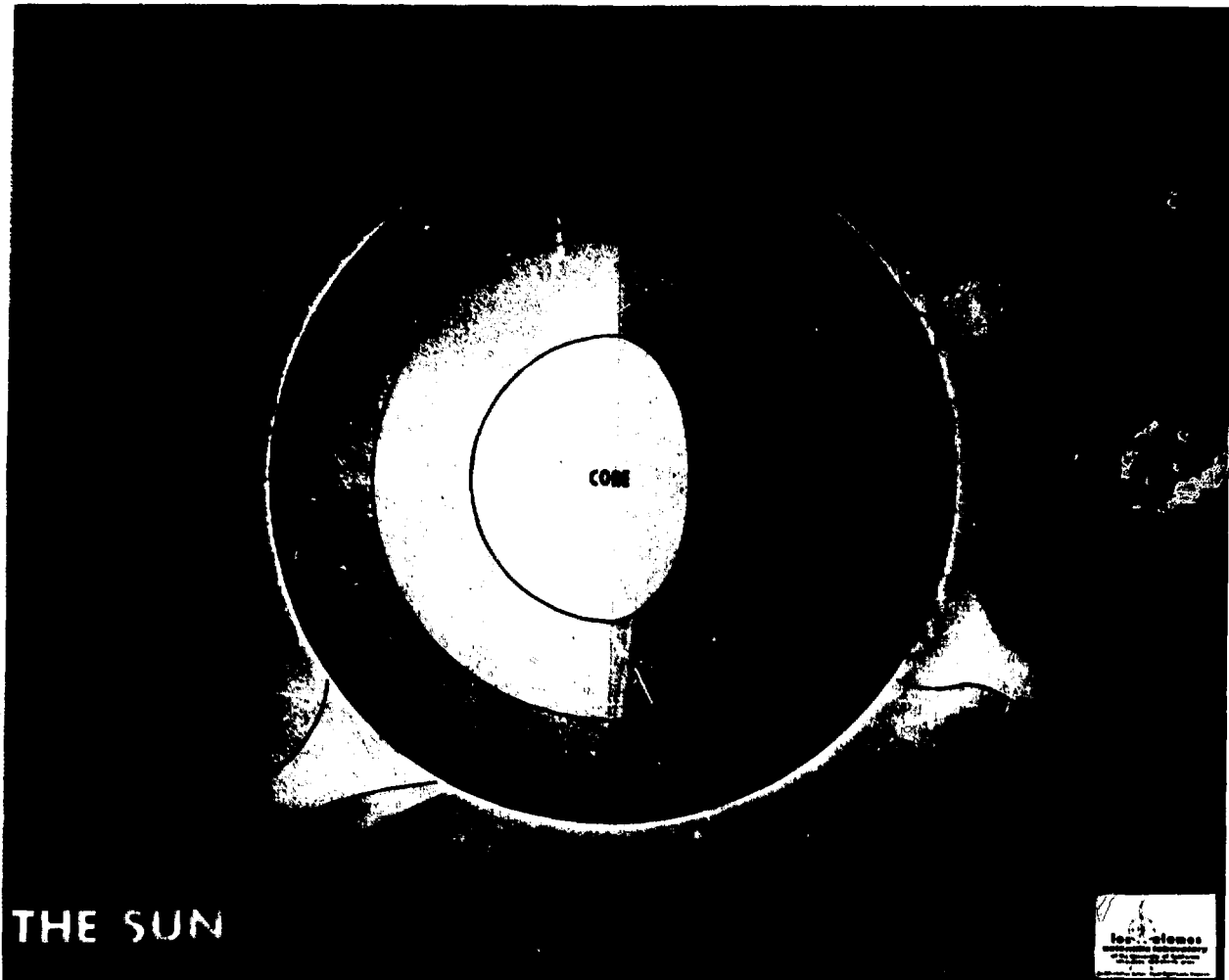
earth and sun as an interacting system. Solar radiation produces and controls our natural environment, which indeed has undergone drastic change over geological time and which is susceptible to short-term modifications, as we have come to realize in recent years. Life on earth evolved in consonance with the solar visible light output and the existence of earth's atmosphere and water. Fossil fuels extracted for energy today originated in the changes that have occurred on earth and perhaps also in the solar output over the long time periods. Therefore, solar research must become one of our national priorities, not only to harness solar energy for conversion to useful power but also to understand solar processes and how they influence solar-terrestrial relations.

Radiation emitted as visible light from the sun's surface, the photosphere, starts out as x-radiation deep in the core where the temperature is millions of degrees (see Fig. 4). There the radiation is liberated as the by-product of thermonuclear reactions, by which the plentiful hydrogen is converted into helium and a small amount of helium is converted further into heavier elements. Theoretical models of the sun have led us to believe this process will go on in a practically constant manner for several billion years, generating radiation of high energy (short wavelength), which gradually is degraded to lower energy as it diffuses out toward the surface and eventually is released into space as visible light. Just beneath the photosphere it is difficult for the radiation to pass through by this diffusive process and some of the energy is carried up by convection, a process analogous to water boiling in a pot. Some of the convection bubbles are carried past the visible surface into the lower density chromosphere and corona above, heating these higher layers.

The convection cells are also probably related to the existence and distribution of magnetic fields on the sun. These fields become intensified in the active regions, which are areas of the solar atmosphere characterized by photospheric sunspots, bright chromospheric "plages," arches of very hot plasma in the corona, and the strong magnetic fields linking these features. Figures 5-8 show how solar magnetic fields and gas combine to form remarkably complex features. A continuous wind of ionized solar gas flows in varying intensity from different portions of the sun, eventually encounters the earth's magnetic field, and flows around the earth on into interplanetary space (see Fig. 9). Some gas finds its way inside the magnetic sheath surrounding the earth, is accelerated to high energies, and is stored in the Van Allen radiation belts.

Occasionally violent storms called flares occur in the solar active regions with consequent spewing into space of enormous quantities of high-energy radiation and particles (see Fig. 5). The radiation causes sudden changes in the earth's ionosphere and immediate disruption of short-wave radio communications. A day or two later, the swept-out magnetic field and particles cause auroral storms and sudden changes in the magnetosphere and radiation belts. These solar emissions are shown in Fig. 10.





*Fig. 4.*

*This cross-sectional view of the sun illustrates the present concept of solar structure. Radiation generated by thermonuclear processes in the core streams outward until, near the surface, it merges with bubbling convection cells that assist in transferring energy outward. Bubbles overshooting the thin visible atmosphere (Fig. 3) are in part responsible for the chromosphere, transition region, and corona, all of which actually merge in a complex cauldron of hot gases and magnetic fields.*

Recently established facts and problems call into question the adequacy of solar structure theory for two critical regimes, the core and the convection layer. Predicted levels of neutrino emission from the core have not been confirmed by measurement. Whether the core is rotating remains a question as do both the possible existence of large-scale convection between the interior and surface and the possible variability with time in core properties. The con-

vection layer is believed to be critical to the existence of the chromosphere, the corona, and the 11-year activity cycle of magnetic fields and energetic phenomena. The activity cycle is correlated with terrestrial phenomena, including climate, although we do not yet know the interaction mechanism. It has now been established that this cycle of activity disappeared for several cycles in the late 17th century and that the disappearance coincided with a



Fig. 5.

*Solar activity has many manifestations. Here we see some of the remarkable complexity of the solar chromosphere as viewed in the monochromatized light of hydrogen ( $H\alpha$ ). The white patch is a flare in progress. Ejection of solar gas into space is seen at the limb near the top, but this photograph cannot show the simultaneous emission of huge amounts of high-energy particles and electromagnetic radiations ranging from the radio region to the gamma-ray region that are also emitted during flares. (Sac Peak-AURA photograph.)*

low-temperature period on earth (the "Little Ice Age"). This correlation shows that conditions at the top of the convection layer are subject to variation, which in turn suggests that the spectral distribution of solar radiation has similar variation. On a longer time scale, variation in total solar radiation possibly contributes to the major changes in the earth's climate deduced from the paleontological record.

Thus we must reckon with the possibility that both the total solar radiation and its spectral dis-

tribution vary with time. Although the suspected range of variation may be insignificant in terms of power to be generated from sunlight, it may have profound effects on climate and environment. Clearly, we should strive to understand the processes controlling production of and variation in solar spectral emissions and the interactions by which the earth's total atmosphere responds to solar irradiations.

## B. Interplanetary Medium

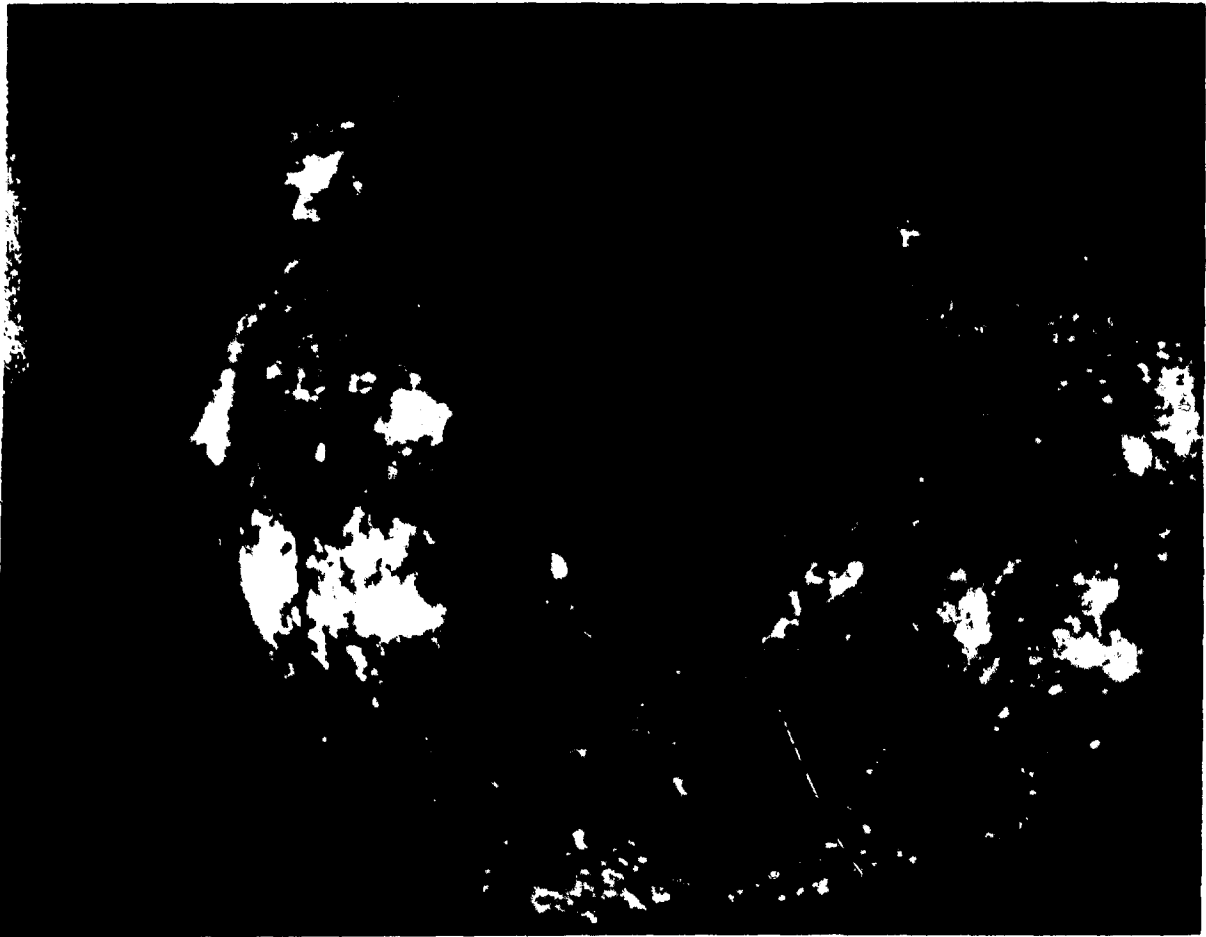
Together, the solar wind and the portions of the localized solar magnetic fields that are carried out by the solar wind dominate the interplanetary medium. There is also an interplanetary magnetic field that remains relatively steady as the sun rotates. This field is the extension of the general poloidal solar magnetic field. Galactic cosmic rays and occasional solar cosmic rays pervade the interplanetary medium. There is a low-concentration population of particles at energies intermediate between solar wind and cosmic rays. Finally, there is dust from the debris of comets and asteroids.

The interplanetary medium is important in the Outer Geosciences because solar-terrestrial processes are linked between sun and earth through this medium and because plasma and wave processes in this medium have theoretical applications to controlled fusion energy technologies.

## C. Magnetosphere, Radiation Belts, and Plasmasphere

Because the earth has a magnetic field, inside of which is the ionosphere and outside of which is the solar wind, there exists an extensive region of very complex fields and ionized gas around the earth. This region contains the magnetosphere, within which are the plasmasphere and radiation belts.

To a person located in space some distance from earth, the three-dimensional environment could be visualized like Fig. 11. The solar wind ions and electrons are diverted when they encounter the earth's magnetic field at 10 to 15 earth radii on the sunward side. Because these ionized particles can flow easily along magnetic field lines but cannot flow across



*Fig. 6.*

*One has to resort to rockets or satellites to view the sun in cww light. The results are certainly worth the effort, as revealed by this photograph in the monochromatized light of ionized helium (He II 304 Å). A great deal of structure is again evident, but it looks different from the structures in Fig. 5 because this emission comes from the transition region between chromosphere and corona, which is higher. Here, we see a great prominence of solar gas lifting off from the sun. As this gas moves away from the sun it produces a transient disruption in the solar corona and interplanetary medium. If it is ejected in the direction of earth, it will affect the magnetosphere. Fast ejections cause magnetic storms and associated phenomena. (NRL photograph from NASA Skylab.)*

them, the resultant flow pattern takes on the appearance shown. A sharp demarcation line called the "bow shock front" is set up. Most of the solar wind flows around the earth between the bow shock front and the magnetopause, but some of it leaks inside by a variety of processes and becomes the

magnetospheric plasma. The streamlines of flow look somewhat like a comet tail.

The magnetopause is another demarcation line. Within it, the earth's magnetic field and the magnetosphere plasma maintain the reasonably well-defined geometry depicted by the streamlines



*Fig. 7.*

*The shock wave associated with a fast coronal transient ejection is evident at upper left in this photograph, taken in white light by a coronagraph in space. For this image the visible disk of the photosphere must be blocked out by an occulting aperture in the telescope. Well-formed corona streamers can be seen in the middle right side (compare Fig. 4). (HAO photograph from NASA Skylab.)*

in Fig. 11. Between the magnetopause and bow shock front is the magnetosheath, a region of turbulent plasma and fields. The polar cusp is a consequence of the electrodynamic interactions of this system; it is a region of weak field strength extending from the magnetosheath down into the polar ionosphere on the sunward side. It is filled with magnetosheath plasma and represents one pathway for interaction between solar wind, magnetosphere, and the earth's upper atmosphere. Another pathway is through the magnetotail, which contains a thin region of generally zero field strength (the neutral sheet) surrounded by a plasma sheet. Interactions in the magnetotail are responsible for accelerating some of the particles that form the radiation belts as well as for magnetic substorm events.

The radiation belts are regions of high-energy particles inside the magnetosphere; their boundaries are defined by the regions where magnetic field lines form closed loops. By a combination of wave-particle and other interactions the electrons and protons in the radiation belts are accelerated to high energies. If we imagine the magnetic field lines to be loops of rope with the ends touching the earth's surface in the polar and auroral latitudes ( $60^\circ$  to  $90^\circ$ ), the high-energy ions move along these ropes and simultaneously spiral around them. The ends of the lines converge in the polar and auroral zones. Because of this convergence (field gradient), the ions are reflected in the opposite direction and continue to bounce back and forth between northern and southern hemispheres, generally moving along the field lines. Consequently, the radiation belts are roughly doughnut-shaped shells around the earth's magnetic equator.

In the same region of space with the radiation belts there is a low-energy plasma of electrons and protons, most of which probably leaks from the ionosphere below. This plasma constitutes the plasmasphere. The high- and low-energy particles rarely collide because their densities are so low. Collisions do occur in the auroral and polar zones, where some of the particles travel down toward the atmosphere far enough to experience a collision before they are reflected by the converging field lines. The particles that collide and remain in the atmosphere are said to have been precipitated. Other loss processes also occur.

Replenishment of magnetospheric particles that precipitate out is determined in part by cosmic rays and in part by the solar wind and its interaction with the magnetosphere. Since the solar wind originates at the sun in preferred longitudes around the solar circumference, the magnetosphere is buffeted alternately by strong and weak streams. These streams tend to alternate not only in density and speed but also in magnetic polarity carried out from the sun. This combination of solar wind conditions is called the sector structure.

In addition to the solar wind there are occasional burst-like ejections of matter from the sun, usually associated with solar flares. Strong bursts cause geomagnetic storms and substorms. The marvelous variety of interactions within this magnetospheric region is more than just a subject for scientific



**Fig. 8.**

*To view the hot corona without an occulting disk, we can use an x-ray telescope. Because the coronal temperature is several million degrees, it emits radiation in the x-ray region of the spectrum. This photograph reveals that the outer range of the solar atmosphere has a structure different from the regions seen in the preceding figures. By viewing the sun in these several spectral regions, and hence different regions of the solar atmosphere, we hope to unravel the complex processes that constitute solar activity. The very bright patches are above sunspot active regions. A large coronal hole runs from above center to the bottom as a dark patch. Magnetic loops are revealed by the thin bright lines of emission near the center and along the 4 o'clock radius. (AS&E photograph from NASA Skylab.)*

curiosity. In Sec. IV we show that significant effects occur at the earth's surface.

#### **D. Earth Atmosphere/Ionosphere**

The density of the earth's atmosphere falls off very rapidly with distance above the surface until it

reaches only a few atoms per cubic centimeter in interplanetary space. In between there are many layers where important natural phenomena occur. Most notable to us at the surface is the weather layer or troposphere, shown at the bottom of Fig. 12. This figure is drawn with a variable vertical scale to permit a better illustration of layers and phenomena. Figure 13 shows that the temperature

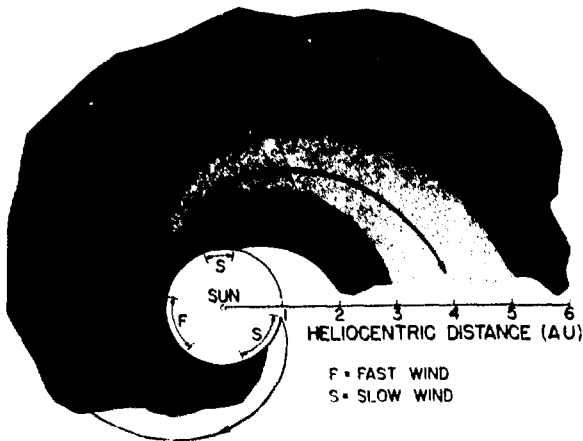


Fig. 9.

*Even when there is no flare in progress, the sun emits streams of matter into space. This is the solar wind. It tends to be emitted continuously but shows enhancements in preferred solar longitudes. One such preferred longitude is illustrated here. Because the sun rotates, the gas takes the form of a spiral (the garden sprinkler effect) as it moves out from the sun into space. Eventually it reaches earth and mostly flows around the magnetosphere, although some of it enters the magnetosphere and contributes to the earth's plasmasphere and radiation belts after some interaction processes. The spiral curve does not become very pronounced for encounters as close as the earth, which is at 1-AU heliocentric distance in this illustration.*

has peaks and valleys related to the absorption of solar uv and x-ray radiation.

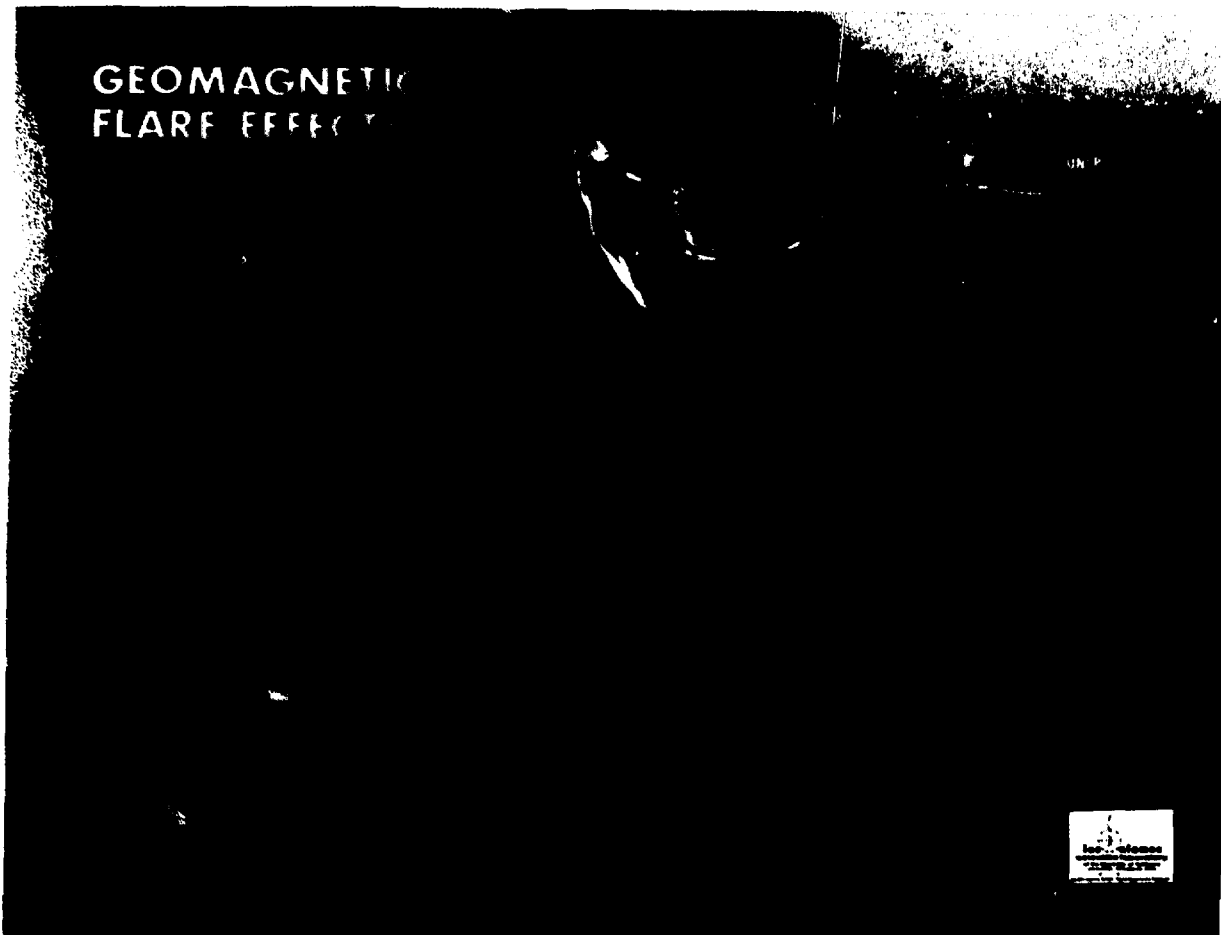
The traditional way to subdivide the atmosphere is to consider it as having a number of layers and boundaries where sharp changes occur in the vertical temperature profile, as shown in Fig. 13. The troposphere is often designated as the lower atmosphere, whose depth varies with latitude and local weather conditions. The stratosphere, or the middle atmosphere, is roughly 30 km deep and extends to 50 km, which is the maximum altitude meteorological balloons can reach. The tropopause is a shallow layer that separates the troposphere and stratosphere, two layers of markedly different temperature gradients. Its height above the ground at a

given time and place is quite variable. For example, the tropopause in equatorial latitudes may be as high as 18 km, whereas in polar latitudes it may be as low as 6 to 8 km.

The upper atmosphere (as distinct from the stratosphere) extends from 50 km to as high as 1000 km and includes the mesosphere, mesopause, and the thermosphere. The upper atmosphere includes the ionosphere, where the concentration of free electrons and ions becomes significant. The ionosphere is divided into three regions: D (50-59 km), E (90-160 km), and F (above 160 km).

Atmospheric density decreases approximately exponentially with altitude; half of the atmosphere lies below 6 km, 99% below 30 km, and 99.9% below 50 km. The dominant species below 100 km are nitrogen molecules (~78.1%), oxygen molecules (~20.9%), and argon atoms (>0.9%). Although these three species make up about 99.96% of the atmosphere below 100 km, the remaining 0.04% is the key to atmospheric behavior. Above 100 km, atomic oxygen is a major constituent. The entire system is powered by solar energy extending over a very broad spectrum from hard x rays to radio frequencies. The solar spectrum intensity is relatively constant above 2000-Å wavelength but is strongly dependent on solar activity at shorter wavelengths. The earth's orbital and rotational motions modulate the energy input, each in a characteristic way. Some energy passes through the atmosphere to the earth (the visible and rf windows), but a large portion is absorbed by the atmospheric gases. The rotational motion accounts for diurnal changes in the weather, wind velocity, cloudiness, etc., and the orbital motion is associated with seasonal changes.

The altitude dependence of density, temperature, and energy absorption produces a strong altitude dependence of fundamental processes and observable phenomena. The earth's motion and magnetic field further complicate the system. Energy absorption produces a great variety of minor constituents either directly by photoionization, photodissociation, and photoexcitation (and related higher energy particle processes) or indirectly by subsequent particle interactions, to provide the final 0.04%. The reactive species of importance include electrons, atoms (O, N, ...), positive ions ( $O_2^+$ ,  $N_2^+$ ,  $NO^+$ ,  $O^+$ ,  $NO_2^+$ , ...), negative ions ( $O_2^-$ ,  $O_3^-$ ,  $CO_3^-$ ,  $NO_2^-$ ,  $NO_3^-$ , ...), derived molecular species ( $O_3$ ,  $NO$ ,  $H_2O_3$ , ...), free radicals (OH,  $HO_3$ , ...), excited states



**Fig. 10.**

*Artist's concept of some of the solar emissions responsible for terrestrial effects. The geyser-like stream depicts (in an oversimplified way) how some solar flares hurl a storm cloud of charged particles and electromagnetic radiations into space. If the charged particle cloud is directed toward the earth, it causes the glowing aurora borealis and various geomagnetic disturbances. The euv and x-ray emissions cause sudden changes in the ionospheric electron concentration; in turn, radio propagation around the earth by ionospheric reflection is disrupted.*

of atoms and molecules [ $O(^1D)$ ,  $O_2(^1\Delta_g)$ ,  $N_2^v, \dots$ ], and complexes [ $O_4^-$ ,  $N_4^+$ ,  $(H_2O)_n$ ,  $H^+, \dots$ ]. Trace amounts of water and carbon dioxide also play important roles.

Both the composition and the dynamics of the upper atmosphere are affected by natural and man-made perturbations. Among natural perturbations are the solar wind, x-ray and  $\gamma$ -ray pulses, and

cosmic rays from outer space (all of which excite and ionize atoms and molecules in the upper atmosphere); cosmic dust from meteoritic showers in the upper atmosphere; and volcanic eruptions that inject particulate matter and various chemical species (often in copious amounts) in the troposphere and the stratosphere.



*Fig. 11.*

*Earth's magnetosphere as shown here is shaped on the outside like a comet. The solar wind pressure pushes the earth's magnetic field into a slightly flattened shape on the sunward side and stretches it out into a long tail on the side away from the sun. Several interaction processes are responsible for the plasma and magnetic field conditions inside the magnetosphere, including the plasma sheet, polar cusp, and high-energy particle radiation belts.*

The sources of man-made perturbations are power generation and consumption, weather modification, and nuclear weapons testing. The 1963 test ban treaty prohibits nuclear weapons tests or any other nuclear explosion in the atmosphere, in outer space, or under water. However, the treaty has not been signed by France or by the People's Republic of China. Clearly, power generation and consumption are the most significant man-made causes of atmospheric perturbations. Fossil fuels contribute extensive amounts of chemical and particulate pollutants to the environment, primarily in the troposphere. The advent of the supersonic transport and the National Aeronautics and Space Administration's (NASA) future use of the space shuttle system have extended the perturbation domain well into the stratosphere.

Although naturally occurring atmospheric perturbations affect primarily the upper atmosphere and the stratosphere, whereas artificial perturbations occur generally in tropospheric altitudes, recently discovered cyclic processes have helped focus attention on the coupling that exists between the lower and the upper atmospheres. In particular, a 14-day cycle has been discovered in the circulation pattern between the troposphere and the stratosphere over the northern hemisphere. The cycle was first theorized 8 years ago, and its existence now has been partially confirmed by National Oceanic and Atmospheric Administration (NOAA) scientists. The troposphere and the stratosphere are thus coupled by a vertical exchange of energy from the troposphere into eddies in the lower stratosphere.



# AEROSPACE ENVIRONMENT

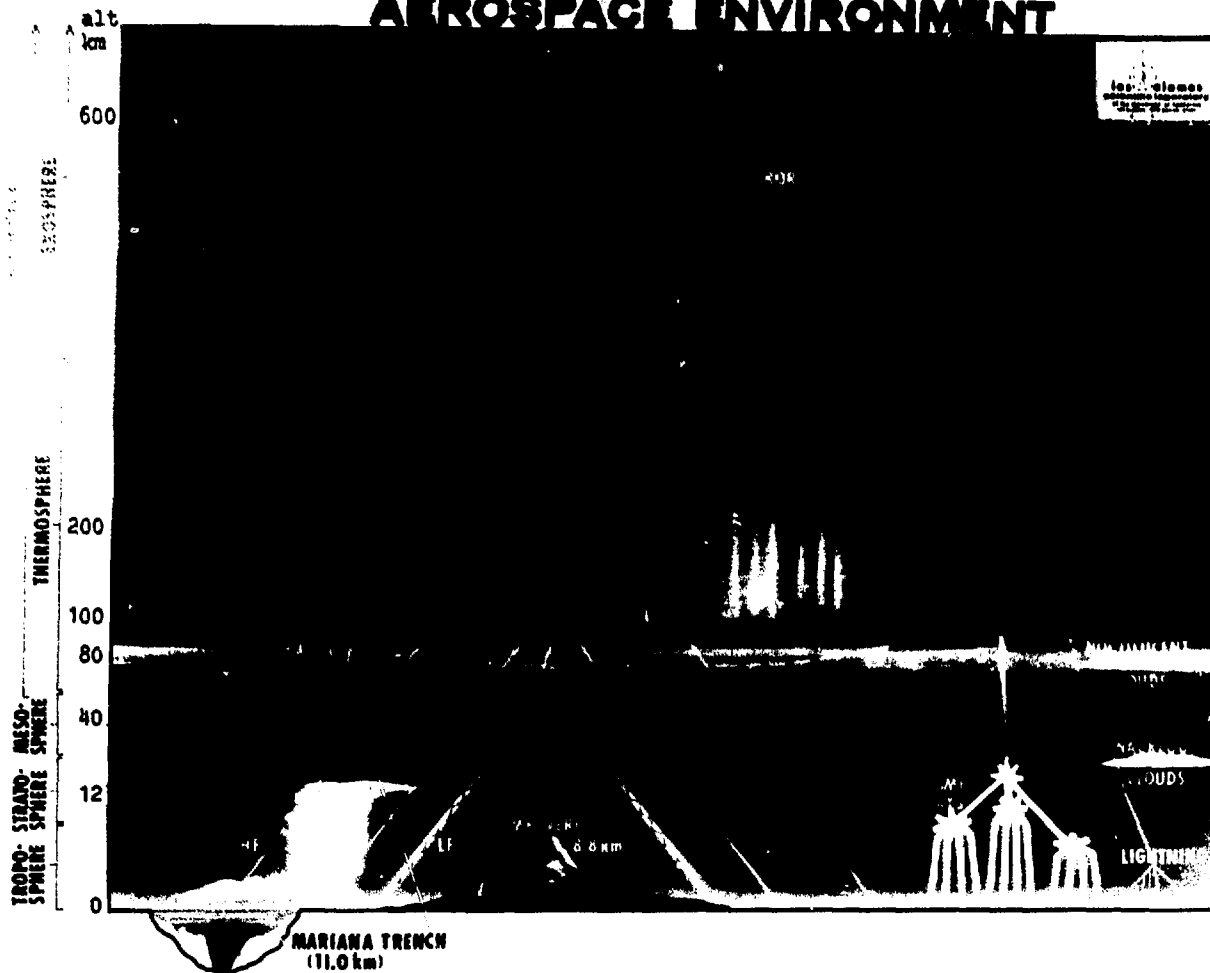


Fig. 12.

A vertical profile of the earth's atmosphere and ionosphere showing some of the many phenomena that are part of the Outer Geosciences. The vertical scale is broken in places and nonlinear.

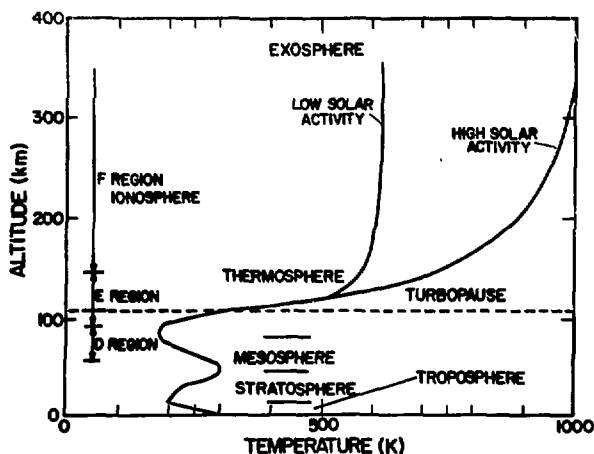


Fig. 13.

Temperature of the earth's atmosphere as a function of height above the surface. The temperature distribution through the atmosphere provides a basis for dividing the atmosphere into layers or spheres. The troposphere generates weather phenomena. The stratosphere is the location of the ozone layer. The exosphere is the outermost portion of the atmosphere, where the gas is so rarefied that collisions between gas particles occur only rarely, causing the temperature distribution there to be isothermal with height.

Visible sunlight penetrates the atmosphere with very little absorption. Therefore the tropospheric layer is heated by contact with the surface and by absorption of infrared radiation from the surface. Because all this heat input comes from the bottom, the temperature decreases with distance above the surface, as may be verified when one goes from a valley to a high mountain. The rate at which the temperature drops with altitude leads to an unstable situation. Convection sets in and the atmosphere constantly mixes itself as cells of gas circulate in the well-known manner where warm air rises and cooler air from above descends to take its place.

At the level of the tropopause the water vapor has condensed out, thus removing the major source of infrared absorption from below. Hence the overlying atmosphere is largely in radiative equilibrium with the solar radiation from above providing the heating (uv, euv, and x rays). The higher levels of the stratosphere contain ozone and are heated by the solar uv. This heating from above causes a temperature inversion in the stratosphere between the tropopause and the peak ozone layer (~25 km), which makes the stratosphere stable against convective mixing.

The temperature rise caused by ozone absorption peaks out at about 50 km and then falls again to about 80 km. This band is the mesosphere, another region of falling temperature that is unstable against convection. At still greater altitudes solar uv below 100 Å is absorbed, and another temperature rise occurs in thermosphere (~80 to 700 km). Above 1000 km the temperature approaches a constant boundary value (~1000 K).

The two convection regions, together with occasional overshoots into the neighboring stable regions, lead to a complete mixing of the atmosphere up to about 120 km. At greater heights the individual gas species take up different distributions with altitude, depending on their molecular weights, by a process called diffusive separation.

In the ~80- to 200-km range, solar euv and x-radiations are absorbed predominantly by ionizing the atmospheric gases. Thus the solar flux is responsible both for heating the upper atmosphere and for creating the ionosphere. The ionosphere extends from ~60 to ~300 km, above which the ionization density falls off and the ionosphere merges with the

plasmasphere. The energy absorbed through ionization by solar radiation during daytime is converted by gas reactions into gas kinetic energy (heat). The heat input is conducted downward until equilibrium is reached. Above 250 km so little solar energy is absorbed that a negligible temperature gradient is needed to conduct heat downward; thus thermosphere temperature tends to be nearly constant above 250 km. It relaxes fast enough, however, that the temperature drops at night when the sun is not providing heat input. Similarly, both ionization and temperature of the upper atmosphere vary over the solar cycle, because the incoming solar x rays and euv fluxes vary with solar activity.

Figure 12 shows how the ionosphere is used to reflect radio waves. A given frequency is reflected from a specific electron density layer. Consequently, any process that changes the electron density will perturb certain communication frequencies. Perturbations arise from winds and tides in the upper atmosphere and from variations in solar flux. Major changes occur during solar flares because a sudden burst of harder x rays penetrates into the 30- to 80-km region and creates momentary excess D-region ionization. In the 5- to 60-km region, the dominant source of ionization (except during solar flares) is cosmic rays. Near ground level, ionization of the atmosphere is due mostly to natural radioactivity of the surface. Thus the atmosphere has some electrical conductivity at all levels, which for several reasons varies with solar activity. The variable atmospheric conductivity is one hypothesized mechanism by which weather may be related to solar activity.

Figures 14 and 15 illustrate how the solar visible radiation output drives the circulation of the earth's troposphere on a global scale. These depictions, however, are highly idealized as a pattern averaged over the globe and over years of observation. At any one time the pattern could look quite different and in the mid latitudes the illustrations are not fully consistent. Both figures emphasize the north-south component of circulation along a meridional slice.

Incoming sunlight penetrates the atmosphere to the surface where some is reflected (albedo) and the rest is absorbed. The surface in turn emits infrared radiation, which is absorbed by the atmosphere and heats it up. The heating rate at the surface is greater near the equator than in the polar regions, but the

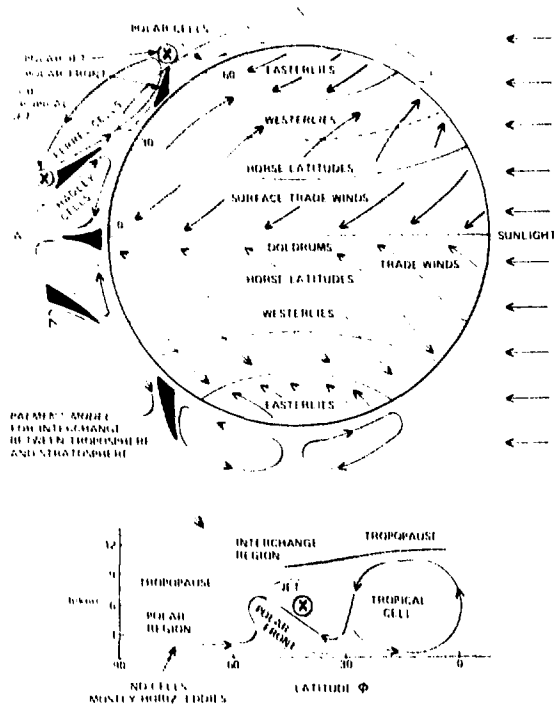


Fig. 14.

A section through the earth along a meridian plane showing the general circulation of the atmosphere as driven by the unequal solar heating between poles and equator. The surface trade winds and polar easterlies find explanation in the deflection of circulating air masses by the earth's rotation. The prevailing mid-latitude westerlies probably owe their existence primarily to large-scale frictional forces between the surface and "wave regime" circulation at these latitudes. The lower portion has a little more detail to emphasize Palmen's model of the interchange between troposphere and stratosphere.

cooling to space is about the same as from near the tropopause where water condenses out. The difference in heating is what causes the atmosphere to circulate, on the average in giant cells as depicted. Warm air rises in the equatorial region and moves toward the poles. On the way it is deflected by the earth's rotation, which prevents the circulation cells from extending all the way to the poles. Instead, the circulation returns equatorward along the surface,

giving rise to the tropical trade winds. Similar air deflection in the polar cells gives rise to the polar easterlies. At the intersection of cells from the polar and tropical zones the atmosphere responds to the clash of warm and cold air masses by setting up strong winds in a generally east-west direction along the boundary (the jet stream at high altitudes). The undulation of this boundary around the earth is called the circumpolar vortex. On the surface, local segments of the circumpolar vortex produce warm and cold fronts preceded or followed by high- or low-pressure "cells." Thus in mid latitudes we speak of the "wave regime" of circulation to describe the flow with a large-amplitude horizontal wave motion at higher altitudes (as seen on the 500-mbar maps on TV) and the breakup into eddies about high and low pressures at lower altitudes (the surface weather map on TV). Figures 15 and 16 are attempts to illustrate these general atmospheric circulation patterns in three dimensions. The north-south component is emphasized in Fig. 15, whereas Fig. 16 shows how the strong east-west component causes the Ferrel and polar cells to take on the appearance of giant cells of predominantly horizontal circulation. The prevailing patterns depend not only on the season but also on the geography of land masses and oceans. NOAA scientists believe a slight warming of the mid Pacific ocean caused the high-pressure bulge seen along the west coast of North America. This ridge in combination with the unusual high centered over the North Pole caused the severe winter of 1976-77 in the eastern United States. The polar high-pressure cell may have been influenced by the minimum of solar activity.

## E. Climate and Weather

Usually, we do not think of climate and weather as related to solar-terrestrial processes. Yet we have just shown how solar radiation drives the atmosphere at all levels. Details of weather and climate (the long-term average weather) depend on additional parameters, particularly on the coupling between atmosphere and oceans, land masses, and ice and snow masses. Figure 17 illustrates the components of the climate-weather system. Models must take account of all these components, as far as possible. The primary influences that are external to

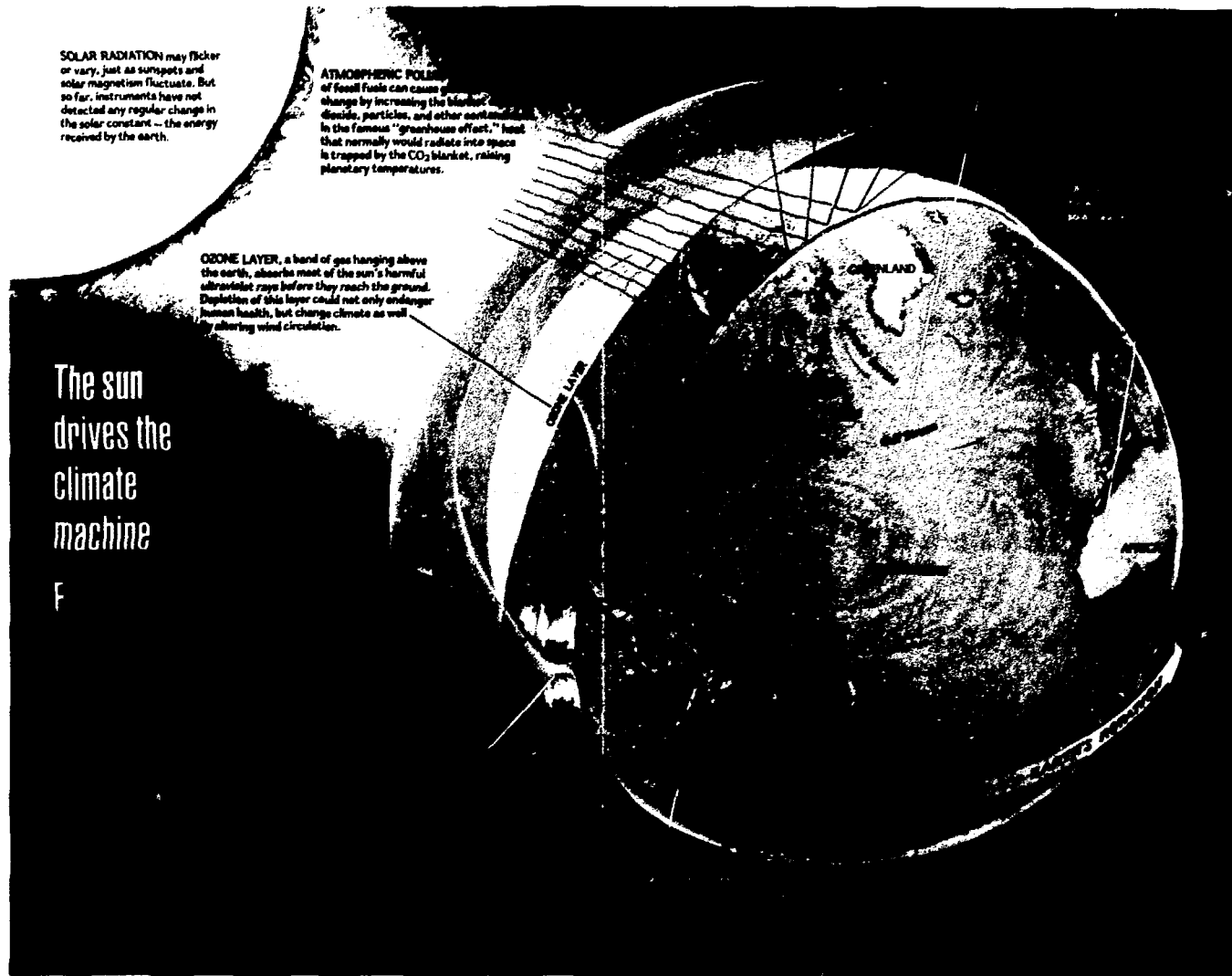


Fig. 15.

A three-dimensional view of the general circulation of the earth's atmosphere emphasizing the latitudinal motion in "cells" and the jet stream formation at the

upper-level boundaries of cells with different temperature air masses. Figure 14 would be a slice out of this figure along a meridian plane. (Illustration with the permission of National Geographic Society.)



**NORMAL NOVEMBER:** Warm surface water in the central Pacific and cool water off South America reflect usual conditions for the month.



**NOVEMBER 1976:** Shifts of as little as 2°C in sea-surface temperatures may have intensified unusual pressure systems and the winter that followed.



**NOVEMBER 1977:** Low pressure in North Pacific and high pressure off North America's west coast strengthen a bulge in the normally circular pattern of air movement.

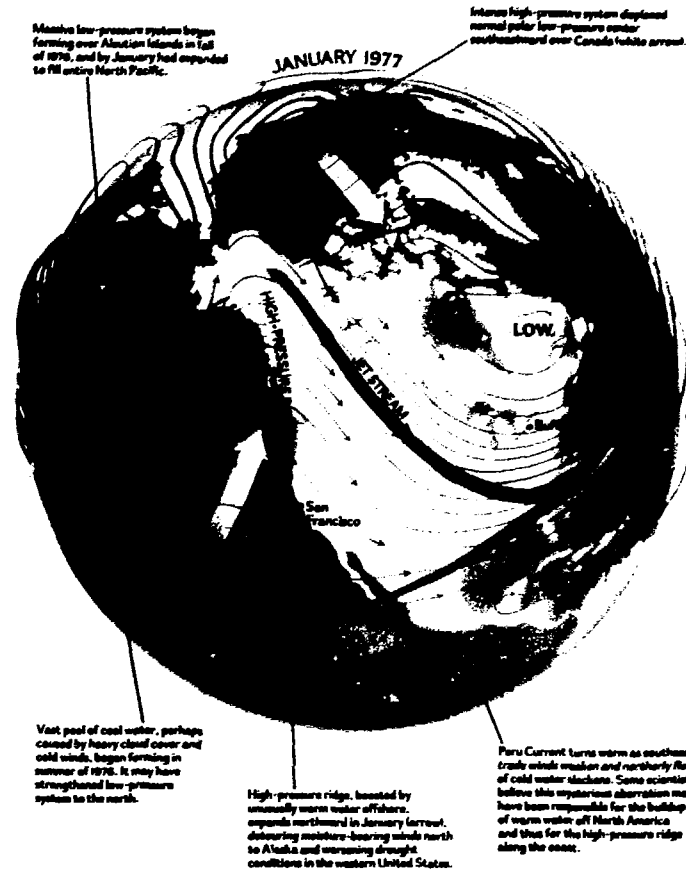


Peru Current delivers cool water into the equatorial Pacific.

## Ill winds blow in a bad winter

LOPING AROUND a huge low-pressure system in the North Pacific (right), and deflecting off a high-pressure ridge along North America's west coast, the earth-circling jet stream and its accompanying westerlies were diverted to Alaska in a pattern unbroken for most of the winter of 1976-77. Turning back to the south, and accelerated by a shift of the normal Canadian low to the southeast over Newfoundland, the winds—now bearing a freight of Arctic air—funneled straight out of the northwest into the United States. And the disaster was born.

Some scientists look to the oceans and their vast pools of warm and cold water (upper left) for keys to long-range prediction of such radical shifts in wind circulation. Though experts agree that sea-surface temperatures are influenced by the atmosphere, which in return is affected by the more heat-retentive water, they differ on the importance of ocean feedback to continental weather. Changes in the Peru Current, for example, are seen by some as symptoms, not causes, of deviant weather patterns.



PHOTOGRAPH BY THE U.S. AIR FORCE AND NATIONAL AERONAUTICS AND SPACE ADMINISTRATION. DRAWING BY NATIONAL GEOGRAPHIC SOCIETY.

**Fig. 16.**  
A three-dimensional perspective view of general circulation in the northern latitudes, emphasizing the tendency for horizontal motion to predominate at mid

to high latitudes and showing the anomalous pattern associated with the unusual winter of 1976-77. (Illustration with the permission of National Geographic Society.)

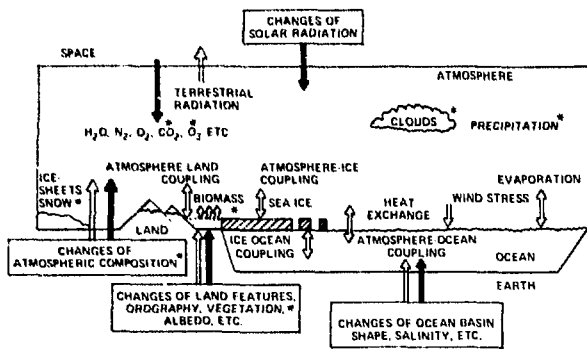


Fig. 17.

Components of the climate-weather system. Full arrows (→) are examples of external processes, and open arrows (⇌) are examples of internal processes. Components with a \* can be modified by man's energy programs.

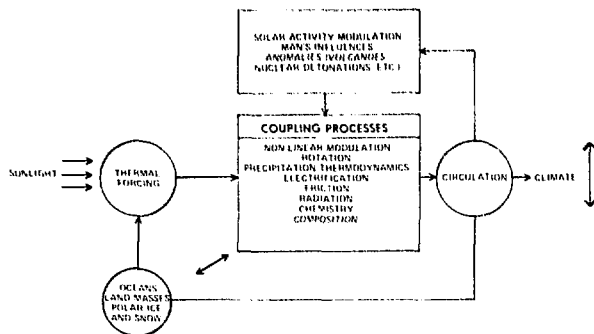


Fig. 18.

A flow chart for some processes that must be included in models of the climate-weather system. Although solar visible radiation predominates in thermal forcing of the atmospheric circulation, the other thermal-forcing factors and the coupling functions determine the details of weather and climate.

the system are (1) the solar radiation, which drives the system; (2) solar activity, which somehow through solar-terrestrial processes modulates the system; and (3) man's activities, which can become significant in future years and may already be significant regarding carbon dioxide and ozone.

Figure 18 shows in a rudimentary way how to model the weather-climate system. We have seen that the difference in net solar heating with latitude

provides the primary thermal forcing function of atmospheric circulation. However, the actual circulation is also influenced by the water content of the atmosphere and the interaction of the atmosphere with land masses, oceans, ice and snow masses, and with man's technologies. When all these factors have been included and the computed circulation has been averaged over intervals long enough to smooth out small-scale eddies, the model represents the climate. Variations in climate can arise from changes in the direct forcing functions or in the coupling functions. The double-ended vertical arrow at the right-hand side of Fig. 18 indicates that a variability range exists in climate from all causes.

Climate data exist from historical records over the past few hundred years, from tree rings extending back as much as 10 000 years, and over longer periods from cores taken from the ocean bottom and land sediments and from polar ice packs. These data indicate external causes of climate variability as well as causes that are part of the system. Over periods of years to hundreds of years, significant externally forced climate variability can be caused by volcanic events, solar variability, and human impacts. A large effort is under way to monitor human impacts, but the first two factors are both difficult to evaluate and not studied systematically at present.

## F. Interactions of Possible Significance

We have defined the relevance of Outer Geosciences to DOE interests primarily in terms of processes that occur on a global scale, implying a concern for interaction processes that link the lower atmosphere and earth surface to the upper atmosphere and magnetosphere. Global processes important to control of the atmospheric/solar-terrestrial system dynamics include circulation, waves, electric and magnetic fields, current systems, chemical reactions, and radiation transfer. The following are a few global-scale interaction processes.

- (1) Electric currents provide an important energy transfer mechanism between the magnetosphere and ionosphere; perhaps also to the troposphere.

- (2) Any circulation changes (convection) in the magnetosphere require the flow of currents into and out of the auroral zone.
- (3) Convection of the solar wind is the dominant source of energy input to the polar region upper atmosphere.
- (4) Waves and circulatory motions in the atmosphere are influenced by the geomagnetic field.
- (5) Magnetospheric storms produced by outbursts from the sun cause a wide variety of global effects both at high altitudes and on the earth's surface.
- (6) Energy transport by gravity waves and tidal motions connects the troposphere to the upper atmosphere at very high levels where direct convective circulation cannot reach. Gravity waves also carry energy from auroral regions to lower latitudes.
- (7) The many trace molecular constituents introduced into the atmosphere by man-made and natural sources have important controlling effects on numerous global chemical reaction cycles.
- (8) The chemical balance of the upper atmosphere is affected by the large-scale circulations, which can enhance or degrade some species at particular global locations (usually related to seasons but not restricted to this case).
- (9) Stratospheric transport of energy and chemical processes involves both diffusion and a broad spectrum of atmospheric waves whose periods range from minutes to weeks, and probably to longer periods, and whose distance scales extend from meters to the circumference of the earth.
- (10) Tropospheric thunderstorms provide paths for currents between the lower and upper atmosphere.

Interaction processes most worthy of immediate study and support over the next few years include the following.

In solar physics the entire complex of plasma-magnetic field interactions has potential relevance to understanding processes in the earth's magnetosphere and atmosphere. In addition, many of the processes are similar to processes in controlled

magnetic fusion and laser fusion systems. Important interaction processes include plasma instabilities, wave-particle interactions, magnetic merging, convection, generation of magnetic fields (dynamo processes), and conversion of magnetic energy into heat energy. Nuclear interactions in the solar interior and their observable consequences in neutrino emission and solar structure are relevant to our understanding of how to apply the basic laws of physics.

In the solar wind-magnetosphere regime, magnetic merging must be studied to gain a better understanding of how electromagnetic energy is converted to particle energy. In both the magnetosphere and the sun, nature seems to have remarkably efficient ways to move ionized gas across magnetic field lines and to accelerate the gas particles to high energies. Magnetic merging is one of the most likely acceleration mechanisms. Particle diffusion across a magnetic boundary, especially collisionless diffusion, needs more study in comparison to plasma-magnetic field configurations that permit bulk transport of the plasma across the field. The collisionless shock wave is important in the magnetosphere and solar wind as well as in many laboratory plasma confinement experiments, yet it is poorly understood theoretically. The varieties of magnetic, particle, and wave interactions involved in magnetic storms and substorms must be sorted out and understood, especially because of the practical need to anticipate occurrence times and the resultant disruption of power transmissions and communications and because of their contributions to the energy budget of the neutral upper atmosphere. Precipitation of magnetospheric particles into the atmosphere is not well understood, but the growth of instabilities involving wave-particle interactions is of central importance. Recent experiments have given good evidence that harmonics of earth power systems actually couple to magnetospheric particles and cause precipitation. Much progress has been made recently on delineation of convection in the magnetosphere; this subject needs further detailed study because magnetospheric convection couples to the ionosphere and neutral upper atmosphere by way of ion drag.

Among interactions of importance in the upper atmosphere that seem in need of improved understanding, the most urgent probably are the large- and small-scale dynamic processes occurring within the thermosphere, at the thermosphere-magnetosphere boundary, and between the mesosphere and stratosphere. Next in importance is probably the investigation of the exchange of energy, momentum, charge, and mass within the ionosphere-thermosphere-magnetosphere system during auroral processes. Finally, the chemistry and exchange transport of minor constituents between the thermosphere and mesosphere needs further elucidation, with simultaneous consideration of the effects of upward propagating planetary, tidal, and gravity waves. The search for processes to explain the influence of solar activity on weather and climate may require global transport models including each of the above interactions.

The atmospheric distribution of nitric oxide is particularly important. Nitric oxide has a strong influence on ozone concentrations in the stratosphere and its  $\text{NO}^+$  ion may control the ion-chemical interactions that produce hydrated ions at high altitudes. Ion-induced nucleation may be important both to the growth of particulates in the upper atmosphere and to the sun-weather connection.

We do not have an adequate concept on which to build models of Outer Geosciences phenomena that affect weather and climate. By implementing the National Climate Plan, we hope to obtain improved data from the climate- and weather-controlling factors shown in Fig. 18. However, the plan was generated before the significance of solar-terrestrial processes to climate modulation was appreciated fully, and this report can be considered an addendum to the National Climate Plan, wherein we emphasize the role of solar-terrestrial processes.

How could processes high above the troposphere have anything to do with events within the troposphere? There must be some interchange mechanism between the upper and lower atmosphere, and the mechanism must be sensitive to the variations of solar activity. Possible propagators of the solar influence include the following.

(1) Some portions of the solar wind find their way through the magnetosheath and the polar cusps directly into the upper atmosphere in polar latitudes. Other portions are modified in energy,

stored in the radiation belts, and eventually precipitated into the atmosphere, mostly in auroral latitudes.

(2) Solar uv, euv, and x rays are absorbed from the tropopause up to thermosphere levels and are responsible for both the existence of the ionosphere and the heating of the upper atmosphere. Recent discoveries show that higher than expected concentrations of atmospheric gases have reached magnetospheric levels, by processes not yet elucidated. Similarly, there is interchange between the troposphere and upper atmosphere, at least in part through the general circulation and differences in tropical and polar tropopause levels as depicted in Fig. 14. These interchanges between atmosphere and magnetosphere and between troposphere and stratosphere may be important to the sun-climate coupling.

(3) Solar cosmic rays penetrate to stratospheric levels in the earth's atmosphere during some very energetic flares. Cosmic rays from outside the solar system can reach the lower stratosphere and upper troposphere, where they are the principal source of ionization. Their intensity varies with solar activity, which modulates the shielding effect of the interplanetary magnetic field. Near ground level, ionization of the atmosphere is due mostly to natural surface radioactivity. Thus the atmosphere has some conductivity at all levels above the surface. The distribution in height of this conductivity depends on solar activity and the circulation of the atmosphere.

(4) Other possible propagators of a solar influence on the earth's atmosphere are variations in total solar visible radiation, infrared radiation, or the extended solar magnetic field. The last is already included in the solar wind category. Variations in visible solar radiation over periods up to a decade are <1%, so that only longer term variations in visible radiation are likely to be important. Infrared observations have not been made with sufficient accuracy or duration to permit anything other than speculation at present.

Given the above propagators of a solar activity influence on man's environment, we need to explore possible interchange mechanisms in the earth's atmospheric system whereby the solar activity propagators may trigger or modulate atmospheric processes. In general, we must find a process by



which the solar propagator modulates the complex interactions between atmospheric composition, photochemistry, dynamics, and radiative transfer. Some potentially viable interchange mechanisms that have been suggested include the following.

- (1) Convection in thunderstorms can provide direct interchange of energy and composition between troposphere and stratosphere.
- (2) Electric currents through thunderstorms can couple the troposphere to the entire upper atmosphere including the ionosphere. At least one hypothetical model has been outlined for modulation of cloudiness and rainfall by solar-flare-induced changes in conductivity of the atmosphere.
- (3) Winds and wave motions pervade the entire atmosphere and provide a transport process for energy and composition.
- (4) Transport also occurs by molecular and eddy diffusion through all levels of the atmosphere.
- (5) Radiation transfer in the atmosphere is particularly important in the ir and uv ranges. Changes in atmospheric composition, even of some very minor trace constituents, can have a major effect on radiation transport.

The coupling between solar propagators and atmosphere processes usually will be changed when unusual species are injected into the atmosphere. Such injections arise from volcanic eruptions, nuclear explosions, high-altitude aircraft and space vehicle exhausts, debris and effluents from space activities, and man's activities at the surface.

There are more interactions between sun and earth than the few mentioned here. The variety and complexity of known solar-terrestrial phenomena have increased substantially since the advent of the space age. However, we don't have to decipher every minute detail of every solar and terrestrial phenomenon to meet national goals of energy production and environmental protection. Instead, the scientists must accumulate in a coherent way enough knowledge of solar and terrestrial processes to permit recognition of what is essential to our goals. Not only should we store up facts, but also we must abstract and simplify an increasingly complex set of facts to the point where we can develop theories that explain and predict phenomena. Thus the key to progress is knowing what measurements should be made and formulating the results into

theories that represent the essential features of the real sun and real earth on time scales important to human beings.

#### **IV. RELEVANCE OF OUTER GEOSCIENCES TO DOE MISSIONS AND NATIONAL INTERESTS**

##### **A. General Case for DOE**

DOE must address the following basic question. How will energy production, transmission, and control be influenced by and influence the natural environment over both short and long periods? By law, every DOE division must answer this question. Formulation of a satisfactory answer depends critically on existing knowledge of solid earth, oceans, the extended atmosphere, and the sun as parts of an interacting and evolving system. Thus, DOE has a compelling self-interest in fostering expansion of fundamental knowledge of the total system.

In response to the legally imposed requirement, DOE has an Environmental and Resource Assessment Program charged with assessments in three basic categories—environment, technology, and resources (ETR). The ETR assessments require geophysical, atmospheric, and solar data. From a long-term perspective we must consider both the evolution of the natural environment and man's effects on it. Thus the data base for resource assessment is time dependent, and all three ETR assessments are interdependent. DOE's task is complex, requiring considerable scientific knowledge, sometimes not available. For example, it was not possible to draw firm conclusions about the effects of SST exhausts on the ozone layer because knowledge of the stratosphere was inadequate. Similarly, we cannot forecast future energy needs for a model world accurately because there is neither adequate knowledge of the many factors (solar flux, volcanic dust, transportation and industrial emissions, etc.) that control the climate nor the climate feedback that must influence decisions on energy production.

Virtually all environmental impact statements formulated by DOE or received by DOE have been limited to the *present* "inner environment." A similar situation exists regarding technology and

resource assessments. "Environmental impact" is usually taken to mean pollutants and health, ecological, socioeconomic, and long-term effects. Long-term effects have largely been neglected or ignored in environmental impact statements to date. We argue that long-term and global effects need serious consideration now. If DOE is to meet its responsibilities to develop energy technologies while protecting the environment, all assessment statements must be formulated to look ahead to the long-range evolution of the atmospheric/solar-terrestrial system, that is, the Outer Geosciences domain. Problems posed by SST exhausts and fluorocarbon releases have dramatized the importance of this outer system to such assessments. In this section we list additional specific interactions between man's activities and solar-terrestrial processes. Two points are clear from the known interactions. Our understanding of the natural system is inadequate, and the outer geosciences are important to our understanding of the biosphere. Accordingly, any basic research role assumed by DOE must include both surface and outer geosciences.

Like other agencies DOE has recognized the importance of supporting basic research in areas relevant to its mission. Relevant basic research should be supported both to augment the base of fundamental knowledge required to make quantitative assessments of the consequences of activities in the agency's mission and to foster a community of scholars whose expertise can be used to make technical evaluations. Also, basic research must precede applied research for technological development. In DOE's National Plan,<sup>1</sup> there is clear recognition of "a real responsibility to identify available energy alternatives and to improve knowledge of their environmental implications. Extensive research must be conducted if the public is to be informed of the true nature of the trade-offs and the implications of the various choices." Furthermore, "Environment planning and implementation must therefore ensure support for long-term environmental R&D in the face of pressures to turn full attention to near-term demands." Withdrawal from basic research in systems known to influence man's activities is an invitation to decay for a modern society. We maintain here and in the following sections that the outer geosciences must not be neglected.

## B. Specific Cases of National Interest

In this section we briefly describe some known situations where atmospheric/solar-terrestrial processes interact with human activities. Each interaction is of major socioeconomic concern to the nation, and some of them are directly related to the DOE mission (marked \*). Table I summarizes some of the activities and solar-terrestrial phenomena.

1. **\*Climate and Weather.** No quality of our present-day terrestrial environment is more crucial than the state of weather and climate. The energy that the sun radiates toward our planet is the most important energy source sustaining global-scale atmospheric motions and fueling daily weather.

Weather and climate are ever changing. Just as no 2 days of world weather patterns are alike, so no 2 years, no 2 centuries, no 2 geological epochs are identical in their climatic conditions.

Weather and climate are perpetually variable for many reasons. We know that weather and climate are shaped through complex physical interactions between the atmosphere, the oceans, the snow and ice in polar regions, and other environmental conditions. To a large extent, the variability of weather and climate is likely to be self-stimulated by these interactions. Also in part the variability of the atmospheric processes arises from the random nature of turbulence in a gaseous medium. There are several indications, however, that part of the weather and climate variability is governed by external influences, in particular by changing conditions on the sun, whose coupling to the atmosphere we do not yet understand.

Over the past 100 years, and especially since 1950, many correlations of the earth's weather and climate with the sun or solar-induced phenomena have been reported. Rainfall, temperature, pressure, thunderstorms, influx of stratospheric air into the troposphere, vorticity area, and other meteorological phenomena have been correlated with sunspot number, the 27-day solar rotation, solar flares, and both the quiescent and the disturbed geomagnetic field. Usually the effects are too small to have practical significance within our present understanding of weather and climate. But in some

TABLE I

HUMAN ACTIVITIES INTERACTING WITH SOLAR-TERRESTRIAL PROCESSES

<u>Activity</u>	<u>Solar-Terrestrial Process</u>
<b><u>Civilian Application Areas</u></b>	
*Electric power companies (energy transmission)	Magnetic storms
*Space power systems	Ionosphere Magnetosphere Geomagnetic activity
*Pipelines	Magnetic storms
*DOE communication (prospective)	X-ray and uv flare emission Magnetic storms
*Geophysical exploration	Magnetic storms Substorms
*Energy production, agriculture, and transportation } complex interaction sequences }	{ Climate weather, and solar activity }
Long-line telephone communication	Magnetic storms
Civilian hf communication	X-ray and uv emission
General Services Administration	Magnetic storms
Voice of America	Substorms
Coast Guard	Polar cap absorption
Commercial companies	
Various state agencies	
Civilian satellite communication	Magnetic storms Substorms Ionospheric irregularities
Commercial aviation	
Mid-latitude communication (VHF)	Solar flare radio emission
Navigation (VLF)	Magnetic storms Polar cap absorption
High-latitude communication (VHF)	Magnetic storms Substorms Polar cap absorption
High-altitude polar flight radiation hazard	Proton events
<b><u>Military Application Areas</u></b>	
*DOD hf communication	X-ray emission uv emission Ionospheric structure Polar cap absorption Magnetic storms Substorms
*DOD reconnaissance (radar, oth, sat)	Polar cap absorption Magnetic storms Protons
*Spacecraft survival (radiation damage and charging)	Magnetosphere and ionosphere Charged particles
DOD SATCOM communication	Magnetic storms Substorms Protons Ionospheric irregularities
DOD navigation	X-ray emission uv emission Magnetic storms Polar cap absorption

cases, especially rainfall modulation at some geographic locations, the effects can be up to 50% and can have major significance. Both the recent drought in the Western United States high plains and the past severe winters in the East fit the pattern of the predicted solar cycle modulation.

A one-to-one correlation does not exist, in the sense that a specific change in weather or climate will always follow a specific solar change. On the other hand, the reality of solar-induced *modulation* of atmospheric processes is becoming well established as more data accumulate and are subjected to critical tests of significance. The modulation of large-scale atmospheric processes is such that pressure, temperature, and precipitation are affected differently at different global locations and times. Early skepticism is now being replaced by a genuine concern to find explanations by way of interaction mechanisms. The explanations clearly are an essential research goal at present because they must precede any attempt to incorporate solar-terrestrial effects into global climate and weather models for prediction.

Ultimately the decision to support research on interactions between climate and weather and solar-induced phenomena must rest on whether the effects are significant. Recently three strong pieces of evidence have been added to the many correlations found in the literature.

- (a) The magnetically reversing solar wind boundaries that sweep by the earth every several days are followed by small, systematic changes of atmospheric flow.
- (b) The 22-year magnetic cycle on the sun appears to modulate the geographical scale of major droughts that afflict the Western and Central United States.
- (c) Long-term variations of the mean solar activity level, from one century to another, appear to have stimulated equally long-term changes of terrestrial climate, such as those associated with the Little Ice Age in the 15th to 19th centuries.

DOE's interest in atmospheric/solar-terrestrial research cannot be tied simply to effects on weather, because no meaningful alterations of energy policy or planning can be tied to factors varying over periods of less than a month. The effects on climate and its global

variations over years, on the contrary, are germane to DOE's mission of fostering energy production, distribution, and conservation.

**2. \*Energy Transmission Lines.** The waves and current systems of the ionosphere and magnetosphere produce undesired effects on long conductors by inducing currents in the conductors.

Geomagnetic storms, which are intense worldwide changes in the earth's surface magnetic field in response to plasma bursts from the sun, can disturb power distribution systems severely. Numerous power outages have been traced to this cause since 1940. Sometimes the problem is erratic induced operation of differential relays, sometimes tripping of circuit breakers, and sometimes the complete failure of a power transformer, such as the failure at the British Columbia Hydro and Power Authority following the August 1972 solar flare activity.

One cause of such disruptions is the induction of voltages on transmission lines with large separations between ground points. Induced 10 V/km voltages are sufficient to cause disruptions and these levels are sometimes generated in magnetic storms. A more serious effect is the current induced in the windings of power transformers. Such a current can reach 100 A and saturate a transformer core causing thermal degradation and decreased transformer lifetime. Lifetime affects the cost of power and thus influences everyday usage. Major disruptions are infrequent but devastating in their consequences.

Administrators under pressure to solve immediate problems might argue that further basic research is unnecessary, that we should design around the problems. To some extent this is possible now. However, had the argument been accepted years ago and had we not found the correct explanation, we could have entered an era of major power distribution systems with incorrect system designs and with disastrous results. Basic research on the solar-terrestrial system, in this case the magnetosphere-ionosphere regime, will continue to provide useful new understanding to power system designers.

**3. \*Geophysical Explorations for Minerals and Petroleum.** In exploration geophysics, magnetic surveys are conducted to obtain information about subsurface rocks and minerals. Most surveys involve measurements of the total intensity of the

earth's magnetic field across the survey area. Of necessity, the measurements include time fluctuations of the field, and one problem that must be dealt with is separation of the unwanted time variations from the desired spatial variations. The nature and seriousness of the problem, and its solution, depend on the nature of the geophysical survey.

Most magnetic surveys are made with airborne magnetometers, and probably more than one million line-kilometers are flown every year all over the world. The most common survey objectives are to assist with geological mapping and mineral exploration. Another type of survey is common over the oceans, where the structure of the oceanic crust is revealed by the magnetic anomaly patterns recorded in data obtained by towing magnetometers behind ships and sometimes from near the ocean bottom. Finally, there are ground magnetometer surveys, usually restricted today to local detailing of individual mineral prospects.

Various methods of separating geomagnetic time variations from the desired surface spatial variations have met with limited success. Because exploration and budget flows cannot be modified to fit the sunspot cycle, a large fraction of such exploration surveys can be wasted effort or can lead to false conclusions about mineral or petroleum deposits.

Although geomagnetic variations may seriously hamper exploration for minerals and oil, they can also be used to advantage, particularly to determine resistivities of sedimentary rocks in the earth's crust to 10<sup>3</sup>-km depths. Useful geomagnetic variations include pulsations (periods of up to a few minutes), substorms (15-150 minutes), storms, the daily variation dynamo, and the ionospheric ring current decay fields (periods of hours to days). Study results are useful in determining the composition and structure of the earth's crust.

**4. \*Pipelines.** The Alaskan oil pipeline and the proposed Al-Can line have dramatized the use of pipelines to distribute oil and natural gas over continental distances. Less dramatic but still important to the public is the fact that this method of energy distribution is influenced by solar-terrestrial physics processes. The influence is exerted in the form of electrical currents induced in the metal pipes by geomagnetic variations and the consequent enhanced corrosion rate of the pipes. At low and mid

latitudes the corrosion rate is negligible, but a nuisance effect exists from the induced-current interference with normal pipeline corrosion survey engineering work. This problem has caused implementation of a regular NOAA service for predicting induced-current activity.

At auroral zone latitudes (~60-70°) the induced currents from magnetospheric and ionospheric changes are much more frequent and stronger. Their interference can be a severe problem during corrosion survey engineering studies and for the pipeline monitoring and control electronics.

**5. \*Communications.** Fluctuations of radio frequency signals propagated through the ionosphere have long been a concern to designers of civilian and military communication systems. The fluctuations occur at all frequencies, from vlf (<3 MHz) to hf (3-30 MHz) and up. It was believed that if microwave frequencies (GHz and higher) and increased communication bandwidth were used, the ionosphere would no longer be a problem because it is essentially nonabsorbing at such frequencies. For communication by way of orbiting spacecraft, this mode has removed much of the fluctuation associated with time scales from seconds to years.

However, since initial implementation of the INTELSAT network (using 4 and 6 GHz), signal amplitude scintillations (with peak-to-peak excursions ranging from 1 to 10 dB) have been reported frequently from some earth stations located at low latitudes. Studies of the fluctuation characteristics and patterns suggest that they are produced by irregularities in the ionosphere F-region (200-300 km).

Almost always, the scintillations are observed shortly after local ionospheric sunset during the months near equinox. As the number of sunspots decreases, the total number of days on which scintillation is observed decreases. Apparently, the diurnal pattern does not change as the level of solar activity changes.

As yet no theory satisfactorily explains the production mechanism of the ionospheric irregularities producing the scintillations in this frequency range. In addition, there is little information pertaining to the thickness and spatial distribution of these irregularities. Such information is necessary for the development of a theory to correlate vhf and GHz scintillations.

Continued use of shortwave communications (3-30 MHz), which operate by reflection of the signal from the ionosphere, will require constant attention to ionospheric changes induced by radiation and particle fluxes from the sun and magnetosphere. In recent years we have learned that irregularities in the ionosphere arise not only from direct solar-induced perturbations but also from a complex set of interactions between the neutral atmosphere, ionosphere, and magnetosphere, and man-caused effects.

Telephone and telegraph cable communications are perturbed by solar-induced geomagnetic variations. For example, unexplained outages of the Bell System's L-4 long-haul cable system occurred on 24 days between January 1969 and August 1971. Some of these outages probably were caused by geomagnetic effects in this period near the solar activity maximum. A particular storm in August 1972 was studied in detail from ground-based and satellite data. The induced line voltage caused by the sudden compression of the geomagnetic field was more than sufficient to shut down the system.

Exactly what mechanism produced the large surface magnetic variations in August 1972 is not known, but it appears they were associated with large asymmetric distortions of the earth's magnetosphere and hence were magnetopause currents, rather than classic ionospheric currents. This investigation is relatively undeveloped at present and, if pursued vigorously, should increase understanding of solar wind-magnetospheric interaction processes and should help to reduce cable communications difficulties.

Reliable communications are important to all sectors of our government and society, but especially to our national security sector, represented in DOE by the Office of Military Application.

**6. \*Effects of Space Radiation on Systems in Space.** Looking toward the future, we see an enormous expansion in the number of space systems designed to serve terrestrial applications and terrestrial customers. The investment in such space systems is likely to run into tens of billions of dollars. Even savings of fractions of a per cent, derived as a result of better information regarding the energetic radiation, translate directly into savings that run into tens of millions of dollars.

The radiation environment at the synchronous orbit, where most earth application spacecraft will be located, consists primarily of electrons and protons. Order-of-magnitude changes in intensity are very common. The fluxes of low-energy particles, electrons and protons with energies  $< \sim 20$  keV, are sufficiently intense to degrade thermal control surfaces and exterior coatings; this portion of the particle energy spectra also determines whether the spacecraft-charging phenomenon occurs. The high specific ionization of protons in the hundreds of keV to MeV energy interval mandates the complete coverage of solar cells for protection. Trapped energetic electrons are the remaining major cause of radiation damage both to solar arrays and to semiconductor devices contained in the deep interior of a spacecraft. For example, the typical spacecraft solar cell array loses a few per cent of its original power output each year of exposure.

The useful lifetimes of radiation-sensitive devices such as computer memories are determined totally by their accumulated radiation dose. Thus, a considerable premium is placed on accurate knowledge of the space radiation environment so that quantitative predictions of component lifetime (or necessary shielding weight) can be made. The spacecraft designer needs 10% radiation prediction accuracy, but at present space scientists can offer no better than a factor of 2.

On the other hand, wave-particle interactions studies are now sophisticated and precise enough that laboratory experiments to change the energetic particle populations seem feasible using man-generated beams of properly tailored electromagnetic waves. Although the practical effects of such experiments, if successful, may seem on the surface desirable (for example, sweeping the synchronous "corridor" free of energetic electrons), no one has yet considered how to write an environmental impact statement for such a necessarily global experiment.

Degradation of space systems is now important to DOE's national security space activities. It will become even more important economically and socially if large space power systems are ever built.

**7. Electrostatic Charging on Spacecraft.** An electrically isolated probe inserted in a plasma

generally will assume a negative electrostatic potential with respect to the undisturbed plasma. The magnitude of this potential is of the order of the electron temperature expressed in electron volts. Thus, potentials of a few volts are commonly observed on spacecraft in the plasmasphere, but potentials  $>10\ 000$  V can be seen on spacecraft in the plasma sheet or in plasma cloud regions of the magnetosphere.

A spacecraft's overall charge state probably has minimal effect on operations. If the vehicle is charged negatively for long periods, some increased surface degradation owing to ion bombardment will be noticed. The major operational effect arises from differential charging. Nearly all spacecraft exteriors consist of various insulators. This type of outer surface usually is needed for thermal control. However, the charge stored on different parts of the spacecraft can cause differential potentials of thousands of volts between insulating surfaces.

Discharges from external vacuum-deposited aluminum (VDA) can remove the outer surface and thus degrade thermal properties. Similarly, the outer surfaces of optical elements can be affected seriously. More serious is the now convincing evidence that several different classes of spacecraft operating in synchronous orbit experience operating anomalies caused by discharges produced by electrostatic charging. Noise on the spacecraft command lines often gives false commands. In at least one case, total loss of an Air Force spacecraft probably occurred because of extreme differential charging prolonged by an intense geomagnetic sub-storm.

Theoretical and experimental studies to understand and control spacecraft charging are currently under way under sponsorship of several agencies. The level of understanding needed varies with the user. Scientifically, some investigators want to understand the phenomenon completely as an interesting plasma physics problem with far-reaching cosmological implications. Magnetospheric physicists want to measure uncontaminated natural plasmas. Practically, many systems offices are trying to run operational spacecraft, and they simply want to fix the problem of extraneous commands with as little redesign of existing vehicles as possible. For many operational and future spacecraft, the question becomes one of probability and economics, topics that interest all agencies involved in space ac-

tivities, including DOE. What construction techniques will have the highest expected return (for instance, communications, weather observations, or space power systems) for the lowest price? An answer to that question requires better understanding of the earth's radiation environment and consequent materials response before specific recommendations can be made to the spacecraft designer.

#### **8. People in High-Altitude Flight or in Space.**

Astronauts in space need protection from cosmic rays, especially during major solar flares. Now that space stations are being considered for habitation over long time periods, we must know the space radiation environment in great detail so that people in space may be protected from overdosage. There is also a potential radiation hazard to pilots of high-altitude jet aircraft flying repeatedly over the polar regions or at very high altitudes in mid latitudes. Although the particle flux at energy high enough to penetrate an aircraft skin is small, the pilots are concerned about both the particle and secondary x-ray dosage accumulated over many flying hours. In rare events that may occur once per solar cycle, even passengers may be exposed to the dosage near the maximum permissible dose during a single 2-hour flight.

Both pilots and passengers in commercial jets have encountered the problem of ozone irritation. Exposure to concentrations above 0.3 ppm causes irritation to the eyes, mouth, and throat, decrease in night vision, shortness of breath, coughing, and chest pains. Evasive action, such as flying at lower altitudes or on the poleward side of the jet stream, often can be taken, because a great deal has been learned in recent years about the daily, seasonal, and geographic distribution of ozone in the atmosphere. However, abnormally high ozone concentrations may occur and persist for short periods at certain geographic locations and altitudes near and above the tropopause. The reasons for these occurrences are not known at present. Ozone of course has a beneficial effect in that it absorbs the solar uv radiation that otherwise would be a human health hazard. Ozone is one component of the atmospheric/solar-terrestrial system that must be well understood to keep its advantages but avoid its disadvantages.

The hazard to people in space will be especially important to DOE if space power systems are to be constructed.

All the above interactions involve an influence exerted on human activities by solar-terrestrial processes. Below we list some interactions where human activities change the natural atmospheric/solar-terrestrial system.

**9. \*Space Power Systems.** Among the prospects for meeting our country's energy needs in the 21st century, perhaps the boldest, and certainly the most exciting, are space power systems. As currently envisioned, huge power stations, each capable of serving a large city, would orbit at geosynchronous altitude and would transmit space-generated microwave power to earth. The power would be obtained by collecting solar radiation and converting it to microwaves. We are not speaking for or against space power systems, but we point out the need for Outer Geosciences information in their evaluation and implementation.

The impact of space power systems on the ionosphere needs careful consideration. The microwave spectral region was selected for power transmission largely because of the atmosphere's transparency to such frequencies. Thus, interactions between the beam and the medium should be of little or no consequence. Preliminary systems studies, however, have identified potential ionospheric problems related to microwave transmission and space-vehicle exhaust products. Because such problems could affect communications systems and other microwave transmissions, they must be considered in space power system design and development. Because the problems can be evaluated only within the limits of our knowledge of the natural ionosphere and its coupling to the neutral atmosphere, we must continue improving our knowledge of these parts of the atmospheric/solar-terrestrial system.

Base-line designs of power satellites call for an average flux through the atmosphere of  $\sim 100 \text{ W/m}^2$  in a beam  $\sim 7 \text{ km}$  in diameter. Only  $\sim 0.001\%$  of the energy in the beam will be absorbed in the ionosphere, and thus there will be virtually no impact on the transmitted power level. On the other hand,  $0.001\%$  corresponds to  $1 \text{ mW/m}^2$ , which is of the same order of magnitude as the solar energy con-

tained in wavelengths shorter than  $1000 \text{ \AA}$ , or euv. This solar energy represents the major source of heat and ionization in thermosphere and ionosphere. A comparison of solar euv and microwave energy absorption rates in the upper atmosphere shows that the absorbed microwave energy would exceed the solar euv by an order of magnitude above  $120 \text{ km}$  altitude.

Although we do not know exactly what effects might be stimulated by high-power microwave transmission, the results of the recent ground-based rf ionospheric modification experiments indicate what might occur. The energy absorbed from the heater beam by the ionospheric electrons raises the electron temperature. The electron heating results in a spatial redistribution of the electron density owing to thermal expansion along the earth's magnetic field lines. Because the electrons diffuse up the field lines, the expansion results in a depletion in the electron density in the upper ionosphere. In contrast, in the lower ionosphere, the enhanced electron temperature lowers the rate of electron-ion recombination, increasing the electron density. Increased power levels excite plasma instabilities, which produce additional nonlinear absorption of the heater beam, resulting in the generation of field-aligned density irregularities. The irregularities give rise to various scattering phenomena, the outstanding examples being spread-F.

Of course, any ionosphere modification by the microwave beam of a space power system will likely be localized in extent and thus will have a global-scale effect only after some time. The energy absorption is confined initially to the beam width ( $\sim 7 \text{ km}$ ), although subsequent interactions and the excitation of plasma instabilities will increase the sphere of influence beyond the beam width limits. Because of the coupling between thermosphere and ionosphere, some changes may be induced in the neutral structure that would provide "feedback" to the ionosphere. For example, enhancement of the neutral temperature within the beam would lead to changes in neutral composition, which, in turn, would affect the electron-ion recombination rate and hence the electron density. The heated air column, which presents a discontinuity in the medium, could also give rise to atmospheric gravity waves. The wave features would be impressed on the ionized component.



**TABLE II**  
**POSSIBLE EFFECTS OF MICROWAVE PROPAGATION**

**Ionosphere**

- Electron temperature increase
- Electron density decrease in D-region, increase in F-region
- Modification of electron energy distribution
- Anomalous absorption and heating, leading to field-aligned irregularities and radio scattering phenomena

**Thermosphere**

- Neutral temperature increase
- Modification of relative composition
- Modification of airglow characteristics
- Excitation of or modification of atmospheric gravity waves

**Mutual coupling effects**

- Neutral composition affects the electron-ion recombination rate
- Ion density affects the neutral wind system
- Neutral winds and gravity wave structure affect the ion distribution

The possible effects of microwave transmission in the thermosphere and ionosphere are summarized in Table II. Whether any or all of these phenomena would have significant consequences as a result of space power systems is a question yet to be answered.

Exhausts from vehicles used to carry space power systems to orbit also must be considered. The sheer size of a power satellite,  $10^7$ - $10^8$  kg, indicates the high level of vehicle activity that will be needed to lift, assemble, service, and maintain a fleet of 50-100 power satellites. It is estimated that the equivalent of 10 space shuttle launches per day will be necessary during the peak construction period.

At ionospheric altitude, advanced heavy lift launch vehicles will probably expel only water vapor. However, the expulsion of large quantities of water molecules can produce significant changes in the local ionospheric structure, as was strikingly demonstrated during the launch of Skylab 1. Water molecules interact efficiently with atomic oxygen ions, resulting in increased rates of electron-ion recombination. In the case of Skylab 1, a substantial depletion ( $\geq 50\%$ ) of the total electron content persisted for several hours and encompassed a region  $\sim 2000$  km in diameter.

Water vapor from booster engines could also affect the ionosphere D-layer, which is composed mainly of water cluster ions. The continual injection of water vapor in substantial amounts is quite likely to affect the ion formation rates and, hence, the properties of the layer.

In addition to the launch vehicles, which ascend only to low earth orbit, orbit transfer vehicles will be needed to tug the assembled satellites to geosynchronous altitude. These transfer vehicles require a high-performance propulsion system, with the likely candidate being the solar-electric propulsion system. Such a system operates basically by acceleration and then expulsion of a heavy, ionized metal. Preliminary studies have not indicated serious pollution problems in the ionosphere or magnetosphere; however, further investigation using realistic traffic models is necessary.

It is the coupling between processes in the atmosphere-ionosphere system (Table II) that both complicates the analysis of consequences and makes necessary continued basic studies of this system.

If DOE ever promotes space solar power systems, the factors of communications, effects of space radiation on systems in space, and people in high-altitude flight or in space will be very important to

its mission. Conceptual studies have been made of space power systems using satellites that carry gaseous core nuclear reactors to generate power. The power is converted to a laser beam and transmitted to the space shuttle or to manned space stations. Understanding of the solar-terrestrial system will be vital to DOE.

**10. Earth-Based Power Systems.** Ground-based and balloon experiments carried out over the past decade have shown that discrete vlf emissions cause precipitation of electrons from the magnetosphere into the atmosphere. The association was found first with natural vlf emissions and explained in terms of a cyclotron resonance interaction at the geomagnetic equator. Subsequently, a high-power transmitter on the ground was used to trigger such precipitation and the transmitted signal actually was amplified in the process. During these experiments, the signals sometimes were inflected (reversed in slope) at frequencies exactly matching the known harmonics of the Canadian power distribution system. The explanation is that harmonic radiation from power distribution grids is amplified in the magnetosphere and affects vlf transmissions and electron containment in the ionosphere-magnetosphere. Independent measurements with receivers on satellites revealed a similar result triggered by the Russian vlf communications station UMS. Because there already are numerous high-power communications transmitters around the world, with more projected for future communications and navigation, and because of the power distribution network in North America and Europe, the distribution of particles in the earth's natural radiation belts may already be strongly influenced by man's transmissions. As we project future world power needs, we should know what effects transmission will have on the radiation belts and whether interactions of particles precipitated out of the belts have anything to do with climate or weather.

**11. Injections into the Atmosphere.** Injections of chemical and radioactive species into the atmosphere from power generation systems, industrial processes, transportation, and other human activities may alter not only the total radiation balance of earth (carbon dioxide is an example) but also the spectral radiation balance (ozone-

fluorocarbon is an example). Concentrations of trace molecular species in the atmosphere are influenced by wave transport and molecular and eddy diffusion processes as well as by variability in the sun's ultraviolet spectrum. Although much attention has been given to local effects of injected pollutants, especially by the Environmental Protection Agency (EPA), the Department of Transportation (DOT), and the Energy Research and Development Administration (ERDA), the global and long-term effects have not been modeled in depth, partly because not enough basic knowledge exists to permit such a broad assessment.

Here we summarize a few potentially active injections that could have global effects on the atmosphere, climate, human health, or all of these. The roles of  $\text{NO}_x$  from high-altitude aircraft exhausts and fluorocarbons from aerosol spray cans have been so thoroughly discussed that we shall not belabor them further here.

•  $\text{CO}_2$

During the past 2 years the importance of  $\text{CO}_2$  injections into the atmosphere has been recognized and well documented. As a by-product of energy production from fossil fuels and biomass fuels,  $\text{CO}_2$  has special relevance to DOE.

Carbon dioxide has a direct effect on the earth's climate. Increasing the  $\text{CO}_2$  concentration will warm the atmosphere if all other factors are unchanged, because  $\text{CO}_2$  permits sunlight (visible) to pass through to the earth's surface and heat it. But the earth reradiates infrared, which is blocked by  $\text{CO}_2$  from escaping back to space. An increase in  $\text{CO}_2$  concentration in the atmosphere changes the balance between incoming sunlight and outgoing earth radiation with a consequent increase in the tropospheric temperature. A comprehensive analysis of the  $\text{CO}_2$  problem has been given in the report of the Panel on Energy and Climate of the National Academy of Sciences.<sup>2</sup>

The chief concern about  $\text{CO}_2$  is its effect on climate. Reliable model calculations show that doubling the atmospheric  $\text{CO}_2$  will cause  $\sim 3^\circ\text{C}$  rise in the average temperature of the lower atmosphere at mid latitudes and a 7% increase in average precipitation. The temperature rise in polar regions will be about  $10^\circ\text{C}$ . Calculations and measured

trends of CO<sub>2</sub> concentration in recent years show that within a hundred years the global mean air temperature should rise a few degrees. Climatic effects of CO<sub>2</sub> release may be the primary limiting factor on energy production from fossil fuels over the next few centuries. To understand the problem and the possible remedial actions we now need (1) a better understanding of the partitioning of carbon among the biosphere, oceans, and atmosphere and (2) continued development and verification of climate models. These needs, quoted from the NAS report,<sup>2</sup> re-emphasize our theme of global interrelationships in the outer geosciences domain. Adequate means to monitor climate and further studies of the sensitivity of climate to disturbances in the radiation balance will be needed.

Factors other than CO<sub>2</sub> can also disturb the atmosphere's radiation balance or dynamics. For example, the chlorofluoromethanes from aerosol spray cans have the same direct effect of blocking the outgoing infrared radiation.

#### • NO<sub>x</sub>

Supersonic aircraft are not the only source of NO<sub>x</sub> injections into the atmosphere. Probably the largest source is nitrogen fixation by plants. Increased worldwide use of nitrogen fertilizers in recent years has accelerated natural NO<sub>x</sub> release. Nitrous oxide (N<sub>2</sub>O) is released into the atmosphere wherever fertilizers are used. There it is decomposed into nitric oxide (NO), which in turn depletes ozone by a cyclic reaction process. Monitoring programs have not been going on long enough for us to be sure whether measured N<sub>2</sub>O increases are from natural or man-made causes. The situation with NO<sub>x</sub> is similar to the situation with many trace constituents of the atmosphere. Their potential importance has been recognized only in recent years, so no large body of data exists. Fortunately the situation can be improved now that satellite monitoring is available. It is possible with the use of LIDAR and ir, uv, and microwave spectroradiometers to monitor a wide variety of climate parameters and atmospheric species on a global scale and continuously into the future. DOE should continue its involvement in such programs as the National Atmospheric Sciences Program, the National Climate Program, and the Middle Atmosphere Program.

#### • Other Injections

A wide range of potentially active elements and compounds have been identified in the atmosphere. Examples include arsenic from burning coal, sulfuric acid from automobile exhausts through catalytic converters, and spray can releases of chlorofluoromethanes and their decomposition products. Sulfuric acid probably will not reach harmful concentrations.

### V. OUTER GEOSCIENCES AREAS OF EMPHASIS FOR DOE

The Outer Geosciences are supported by several government departments and agencies with emphasis depending on the needs and mission of the particular agency. To gain a balanced and realistic view of the role to be recommended for DOE we consulted with all agencies having a major role in science support. Table III shows the approximate funding by government agencies for atmospheric/solar-terrestrial research. We not only reviewed their existing programs but also solicited individual views about new thrusts for DOE that would complement the programs in their agencies.

It is clear from the reviews of programs in Appendix B and from Table III that several agencies support research in solar-terrestrial areas and that substantial efforts in tropospheric and stratospheric sciences are sponsored by NOAA, National Science Foundation (NSF), Department of Defense (DoD), NASA, DOT, EPA, and DOE. This simply illustrates government recognition of the importance of these science disciplines to their missions and to national interests. One should not thereby draw the conclusion that DOE should maintain the status quo. Neither should DOE simply insert additional dollars into a currently popular discipline area. Instead, DOE needs a selective expansion in *basic atmospheric/solar-terrestrial studies* to provide the basic expertise for long-range DOE goals and planning. The need is especially noticeable in the solar-terrestrial category, where DOE support is now the lowest of all the relevant agencies. DOE needs to fill the gap between the largely undirected research supported by NSF and the largely directed and narrowly restricted research supported by EPA and other agencies.

**TABLE III**  
**GOVERNMENT FUNDING FOR ATMOSPHERIC/SOLAR-  
 TERRESTRIAL RESEARCH**  
 (millions of dollars)

Agency	Meteorology and Atmospheric Sciences <sup>a</sup>	Solar-Terrestrial (Everything above Tropopause) <sup>b</sup>	Specific Funding for Climate Research <sup>c</sup>	
	FY 78	FY 78	FY 78	FY 79
DOE	17	1.3	3.0	4.5
NSF	50	25	20	21.2
NOAA	50	5.2	11.8	20.0
NASA	20	23	2.5	14.7
AF	7	28	} 31.5	35.5
ARMY	15	2		
NAVY	10	2.5		
EPA	15	0	1.7	2.0
DOT	20	0	---	---
OTHER	10	8	---	1.0
<b>TOTAL</b>	<b>224</b>	<b>82</b>	<b>71</b>	<b>104</b>

<sup>a</sup>Includes physics, dynamics, chemistry, radiation, observation, description, prediction, modification, systems, and support.

<sup>b</sup>Includes the sun, interplanetary medium, cosmic rays, magnetosphere, energetic particles, plasmas in space, aurorae, airglow, upper atmosphere (chemistry, structure, dynamics, and radiation, all above the tropopause), and instrumentation.

<sup>c</sup>This is not separate funding but rather the fraction of the atmospheric-solar-terrestrial funding destined for support of climate-related research.

One characteristic that stands out in this synopsis of government research programs is that everyone is involved in pollution measurement with generally large efforts, but that very limited efforts exist to synthesize experimental results into comprehensive models for assessment purposes. On the global scale where interactions within the entire atmospheric/solar-terrestrial system need consideration, no organizational structure in the nation provides the interdisciplinary research coordination needed to ensure the availability of adequate information for policy decisions. This condition limits the value of environmental impact assessments so that only short-range and local evaluations can be made. It precludes the coherent assimilation of new atmospheric/solar-terrestrial knowledge into long-term global predictions that could serve the needs of

policy-makers. The organization of such a program is beyond the scope of this report, but we cannot avoid pointing out this need. It is premature to expect a grand program for the solar-terrestrial system analogous to general circulation models of the atmosphere. Nevertheless, it is time to start an organized inquiry into interaction processes and to encourage scholarship with a broader perspective.

From these reviews and discussions two specific sets of recommendations emerged. One was for a balanced support of basic research covering the full range of phenomena in the sun-earth system. The second was for emphasis on the following topics that were considered to have the most immediate relevance.

- (1) Sun-climate and sun-weather studies with special attention at first to the problem of

finding mechanisms to explain the observed correlations.

- (2) Solar physics studies with special attention to the activity variability and variability in radiative and particle emissions.
- (3) Magnetospheric processes involving coupling to the atmosphere and ionosphere.
- (4) Upper atmosphere physics and chemistry with emphasis on trace constituents and global transport.

The categories recommended for immediate emphasis should not be assigned all the available support but rather should be given priority within a program having the balance recommended in the first category. There should also be a reasonable balance between research supported in-house in DOE laboratories and that done through proposals from universities and the private sector.

Opinions solicited from within DOE laboratories emphasized the importance of atmospheric sciences, no doubt reflecting the initial trend in ERDA toward studies of the short-term and local effects of energy pollutants. These opinions are valid and have been included throughout this report, but the disciplines most in need of augmentation are longer term basic studies of the upper atmosphere and solar-terrestrial environment to meet the three main DOE concerns in the Outer Geosciences. The concerns are

- (1) to provide immediate assessments of the interaction between energy technologies and the earth/atmosphere system based on existing knowledge of the system,
- (2) to promote the increase in knowledge of the atmospheric/solar-terrestrial system that will help the nation avoid mistakes that could be harmful to future generations, and
- (3) to assure that the information base being built up includes sufficient breadth to encompass national security and possible future energy activities in space.

Appendix A outlines a potential DOE program with options for two levels of support. Appendix B outlines existing government programs.

## ACKNOWLEDGMENTS

Although this report was compiled by an individual, the content includes information from

many sources. In addition to our own teaching and research notes, we drew freely from other government reports and from individuals. Reports that were especially helpful include

1. A United States Climate Program Plan (February 1977 draft); ICAS;
2. Energy and Climate (June 1977); NAS, Geophysics Study Committee;
3. The Upper Atmosphere and Magnetosphere (1977); NAS, Geophysics Study Committee;
4. National Atmospheric Sciences Program (May 1976); ICAS 20-FY77;
5. Solar Terrestrial Programs; A Five Year Plan (June 1977); NASA;
6. Environmental Research Laboratories Programs and Plans (FY 1976); NOAA; and
7. Impacts of Ionospheric/Magnetospheric Processes on Terrestrial Science and Technology (1977); NAS, Study on Space Plasma Physics.

Individuals whose advice was particularly helpful include David Beard, University of Kansas; Anthony Broderick, DOT; Robert Brownlee, Los Alamos Scientific Laboratory; Kenneth Davies, NOAA; Richard Dow, NAS; Edward Dyer, NAS; John Eddy, Smithsonian Astrophysical Observatory and Harvard; David Evans, NOAA; Eldon Ferguson, NOAA; Joseph Fletcher, NOAA; Thomas J. Gross, DOE; Kirby Hanson, NOAA; Richard Hart, NAS; Frank Hudson, DOE; James Hughes, Office of Naval Research (ONR); Glen Jean, NOAA; Louis Lanzerotti, Bell Laboratories; Robert Manka, NSF; Ralph Markson, Massachusetts Institute of Technology; Murray Mitchell, NOAA; Henry Mulaney, ONR; Denis Peacock, NSF; Elliot Pierce, DOE; Henry Radoski, Air Force Office of Scientific Research; Walter Roberts, Aspen Institute; Erwin Schmerling, NASA; Alan Shapley, NOAA; and Harold Zirin, California Institute of Technology.

## REFERENCES

1. "A National Plan for Energy Research, Development and Demonstration; Creating Energy Choices for the Future. Vol. 1. The Plan," Energy Research and Development Administration report ERDA 76-1 (1976).
2. National Academy of Sciences Report of the Panel on Energy and Climate, Geophysics Study Committee (1977).

## APPENDIX A

### OUTLINE OF AN OUTER GEOSCIENCES PROGRAM WITH SUGGESTED FRACTIONAL SUPPORT

The following outlines and suggested fractional support levels represent the views of the author after consideration of recommendations from many individuals and agencies on how to make the Outer Geosciences program consistent with recommendations in Sec. V. It should not be taken as a mandatory allocation because any real life program depends on availability of scientific manpower with relevant expertise, the receipt of proposals, and the available financial levels.

Table A-I gives suggestions based on the assumption of a major program (>\$10 million). Table A-II gives suggestions based on a low-level initial program (\$1 to \$2 million per year). In such a low-level program one would have to emphasize general studies that overlap specific subdisciplines as much as possible.

Sun-climate and sun-weather relationships have been established statistically. Any effect of the sun on climate has particular relevance to DOE in the areas of energy demand and distribution. Numerous agencies and individual scientists have suggested that DOE should contribute more to improved understanding of these relationships. Now we must sort out the conflicts in analysis schemes, develop improved correlation indices, investigate the propagators of the solar influence, and analyze processes (mechanisms) by which solar influence is transferred to the atmosphere.

Solar activity and solar variability (total output) may or may not be related. There is certainly good evidence that climate is affected by solar activity, and we can show that small changes in total solar output (<1%) can affect climate significantly. Prediction of solar effects on weather and climate ultimately will be tied to better understanding of what causes the solar variability itself. Much understanding of controlled thermonuclear reactions (CTR) and laser fusion plasmas can be gained from studies of the dynamic solar plasmas associated with solar activity (magnetic loops, flares, particle streams, wave-particle processes, etc.). This discipline needs basic science studies to clarify the

complex magnetohydrodynamic (MHD) processes going on when the solar convection and differential rotation interact to generate magnetic fields and then further interact to heat the chromosphere-corona and produce violent flare outbursts.

Magnetospheric and interplanetary processes involve complex wave-particle-magnetic-field interactions in a lower density regime than on the sun. Here too there are many parallels to CTR and laser fusion problems. Many DOE military applications take place in this environment, hence its nature and variability affect design and operation of space military missions. Magnetospheric coupling to the atmosphere is one avenue by which the sun-weather influence may be propagated. Thus programmatic applications will be centered on such processes as MHD convection, particle acceleration, wave-particle interactions, the plasma environment (monitoring), and coupling to the atmosphere.

The atmosphere, ionosphere, and plasmasphere constitute a single system viewed from perspectives that shift from neutral to ionized-particle composition. Global transfer processes link the atmosphere from low to high levels and in turn link the atmospheric system to magnetospheric and solar variations. Programmatic needs are twofold: (1) monitoring the composition of and processes in the atmosphere from the stratosphere to the thermosphere and (2) basic science to relate the complex processes of large-scale mass transport, radiative transfer, photochemistry, and MHD modulations to climate and to environmental control.

The above programmatic needs must be fostered by encouragement of and support for theory and data analysis. Analysis of large quantities of existing data can help meet the above needs. On the national scale we must encourage young theoreticians to study global interactions in the atmospheric/solar-terrestrial system. Scientific specialization hinders the type of synthesis needed to infer mechanisms for sun-climate relations and to recognize solar-terrestrial situations that have applications in controlled fusion and other programs. The ultimate

**TABLE A-I**  
**OUTER GEOSCIENCES SUBDISCIPLINES WITH SUGGESTED**  
**FRACTIONAL SUPPORT FOR MAJOR PROGRAM**  
 (~\$10 M)

<b>Subdiscipline</b>	<b>Suggested Fractional Support (%)</b>
Sun-climate and sun-weather relationships	30
Development of improved correlation indices	
Study of specific mechanisms	
Processes related to atmospheric conductivity	
Processes related to atmospheric composition	
Study of solar propagators	
ir, uv, euv, x-ray radiations	
Solar wind and flare particle emissions	
Solar variability	15
Solar "constant"	
Convection	
Differential rotation	
Magnetic field generation and dissipation processes	
Chromosphere-corona heating processes	
Flares and related phenomena	
Solar wind origin and propagation	
Magnetospheric processes	15
Convection	
Wave-particle interactions	
Particle acceleration mechanisms	
Particle loss mechanisms	
Dynamics of coupling to atmosphere-ionosphere	
Atmosphere-ionosphere-plasmasphere	30
Dynamics and transport	
Radiative transfer	
Photochemistry	
Composition	
Magnetohydrodynamic and plasma physics processes	
Large-scale models	
Aerosols	
Theoretical and data analysis	10
Analysis of existing data	
Expansion of theoretical capability by special support for young theoreticians	
Coordination and relevance project at DOE HQ	

**TABLE A-II**  
**OUTER GEOSCIENCES SUBDISCIPLINES WITH SUGGESTED**  
**FRACTIONAL SUPPORT FOR LOW-LEVEL PROGRAM**  
**(~\$1-2 M)**

<b>Subdiscipline</b>	<b>Suggested Fractional Support (%)</b>
Sun-climate-weather Mechanisms Solar propagators Coordination and relevance study at DOE HQ	35
Sun-solar wind-magnetosphere Convection in magnetized plasma Waves and wave-particle interactions Dynamic processes involving particle acceleration Generation and dissipation of magnetic fields	35
Atmosphere-ionosphere-plasmasphere Dynamics and transport Photochemistry Composition	30

utility of an atmospheric/solar-terrestrial program to DOE probably will be determined by the presence somewhere within DOE of persons capable of assimilating and correlating the new information from diverse disciplines so as to provide coherent input at the policy decision and planning levels.

This program can be implemented through grants to university scientists and projects within DOE laboratories. Much of the program can be carried out by augmentation of existing projects and coordination of existing and new projects by a small

scientific staff at DOE-HQ or at some designated DOE field center. This scientific staff will provide all DOE management levels with planning and assessment information. No new organization structure within DOE is needed. The scientific staff would not only provide information but would actively coordinate research and activities between the NOAA Climate Program Office and the DOE Climate Program Office. It would have representation on the Climate Users Steering Committee.



## APPENDIX B

### EXISTING PROGRAMS IN GOVERNMENT AGENCIES

#### I. INTRODUCTION

Several government agencies support research in specific areas of the atmospheric/solar-terrestrial disciplines for reasons related to their individual missions. In recent years there has been an increasing effort to coordinate some research areas by discipline. A National Climate Plan, a National Atmospheric Sciences program, and a Middle Atmosphere Program are now documented and probably will be implemented. It would be most productive to society as a whole to have such a coordinated national approach to atmospheric/solar-terrestrial studies as a major discipline.

In the following paragraphs the existing programs in various agencies are discussed in outline of efforts without many specific details. Some of the information has been condensed from ICAS 20-FY77 (the National Atmospheric Sciences Program),<sup>1</sup> some was obtained by direct contact with individuals in the agencies, and the remainder from a variety of sources. Any omissions or slights are unintentional.

#### A. DOE

DOE, the leader in the new National Solar Energy Program, is the principal Federal source of information and expertise in the whole area of power generation and related activities. As such, it must be the principal agency for basic knowledge on questions such as the effects of climate on power generation; solar-terrestrial effects on distribution of power and location of new energy resources; and the prediction of power system effects on both the local and global environments through injections of carbon dioxide, heat, particulate matter, trace metals, organic compounds, various noxious and chemically active compounds, radioactive gases, and electromagnetic emissions.

Much past effort has centered on the transport, diffusion, and health impact of radioactive materials from nuclear weapons testing, releases from reactors and reactor fuel processing, hazards

from beryllium and plutonium processing, and other nuclear-related activities. In recent years the emphasis has shifted to the problems of nonnuclear technologies and has concentrated on tropospheric processes such as particle formation, atmospheric transport and diffusion of fossil fuel pollutants and radionuclides, and other topics related to local and regional effects of energy technologies. In the last year or so there has been increased attention to the question of global interaction processes and the need for a long-range perspective and planning. Our conviction of the importance of basic science in atmospheric/solar-terrestrial disciplines to DOE's long-range goals has prompted this report.

The DOE solar energy development technologies are supported by studies on the variations in *solar fluxes*, both direct and diffuse, under varying weather conditions. Investigations on the solar spectral characteristics involving spatial and temporal variations are included. A strong program related to a study of *wind profiles* in different terrain is part of the establishment of site-selection criteria for wind power stations.

The present *atmospheric sciences* program includes some basic research in meteorology, including projects on global circulation and transport, turbulence, diffusion, cloud physics, and boundary layer behavior. Studies related to the basic chemical reactions of atmospheric gases in the molecular, atomic, and ionized states and in the photochemical interactions that initiate many of the atmospheric chemical transformations have been increased.

The major DOE atmospheric program is the *Multistate Atmospheric Power Production Pollution Study* (MAP3S). The purposes of this program are to furnish the atmospheric information necessary to assess the biomedical, bioenvironmental, and weather modification effects of current power production practices in the northeastern quadrant of the United States and to apply the techniques that will be developed to the assessment of the atmospheric effects of major new fuel use strategies.

There is a strong emphasis in MAP3S on field studies to develop high-quality data on SO<sub>2</sub>, sulfate,

and related pollutants and to parameterize the transport, transformation, and removal processes. A series of ground stations is operated to collect and monitor rainfall for power plant related pollutants, particularly sulfuric and nitric acid. The data from field studies will be used to test mathematical models and to provide guidance for further model and field experiment iterations. Field tests are also conducted using new chlorofluorocarbon tracers in an attempt to validate trajectory models over thousand-kilometer scales. Supplementary control systems regulating the emissions from fossil fuel plants are also being studied.

The program on the effects of heat and *moisture release* from proposed large nuclear and nonnuclear energy centers will be continued. There is concern that the rejected heat and moisture can produce not only local effects but also can cause thunderstorms and other severe atmospheric effects.

The *Atmospheric Release Advisory Capability* (ARAC) system includes the centralized base at Lawrence Livermore Laboratory and a direct linkup with two major DOE nuclear sites at Rocky Flats, Colorado, and the Savannah River Laboratory, South Carolina. The linkup is part of a long-range plan to provide 24-hour atmospheric forecasting service to all major DOE nuclear sites for use in case of nuclear incidents.

For both nuclear and nonnuclear constituents, DOE operates aircraft (Project Airstream), a balloon-borne high-altitude *sampling program* (Project Ash Can and Stratcom), and a surface air- and rain-sampling program in both the northern and southern hemispheres for sampling atmospheric radioactivity. Other constituents, such as nitric acid vapor, nitric oxide, hydrogen chloride, and sulfates, will also be measured in the stratosphere under DOE sponsorship and by guest payloads of other agencies on these flights, if they are continued.

DOE systematically measures *chlorofluorocarbons* in the lower stratosphere from a WB-57F aircraft in response to the continuing concern over the effect of these materials on stratospheric ozone.

One- and two-dimensional *computer modeling* programs are supported so that effects of trace-constituent injections can be calculated. This project includes a national ozone data archiving activity. Three-dimensional modeling is also supported through NOAA.

A small amount of research above the troposphere has been supported by DOE. This includes an auroral project from ground-based instruments (related to magnetospheric dynamics) and the following projects aimed at *magnetospheric processes*: a small substorm analysis project, a more extensive data analysis project using data from Vela and other satellites with charged-particle monitors, and a rocket project to study the magnetospheric response to releases of tracer atoms. The rocket project is being phased out as DOE withdraws from supporting an in-house rocket program. Individual projects support radiation models, studies of air-glow, cosmic rays, aerosols, dynamic interaction of plasmas with the upper atmosphere, composition of the atmosphere, and climate modeling. We think it is important to expand and coordinate research efforts in the Outer Geosciences areas from the stratosphere to the sun.

Current funding levels are running about \$17 million per year on atmospheric studies of all kinds and about \$1.3 million per year on upper atmosphere and magnetosphere studies, with a small portion in each category devoted to basic research related to global problems and long-range goals.

## B. NSF

Basic research is the primary responsibility of NSF. Accordingly, this agency has a well-rounded program in atmospheric/solar-terrestrial research in its Atmospheric Sciences Division. The program includes support for the National Center for Atmospheric Research (NCAR), the National Astronomy and Ionosphere Center (NAIC), Kitt Peak National Observatory (KPNO), Sacramento Peak Observatory (SPO), and international endeavors such as the Global Atmospheric Research program (GARP) and the International Magnetospheric Study (IMS). Support categories include meteorology, aeronomy, solar-terrestrial, atmospheric chemistry, and special projects. NSF generally does not have an executive-type program with specific mission goals. Rather basic research support comes about by peer review of unsolicited proposals. Nevertheless the agency is organized around discipline areas, and program managers have some leeway to distribute funds for emphasis

in topical subdisciplines. Thus atmospheric chemistry was emphasized in the meteorology and aeronomy programs until a separate program was set up in FY 1977.

The *Meteorology Program* supports basic research into most aspects of troposphere and lower stratosphere science, primarily through research grants to university scientists. The program objective is to improve basic knowledge of tropospheric processes to permit better weather prediction, beneficial weather modification, and environmental protection.

The *Aeronomy Program* supports research on the physical, chemical, and dynamical processes in the upper atmospheres of the earth and the other planets. These investigations include field and laboratory experiments, as well as theoretical investigations. Field experiments are principally designed around the radio and optical regions of the electromagnetic spectrum. *Radio* experiments are either active or passive. Active experiments are designed to probe the upper atmosphere by transmitting a radio signal into the upper atmosphere, receiving the signal, and studying the changes that the atmosphere has caused. Passive experiments are designed to monitor naturally occurring signals that have propagated through the upper atmosphere. *Optical* experiments are designed to measure photon emissions from the upper atmosphere, using a variety of spectrometric techniques to derive information about the atomic and molecular processes responsible for the emissions. *Laboratory* experiments are designed to determine reaction rates, microscopic energy exchange processes, and reaction products. *Theoretical* investigations have been directed principally to modeling calculations intended to synthesize individual-process results into an understanding of the atmosphere as an interactive system and to studies from first principals of nonequilibrium processes. Unfortunately it is very difficult to organize this important synthesis effort in an agency that responds to unsolicited proposals.

The *Solar-Terrestrial Program* supports experimental and theoretical studies on the energy output of the sun and its effect on the atmosphere of the earth and the planets. Experimental studies are aimed at measuring the complete spectrum of particles and waves emanating from the sun, ranging from the longest radio waves to the short gamma

rays, and all accessible energies of cosmic-ray particles including their composition and modification in the interplanetary region. The objective of theoretical studies is to understand the overall interaction of these energy forms with the upper atmosphere.

Implementation of these aims in the next few years will be greatly assisted by IMS. NSF has a lead role in the construction and operation of the ground-based equipment that is an essential part of IMS. Procurement of magnetometers, photometers, ionosondes, all-sky cameras, and riometers was initiated in FY 1976 with installation and operation completed in FY 1977.

Initial planning has started on the funding of experiments associated with the increased solar activity expected in 1979-80, the solar maximum year. These experiments naturally will follow the IMS and conceivably could use most of the same equipment. Of special interest are experiments designed to measure the possible variability of the total energy output of the sun and the consequent impact on the earth's atmosphere. Positive results will have implications for the climatology of the earth.

The *Atmospheric Chemistry* program, just getting started as a new category, incorporates portions of the research previously supported in meteorology and aeronomy. It is intended to provide a broad base of knowledge about atmospheric chemistry to complement the more directed efforts of EPA, DOE, NOAA, and NASA, with emphasis on trace species in the stratosphere and the cycles of gases and aerosols in the troposphere (carbon, sulphate, etc.). From past experience it seems likely that EPA, NOAA, and NASA will emphasize field measurements and remote sensing from local to global scales, and NSF grants will be given in the areas of theory, data analysis, and laboratory projects. Because NSF, NOAA, DOE, and NASA are increasing their atmospheric chemistry research, there will be a period when roles must be sorted out through interagency coordination. This should not be a problem because the atmospheric chemistry scientific tasks are rather well defined.

NSF participates in several international research programs. GARP is an international scientific effort to expand our understanding of both the transient behavior and the statistical properties of large-scale atmospheric phenomena. Such an undertaking

needs talents from many scientific and technical disciplines. Within the United States, NOAA is the lead agency for coordinating the GARP effort between the seven supporting Federal agencies [Department of Commerce (DOC), DOD, DOE, DOT, EPA, NASA, and NSF]. The primary NSF/GARP responsibility is to focus the scientific expertise of university scientists on GARP-related research.

The highest priority NSF/GARP item initially will be to support the analysis of data obtained from the GARP Atlantic Tropical Experiment (GATE). In the years ahead, the analysis and interpretation of GATE data by university scientists will be an important NSF/GARP component.

The First GARP Global Experiment (FGGE) is primarily a worldwide observation program scheduled to begin in FY 1979. NSF will support the participation of university scientists in the national and international FGGE planning.

Several regional experiments are planned in conjunction with FGGE. NSF will sponsor participation in all of them. They include the Polar Experiment (POLEX), a study of the polar energy budgets; the Monsoon Experiment (MONEX), a study of the dynamics and thermodynamics of the monsoon belt; and the Indian Ocean Experiment (INDEX), a study of the physics and dynamics of the equatorial and western Indian Ocean.

NSF will continue to provide long-term support for scientists involved in the development and use of numerical models of the atmosphere and the ocean. The combination of numerical modeling and observational analysis and interpretation will continue to be the foundation of the GARP effort.

Research having application to the atmospheric sciences is also conducted in the following projects within the context of the International Decade of Ocean Exploration. (1) The Coastal Upwelling Ecosystem Analysis project includes a physical component to study the processes responsible for upwelling of cold, nutrient-rich subsurface water. Because coastal upwelling usually occurs in response to favorable winds, measurements of meteorological variables are made by satellites, aircraft, ships, and buoys. (2) The North Pacific Experiment (NORPAX) is studying long-period, large-scale ocean-atmosphere coupling. NORPAX includes atmospheric measurements from Pacific

islands, buoys, ships, and aircraft, as well as the interpretation of satellite data. NORPAX, begun in FY 1973, should continue for 10 years. NORPAX is funded and managed jointly by NSF and the Office of Naval Research. (3) In the International Southern Ocean Studies project, atmospheric measurements from ships, satellites, and local land stations will be studied to determine the role of the atmosphere in forcing the circumpolar current. (4) The Climate: Long-Range Investigations and Mapping and Prediction project is a study of environmental conditions during past ice ages. Charts of sea surface temperatures are derived by studying fossils in deep-sea sediment cores. These charts, along with ice margin, albedo, and sea-level data, are used in a numerical climate model to simulate atmospheric conditions and possibly to learn some causes of climate change.

The objective of the separate Climate Dynamics Program is to develop a basis for predicting climate variations and for assessing the impact of these variations on human affairs. Toward this end, the program supports research that contributes to knowledge of the natural variability of climate and to understanding of the physical processes governing climate. The research to be supported initially falls into four areas: (1) data assembly; (2) climate analysis; (3) climate simulation and prediction; and (4) climate impact assessment.

NSF supports several national centers for research. The mission of NAIC is to provide the scientific community with advanced visitor-oriented facilities and instrumentation for frontier research in radio and radar astronomy and aeronomy. About one-third of the research effort is in upper atmospheric sciences.

The principal observing facilities are located in Puerto Rico, about 12 miles south of Arecibo. The major instrument is a 305-m fixed spherical antenna.

The continuing goal of NAIC aeronomy programs is the improved understanding of the properties of the earth's upper atmosphere. The NAIC radio/radar telescope and other facilities enable scientists to study photochemical and dynamic processes in the atmosphere. These processes include various radiative phenomena such as photoionization and emission; the coupling between

ions, electrons, and neutral particles; particle motions caused by winds, tides, gravity waves, and plasma instabilities; and energy transport mechanisms in the atmosphere. NAIC also maintains an airglow facility with high-quality photometric and spectrometric capabilities.

KPNO was founded to support the science of optical astronomy in the United States. As a national center, its major objectives are to provide first-rate facilities and equipment to all qualified astronomers and to develop techniques and instrumentation for frontier astronomical research.

The observatory maintains an outstanding staff of scientists studying the stars, the sun, and the planets. Stellar and solar telescopes, advanced auxiliary instrumentation, and data reduction equipment are available.

Atmospheric research at KPNO consists primarily of studies of planetary atmospheres by both ground-based and spacecraft observations. A small monitoring program of terrestrial aeronomy is also pursued. Some very good solar studies also are carried out, especially in optical spectroscopy, magnetic fields, and plasma motions. Solar data are available to outside scientists on request.

SPO is a similar facility for high-quality optical observations of the sun. Recently, it has been taken over by NSF from the Air Force and has not yet been designated a national center, although it has some of the finest equipment in the world and some very competent solar scientists.

NCAR works closely with university scientists and Federal agencies to attack selected problems of national and international importance and to provide atmospheric research groups with facilities and services not feasible for individual universities to acquire and operate. NCAR participates in the international GARP effort, primarily by a numerical weather prediction project, and in various subprograms of GARP such as FGGE and GATE. There is a data analysis project on the Nimbus-6 tropical wind energy conversion and reference level experiment. A three-dimensional global circulation model of the troposphere has been developed and is used for studies related to weather and climate. A three-dimensional model of the stratosphere is being developed.

An advanced study program at NCAR provides (a) postdoctoral appointments encompassing a broad range of atmospheric science areas; (b) a sum-

mer colloquium consisting of lectures, seminars, and workshops on weather-forecasting models and systems; (c) social and economic studies of hail suppression and of weather forecasting; and (d) graduate, undergraduate, and minority fellowship programs.

Solar physics studies are carried out by the High-Altitude Observatory (HAO), a division of NCAR. HAO is at the forefront of research on non-equilibrium thermodynamics of the chromosphere, studies of the structure and electron density in the corona, and three-dimensional models of the solar wind. Increasing attention is being given to subsurface solar dynamics to gain better understanding of differential rotation and the magnetic activity cycle.

Facilities offered to the research community by NCAR include four research aircraft; a balloon launching service; major computing capability with remote access; a field observation network of radar, lidar, and other sensing systems; and instrumentation development services.

NCAR is also involved with atmospheric/solar-terrestrial research in the polar regions as part of international projects. As part of the IMS, aurorae, cosmic rays, geomagnetic activity, electric fields, particle precipitation, and changes in the ionosphere are measured at Siple Station, Antarctica. Ground-based and balloon measurements are also made near Arctic locations that are magnetically conjugate to Siple Station. Several meteorological parameters measured in both polar regions are used to study the role played by the ice packs in global atmospheric circulation and the ocean-ice-atmosphere interactions. Ice cores drilled in Greenland are a major source of data on climate extending backwards for millions of years.

NSF allots about \$50 million per year to meteorology and about \$25 million per year to the broad solar-terrestrial category, which includes all disciplines but meteorology.

### C. NOAA

NOAA conducts a research program in the atmospheric and solar-terrestrial sciences that includes many aspects of the entire field. The primary emphasis in NOAA is on the weather—how to describe, understand, and predict it. Its program

covers all scales of atmospheric phenomena from local to global and long term. Increasing emphasis is being placed on the role of oceans in meteorology and climate dynamics. Both theoretical and experimental programs are stressed. Relevant divisions of NOAA are the Environmental Research Laboratories, the National Weather Service, the National Environmental Satellite Service, and the Environmental Data Services Center.

Some NOAA programs include participation in the World Weather Program, weather modification, weather and climate modeling, ground-based monitoring of solar and atmospheric parameters, satellite monitoring of atmospheric and solar-terrestrial parameters, severe storm research, and cooperative and service programs with other agencies and institutions.

Under the World Weather Program, NOAA is the lead agency for U.S. participation and concentrates its support in GARP, an international program aimed at improved weather forecasting and a better understanding of climate. Most noteworthy of the numerous GARP subprograms is the global monitoring experiment FGGE involving satellite and ground-based data collection. U. S. FGGE activities include scientific planning, computer processing and modeling, data analyses, archiving, and sophisticated observing systems.

The Geophysical Fluid Dynamics Laboratory (GRDL) conducts fundamental investigations of the dynamics of geophysical fluids, the atmosphere, the hydrosphere, and the cryosphere, over large time and space scales. Application areas include atmospheric forecasting (days to months), the evolution of climate, dispersion in the atmosphere and oceans of inert and interactive substances, evolution of hurricanes, and clear air turbulence. Most of the studies are done with large three-dimensional computer models. GFDL will be heavily involved in the GARP data analysis.

The National Meteorological Center (NMC) is also a numerical modeling facility, but it has a more immediate objective, namely, to increase the accuracy of daily public weather forecasts. NMC seeks access to better data sources and improved methods of handling and analyzing these data.

The Center for Climatic and Environmental Assessment analyzes data to assist decision making concerning national policies and planning, usually

by contract to another government agency. Examples include (1) models that relate climate to crops and provide crop yield estimates and (2) models that relate natural gas usage to weather conditions and population so that gas allocation decisions can be made. This activity is needed within DOE, and DOE support for basic research is important to the success of such an assessment center.

The Center for Experimental Design and Data Analysis analyzes data for national and international programs such as GATE, FGGE, and the U.S. Climate Program. CEDDA personnel also interact directly with these groups when they set up experiments to assure manageable data handling and analysis capability. Processed data are distributed to the experiment scientists and to archiving centers.

The Cooperative Institute for Research in Environmental Sciences is a joint NOAA and University of Colorado program. It promotes research in several geophysical disciplines, including electromagnetic wave propagation theory, micro- and mesoscale atmospheric dynamics, solid earth geophysics, physics of the upper and lower atmospheres, and solar-terrestrial relationships. Most of the present NOAA-sponsored effort concentrates on applications of electromagnetic wave propagation. Complementary experimental work is carried out by the Wave Propagation Laboratory.

NOAA's Air Resources Laboratory (ARL) deals with the use of meteorology to understand and predict man's influence on his environment. Within ARL, a Geophysical Monitoring for Climatic Change (GMCC) program provides quantitative data needed for predicting climate change. The data consist of (a) dependable measurements of the existing amounts of natural and manmade contaminants in the atmosphere, (b) determination of the change rates of the amounts, and (c) measurement of the atmospheric properties affected by the contaminants. The program presently maintains four stations scattered over the globe measuring solar flux, aerosols,  $\text{NO}_2$ ,  $\text{O}_3$ ,  $^{14}\text{C}$ , and surface chlorofluorocarbons. Other atmospheric species are monitored through occasional cooperative programs. Some GMCC stations monitor  $\text{NO}_x$ ,  $\text{NH}_3$ ,  $\text{H}_2\text{S}$ ,  $\text{SO}_2$ , and precipitation composition.

ARL also concentrates on studies of the physical processes affecting the transport, diffusion,

transformation, and deposition of air pollutants. Portions of the ARL program are tied to and supported by DOE activities, including very close associations with Oak Ridge National Laboratory on the meteorology of pollutants, with the Nevada Test Site on the meteorology of nuclear testing, and at various locations on the meteorology of nuclear reactors and nuclear debris from atmospheric weapon tests by other countries. Theoretical transport models are being developed and improved to permit simulations of various hypothetical and real changes in the atmosphere and to trace the consequences globally as far as possible.

In recent years, ARL studies of existing data sets have shown the climatological problem in perspective and emphasized the roles of various internal and external effects on climate, including evidence of the influence of solar activity on climate.

The Aeronomy Laboratory program encompasses research into upper atmospheric physics and chemistry by theoretical studies, Doppler radar measurements, optical techniques, balloon sampling, and a laboratory reaction-rate program. Field measurements are made on  $\text{NO}_2$  and  $\text{OH}$  in the upper atmosphere and on  $\text{ClO}$  and  $\text{NO}$  near the surface. Each NOAA research effort has been highly productive and at the forefront of developments in solar-terrestrial and upper atmosphere science. Contributions have been made to the understanding of a wide range of processes, from the dynamics of particles in the solar corona to the chemistry of numerous species in the D, E, and F regions of the earth's atmosphere.

The Space Environment Laboratory (SEL) conducts research in solar-terrestrial physics, develops techniques necessary for forecasting solar disturbances and their subsequent effects on the earth environment, and provides continuous real-time environment-monitoring and forecast services. Much of this program is in direct response to users' needs as outlined in Sec. I. Research areas emphasized in SEL are plasma processes in the interplanetary medium, magnetosphere, and ionosphere. An instrumentation group develops new measurement techniques for plasmas, electromagnetic fields, and other parameters. A rocket project and several satellite projects are kept active on a continuing but infrequent basis. Solar-terrestrial data are available to a wide user community both in

real time and in tabulated form for dissemination by the Space Environment Services Center (SESC). SESC provides data, analyses, and forecasts to national and international users.

NOAA's National Environmental Satellite Service is a research and monitoring program intended primarily to develop an atmospheric temperature and constituent profiling system that has global coverage and is operationally independent of the worldwide radiosonde network. The TOVS (TIROS-N) satellites will measure  $\text{CO}_2$ ,  $\text{H}_2\text{O}$ ,  $\text{O}_3$ ,  $\text{O}_2$ , and other atmospheric constituents as well as radiometric temperature and humidity profiles. The SMS/GOES satellites measure surface temperature, cloud types and heights, wind vector fields, earth surface imaging over the U.S., and various solar-terrestrial parameters including solar particle and x-ray fluxes. Experiments on Nimbus and other satellites include measurements of tropospheric temperature and liquid water profiles, sea surface temperatures, snow coverage and run-off melt, ice surveys, positions of major ocean currents, solar radiation incident upon and reflected from the earth, and air pollutants and trace constituents. Seasat mission commenced in 1978, and Stormsat mission will commence in 1982, for observations obvious from their names.

The research interests in NOAA run parallel to what we are advocating for DOE in this report. The distinction of roles between the two agencies is that NOAA will extend its existing satellite and rocket monitoring programs and develop its theoretical models of solar-terrestrial processes, whereas DOE should support selected individual efforts in various institutions (perhaps including some efforts in NOAA). DOE-supported projects should represent basic research with relevance to energy-related technologies on a global scale. This research would include such studies as global circulation models of the atmosphere, coupling mechanisms between various portions of the atmospheric/solar-terrestrial system, sun-weather and sun-climate relationships and mechanisms, and basic solar activity.

NOAA spends about \$50 million per year on tropospheric studies and about \$3 million per year on upper atmosphere and solar-terrestrial projects. In FY 1978 emphasis on stratospheric studies increased at about \$2.6 million, while funding for the remainder of upper atmosphere and solar-terrestrial

dropped to about \$2.6 million, for a total of \$5.2 million on upper atmosphere and solar-terrestrial.

#### D. NASA

NASA programs in atmospheric/solar-terrestrial sciences have evolved in separate offices. Meteorology and technology development are supported through the Office of Applications (OA), while the Office of Space Sciences has a Solar-Terrestrial Programs Office (ST). ST is a broadly based program covering everything from the tropopause to the sun. The Upper Atmosphere Program, formerly a separate office but now in ST, was set up in response to an assignment given NASA by Congress in the FY 1976 Authorization Act. The assignment is to develop and implement a comprehensive program of research, technology, and monitoring of phenomena in the upper atmosphere to provide an understanding of and to maintain the chemical and physical integrity of the earth's upper atmosphere. ST, OA, and other programs are coordinated by a steering committee.

NASA plays two roles in the national atmospheric/solar-terrestrial science programs. It builds and launches satellites for other sponsors, such as NOAA, and it carries out its own research programs, including the lead agency role in stratospheric research mentioned above.

The *research projects* sponsored by NASA include specific satellite missions that are individually approved and level-of-effort programs with separate managers. The latter category includes rockets, balloons, data analysis, and supporting research and technology. The supporting research and technology program covers laboratory studies and theoretical work related to particular disciplines. It also provides for development of new instrumentation concepts and hardware for future space missions. Data analysis funds usually are allotted after completion of space missions. The SR and T data analysis programs are vital to obtain maximum scientific results from space missions and to provide continuity between missions.

The relevant program offices in ST are Upper Atmosphere, Space Plasma Physics, and Solar Physics.

*Space missions* related to the atmospheric/solar-terrestrial sciences have included the Atmospheric Explorers (AE), the Applications Technology Satellites (ATS), the International Satellites for Ionospheric Studies (ISIS), the International Sun-Earth Explorers (ISEE), and interplanetary probes such as the Pioneers and Viking. AE missions are devoted to aeronomy, measurements of the composition, density, and temperature of the atmosphere from 100 to 250 km. ATS missions carry instrumentation primarily for measurements of particles and fields at geostationary altitudes (42 000 km). ISIS satellites are built in Canada and are used in a cooperative program with NASA. Measurements are largely a combination of AE and ATS types, but from high-inclination orbits ( $\sim 88^\circ$ ) and with much emphasis on additional observations of optical aurorae. ISEE missions measure primarily solar wind particles, cosmic-ray particles, and magnetic fields in the interplanetary medium along the ecliptic plane. The interaction between magnetosphere and ionosphere-upper atmosphere will be investigated by the Electrodynamics Explorer (EE), if the project is approved by NASA and the Office of Management and Budget as a new start. EE will fill the observational gap between ISEE and AE/ATS/ISIS missions. An Out-of-Ecliptic (OOE) mission is planned to follow up ISEE with a trajectory to permit three-dimensional structure of the solar wind, energetic particles, and fields in interplanetary space.

The above missions involve primarily in situ measurements of parameters at the satellite position. To obtain more global coverage and three-dimensional profiles of the atmosphere-magnetosphere system, experiments for remote sensing (such as lidar and ir spectrometer/radiometers) and active perturbation (such as electron accelerators and explosive releases) should be added. It is intended to carry out such comprehensive experiments in space from the space shuttle by means of an AMPS program (Atmosphere, Magnetosphere, Plasmas in Space) that uses much of the instrumentation developed in the previous programs.

*Solar physics* has been supported by NASA through the Orbiting Solar Observatories (OSO), the Skylab Apollo Telescope Mount (ATM), the



Solar Maximum Mission (SMM), and rocket experiments. The last OSO mission and the ATM program are nearly complete. SMM will occur around 1980. From these missions a great deal has and will be learned about the solar atmosphere and activity cycle, as well as about solar-terrestrial processes. Follow-on missions in solar physics are planned for the space shuttle.

Until the early 1980's the solar physics emphasis will be on flare phenomena and their terrestrial effects, on energy transport through the solar atmosphere, and on the structure of the solar corona with special attention to coronal holes and the transition from corona to solar wind. In the mid to late 1980's emphasis probably will shift to the three-dimensional structure of the solar wind; high-resolution studies of the solar atmosphere in all wave-lengths, including atmospheric motions of all kinds and magnetic fields; and follow-on studies of flare phenomena.

A set of new-generation solar instruments, to be brought on line in the early 1980's, initially will be flown as Spacelab instruments. We hope they will be perfected so that a Solar-Terrestrial Observatory (STO) can be maintained in space around 1990, either as a shuttle-launched free flyer or as a dependent satellite attached to the power module for 2 months at a time.

The *Space Plasma Physics* office plans to build new comprehensive observational programs around instrumentation and concepts used effectively in past missions, such as AE, ATS, and rockets. We hope that the Electrodynamics Explorer will be approved. An Upper Atmosphere Explorer is in the definition phase in cooperation with the Upper Atmosphere office. A barium-release satellite has been proposed. Two satellites to study the equatorial ionosphere may be launched in cooperation with the Italian government. There is a rocket program for specific exploratory and development experiments, such as active magnetospheric probing with electron beams injected from a rocket. Laboratory plasma studies are supported by grants and by a NASA plasma chamber at Johnson Space Center.

The major 1980's plan is a series of space shuttle launches of the AMPS package for comprehensive and coordinated experiments. Areas to be emphasized are (1) the neutral chemistry of the atmosphere, especially the budget and chemistry of

atmospheric chlorine compounds, (2) the energy budget and dynamics of the atmosphere, (3) solar radiation variability, (4) magnetospheric electric fields, (5) magnetosphere-ionosphere current systems, (6) sources and acceleration of magnetospheric plasmas, and (7) wave generation and wave-particle interactions.

In *atmospheric research* the ST office will emphasize the chemistry, dynamics, and energy balance of the atmosphere between 10 and 500 km, and the coupling of this region with the troposphere below and the ionosphere-magnetosphere above. The Upper Atmosphere Office within ST has more narrowly defined goals. They are to acquire sufficient understanding of the atmosphere so that man-caused perturbations of the stratosphere can be assessed, and changes in the opacity of the stratosphere to solar (especially uv) radiation can be determined.

To meet these goals the Upper Atmosphere Office has a long-term basic science program in stratospheric chemistry and dynamics and a short-term assessment program to use all data as they become available to assess the consequences of aircraft exhausts, space shuttle operations, and chlorofluoromethane releases. The Office plans to implement the program with (1) field measurements using ground-based instruments, balloons, rockets, and satellites; (2) laboratory experiments on reaction rates and photochemical and spectral data; and (3) theoretical studies. The measurements program will be keyed to evaluating specific theoretical models. To provide rapid access to all data by all interested scientists, the Office plans a central location to receive and transmit by telephone the latest experimental results and model predictions. The center will be backed up by a computer data bank.

ST has discussed an even more direct data approach whereby the central location receives all raw data by microwave link to satellites or ground stations and every project scientist can interact directly by telephone and remote terminal to extract the data he needs.

NASA will sponsor one experiment on the space shuttle in 1980 to explore the electrification link in solar-terrestrial processes. A geophysical fluid flow experiment on Spacelab 1 and a cloud physics laboratory on Spacelab 3 will have applications to

both solar convection and the earth's atmosphere. The agency hopes to have an evolutionary version of a Solar-Terrestrial Observatory in operation before 1990. It is possible and desirable for DOE to partially support similar projects in the future. Partial DOE support for theoretical studies, instrument design concepts, or laboratory studies would make possible some good Outer Geosciences experiments that otherwise might not come to fruition as hardware to be put in space through the Space Transportation System.

NASA spends about \$20 million per year on meteorology and about \$23 million per year on aeronomy and solar-terrestrial work. These numbers do not include costs of satellite projects, which probably average \$25 to \$50 million total.

## E. Air Force

Many current and future Air Force systems are sensitive to meteorological and solar-terrestrial elements. This sensitivity often becomes a crucial factor during both the design of a system and its actual operation. The goals in the Air Force's meteorological program are increased understanding of atmospheric processes and improved methods of observing, processing, displaying, forecasting, and, in some cases, modifying meteorological elements to promote safe and efficient operations. Thus, much Air Force effort is directed toward operational systems and applied meteorology.

*Meteorological* efforts under way include

- (a) an operation thermal fog dispersal system,
- (b) a mobile lidar system for determination of visual slant range,
- (c) a laser ceilometer to measure cloud-base heights and ceilings,
- (d) automated surface weather observations,
- (d) automated surface weather observation systems,
- (e) Doppler radar systems to measure and display wind shear,
- (f) numerical weather prediction techniques,
- (g) automatic processing techniques for satellite images, and
- (h) development of reference climatology for military systems design.

Air Force *solar-terrestrial* research and development programs are directed toward the description and prediction of the physical, chemical, radiative, and magnetic environment of the upper atmosphere, the ionosphere, and near-earth space. The purpose is to obtain accurate quantitative data for specifying and modeling the radio and optical-infrared propagation characteristics and the effects of naturally occurring and manmade phenomena in these regions on the performance of military systems. The general program is built around tasks that are further subdivided into specific projects outlined below.

Objectives in the *Upper Atmosphere Physics* research program include the determination of the environmental impact of Air Force operations in the stratosphere, the provision of improved balloon and sounding-rocket capability to support Air Force missions, and the study of satellite system degradation caused by spacecraft charging. Atmospheric density and structure-to-rocket and -to-satellite altitudes are being determined using drag-sensing accelerometers, ionization gauges, and laser-scattering techniques. Ion and neutral chemistry laboratory experiments are conducted by mass spectrometry to determine reaction rates during disturbed atmospheric conditions. Rocket experiments are carried out to obtain wind, temperature, and diffusion coefficients. Solar uv radiation is observed by rocket- and satellite-borne spectrometers. From these measurements models for both the normal and disturbed atmospheres will be developed and tailored for use in the design and operation of Air Force systems. The stratospheric program involves measurements of gaseous composition, aerosol characteristics, uv radiation, chemistry, and the development of transport models.

Characterization of the *geosynchronous satellite altitude environment* is of major concern to the Air Force. A handbook is being prepared to specify the full variability range that can be expected at this altitude. Data from the Air Force SCATHA satellite, which was launched in CY 1978, will be included in a handbook supplement. SCATHA satellite instrumentation will include electrostatic analyzers, charged-particle flux spectrometers, and electron and ion beam systems to assess the feasibility of actively controlling satellite charging and discharging.

In the *Optical Physics* research program, infrared properties of the atmosphere are being investigated for their effects on optical/ir sensing systems. Computer code development for atmospheric transmission and emission calculations is continuing. Optical phenomena associated with a disturbed atmosphere at high altitudes are measured by aircraft, balloon, and rocket-borne instruments. The ir, visible, and uv sky backgrounds, zodiacal light, and earth limb radiance, and their effects on optical/ir surveillance and tracking systems will continue to be investigated.

The field measurement phase of the Optical Atmospheric Quantities in Europe program is under way. This is a 2-year multinational observational program to document low-level atmospheric optical properties in Europe. The Air Force operates one of nine stations in the network. Research on optimized spectral filtering and ozone and water vapor transmission will be directed toward improving the atmospheric sounding capability of the Defense Meteorological Satellite Program. In addition, high-resolution spectral measurements in the atmosphere for use in laser transmission codes are being carried out.

In *ionospheric research*, measurements are made to determine the amplitude and phase fluctuations of satellite-to-ground radio signals in the uhf band. A global network of observing stations has been set up to measure the behavior of signals as they traverse ionospheric irregularities. This network will be expanded to include two or three new stations in the equatorial region, where the scintillation effects on transionospherically propagated radio waves are high. Total electron content, variations of which produce range errors in navigation and radar detection systems, will continue to be observed on a global basis. These data will be used to develop refined models of total electron content for range-error correction schemes and to study ionospheric structure and dynamical processes during both quiet and disturbed geophysical conditions.

The effects of gradients in electron density on oblique, hf propagation will continue to be studied with particular emphasis placed on simulating hf propagation characteristics in the polar ionosphere. The Goose Bay Ionospheric Observatory monitors geophysical phenomena under auroral conditions. Techniques to use the Goose Bay data to predict the

structure of the ionosphere in the polar region will be developed. Using satellite observations, air-borne data, and ground-based observations, the interrelationship between processes occurring in the magnetosphere and the subsequent ionospheric manifestation will be studied.

Methods to predict *geomagnetic activity* are sought using data obtained from the magnetometer network of the Air Force Geophysics Laboratory (AFGL). In addition, the performance of satellite-to-ground communications links is being studied under various magnetic activity levels.

The *charged particle* population in the earth's magnetosphere is being analyzed using data obtained on board existing satellites. Instrumentation to monitor electron fluxes in the 0.5- to 20-keV energy range will be designed and fabricated for inclusion on board defense meteorological satellites. In situ satellite observations of electron density will be analyzed, and regions of irregularities will be modeled. Techniques to use measurements of electron density and temperature, and ion temperature and mean mass at satellite altitudes to improve total electron content models will be developed. Data obtained by satellites in the interplanetary medium will be investigated to develop means of forecasting geophysical disturbances, principally polar cap absorption events (PCAs) and geomagnetic storms.

In *solar research*, observational and theoretical studies of the physics of energy transfer in the solar atmosphere, the origins of the geophysically active solar disturbances, and conversion from magnetic energy to thermal and kinetic energy are supported. A further objective is the study of nonflare solar activity, such as the corona, sunspots, and prominences, to clarify the role of the corona both as the site for solar activity and as the propagation medium. Solar radio emissions are measured to predict solar events based on unique characteristics of solar radio bursts. Examples of operationally useful radio burst signatures are the U-shaped spectrum, which is a highly reliable precursor of proton events and resultant PCAs, and the integrated flux density, which permits prediction of the proton flux magnitude and the PCA severity.

The Air Force spends about \$7 million per year on applied meteorology and about \$28 million per year

on the solar-terrestrial category. Within the solar-terrestrial category about \$1.7 million per year is provided through the Air Force Office of Scientific Research to support relevant basic research in the Outer Geosciences. Only the last category is generally available to nonmilitary scholars outside the Air Force laboratories.

## F. Army

The principal objective of the Army's atmospheric sciences research and development program is to develop techniques and equipment for weapons systems, field operations, and Research and Development Technology and Employment (RDTE) activities.

Because the state of the atmosphere affects Army operations and weapons systems, projects in atmospheric sensing, atmospheric transmission, development of state-of-the-art data acquisition and prediction systems, development of techniques to overcome certain adverse weather conditions, and extension of the coverage area into enemy territory by satellite remote sensing systems are needed. These needs parallel Air Force and Navy needs. Distinctions arise from the differing atmospheric regimes encountered; the Army is concerned mostly with the troposphere over land, the Navy with the troposphere over oceans, and the Air Force with the upper atmosphere.

Recent developments in *remote sensing* technology using electromagnetic waves and acoustics to sense specific atmospheric parameters are making the development of real-time remote atmospheric measuring systems possible. For RDTE of advanced electro-optical and laser sensing systems operating in visible, near-ir, ir, and microwave spectral regions, essential data on the absorption, refraction, and scattering of electromagnetic radiation by atmospheric gases and suspended particles and aerosols must be obtained. *Laboratory* and *field measurements* are being conducted to provide essential data for atmospheric modeling and subsequent technology development. Research is conducted to formulate and validate atmospheric models that characterize the diurnal, seasonal, and geographical variations in atmospheric optical environmental parameters such

as are encountered in haze, fog, dust, rain, hail, snow, and smoke.

Just as with the Air Force, various *data acquisition and control systems* are being developed to assimilate input data on atmospheric conditions and to calculate output control functions for targeting, etc.

*Satellites* are particularly adept at acquiring data over enemy territory and thus facilitating the planning of tactics to take advantage of meteorology on battlefield operations. An automated nuclear fallout prediction system is being developed based on satellite radiometric data that will provide the battlefield commander with real-time information for operations or planning relative to nuclear-burst effects on the battlefield. The Army has in operation at White Sands Missile Range a Direct Readout Ground Station capable of handling all data generated by Synchronous Meteorological Satellites. After 6 months of operational SMS-A system support the station now operates on a research and development basis acquiring research data from the three SMS satellites.

A *support program* provides meteorological support to Army RDTE activities and other organizations and to users of White Sands Missile Range. Detailed meteorological data are obtained from the surface to 100 km using standard and special-purpose instrumentation. In FY 1975 meteorological support was furnished for 629 programs of 55 Army RDTE activities at 13 meteorological locations and for 8 programs at temporary sites. Meteorological support was provided for 120 RDTE programs at White Sands Missile Range (Army, Navy, Air Force, and NASA) involving approximately 3800 range missions. The support program includes the Army's participation in the Cooperative Meteorological Rocket Network. Support was also furnished for the Army's demilitarization and detoxification activities.

The primary objectives of the Army's *Aeronomy program* are to determine, understand, and predict the upper atmospheric environment likely to be encountered by military systems. Research includes measuring the upper atmosphere properties essential for the understanding of electron, ion, and molecular interactions critical for modeling, and combining the results of the direct measurements and the laboratory studies to develop and evaluate

mathematical upper-atmosphere models that describe and predict the expected high-altitude environment for these military systems. Areas of effort consist of atmospheric environmental measurements, atmospheric code evaluation, and reaction rate measurements. Additional efforts are expended to define and to interpret ionization and excitation phenomenology of the atmosphere. A coordinated approach is being taken through utilization of the extensive White Sands Missile Range facility to conduct upper-atmosphere research with rocket- and balloon-borne systems and through cooperative atmospheric sounding experiments with other government agencies.

It is in the complex atmospheric region of 10-120 km (stratosphere-mesosphere) that nuclear weapons would be deployed and in which Ballistic Missile Defense (BMD) systems must operate. It is also in the 10- to 120-km region that the least information concerning atmospheric composition and its variability is available and the currently available techniques are inadequate to predict accurately the atmospheric states with respect to composition and structure as a function of time and space. An experimentally verified chemical kinetic model is being obtained in the 10- to 120-km atmospheric region by conducting near-simultaneous data acquisition experiments (balloon-borne to 55 km, rocket-borne from 55-120 km) that relate the 35 measured chemical constituents of the atmosphere to its measured thermal, hydrodynamic, and charged-particle structure and to incident-ionizing solar radiation.

Army funding in applied meteorology is about \$15 million per year and in upper atmosphere studies, about \$2 million per year. A few isolated projects can be linked to basic research.

## G. Navy

Naval interest in the atmospheric/solar-terrestrial sciences stems from operational requirements for improvements in communications, acoustic propagation, remote and direct sensing of the environment for meteorological prediction, including subsurface and surface sea conditions, and electromagnetic energy propagation through the atmosphere throughout the spectrum (from x-ray, uv,

and visible to long-wave radio frequencies) in connection with detection procedures, surveillance, and discrimination techniques. This program seeks knowledge necessary for solving Navy and Marine Corps problems of communications, weather prediction, night vision, optical transmission through the atmosphere, and safe launching of missiles at sea beneath electrified clouds. The program entails research into solar phenomena and emissions, the ionosphere, and the lower atmosphere. Other investigations deal with atmospheric structure, cloud and clear-air electrical processes, the composition and distribution of atmospheric nuclei, warm fog, the trade wind cumulus clouds, and the associated weather patterns. The program includes studies in cloud physics and atmospheric dynamics, using rocket soundings and lasers to accumulate more information on the 30- to 70-km stratum.

A Global Extended-Range Automated Environmental Prediction System is being developed to improve the skill of numerical forecasts over oceans for increased periods of time, initially to 72 hours and, later, to 10 days and beyond. Development of numerical models to predict energy exchange processes and the distribution of significant characteristics of the air-sea interface and of the marine planetary boundary will continue. Evaluation and selection of numerical models of the atmosphere, ocean, and ionosphere for integration into GERAEPS will be attempted.

Prototype *automatic weather stations* for unique environmental situations, such as remote cold climate and sea surface, have been fabricated and have undergone limited testing.

The *Minirefractionsonde*, under development, is a unique miniature radiosonde that will measure temperature, pressure, and humidity profiles of the marine atmosphere.

The vertical distribution of *water vapor* to a 30-km altitude is being measured monthly by the Naval Research Laboratory from a site near Washington, D.C. The program provides the only source for in situ measurements of stratospheric water vapor over this range of altitude. The measurements, begun in 1964, constitute the longest data sequence available for the study of stratospheric water vapor concentration and variability. They provide a reference base that

allows for the early recognition of major perturbations and changes as they appear in subsequent observations.

The *Environmental Prediction Research Facility* is developing techniques to extract meaningful air-sea interface information from advanced sensors aboard available environmental satellites. Emphasis is placed on tactical use of the data extracted. Ways to use these data in the Navy's analysis and prediction system will continue to be a prime activity area. Analysis of data from the Defense Meteorological Satellite Program and the National System should improve tactical support capability to the operating forces.

*Solar-terrestrial research* is supported at a more fundamental level than meteorology. This effort, directed by the Office of Naval Research (ONR), contributes to the Navy interests cited above, but the mode of execution is chiefly by grants for research rather than for development of operational systems. Thus the emphasis on operational systems is one step further off, because the basic phenomena are less clearly understood. The Naval Research Laboratory also contributes in this discipline.

The program includes the following areas. Magnetospheric physics research is intended to improve our understanding of geomagnetic storms, particle acceleration processes, coupling to the ionosphere, and spacecraft-charging phenomena. Solar physics research concentrates on solar regions responsible for solar flares and interplanetary shock fronts to determine whether prediction of solar flares and geomagnetic storms is possible by identifying detectable precursors. Small efforts are devoted to wave-particle interactions in the magnetosphere, which affect vlf wave propagation and cause particle precipitation, and to upper atmosphere chemistry and structure.

ONR has been the major funding source for atmospheric electrical research for the past two decades. The agency hopes to continue this support and other investigations that can help explain the sun-weather relationships. Navy funding for applied meteorology is ~\$10 million per year, and ~\$2.5 million per year for the broad solar-terrestrial category. Much of the latter is for basic research relevant to Navy goals.

## H. EPA

The EPA research programs are carried out at the 15 laboratories of the *Office of Research and Development* (ORD), 4 of which (concerned with air pollution) are located in the Environmental Research Center facilities at Research Triangle Park, North Carolina (ORD-RTP). Much EPA research and development is contracted to industry and universities. The program directly supports mission functions. It is concerned primarily with establishing and enforcing pollution control regulations and with the provision of pollution control technology. For this reason it is the exemplar of the local, applied, short-range atmospheric research concept. In the conduct and management of research related to the above objectives, the major "product" of ORD is the documentation of the scientific and engineering knowledge to provide a substantial information base upon which Agency-level decisions can be made.

The principal efforts in the field of *environmental atmospheric sciences* research involve (1) studies of the physical and chemical transformations of pollutants from source to receptor in the atmosphere; (2) development of techniques and instruments for measuring pollutants at local sources and in the ambient air; (3) development and evaluation of air quality models; (4) determination of the effects of pollutant and thermal emissions on visibility, weather, and climate; and (5) support of abatement and compliance efforts. The first two efforts are executed primarily by the Chemistry and Physics Laboratory, whereas the Meteorology Laboratory provides most of the support to efforts 3 and 4.

A major *monitoring program* is required by the EPA mission. Part of the applied atmospheric research program overlaps with the monitoring requirement. Development of instrumentation for monitoring is an ongoing concern as new air quality standards are mandated by Congress and new pollutant species are recognized.

Although research programs on *halogenated pollutants* have been under way for several years, recent findings on ozone-fluorocarbon interactions in the stratosphere have given new urgency to studies in this area. Studies include field measurement of

ambient levels of halogenated compounds, laboratory studies of photochemical reactions, determination of diffusion rates, and delineation of removal processes.

Investigations also continue on the physical and chemical properties of *aerosols* at their source in the air. The major sinks for aerosol pollutants and their removal rates are being defined. In addition, aerosol effects on gas-phase atmospheric chemical reactions are being investigated, along with the gas/particle conversions and the particle removal processes. Detailed studies aimed at producing scientific data basic to the promulgation of fine-particle standards and to the development of effective control procedures are pursued.

In support of its responsibilities for *pollutant transformations*, the Chemistry and Physics Laboratory (CPL) has the following studies in progress.

- (1) Formation in and removal from the atmosphere of noxious gases, such as sulfur and nitrogen oxides, carbon monoxide, and hydrocarbons.
- (2) Tropospheric abundance and chemistry of halogenated compounds.
- (3) Transport of oxidants (mostly ozone) from urban to nonurban areas and chemical processes between oxidants and other species.
- (4) Sources, sinks, and physical and chemical properties of aerosols.
- (5) Effects of air pollutants on materials.
- (6) Support of various local and regional pollution study projects.

For its task on techniques to *measure pollution*, CPL has developed several instruments to measure aerosol particle properties, gaseous pollutants in ambient air, and both particulate and gaseous emissions from localized sources.

The Meteorological Laboratory supports the *air quality model work* by maintaining a central computer facility called the User's Network of Applied Models of Air Pollution. The accessible models apply to situations such as urban pollution from automobiles and downwind concentrations left from smokestacks.

In support of *pollutant effects* effort ML administers the operation of a network of atmospheric turbidity stations, two sites for routine meteorological soundings and 25 stations in the St.

Louis area that measure a wide variety of pollutants along with standard meteorological parameters. Arrangements have been made for NOAA to evaluate the measurements in the context of atmospheric models. ML also has developed a set of instruments for its measurement needs and a wind tunnel to answer specific questions about emissions from stacks and automobiles.

The ORD-RTP *monitoring* efforts include a methods standardization and performance evaluation program, a quality assurance program, a National Air Surveillance Network, a Fuels Surveillance Network, a Membrane Filter and Precipitation Network, a continuous air-monitoring program, and a technical assistance program.

The National Air Surveillance Network has 250 sampling sites located throughout the United States. The air at each site is sampled for particulates, sulfur dioxide, and nitrogen dioxide. Other monitored species include lead in gasoline, trace metals, asbestos, etc.

EPA has no research in solar-terrestrial processes or in the upper atmosphere other than the stratosphere. The agency spends about \$15 million per year on applied meteorology.

## I. DOT

DOT's research efforts in the atmospheric sciences relate to departmental responsibilities for solution of transportation problems and for developing national transportation policies and programs. Pertinent research is conducted by the Office of the Secretary, the Federal Highway Administration (FHWA), the Federal Aviation Administration (FAA), and the U.S. Coast Guard.

The Office of the Secretary maintains an experimental program to determine the concentration and diffusion of atmospheric *pollution along* heavily used *highways*, with automobile exhausts the prime concern.

FHWA is also concerned with pollution along highways, but the approach is rather more general. FHWA looks at environmental factors involved in location, design, construction, and operation of highways, such as fluid dynamics in the vicinity of highway structures and control of dust during construction.

FAA has an *Aviation Weather Program* to provide weather information services to the aviation community as efficiently and accurately as possible. It is concerned with weather modification techniques (such as fog dispersal), technology development for acquisition and dissemination of weather information, and hazardous weather research and evaluation. The agency's interests overlap those of other agencies, especially NOAA, the Navy, and the Air Force, and close cooperation is maintained.

FAA conducts programs to identify, characterize, quantify, and develop methods for control of *air pollution* from the U.S. civil air transportation system and facilities. The broad program objectives are to develop prediction techniques, to demonstrate the feasibility of emissions reduction, and to conduct analyses in support of its various rule-making efforts. In addition, the programs develop the technical support, including environmental impact modeling, necessary to guide preparation of environmental impact assessments of all FAA activities, including airports, airways, and air traffic control improvements.

The FAA's *Low-Altitude Emissions Reduction program* provides the technical base required for regulation. Specific projects include the following.

- (1) *Airport Model*. Development and refinement of an analytical model of airport air pollution is continuing. FAA has installed pollution-monitoring equipment at Dulles Airport, and data derived from this and similar systems in FY 1977 and 1978 will be used to improve the airport modeling capability.
- (2) *Turbine Engine Emissions*. Characterization and quantification of emissions levels from aircraft gas turbine and piston engines will be continued as part of the agency's responsibility in setting and enforcing aircraft emission regulations.

The DOT Climatic Impact Assessment Program (CIAP) report concluded that there was an immediate need for development of a scientific basis for regulations, on both national and international levels, to ensure that future increases in high-altitude air traffic would not be accompanied by a degradation in environmental quality. In response to this recommendation, and those of the National Academy of Sciences Climatic Impact Committee, the FAA announced initiation of its *High-Altitude*

*Pollution Program (HAPP)*. The program's overall goal is to provide the data and analyses required to permit continued growth of safety, efficiency, and economy in air transportation while ensuring that aircraft emissions, during high-altitude cruise operations, do not cause adverse environmental effects. The program consists of the following elements.

- (1) *Modeling* of relevant photochemical and chemical processes and atmospheric transport phenomena.
- (2) *Requisite field measurements* to help develop and test atmospheric models.
- (3) *Appropriate laboratory measurements*.
- (4) *An engines and fuels* element, to develop an accurate data base for engine emission characteristics.
- (5) *An assessment* phase relating aircraft operations to their impact on the stratosphere and determining the need for regulation.
- (6) *A monitoring* effort to determine changes from base-line values of atmospheric constituents. [HAPP confines itself largely to assuring that the appropriate monitoring agencies (NOAA, EPA, WMO, etc.) respond to HAPP's needs.]

The HAPP organization recognizes the importance of long-range basic research in the atmospheric sciences and in coupling processes that tie the Outer Geosciences domains into an interactive system. Although the HAPP program is organized to address a specific problem, there is continual interaction with other agencies involved in fundamental research.

The U.S. Coast Guard, as a maritime operating and law enforcement agency, has a large marine and coastal weather observation and reporting system. The Coast Guard's weather program is conducted as a cooperative effort with the National Weather Service and Naval Weather Service, which use the collected data in their marine weather forecasting systems. The prime objective of the program is to ensure the high quality of *weather observations* because they are important input data for the marine weather forecasts.

There is no solar-terrestrial research program in the Department of Transportation although HAPP contributes indirectly to aeronomy. Funding by



DOT for applied meteorology and environmental atmospheric studies is about \$20 million per year.

### **J. Other Agencies**

Several other government organizations have small research programs in atmospheric or aeronomic sciences. They are the Department of Agriculture, the National Bureau of Standards, the Defense Nuclear Agency, Department of the Interior, and the Advanced Research Projects Agency. Together, these agencies spend about \$10 million per year on meteorology and weather modification, and about \$8 million per year on the solar-terrestrial system.

## **II. SUMMARY**

Table III summarized the approximate major expenditures by government agencies on atmospheric/solar-terrestrial sciences. The amounts were derived in part from personal contacts with other agencies and in part from the report ICAS 20-FY 1977.<sup>1</sup>

One should keep in perspective the relative costs of all kinds of national activities. The total federal expenditure on atmospheric/solar-terrestrial sciences in FY 1977 was about \$300 million. During the same period, very nearly the same amount was spent on high-energy physics. Both disciplines are important to the national interests. Discussions with program managers and participating scientists in both disciplines reveal that funding is already too constricted to support the competent scientific projects that have been proposed. In spite of the comprehensive goals stated in each agency's program description, numerous productive groups in the system are seeing their projects decline, and many projects of national importance have been proposed but cannot be funded.

## **REFERENCE**

1. "National Atmospheric Sciences Program Fiscal Year 1977," Interdepartmental Committee for Atmospheric Sciences report ICAS-20 (May 1976).