High-Altitude Observation Techniques

A variety of tools besides satellites are available for the study of upper atmosphere physics.

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It may be surprising to many not acquainted with upper atmosphere research to learn that the greater part of all we know today about the structure of the upper atmosphere has been discovered without instrumented satellites. Two important bits of information provided by satellites about the upper atmosphere have so far been made public: (i) The atmosphere from 500 to 1000 km above the earth is between 16 and 40 times as dense as was thought in 1955. (ii) The soft radiation, previously detected above 50 km by balloon- and rocket-borne Geiger counters and now known to be contained in two belts at about 3000 and 14,000 km, is at least 100 times as great as was formerly believed (*1*). This survey has been prepared to explain briefly how the chemical composition, ionization, density, temperature, and motion of the atmosphere above 10 km can be studied by methods some of which use balloon and rocket instrumentation but most of which actually use ground-based observations of atmospheric phenomena.

Some Methods of Study

A classical method used to give good estimates of upper air temperatures and winds involves the anomalous propagation of sound. This method presupposes a knowledge of the molecular weight and the ratio of specific heats for the atmosphere at all levels traversed by the sound wave. The maximum height at which the wind and temperature can thus be measured is usually taken as about 50 to 60 km for ground-based explosions. With grenades exploded from rockets, the upper limit may be extended to 80 km (*2*). Sound waves with very low frequencies (0.1 cy/sec) can be bent back in the ionosphere at altitudes of about 170 km (*3*). Such sound signals can give a value for the expression

$$c_pRT/c_vm$$

where c_p/c_v is the ratio of specific heats and R/m is the gas constant for the medium. Unless these ratios are known, the temperature T (°K) cannot be found. According to Hulbert (*4*) the composition of the atmosphere is approximately constant to about 150 km, and, hence, the use of sound waves is valid for the study of temperature and wind within this region.

Winds, temperature, atmospheric composition, solar radiation, and electrical conductivity have been measured with instruments sent as high as 42 km with large balloons (*5*). Similarly, rockets have been instrumented for studies at still higher altitudes. Mass spectrographs and ion spectrographs carried aloft have provided information about the presence of argon and of atomic and molecular forms of both oxygen and nitrogen up to 220 km. Photon counters sent aloft have measured solar ultraviolet and x-ray energy available for ionization and photodissociation (*1, 4*). In addition, other instrumentation has verified the indirectly determined vertical variation of temperature and has given much information about cosmic and soft radiation (*1*).

Before the atmosphere beyond the range of balloons is considered, some mention might be made about the study of the vertical distribution of atmospheric ozone with ground-based instruments. Götz, Dobson, and others (*6*) found means of determining the total amount and the vertical distribution of ozone. The total amount is determined by measuring the intensity of solar radiation at two different wavelengths, one at which the ozone absorption is strong, a second at which it is weak. The measurements are made at two different zenith angles. With proper measurements and laboratory-determined constants, the total ozone can be found. The mean height of the ozone layer may be estimated by studying the ozone absorption in light scattered from the zenith with the sun at various low elevations (*7*). Epstein (*8*) has presented a ground-based method for finding the vertical ozone distribution from knowledge of the total ozone content together with knowledge of the infrared absorption of solar radiation by ozone and the rate at which ozone radiates in the infrared. Paetzold (*9*) reports that a study of the sunlight reflected from the moon's surface right at the edge of the earth's shadow during a lunar eclipse will allow a determination of ozone distribution in the earth's atmosphere up to 45 km for various latitudes. The argument is that with a tangential path of solar rays there is a large decrease in the yellow-orange (Chappuis) spectral region, causing a blue-green coloring of the earth's shadow near the shadow limit. This zone represents an optical copy of the atmospheric ozone layer.

An interesting ground-based technique for finding the density distribution in the atmosphere between 10 and 70 km is the nighttime use of a modulated searchlight beam directed upward. The back-scattered light is observed from the ground at a point about 20 km from the searchlight. If Rayleigh scattering is assumed, the intensity of light will be a function of air density (*10*).

The observation of meteorites both by photographic means and by radio echoes provides considerable information about the atmosphere from 60 to 120 km. Air density, winds, and wind shear have been deduced from photographs of meteorites (*11*). Booker (*12*) states that information about atmospheric turbulence can be deduced from photographic observation of meteor trails. Atmospheric pressures and scale heights can be found from radio studies of meteor trails (*13*). Robertson (*14*) reports that a 27-megacycle-per-second

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Doppler-radio system has been used to estimate winds from meteor trail drift at 80 to 105 km; these winds appear to have prominent 12- and 24-hour tidal harmonics. Greenhow (*15*) has calculated the atmospheric diffusion coefficient by use of 8.27- to 8.35-meter radio measurements of echoes from meteor trails between 80 and 100 km.

Winds in the region between 30 and 90 km have been measured both by the observation of sound waves from grenades released from rockets (*2, 16*) at various altitudes and by the observation of radar return from vaporized, metal-coated, thin plastic strips (chaff) released from rockets (*17*). Metallic sodium vapor ejected from Aerobee rockets during twilight hours creates a sodium emission cloud at 5890 angstroms, and observation of these clouds provides wind information at 85 to 200 km (*18, 19*). Figure 1 shows wind-distorted sodium trails extending from an altitude of 100 km to about 200 km. Methods for computing wind velocities from such photographs have been described by Manring (*19*).

The natural phenomena known as noctilucent clouds, which occur at heights of about 80 km and apparently consist of volcanic or meteoric dust, offer some opportunities for making qualitative estimates of air turbulence and vertical stability. Ludlam (*20*) states that theodolite tracking of a noctilucent cloud element to get its velocity is difficult because these clouds usually lack elements which are well defined and which retain their identity. Rapid changes in the clouds and the presence of billows suggest a steep lapse rate and considerable stirring. Noctilucent clouds probably do not exist at latitudes less than 55 degrees, and so this source of information is limited geographically.

Ionospheric Studies

Studies of the ionosphere have provided information about the electron density and the temperature in the ionized layers; attempts have also been made to measure the size as well as the drift of the ionospheric irregularities. Radio noise should contain a component due to thermal radiation from the ionosphere, and this radiation, which is very weak, has been identified and measured (*21*); temperatures measured in this way range from 240° to 290°K. The rate of ion production at a given height is extremely sensitive to temperature changes, and so diurnal and seasonal height changes in ion-forming layers are found to correspond to diurnal and seasonal temperature changes (*22*). The daily and annual variations in F layer ionization (at about 180 km) suggest that the gradient of the temperature inversion in that layer is less in summer than in winter, and also that the warm layer is thicker in summer than in winter (*23*). Studies of the E and F_2 layers, with ionization ascribed to atomic oxygen, give temperatures of 190° to 220°K at about 110 km and 500° to 1200°K at about 250 km (*24*). The wide range is partly seasonal and partly related to solar activity, with the highest temperatures occurring in a summer of great solar activity.

Observation of radio echoes reflected from the moon shows slow variations in the mean daytime amplitude of the echoes. The plane of polarization of the radio waves is rotated due to the presence of the earth's magnetic field, and the extent of rotation depends upon the total electron content along the line of sight to the moon. J. V. Evans (*25*) explains that a technique has been developed for the deduction of the amount of rotation and thus for the determination of the total electron content.

Scintillations of radio stars have been shown to be caused by phase changes

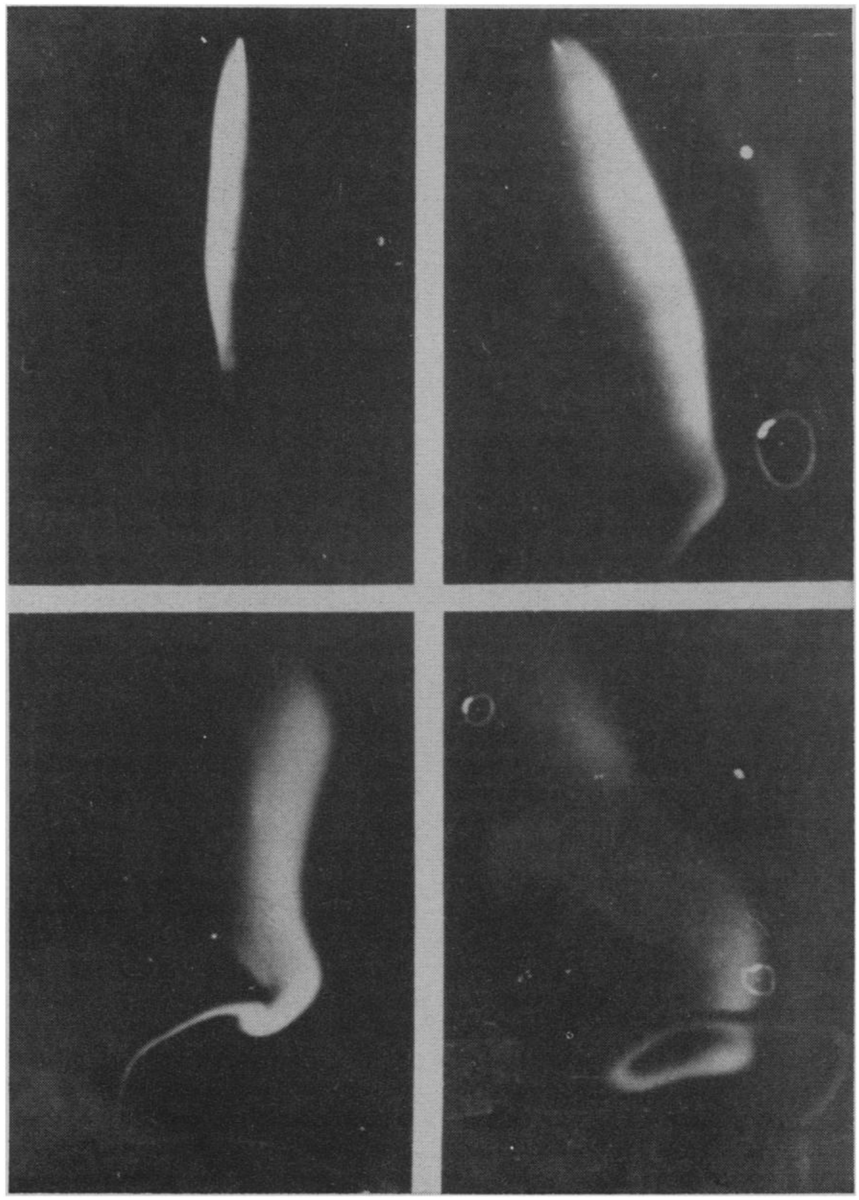

Fig. 1. Two sets of simultaneous photographs of a morning-twilight sodium trail, New Mexico, 26 November 1957. The upper pair, showing the trail over an altitude range from about 110 to 200 km, were taken when the rocket was near the zenith; the lower pair were taken about 5 minutes later. The left-hand pictures were made at Socorro, 211 km north-northeast of Deming, where the right-hand pictures were taken. [Courtesy Air Force Cambridge Research Center]

in the incoming radiation as it traverses irregularities in the electron density of the F region. The motion of ionization in the F region is probably related to turbulence and eddies in the dynamo region (135 to 150 km) through interaction between the earth's magnetic field and the electric field (*26*).

Vestine (*27*) has shown that, since geomagnetic disturbances can be represented by atmospheric electric-current systems and, in turn, the current systems can be replaced by equivalent atmospheric wind systems, it may be possible to deduce air motion in the E and F layers (100 to 300 km) from geomagnetic data.

Benyon and Goodwin (*28*) note that at about 100 km there is a high correlation between the magnitude of the drift velocity of ionospheric irregularities and the horizontal temperature gradient. This suggests that the study of the vertical structure of ionospheric drift may provide important information about the temperature of this part of the atmosphere.

Density beyond 300 Kilometers

Recent spectrographic and radio studies of the solar corona seem to support the idea that the atmosphere of the sun extends to and beyond the earth. According to Chapman (*29*) the earth and its atmosphere are immersed in this solar gas and must act as a sink of heat. Nicolet (*30*) suggests a figure for the heat conducted by atomic hydrogen from the corona to atomic oxygen in the earth's atmosphere of about 36 ergs per square centimeter per minute (as compared with the "solar constant" of about 8.4×10^7 erg/cm^2 min). Chapman's argument finds support in the comparatively large densities discovered from tracking artificial satellites and also from studying radio whistlers. Whistlers apparently are caused by thunderstorm electrical discharge (sferics) with an energy spectrum peaking in the 10- to 20-kilocycle-per-second range. The sferics travel through the ionosphere and on to altitudes of 500 to 5000 km or more, following the lines of flux of the earth's magnetic field out and then back to the opposite hemisphere. For this to occur, the average electron density of the atmosphere must be considerably greater than any previous estimates, about 400 electrons per cubic centimeter (*31*). Studies of the extension of the solar corona can be made by observing how radio waves from the radio star Taurus vary in intensity as they travel the outer corona (*32*). Since anomalies in the solar gas cloud appear to be related to changes in the earth's magnetic field, it may be possible to learn more about these anomalies by means of induced currents in transoceanic cables (*1*).

The flow of atomic hydrogen into the outer atmosphere means that the outer atmosphere must be more dense than has been thought. It is interesting to note that one piece of indirect evidence led for a time to contrary conclusions. From studies of the absorption of solar x-rays and the dissociation of oxygen up to about 165 km, some observers, by extrapolating the derived density distribution, calculated an upper atmosphere of considerably smaller density (*33*). This view was bolstered for a time by the idea (reminiscent of the early arguments about the stratosphere) that the high atmosphere should be isothermal and in radiational equilibrium. Chapman and Nicolet have countered such arguments, and the weight of evidence is for the more dense upper atmosphere above 300 km, with the temperature, as represented by the kinetic energy of the molecules, increasing with height. Here we have a case of different indirect evidence giving far different ideas about the density of the upper atmosphere. On the one hand the arguments for thermal equilibrium called for a low-density, isothermal upper atmosphere, while the observations of whistlers called for a contrary conclusion. Finally, a third indirect method, by visual, photographic, and radio tracking of the artificial satellites, provided evidence in support of the denser atmosphere. Sterne (*34*) gives a simplified formula for inferring air density at perigee from visual observations of artificial satellites. Calculations based on observations of sputnik I and reported by Harris (*35*) give an atmosphere at 400 km which is 40 times as dense as the ARDC (Air Research and Development Command) model atmosphere at that level. Later data, reviewed by Kallman (*36*), are in substantial agreement with Harris' conclusions.

A device constructed but not yet used for determining high-altitude density is the satellite balloon, a 12-foot, spherical plastic, aluminum-covered balloon carried aloft in collapsed state by an Explorer satellite. When the satellite is in orbit, the balloon is released and inflated by a bottle of gas. It then will orbit like the satellite, but air drag will act to slow the balloon more rapidly than it slows the satellite. A study of the positions of the satellite and balloon should give more information about the density of the outer atmosphere. The balloon would be large enough to be visible by eye from the earth's surface during twilight hours (*37*).

Studies of the emission spectrum of the aurora and night airglow provide information about constituents of the outer atmosphere. The aurorae are most frequent at heights of 100 to 120 km, but they are observed from 63 to 400 km. Sunlit aurorae may occur as high as 1100 km (*38*, p. 422). Atomic oxygen, nitrogen, and hydrogen, the oxygen and nitrogen ions, O_2^+ and N_2^+, and molecular oxygen and nitrogen have all been observed in aurorae. Seaton (*39*) has estimated the N_2/O ratio for heights between 160 and 400 km. He also gives an N_2^+ density above 740 km as greater than 120 ions per cubic centimeter. The night airglow emission is known to originate at heights from 70 km (OH) to 1000 km (oxygen) (*38*, p. 533). Its spectrum, which shows atomic oxygen and sodium, the N_2^+ ion, molecular oxygen and nitrogen, and the OH radical, runs from the violet well into the infrared (10 μ). At one time it was thought that the infrared emission was caused by the recombination of atomic nitrogen, but this emission is now attributed to vibration-rotation bands of hydroxyl (*40*). Phillips (*41*) has observed the width of the oxygen emission line 5577 A in the airglow and the line 6300 A in the twilight flash. These line widths indicate temperatures between 155° and 231°K at 100 km for the former and a temperature of about 750°K for the latter at about 220 km. Studies of the translation and rotation of airglow cells (5577 A emission) have convinced personnel at the University of Colorado High Altitude Observatory that these motions represent true winds at 100 km (*42*).

Conclusions

From this brief survey of some methods available for upper atmosphere research, it appears that there are many tools of widely varied complexity which can be used for such work. Most of these need further research and development. It would seem wise to use the most promising of the indirect measurement techniques near rocket-launching areas and to make the measurements synoptic with rocket studies. It is also important that measurements of the outer ionosphere be matched with satellite data. It is not unlikely that, once certain relations are verified, ground-based observations will be capable of providing hour-by-hour and day-by-day information about the upper atmosphere which would be much too costly to obtain routinely with rockets. Furthermore, some of the indirect methods will permit routine measurements from regions too close to the earth for observations with long-lived satellites.

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Science in the News

Khrushchev Sees Aspects of American Science and Talks About Soviet Achievements

Soviet Premier Nikita S. Khrushchev's trip to the United States closed further the narrowing gap between science and politics. In his statement on arrival, the Premier made the first of many scientific references when he spoke of the Soviet moon rocket and of his country's newly launched atomic icebreaker. Of the moon rocket, he said:

"Shortly before our meeting, Mr. President, the Soviet scientists, engineers, technicians and workers filled our hearts with joy by launching the rocket to the moon. . . . A container . . . with a pennant bearing the national emblem of the Soviet Union is now on the moon. . . . We entertain no doubt that the splendid scientists, engineers and workers of the United States of America who are engaged in the field of conquering the cosmos will also carry their pennant over to the moon. The Soviet pennant, as an old resident of the moon, will welcome your pennant, and they will live there together in peace and friendship as we both should live together on the earth. . . ."

The atomic icebreaker that was mentioned is the 16,000-ton *Lenin,* which started its maiden voyage on 15 September, the day that Mr. Khrushchev arrived in the United States for his 12-day stay. The ship, which can carry enough fuel to cruise for several years, is designed to keep open the 11,000-mile arctic sea route between Murmansk and Vladivostok—a route at present open about 10 weeks each year.

Disarmament Plan Offered

Disarmament, including a nuclear-test agreement and cooperation in the peaceful use of atomic energy and outer space, was a persistent theme in virtually all of the Soviet Premier's speeches. He set the stage for his total disarmament proposal to the United Nations when he addressed the National Press Club in Washington on the second day of his visit. He said:

"The best, the most reliable way to make war impossible would be to place all states, without exception, in conditions where they would have no means of conducting war. . . .

"The Soviet Union and the United States are faced with this alternative: Either the latest achievements of scientific and technical thought—the discovery of the secret of the atom, the development of rockets and the penetration of outer space—will be placed