Solar-Terrestrial Relationships: Weather and Communications

By Walter Orr Roberts

Relatively few of the many branches of astronomy can be said to have applications of direct practical importance. The field of solar-terrestrial relationships is an exception. Two decades of practice have shown the radio operator that solar variations can make the difference between success and failure in getting a message through. Today, we may look for improvements in practical weather forecasting because of new discoveries made on the common border between meteorology and astronomy. Just how far away these advances are will depend, at least in part, on the magnitude and the quality of the effort made in this field.

The effects of the sun on radio communications are well known, even if poorly understood. The influence of solar activity on weather is less apparent, and the reality and nature of the effects are still somewhat controversial. Enough clues exist, however, to convince a substantial group of research workers that changes in the sun’s shortwave emanations and in its corpuscular radiation are reflected in worldwide weather patterns, and that practical gains in both long- and short-term rainfall forecasting and temperature forecasting for large areas of the earth can be expected when these connections are better understood. The fact that the sun exhibits rather stable long-term trends improves the prospects for season-in-advance weather forecasts based on variations in solar activity.

The sun’s effects on weather obviously must be on a large scale. Several factors in the so-called “general circulation” of the earth’s atmosphere give evidence of such solar influences. The results of these large-scale changes, in terms of surface rainfall and temperature, depend very much on local elements such as topography and latitude; a worldwide circulation change that produces rain at one spot may produce drought in another. The ties of sun to local weather are therefore most complex.

The mechanism responsible for responses of weather to solar activity clearly does not involve substantial changes of the sun’s total energy; rather, it involves changes in selected spectral ranges where only a relatively small portion of the sun’s total energy output is concentrated. It is also clear that the most pronounced weather responses are likely to be found at the upper levels of the earth’s atmosphere, where the sun’s variable energy is principally absorbed. However, meteorological observations at such levels are still rather sporadic. Improvements in all types of weather forecasting are likely to come from research on the nature and causes of persistence and sudden changes in the dynamics of the general circulation of the atmosphere. The motions of the upper levels and the possible nature of the mechanisms that start disruptions in the patterns of momentum and mass transport in the earth’s atmosphere require particular attention. Dynamic meteorology is still in its infancy, but the solar astrophysicist has much to contribute. Ten years ago there seemed no real prospect that major advances in long-term weather forecasting would result from solar observations; today they promise advances of in-calcubably vast practical significance.

Without much exaggeration it can be stated that modern solar-terrestrial research began when R. C. Carrington of the Royal Observatory in England made his classic observation of a great solar flare visible in integrated light at

1 High Altitude Observatory, Boulder, Colo.
11 a.m. on September 1, 1859. At the instant of the flare, a fluctuation occurred in the strength of the earth's magnetic field. On the 2 days following, a violent magnetic storm was recorded by magnetometers at the Kew Observatory. Balfour Stewart, the director at Kew, concluded that the terrestrial magnetic disturbances were related to the flare; however, the idea was so unbelievable that most research workers dismissed the sequence of events as a coincidence.

The connection between flares and magnetic storms is now amply demonstrated, although the problem remains of explaining just how a solar flare produces these effects and the even more spectacular phenomena in the aurora and ionosphere. In the years since Carrington's great flare, a whole new science has developed to solve the problems common to solar physics and to terrestrial atmospheric physics.

Both sides of this joint attack have greatly enriched our observational knowledge. The spectroheliograph, the coronagraph, and the solar radio telescope have been the astronomical milestones. Geophysically, the night sky spectrophotometers and ionospheric sounding devices have competed in importance with earth-based, airborne, and rocket-borne cosmic-ray counters, with photometers, and with magnetometers operated with ever-increasing regularity from an ever-increasing diversity of stations. Great advances, particularly in meteorology, have come from the simple fact that we now can prepare daily or twice daily hemisphere-wide charts of airflow and temperature distribution at a wide range of altitudes from which large-scale dynamical studies can be made.

In every facet of terrestrial atmospheric physics, tantalizing connections between sun and earth have been found. But many pieces of the jigsaw puzzle remain to be put in place. Advances of great importance in ionospheric radio communications and in meteorology will undoubtedly appear when we have a satisfactory theoretical explanation that fits together the many known solar-terrestrial relationships.

A specific example may help to illustrate the expected course of progress. We now know that world weather patterns sometimes respond in a rather clear-cut way to changes in the character and level of solar activity as measured, for instance, by the average intensity of the emission of the sun's green coronal line. Although our understanding of the solar physics of the situation is very imperfect, we infer that the observed large changes in the coronal emission probably signify large changes in the total ultraviolet or X-ray emission of the sun. Nonetheless, the total changes of energy of the sun's emission must be very small, probably measured in thousandths or millionths of the solar constant. Not only do the world weather changes require vastly greater energy than the sun's variations can supply but terrestrial physics suggests that the level at which the X-ray or ultraviolet energy is absorbed must be so high that it is difficult to imagine that it could exert a significant influence all the way down into the weather sphere, far below. Yet the problem stands, a challenge and a mystery. No one can doubt that real progress in forecasting will come when we have a satisfactory physical explanation of the link, whether it be a trigger mechanism for amplifying infinitesimal solar changes or some yet unknown cause.

The multitude of phenomena of the ionosphere and the many variations of the effects with latitude and longitude are equally enigmatic problems. Few astronomers or geophysicists today doubt that the earth is subject to highly irregular and unpredictable "showers" of solar corpuscles, or that these corpuscles control important effects in aurorae, the ionosphere, and earth magnetism. Yet, in spite of the brilliant victories of the Chapman-Ferraro theory of such effects, we know that the theory is only a crude beginning, and that it is grossly inadequate to account for major phenomena that are well observed. We particularly need new research to improve our predictions for communications in polar latitudes.

Many simple, but major, questions of solar-terrestrial relationships are yet unanswered. For example, do cosmic rays come from the sun? A few short years ago it was hard to find a working cosmic-ray physicist who would admit that the sun as much as gently modulated the cosmic rays that were believed to come in all directions from outer space. Astronomers generally assumed, without any serious doubts, that per-
haps well over half of the energy of the universe was bound up in these mysterious high-speed particle emissions. Now the view prevails that a major part of the low-energy cosmic rays come from, or are at least strongly controlled by, the sun; and how many of the more energetic cosmic rays also come from nearby, rather than from the farthest reaches of space, is an open question.

The observational-theoretical picture of solar activity needs integration. The vast complex of sunspots, solar magnetic fields, flares, plages, prominences, and the corona needs to be welded into a consistent and understandable unit. From such a unified picture of solar activity, and of the quiet sun as well, will come better understanding of the sun's radiational and corpuscular emissions, particularly those emissions stopped high in the earth's atmosphere. At the moment, it is hard to say whether the solar physicist or the rocket and satellite launchers will be first to specify the nature of the sun's variable emissions as seen from an altitude, let us say, of 250 kms. In any event, the advances in the decades immediately ahead will be spectacular, and the practical stakes in long- and short-range weather forecasting may well surpass the very important gains that can reliably be expected in the field of communications forecasting.