INDIAN STATISTICAL INSTITUTE

TWENTYFIFTH CONVOCATION ADDRESS

Changing Concepts of Atmospheric Environment

Dr. A.P. MITRA, F.R.S.

Director General
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23rd February, 1991

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Mr. President, Mr. Chairman, Dr. Ghosh, Graduating Students, Distinguished Guests, Ladies & Gentlemen:

I consider it a great honour and privilege to deliver the Convocation Address today in an institution which over a period of time has acquired such a level of excellence in India and the world that any degree awarded by it is of great prestige. Those receiving degrees today could therefore consider themselves to belong to a distinguished community. The institute has in the past produced a number of world class statisticians. We in India feel proud of this record.

While going through the Convocation Addresses given in the recent past, I come across several comments that I, myself, would have liked to start with. The first is the comment made by Sir David Cox in his Convocation Address in 1988, which states: "Two key notions which in a sense have a certain duality are those of variability and uncertainty." Prof. C.R. Rao, in the last Convocation Address, talked about 'taming of uncertainty'.

Nowhere are these two more apparent than in atmospheric science. The climate of the earth-atmosphere system has sometimes been considered as the "statistical collective" of its weather conditions during a specified interval of time. This definition is rather vague and so it is difficult to construct a clear definition in mathematical terms. Also, as we will see, the atmosphere means different things to different people. To meteorologists it means a few kilometers of the earth. To an Ionospheric Scientist, it means the region between 60 and 1000 kms and beyond, where there is a sizeable population of ions and electrons guiding, modulating and controlling propagation of radiowaves from low to high frequencies. To a Plasma Scientist, it means the outer reaches of the atmospheric environment, dominated by plasma, or the so called plasmasphere at distances of several earth's radii, where the magnetic field is dominant. But in all these regions there is a multiplicity of variations: variations with the time of the day, variation from one day to another, variations with season and solar cycle, and variations dominated by turbulence and motions of different kinds. There are also random variations within a patch which could be several hundreds of kilometers in extent; this is sometimes called the "geophysical noise".

I have spent much of my life in the study of the Ionosphere and the use of radiowaves for remote sensing of these ionospheric regions. More recently, in the last ten years or so, my interest has shifted to the study of the regions below 60km, which include the stratosphere and the troposphere. These are the regions where human activities are believed to have the maximum effect. In our activities spanning over four decades in the study of these different regimes of the atmospheric environment, several major problems of statistical nature came up and frequently. These include the following:

(i) how to extract small signals out of much larger noise levels,

(ii) global modelling of ionospheric parameters or of neutrals based on a large body of not-always-coherent data,

(iii) imaging of targets by inversion technique from scattering in radio or optical ranges, and

(iv) testing for genuineness of apparent connections between different phenomena, such as sun and weather.

I would like to give you a few examples that we have encountered in the past.

Let us first take the case of detection of small signals from noise. One such case we ourselves were involved with, some forty years ago, concerns the detection of radio emission from Jupiter. This was in the early 50s when Alex Shain and I had just introduced the riometer technique, in which we received radio noise from the galaxy to study the top side of the Ionosphere then inaccessible to ground-based techniques. In the radio flux that we received there was also a small signal from Jupiter which was essentially identical with that from lightning discharges in nature and magnitude. Because these looked like radio atmospherics, and were sometimes superimposed on them, we, in our enthusiasm for introducing a new technique, missed them. Later when Jupiter emission was detected with a specially designed system, several scientists went back to the early records and found that a statistical analysis of the records using a predictable periodicity would have indicated the existence of such a signal, even though embedded in the larger atmospheric noise.

The second case, again an Indian experience, which I would like to mention, was a successful one. This was the detection of a much smaller effect of the X-ray star SCOXI on the nighttime ionosphere. Late Prof. K.R. Ramanathan and his group discovered this effect in 1969 from observations of low frequency radiowaves. Its genuineness, however, is still in question. The third case is of the highly controversial problem of detection of weak global change signals from atmospheric parameters. The primary data considered are temperature records from many stations over the globe over the last 100 years. The target here is to detect a trend - a global warming of half a degree has been concluded from analysis of these records, again from random noise of much larger magnitude. Take the case of temperature observations over India. IMD has analysed ninety years of data, since 1900, of all Indian stations and found that the annual means (or the 5-year running mean) over this entire period lie within $\pm 0^{-}$ (sigma) levels of variability ($\pm 0.25^{\circ}$C). The 5-year mean, however, shows a clear trend of increase within this range of about 0.3°C. We do not need to ignore this trend of increase just because it is smaller than the variability range. If the trend is real, how does one isolate from this total effect the contributions from the increasing concentrations of greenhouse molecules?

Some of the signals are directly identifiable, such as those from volcanic eruptions (discrete events) or from solar flux changes (11-year cycles), but dynamical perturbations or atmospheric loading are not so easy to separate. Or take the case of ozone depletion. Statistical examination of changes in ozone in individual stations or of cluster of stations did not clearly indicate any appreciable change, until the Antarctic ozone hole was discovered. Here again the problem is to separate the monotonically increasing effect of CFC from those of solar cycle and volcanic eruptions and matters get complicated because of the feedback and coupling between the various factors.

Take the second kind of problem: empirical modelling, modelling from a large database. Two important examples are preparation of Internal Reference Ionosphere and Reference Neutral Atmosphere. Both involve large quantity of highly variable data from different stations with different reliabilities. The first empirical ionospheric models, based on worldwide ionosonde network data, was introduced by CCIR (Comite Consultatif International des Radiocommunications) in a computer code as early as 1967 for telecommunication engineers. It was purely based on treatment of data without any physical input, except that a particular coordinate dependent interpolation system that was bound to geographic coordinates was used. Later URSI took up the matter of developing Reference Ionosphere by introducing newer variety of data, like those coming from satellites, and the attempt now was to derive height profiles by introducing a set of mathematical expressions, each valid in a certain height range. Again this was not based on any physical principles, but purely the question of curve-fitting. Even in the 1990 IRI, a new set of coefficients was derived for improved mapping. There was no attempt - nor was it possible at that stage - to link the treatment of data with physical principles.

In the case of the neutral atmosphere Reference models, the earlier International Models (CIRA 1961, 1965 or 1972) also proceeded essentially on the same lines i.e. use data as they exist and wherever they exist subject them to certain criteria of checking data reliability. In this case data came from rocket and balloon measurements and from measurements from satellite drag. Only later was there a combination of data with physical principles. The objective was to have simplicity in computer codes. Models based entirely on physical principles did not find much support.

The third type of problem is that of inversion technique. In radio science we often encounter the problem of building up "images" of targets, whether of aircraft or clouds or clear air turbulence from scattering by these targets of incident radio waves in different configurations. A key problem is the study of scattering signatures. The problems of remote sensing are similar - one attempts imaging of land forms, of forest types, of selected crop areas, of soil composition; or of cloud structures, rainstorm distributions, aerosol loading. Earlier the objective was only to detect; now we would like to know the nature and configuration of the object to be detected. Here the statistical treatment must rely very heavily on the choice of the tools - choice of frequency, whether more than one frequency is required, distribution of transmissions etc., or even where radio remote sensing is to be preferred to optical sensing.

The fourth type of problem concerns the genuineness of an interconnection between two important phenomena. One of the most widely studied and controversial problems is the sun-weather connection. In the 200 years of sun-weather studies, strong opinions have been expressed from statistical relationships both in favour and against. Historical weather data and climatic records derived from proxy indicators - tree rings, deep sea sediments, ice cores and other fossils remains - have shown major variabilities in the past epochs. But positive connection between the 11 year solar cycle and weather are difficult to establish. There are atleast three periods in the immediate past that have strong correlationship with solar activity. The Maunder Minimum in particular provides a major opportunity of serious statistical treatment to separate the solar signal from other phenomena such as volcanic eruptions or general variabilities. The sun-weather connection is a very good example where statisticians and atmospheric scientists should work together.

I have been using examples from the atmosphere in all that I have said so far. But I have really been referring to different parts of the atmospheric environment. One should perhaps at this stage indicate how the concepts of the atmospheric environment have changed over a period of several decades and how its boundaries have gradually expanded.

The book "Upper Atmosphere" by S.K. Mitra was a watershed in this sequence of changing concepts. Before publication of this book, even though Ionosphere had been discovered, the words "atmospheric science" or "atmosphere" only meant meteorology. It is interesting to note what Prof. M.N. Saha said at his INSA Presidential Address in 1939 when the Ionosphere not only had been discovered but also has been studied for more than a decade. He said, "it would probably be considered strange that in spite of the great accretion in our knowledge of physics, and in spite of the large number of qualified men employed in the study of meteorology, we should be forced to admit that success still eludes us. Probably one of the reasons is, as one great physicist once told the present writer, that meteorology has not yet engaged the attention of a Newton, or as I may add, of a Bohr or a Heisenberg. Another reason appears to me that the meteorologists for long have confined themselves to ground phenomena and neglected the upper regions."

The Ionosphere was discovered in 1926. But for a long time this was taken to be a distinct and separate field - different from the atmosphere that the meteorologists understood or were prepared to accept until the publication of S.K. Mitra's book. In this, for the first time, he brought in the total concept of atmospheric environment merging the upper atmosphere with the rest of the atmospheric regions. A very remarkable feature of this book was the inference of high temperature in the upper atmosphere. He discussed at length the various indirect methods of estimating temperatures in the upper atmosphere: from considerations of escape of helium, observations of auroral streamers at heights of a thousand kilometers, twilight flash of the red oxygen lines traceable upto 1300 km, a number of ionospheric parameters such as electron collison frequency, scale heights etc. From the helium escape he concluded that at 600 to 800km the temperature should be of the order of 1000°K; from the observed twilight and auroral luminosity a temperature of 1100°K; from auroral scale heights around 2700°K and from electron considerations around 1500 to 2500°K. Although such values were necessarily gross, the main point was the deduction of high temperature in the upper atmosphere and the first approach of taking the lower, middle and upper atmosphere as one unified entity.

The next change in our concept of the atmospheric environment came with the International Geophysical Year. The discovery of the Van Allen Radiation Belt made another conceptual change of the limits of our atmospheric environment. With satellites continuously monitoring the inter-planetary space and its magnetic fields the earth was found to be immersed in a stream of charged particles flowing steadily outwards from the sun. This solar wind distorts the sun's magnetic field and pulls it out along the radial direction. The interaction of the solar wind with geomagnetic field produces a bow shock upstream in the wind from the obstruction presented by the geomagnetic field, distorts the earth's magnetic field in a comet-shaped region called the magnetosphere and stretches out the geomagnetic lines of force behind the earth to form an extended tail. In parts of these, charged particles can oscillate back and forth trapped by geomagnetic lines of force and particles from the solar wind can enter these trapping regions in ways not then fully understood. The extent of the atmosphere now extended to several earth radii.

These rapid upward expansion of the boundary of the atmospheric environment brought up also the question of national boundary in air or in other words the definition of air space. Should it be the level of flight of supersonic aircraft (which itself goes on changing with time), should it be the level of the tropopause (not a good example since it is variable, 8 km at midlatitudes and 16 km over the tropics); should it be the low temperature boundary around 85 km called the mesopause above which atmosphere changes very rapidly or should it be the level at which satellites begin to disintegrate (levels around 200 km). Or, stretching our vision still further, should it be the level at which the earth's magnetic field ceases to control the earth's environment i.e. the magnetopause. If we accept this last criterion, then we have to expand the national space boundary to several earth radii.

The second major change in the concept of atmospheric environment has been a reversal of the role of the major and minor species. The atmosphere upto about 90km consists mainly of molecular nitrogen and molecular oxygen. At higher levels, because of dissociation of molecular oxygen one gradually begins to have an increasing concentration of atomic oxygen. So the main atmosphere is one consisting principles of O, O_2, and N_2. These are the major species. But it became rapidly clear that a major role is being played by some species which are present in the atmosphere in very minute quantities - in quantities of a few parts per million to a few parts per billion. One such species is the water vapour which has been recognised as an important molecule by meteorologists for a long time. The second minor species that had attracted attention for several decades is ozone which is a photochemical product. However, the recognition of possible hazards arising from ozone depletion by human activities is a very recent one. The third species of this kind is nitric oxide. Its importance came to be recognised during the IGY when one found a preponderance of nitric oxide ions over much of the ionospheric regions. More recently, several other minor species have attracted our attention. These are greenhouse molecules such as carbon dioxide, methane, N_2O. These are also present in small quantities: CO_2 concentration is about 350ppmv, methane about 1.7ppmv, N_2O about 300pptv. Changes that we consider alarming are also very small - about 2 parts per million for CO_2, less than a part per billion for N_2O and 15 parts per billion for methane. All of these are very small in absolute sense but these are worrying us now.

These are worrying us because being such small quantities this can be altered so easily.

The third major change in our concept has been the recognition that these different regions of the atmosphere are coupled through exchange of mass and matter. And linking them together is the solar radiation - both electromagnetic radiation and particles.

Before ending, may I emphasise the critical role that statistics can play in an intelligent study of the global change. The target is to detect a signal of this change from observations of the last hundred years or so, - or in case of ozone-related phenomena - of the last two decades since CFCs came into the scene. There are different views on these changes; even on whether there have been really any changes. The trends that one attempts to detect is masked by larger natural variations, lack of stability of the instruments, little opportunity to check or adjust the instrument (as in the case of satellite measurements), different systematic errors when different techniques are employed. A global warming of half a degree has been the conclusion from a number of such analysis from groundbased temperature measurements and 2-3% for ozone content. Signals from Indian data are not clear - there is good scope for studies here. Also we should examine whether signals might exist in other areas - in the ocean temperature, for example, or sea level rise. Or even in the density of the upper atmosphere.

I hope I have not been too technical or too narrow in the examples I have given. I believe these are important examples. Some are pressing problems. It is necessary that you as statisticians join hands with other scientific groups to bring about a new insight into these problems. This, in India, can be particularly rewarding.

Let me again congratulate you on this very important day in your life.