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Meteorology in the Space Age — The Development and Use of Weather Satellites

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Mr Neal, Senior Meteorologist in the Bureau of Meteorology, began his address by referring to the current age of revolution as being reflected in meteorology by the advent of two important technological developments - the electronic computer and the weather satellite. A 1960 resolution of the General Assembly of the United Nations charged the World Meteorological Organization to use the new technology for the benefit of mankind by increasing our understanding of the atmosphere. This resolution led to the development of the concept of a World Weather Watch.

Only a little over a century has passed since the first weather maps were drawn on the basis of limited surface observations. The area from which observations were available gradually increased and exploration of the upper air evolved successively through mountain observations, balloons, kites, aeroplanes, and radiosondes. By the late 1940s, however, though measurements extended to the top 1 per cent of the atmosphere only about one-fifth of the surface of the globe was monitored and vast areas, notably the oceans, remained as a data void.

The space age in meteorology owes its origin to experimental test firing by the United States of captured German V2 rockets following the Second World War. Cameras were inbuilt into the rocket nose cone to check on flight attitude and the resulting film was found to show apparently useful meteorological information. In the *Bulletin of the American Meteorological Society* in 1949 Major D.L. Crowson of the United States Air Force suggested the meteorological use of such rocket flights and in 1951 the science fiction writer Arthur C. Clarke described a meteorological satellite system. With the advance of rocket techniques an unpublished feasibility study of satellite systems was made by the United States Air Force and in 1954 Dr Harry Wexler published his visionary picture of what might be seen by a satellite camera. Later the same year a TV picture of weather systems taken by a rocket over the continental United States aroused further interest. Following an unsuccessful attempt to have a satellite ready for the International Geophysical Year (1957-58) the first meteorological satellite, owing much to the developmental work of Professor V. Suomi of the University of Wisconsin, was launched on 1 April 1960. Some forty have followed this initial achievement.

Although noting the contributions of the USSR program the speaker confined his further description to the United States satellites, showing the successive growth of the National Aeronautical and Space Administration's (NASA) experimental TIROS (1960-1965), Nimbus (1964-) and ATS (1966-1967) series leading to the corresponding operational series of ESSA (1966-1969), ITOS/NOAA (1970-) and SMS/GOES (1974-).

Although experimenting with infrared sensing, the TIROS series concentrated on TV cloud photography, the satellites orbiting the earth in about 1.5 hours at an inclined orbit of 40° to 50° to the equator. Operational problems resulted from the fact that the satellites were space oriented so that the camera did not always point at the earth and the spacecraft passed over a given point on the earth's surface at different times each day. The data was read out to ground stations in the United States and used to produce diagrammatic 'Nephanalyses' showing type and extent of cloud. Much work was put into studies of cloud recognition using aircraft overflights at the time of satellite passage and further knowledge was gained by photography from manned Gemini spacecraft. Mr Neal showed a number of illustrations, in particular a Gemini view of the northwest coast of Australia where effects of sea breeze and coastal orientation were reflected in the cloud distribution. Such pictures suggested hope of considerable local forecast improvement.

In the operational ESSA series the satellites were put into polar orbit of approximately 2 hours for one earth revolution and were sun synchronous. Thus they passed the same point on the earth twice each day at approximately the same time (around 9 or 10 am and pm). On the daylight pass the pictures were transmitted (from the even numbered satellites) to inexpensive ground stations which were established around the world - the so-called Automatic Picture Transmission (APT) system. The odd numbered ESSA satellites stored and transmitted global TV coverage from the Advanced Vidicon Camera System (AVCS) to ground stations in the United States enabling production of global mosaics. Mr Neal noted the remarkable life of ESSA 8 launched in 1968 with a design life of six months but still functioning in March 1976 after over 33 000 orbits. A further development with the data was the use of the first experimental geostationary satellite, ATS1, as a communications link to transmit hemispheric mosaics from Washington to Melbourne.

The speaker then described some aspects of the interpretation of the TV imagery by reference to illustrations, e.g., the association of the shape and curvature of upper level and surface pressure systems with fields of satellite observed stratiform and convective cloud and the location of pressure centres and trough and ridge axes. In particular, a 3 day sequence showing the evolution of a cut-off low over inland Australia was described and the recently developed Dvorak T number classification of tropical cyclone evolution was displayed.

The limitations of the TV camera were removed by the advent of the radiometer equipped Nimbus and its operational counterpart, the NOAA series. These satellites view the earth by day and night not only in the visible range but also in several other bands of the electromagnetic spectrum, notably the thermal infrared and the microwave. Such observations produce numerical quantitative data and imagery which enables the study of the earth's radiation budget, the assessment of cloud top and sea surface temperature and the detection of precipitation and sea ice distributions. Most importantly the derivation of vertical profiles of temperature and relative humidity is now possible over the globe via the emission spectrum of the well mixed stable atmospheric constituent - carbon dioxide. The most recent of the series (Nimbus 6) enables extension of soundings into the stratosphere, includes in its program the study of sea state and soil moisture, and further acts as a communication station by receiving and retransmitting data from buoys and balloons. An example of night-time imagery in the Nimbus 6.7 micron water vapour absorption band over Australia was displayed. This indicated the poleward edge of the subtropical jet stream as a white ribbon in the imagery - a feature that could not be observed in the concurrent thermal infrared (11.5 micron) imagery. The use of the visible and infrared channels of the operational NOAA series was also discussed.

Mr Neal then described the most recent satellite development - the Synchronous Meteorological Satellite (SMS), which is geostationary about 36 000 km from the earth and views about one-third of the earth's surface. Its capability is to produce visible and infrared imagery each twenty minutes, thus enabling the tracking of cloud elements to derive low and high level wind vectors and to view the evolution of hurricanes and thunderstorms. Two such satellites now view the American sector. Movie loops covering periods of up to three days were shown indicating the development of 'instant occlusions' over the Atlantic, the evolution of hurricane Eloise in the Gulf of Mexico, and such features as rapidly moving high cloud associated with the jet stream and sea surface temperature discontinuities at the Gulf Stream border. The similarity of much of this imagery to that of the Wexler 'vision' was pointed out and the facility to enhance the imagery and view at varying resolutions as high as 1 km were described.

The speaker then outlined the plan for the Global Atmospheric Research Program (GARP) requiring five such satellites (two from the United States already in orbit and one each from Japan, USSR, and the European Space Research Organisation - ESRO). The Japanese satellite, due to be launched in mid-1977, would cover the western Pacific and continental Australia and enable three-hourly continuing observation in both the visible and infrared. At the latitudes of southern Australia the resolution would be 5.6 km in the visible and 9 km in the infrared.

In conclusion Mr Neal pointed out that such an observational system combined with the output of the polar orbiting very high resolution radiometer (VHRR) carried by the NOAA series (which is to be increased to a frequency of four times daily) now present the meteorologist with an extensive range of global data to enable an attempt at the goals of the Global Atmospheric Research Project.

Dr U. Radok enquired why Australia would be limited to three-hourly observations from the Japanese satellite. In reply Mr Neal stated that it was thought that some facility would exist for more frequent observations (probably hourly) in the case of a special need or particular situation. However, the Japanese system was generally more restricted by engineering design than the United States SMS and that this limited the observational frequency.

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