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65 years of meteor radar research at Adelaide

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Over 65 years of radar research using meteor radar at Adelaide University in Australia is very briefly reviewed.

1 Early days

Radio studies of meteors began at Adelaide in 1949, and like many radio and radar based research efforts of that era, grew out of wartime radar research. Lenard Huxley arrived at Adelaide University from the University of Birmingham in 1948 to take the Elder Chair of Physics, and began revitalizing the Department, and establishing a number of research areas (Crompton, 2007)[1]. He was supported in this by the new Vice Chancellor, A.P. Rowe. Both Rowe and Huxley had been at the Telecommunications Research Establishment (TRE) during the Second World War. Rowe had been Chief Superintendent, and Huxley had established and headed the radar training school for both civilian and service personnel in the TRE. In another interesting connection to wartime research, Adelaide graduate Sir Mark Oliphant had drawn Huxley's attention to the advertisement for the position (Blake, 2010)[2].

One of the new research areas to be initiated in physics was radar meteor astronomy, and Huxley asked Graham Elford to pursue this topic. After the first measurements of upper atmosphere winds inferred by the drift of meteor trails were reported by Manning et al. (1950) at Stanford, the Adelaide effort was broadened out to include the study of the upper atmosphere. This became Graham Elford's main research area. In 1950, two Honors students, Des Liddy and Alan Weiss, joined the group, followed by PhD student David Robertson at the beginning in 1951. Robertson had previously worked with Oliphant at Birmingham, and brought considerable technical expertise to the group (Blake, 2010)[2].

Robertson was an amateur radio ham, and it was his personal 500W transmitter located at his home at Mount Lofty, together with receivers in Adelaide, Burra and Kulpara, that was used to make the first observations of meteor trails by the group in 1951. Subsequently, he developed the Adelaide meteor wind radar together with Elford and Liddy, the basic design concepts of which continued to be used at Adelaide until the mid-1970's, and which were also used later for the meteor radar at Atlanta by Bob Roper (Roper, 1984). This system operated at 27 MHz and used a 240 W continuous wave (CW) approach. Robertson submitted his PhD thesis on 'Reflection of radio waves from meteor trails, with applications to the measurement of upper atmosphere winds', in August 1953. Graham Elford followed late in 1954 with his thesis on the investigation of winds in the upper atmosphere. Robertson and Elford (1953) published the first

Figure 1 – the Upper Atmosphere Group 1962. Back row: R. Roper, J. Welsby, C. Nilsson, A. Bastian, B. Stone. Front row: Dr. E. Murray, Miss J. Allister, Miss M. Chapman, Dr. G. Elford.

observations of upper atmosphere winds using the meteor technique after those of Manning et al. (1950). In March 1955, this version of the Adelaide Meteor wind radar was decommissioned.

Beginning in early 1954, with funding from the Australian Antarctic Division, effort was directed to the development of a new radar to measure upper atmosphere winds in the Antarctic. The new pulsed radar system for this work (see *Figure 2*) was developed by Eric Murray. In December 1956, Carl Nilsson, a very recent BSc graduate, took the equipment to Mawson Base and operated it there during the International Geophysical year. Murray analyzed the data for his PhD thesis.

The work on meteor astronomy continued along with the upper atmosphere winds work. Nilsson later completed a PhD on meteor orbits which used some of the Mawson radar data. With support in the form of radar equipment

[1] http://adb.anu.edu.au/biography/huxley-sir-leonard-george-holden-516/text22851
[2] https://physsci.adelaide.edu.au/about/physics/history/documents/physics-in-adelaide-the-1950s.pdf

provided by Sir Bernard Lovell at the University of Manchester, Alan Weiss set up an independent radar system to study meteor showers. This work formed part of his PhD thesis, which he submitted in May 1954. He published his work on the distribution of the orbits of sporadic meteors in Weiss (1957).

2 New field sites

St Kilda

The Mawson meteor radar was very difficult to maintain, and it was decommissioned in 1959. Effort had shifted to

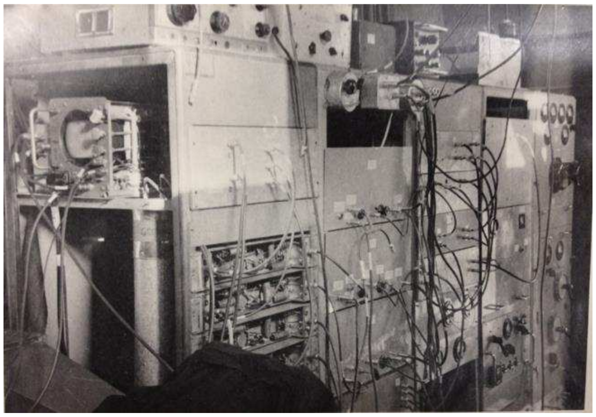

Figure 2 – The Mawson meteor radar. The first upper atmosphere wind measurements on the Antarctic Continent were made using this equipment.

the development of a new dedicated field site at St Kilda, north of Adelaide, and a new radar, with the transmitter located in Adelaide, and the main receiving station at St Kilda was completed in 1958. The arrangement is shown in *Figure 3*, and one of the remote receiving sites is shown in *Figure 5*. The Upper Atmosphere Group in 1962 is shown in *Figure 1*.

Highlights of the work produced using this radar included the determination of meteor orbits, measurements of 'turbulence' intensity, and long term measurements of upper atmosphere winds. Nilsson's work (Nilsson, 1964) resulted in the first set of measurements of meteor orbits in the southern hemisphere (2200 in total). Most orbits were found to lie close to the plane of the ecliptic. Bob Roper was the first person to measure upper atmosphere variability at small scales (< 2 km). His measurements were interpreted as being related to the turbulent dissipation rate at 93 km, but are more likely due to small scale wave motions rather than actual turbulence. Nevertheless, they were a valuable contribution to better understanding the dynamics of this region. Interferometric measurements of the mean wind field (see *Figure 4* and *Figure 6*) continued using this radar until the mid-1970's, although it was run in campaign mode after 1972. Work at the St Kilda field site ceased in the mid-1970's and was relocated to the nearby Buckland Park field site.

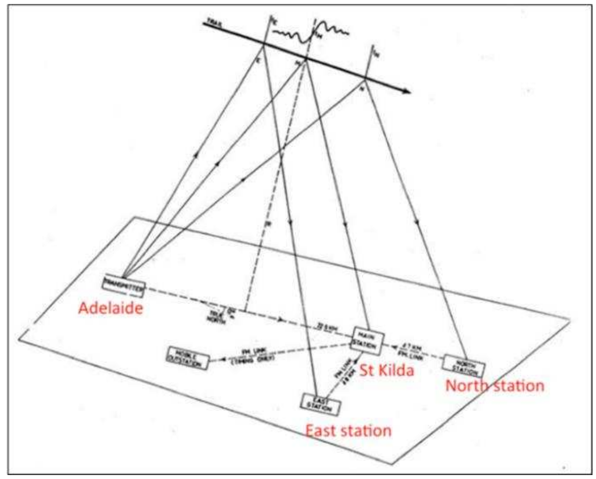

Figure 3 – The multi-station system in 1958. The receiving main site at St Kilda had two supplementary receiving sites about 5 km East and North and the data were sent to the main station via FM links.

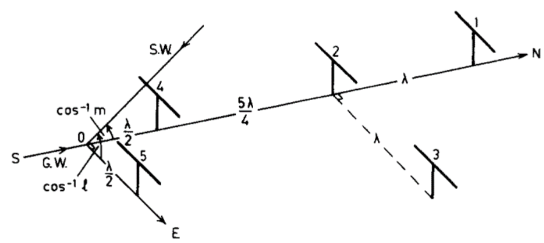

Figure 4 – The interferometer used for wind measurements at the St Kilda field site. Each antenna was a half-wave dipole and the direction cosines of the sky wave were deduced from the relative phases on the five antennas.

Buckland Park

Basil Briggs joined the Department in 1962. He had been a Junior Scientific Officer at the TRE between 1942 and 1946 before joining the Radio Research Group at the Cavendish Laboratory, Cambridge, where he worked from 1946 to 1961. Together with Graham Elford, he developed the large MF/HF radar array at Buckland Park (Briggs et al., 1969). This versatile array was used for investigations of the ionosphere, the neutral atmosphere and of meteors observed at both 2 and 6 MHz. Examples of the latter work include observations of 2 MHz meteor echoes (Brown, 1976), their height distribution (Olssen-Steel and Elford, 1987), and the measurements of winds using 2 MHz meteor trails (Tsutsumi et al., 1999).

3 Decline and rebirth of meteor wind radars

Figure 5 – Bob Roper and Carl Nilsson with receiving equipment at one of the St Kilda remote receiving sites.

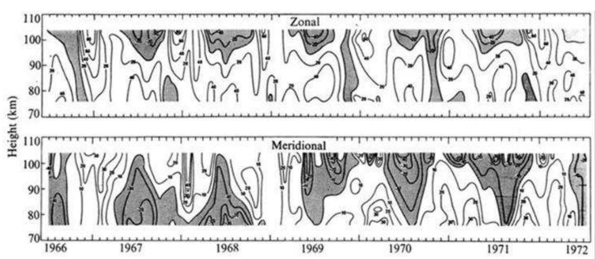

Figure 6 – Six years of upper atmosphere winds measured using the St Kilda radar.

Decline of meteor wind radars

The closure of the St Kilda site and the dedicated meteor radar in the mid-1970's was typical of a general decline of radar meteor upper atmosphere wind research around the world, and the measurement of upper atmosphere winds became more common by using partial reflection radars (see e.g., Reid, 2015). But some new meteor radars were developed in this period. For example, in the early 1970's, the Soviet VETA radars were developed by the Kharkov Institute of Radio Electronics. These formed the basis of an extensive network, albeit one with no height information. This is briefly discussed by Roper (1984). A new meteor radar was also developed in Kyoto by Aso et al. (1979), but generally the technique fell from favor until the late 1990's.

Rebirth of meteor wind radars

Increased interest in using meteor trails for the measurements of upper atmosphere winds came following the advent of ST and MST radars. These powerful radars operating in the lower VHF band were designed to measure winds using the Doppler technique in the Stratosphere and Troposphere (ST), and for the most powerful radars, the Mesosphere (M) as well. By piggybacking a dedicated data acquisition system onto these pulsed radars, their narrow beams could be used for meteor studies. One such system, MEDAC, was developed at the University of Colorado (e.g., Valentic et al., 1996) and used with a number of ST radars.

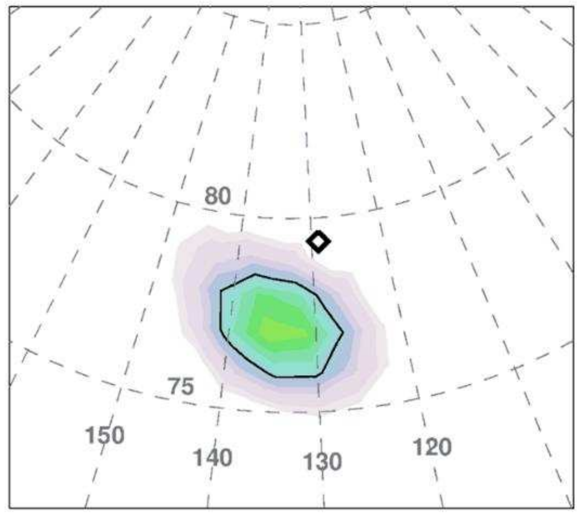

Figure 7 – The Camelopardalids 2014 Activity Map. The diamond is the pre-infall radiant, the solid contour is the full width half maximum (further details in Younger et al., 2015a).

One issue with this approach is that because most meteor trails occur low in the sky, most meteor trails are detected in the radar sidelobes, and without interferometry, their actual location is indeterminate. At Adelaide, the main beam of the radar was directed at 60° off–zenith, successfully avoiding this issue (e.g., Cervera and Reid, 1995).

A variation of this approach using an additional receiving only interferometer together with an MST radar was pioneered on the MU MST radar in Japan (e.g., Tsutsumi et al., 1994). This was followed by the development of a new class of dedicated all-sky meteor radars using an interferometric approach and producing real-time winds in the late early 1990's (e.g., Holdsworth et al., 2004). This development was made possible by the ready availability of cheap powerful computers, and development of solid state transmitters and better data acquisition systems. These radars have now largely displaced the previously more common partial reflection radars used for measuring upper atmosphere winds.

4 Recent work

The 21st centrury has seen meteor radar become a standard tool for the routine measurement of upper atmospheric winds, with radars developed by ATRAD achieving detection rates in excess of 30000 meteors per day. Ongoing wind observations continue to provide deep insights into the structure and dynamics of the atmosphere and how the motions of air masses are coupled between the upper and lower atmosphere (Bossert et al., 2015). The ability to measure atmospheric conditions in the meteor region at higher temporal resolutions has facilitated the studies of mesospheric meteorology, exotic plasma behaviours, and detailed astronomical observations. A substantial breakthrough has been the implementation of the Fresnel transform technique, which provides high-accuracy meteoroid speeds, in addition to producing images of radar reflectivity along meteor trails (Elford, 2004; Holdsworth et al., 2007).

Astronomy has followed a similar path to atmospheric observations, as broad surveys of shower activity (Younger et al., 2009) have given way to detailed investigations of individual showers. Individual showers have enabled the performance of radar techniques to be tested with known populations, further refining established practices (Younger et al., 2012). The unprecedented detection of the Camelopardalids shower of 2014 (Younger et al., 2015b) was the first time that a new shower had been predicted prior to its first occurrence and demonstrated the ability of meteor radar data to be rapidly analysed in response to unusual events (see also Younger et al., 2016).

New fields of research have been opened, as old assumptions have given way to a better understanding of meteor trail plasma. Meteor radar echo durations have been found to be strongly affected by plasma neutralization at lower altitudes (Lee et al., 2013; Younger et al., 2014), which allows observation of the chemistry of the D-region of the ionosphere. Inconsistent temperature estimates can now be explained (Cervera and Reid, 2000; Holdsworth et al., 2006), and new methods of using meteor radar to measure atmospheric density have been developed (Younger et al., 2015a).

Moving forward, the future of meteor radar lies in the establishment of networks of radars to observe not just the conditions above a single site, but the motions of the atmosphere across large areas. Together with Chinese colleagues, the utility of small meteor radars to investigate non-specular echoes and some aspects of plasma irregularities has been explored (Li et al., 2013). Advances in radar sensitivity and echo interpretation are allowing meteor radars to also be used to study the lower portion of the ionosphere, including sporadic E layers. The use of remote receiving sites, such as those used in the St Kilda radar is being reinvestigated using GPS locking, and is a promising new development for the measurement of wind fields over large regions. Astronomical applications will also benefit, as complete coverage of the celestial sphere is achieved, with the observations of multiple sites being assimilated into large-scale virtual observatories.

5 Conclusion

We have very briefly reported on more than 65 years of meteor radar research at Adelaide University. A feature of the work has been observations both in Australia and Antarctica over that period, and of continuing innovation. The group is continuing to exploit the observations for measurements of temperature, density and scale heights in the upper atmosphere, and the use of remote GPS-locked receiving sites. The Adelaide all-sky meteor radars have been commercialized, and there are an increasing number of meteor radars in China.

Acknowledgments

We have relied in part on notes made and conversations with Graham Elford to form part of the background to this work. Graham is the authority and any errors are of course ours.

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