Polar mesosphere summer echoes (PMSE) at Halley (76°S, 27°W), Antarctica

Martin J. Jarvis, Mark A. Clilverd, Mike C. Rose, and Shane Rodwell
British Antarctic Survey, Cambridge, UK

Received 20 October 2004; revised 18 January 2005; accepted 25 February 2005; published 31 March 2005.

[1] Polar Mesosphere Summer Echoes (PMSE) are a pointer to summer mesospheric conditions and have fuelled the debate over temperature differences between the Antarctic and Arctic mesopause regions. However few PMSE observations have ever been made in Antarctica. We present initial PMSE observations from Halley (76°S, 27°W), taken during January and February 2004. These are the first observations at such high southern latitude, the first using a dynasonde for detection, and the first at 28 MHz. PMSE are frequently observed and exhibit a double maximum in diurnal occurrence in contrast to published observations at similar Arctic latitudes. The PMSE season ends slightly earlier, relative to summer solstice, than in the Arctic. The strength of the PMSE appear similar to PMSE observed in the northern hemisphere; this is consistent with published falling sphere measurements showing similar summer mesopause temperatures in January in the Antarctic as in July in the Arctic. **Citation:** Jarvis, M. J., M. A. Clilverd, M. C. Rose, and S. Rodwell (2005), Polar mesosphere summer echoes (PMSE) at Halley (76°S, 27°W), Antarctica, *Geophys. Res. Lett.*, *32*, L06816, doi:10.1029/2004GL021804.

1. Introduction

[2] Gravity wave forcing of middle atmosphere circulation causes summer to winter pole-to-pole circulation in the mesosphere. The associated upwelling at the summer pole causes adiabatic cooling of mesospheric air and the consequent formation of icy particles when the temperature falls low enough for supersaturation to occur [*Hervig et al.*, 2001]. These icy particles are visible to ground observers as noctilucent clouds (NLC) and to spacecraft instrumentation as polar mesospheric clouds (PMC). They can accrete other elements and the resulting aerosols accumulate charge that can reduce the diffusivity of free electrons to produce intense radar echoes, termed polar mesosphere summer echoes (PMSE), from near mesopause altitudes in ground-based radar [*Rapp and Lübken*, 2004]. These echoes have been observed at many radiowave frequencies from a few up to hundreds of MHz [e.g., *Cho and Röttger*, 1997].

[3] There is conflicting evidence about whether the Antarctic summer mesosphere is warmer than that in the Arctic. Comparisons of summer upwelling based on mesospheric wind variances at Davis (69°S), Antarctica, and Poker Flat (65°N) by *Dowdy et al.* [2001] suggest that adiabatic cooling rates are smaller by 25–50% in Antarctica. Models frequently put the Antarctic summer mesosphere several degrees warmer than the Arctic summer mesosphere [e.g., *Siskind et al.*, 2003]. Satellite data from the HRDI experiment showed the temperature at summer solstice at 64° latitude and 84 ± 1.5 km altitude to be 15 K warmer in Antarctica [*Huaman and Balsley*, 1999]. These warmer temperatures would be expected to influence the formation of mesospheric ice particles and reduce the strength of PMSE backscatter echoes.

[4] Conversely however, the first Antarctic rocket-launched falling sphere measurements of the mesospheric temperature profile [*Lübken et al.*, 1999] showed the mesopause temperature to be just as cold in January at 68°S as it is in July at 69°N. The temperature at 82 km (a standard reference height used for falling sphere observations [*Lübken et al.* [1996]) was, within the standard error, also the same in January/July but became several degrees warmer during February in Antarctica than during August in the Arctic.

[5] The first, unsuccessful, attempts to measure PMSE in Antarctica were made during 20 days of January and February 1993 at the Peruvian research station of Machu Picchu (62°S, 58°W) using a 50 MHz radar [*Balsley et al.*, 1993]. *Woodman et al.* [1999] published further results from Machu Picchu reporting PMSE recorded in January and early February 1994. The echoes were ~30 dB weaker than earlier data from Poker Flat in the Arctic (65°N), strengthening the belief that temperatures in the Antarctic might be warmer. However, while temperature is a primary factor in formation of PMSE, neutral air turbulence, water vapour content and free electrons also play their part [*Rapp et al.*, 2003] and so other interpretations are possible. Recently, *Morris et al.* [2004] have reported PMSE observed at Davis (69°S) showing similar backscatter echo characteristics and occurrence properties to those from the northern hemisphere.

[6] To understand the southern hemisphere PMSE results further evidence is needed from different sites. Here we present the first PMSE recorded at Halley (76°S, 27°W). This is the farthest South that PMSE have ever been recorded, it is the first time PMSE have been recorded at 28 MHz and it is the first time that a digital ionosonde has been configured to detect PMSE.

2. Halley PMSE Observations

[7] In early 2004, two 100 m square coaxial-colinear antenna systems were added to the NOAA HF radar (dynasonde) [*Grubb*, 1979] at Halley. The antennas operated close to the upper frequency limit of the dynasonde at 28 MHz, one transmitting and one receiving as described in detail by M. C. Rose et al. (PMSE detection using a dynasonde, submitted to *Radio Science*, 2004). The instrument parameters are given in Table 1.

0094-8276/05/2004GL021804

Table 1. Radar Parameters

Parameter	Value
Peak transmitter power	2 kW
Antenna array area	10,000 m^2
Half power pulse width	60 μs
Range gate	1.5 km
Pulse repetition frequency	100 s^{-1}
Incoherent averaging time	20 s
Receiver noise	10 dB

[8] PMSE soundings were first made on 20 January 2004 for two and a half hours for commissioning tests. Even within this short period the first PMSE echoes were observed; these were centred around 84 km, persisted for more than one hour and had a peak power of ~8 dB above the sky noise. From 24 January 2004 onwards the PMSE mode has been operated continuously for 11 minutes and 20 seconds in every 15 minutes. Interspersed with the PMSE operation are standard ionogram and imaging Doppler interferometer mesospheric wind soundings [*Jones et al.*, 1997], so that the dynasonde performs as a truly multipurpose instrument.

[9] Typical characteristics of the Halley PMSE are shown in Figure 1. This shows an 8-hour time series of the average echo return profile calculated for each 20-second period of raw data (i.e. each profile is the mean of 2,000 pulses). The horizontal banding is the range gating; the vertical white stripes indicate when the dynasonde was operating in other modes. The combination of the long duration of the dynasonde pulses (60 μs) and its wide range gate sampling (1.5 km) precludes examination of fine-scale vertical structure. However, the transmitted Gaussian pulse shape, and hence convolved onto the echo return, has been fitted through each vertical echo profile and the peak of this fitted pulse is marked in Figure 1 by a black diamond. The pulse fit shows extremely good consistency as demonstrated by the slow downward drift of the peak height across a single range gate over ninety minutes from 05 UT onwards. Prior to 05 UT there is evidence of wave structure; on some days wave periods of several tens of minutes with amplitudes of up to 2 km are observed. The data exhibit similar characteristics to those observed with more conventional PMSE radar. We estimate, from the radar equation and instrument parameters, that the maximum volume reflectivity of the data in Figure 1 to be $\sim 5 \times 10^{-14}$ m^{-1}. As the instrument is operating on 28 MHz this would be equivalent to a volume reflectivity of $\sim 1 \times 10^{-14}$ m^{-1} at 50 MHz for a Schmidt number of 100 [*Cho and Kelley*, 1993], and consistent with PMSE observed in the Arctic [*Rapp and Lübken*, 2004].

[10] The PMSE occurrence pattern is shown in Figure 2 by hour of day and day of year. For each 20-second average echo profile, the range-gate sample with the maximum power is selected. Each pixel represents the ninth decile power of these selected values over each 15-minute interval; the ninth decile ensures exclusion of occasional short-lived but very high power echoes from meteor trails. PMSE were detected on most days up until the middle of February when their occurrence rate diminished rapidly.

[11] To determine which Gaussian pulse fits from Figure 1 could be identified as PMSE, an empirical algorithm was derived which compared each fit to its temporal near neighbours to assess continuity and persistence. This algorithm processed the data in two stages. Firstly positive identification was made where an echo was no more than one range-gate height (i.e. 1.5 km) away from their next neighbour, and that criterion applied to a string of at least five samples. Further positive identifications were then made where at least three of a string of seven echoes had already been positively identified as PMSE, and the standard deviation in altitude for those seven echoes was less than 1.0 km. Amplitude was not used as a selection criterion in this algorithm but the outcome was that positive identification was clearly also related to amplitude.

[12] All the 20-second samples positively identified as PMSE from 20 January 2004 (start up) through to the end of February are accumulated in Figure 3 to show the diurnal occurrence pattern. Each pixel represents the sum of echo powers. Diurnal occurrence plots of number density or mean power (not shown here) appear very similar. There are two clear maxima centred around approximately 0600 and 1600 UT (or 0400 and 1400 local solar time). The peak

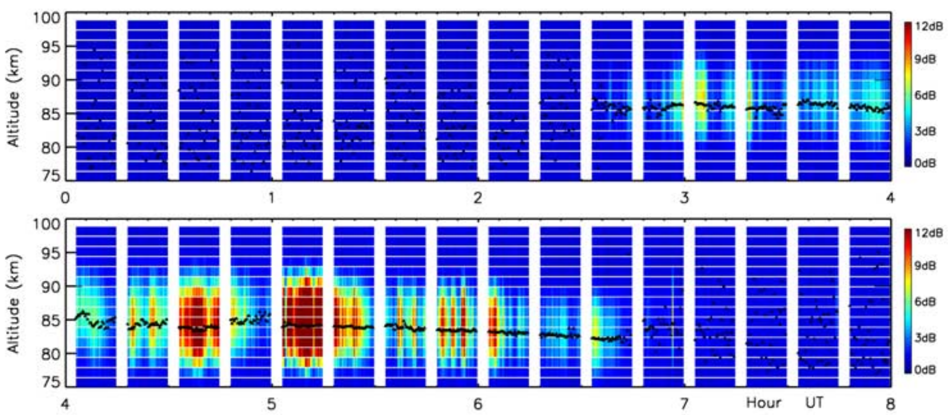

Figure 1. PMSE observed using the Halley dynasonde on 12 February 2004. Colour represents mean echo power over each 20-second interval (see text).

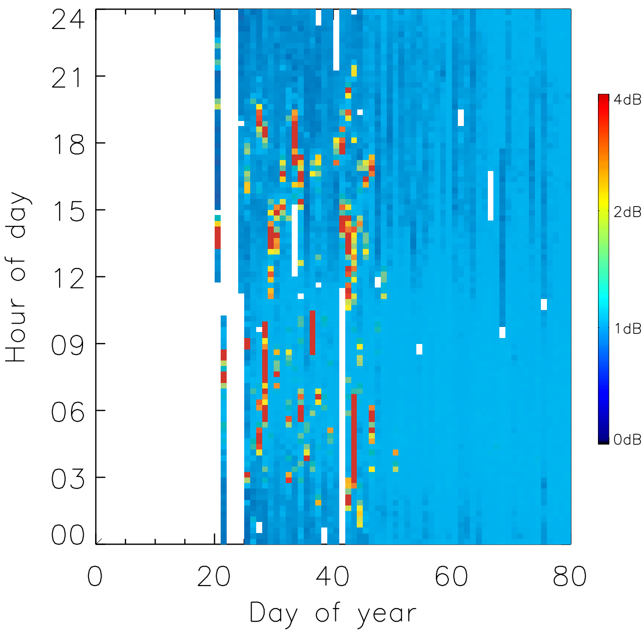

Figure 2. The PMSE occurrence pattern. Colour represents the upper decile power in each quarter-hour interval.

occurrence altitude is 85 ± 2 km as shown in the number density histogram of Figure 4.

3. Discussion

[13] Due to the constraints of equipment installation in the Antarctic environment this initial data only covers the later part of the summer, but there is no doubt, comparing Figures 1–4 with previously published PMSE data from other sites, that the Halley dynasonde is successfully detecting PMSE. There have been no PMSE observations at such high latitude in the Antarctic and the only comparable results in the Arctic are at Svalbard (78°N) and Resolute Bay (75°N). *Latteck et al.* [2000] showed the diurnal occurrence variation at Svalbard to have a single maximum between 8 and 11 UT (between 9 and 12 LT) compared to a double maximum at Andenes (69°N) peaking at approximately 6 UT (7 LT) and at 14 UT (15 LT). *Huaman et al.* [2001] showed high latitude PMSE from Resolute Bay (75°N) to similarly exhibit a single maximum peaking around 14 LT (20 UT), but Poker Flat (65°N) PMSE differed with observations at similar lower latitudes in the European longitude sector where semidiurnal variations were observed, exhibiting a single minimum at around 22 LT in an otherwise uniform occurrence. At Resolute Bay they found the PMSE behaviour markedly influenced by tides in the mesospheric wind field. The Halley PMSE show clear double maxima in marked contrast to the high latitude data from Resolute Bay and Svalbard at similar latitudes but in the northern hemisphere. These double maxima occur approximately 12 hours apart and are strongly suggestive of semidiurnal tidal action; the Halley dynasonde operating in imaging Doppler interferometer mode shows strong semidiurnal tides in the winds at 85 km altitude in summer.

[14] The peak PMSE occurrence altitude at Halley (85 km) is similar to that observed by northern hemisphere radars. The pulse fitting technique used to identify the altitude of each echo peak preferentially selects the lowest identifiable altitude peak and thus double peak structures frequently observed using higher resolution radar are not identified. However close visual inspection of the individual echo envelopes showed little evidence for double peak structure. This is in contrast to measurements by *Rüster et al.* [2001] who found double-peaked structures to be commonplace at 78°N. The almost identical peak altitude between Svalbard and Halley supports the similarity of the thermal structure in both hemispheres in January/July.

[15] Neither the *Huaman et al.* [2001] or *Latteck et al.* [2000] northern hemisphere data at similar latitude to Halley extend to the end of the PMSE season. However, *Lübken et al.* [2004] report on PMSE from Svalbard at the end of the 2001 summer; PMSE began to decrease in occurrence from mid August and disappeared by the end of August. At lower latitude (69°N), *Bremer et al.* [2003] found the mean value for the last day of six PMSE seasons at 54 MHz to be 28 August (equivalent to 27 February in the Antarctic). *Lübken et al.* [1999] showed that, in February, the southern hemisphere mesosphere begins to exhibit higher temperatures than the northern equivalent and thus we might expect an earlier end to the PMSE

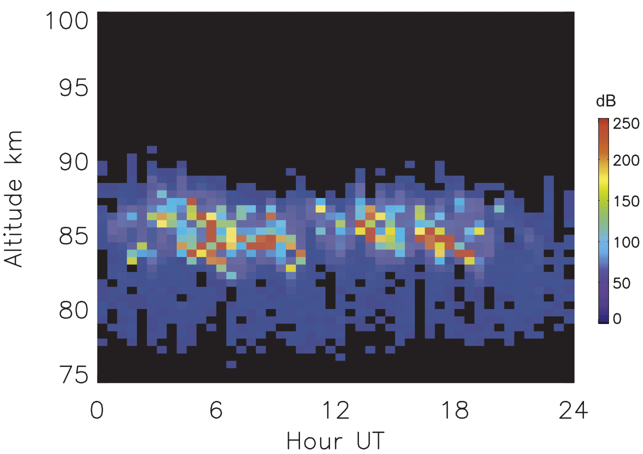

Figure 3. Diurnal occurrence pattern. Colour represents the accumulative power of identified PMSE in 30-minute time and 0.5 km altitude intervals.

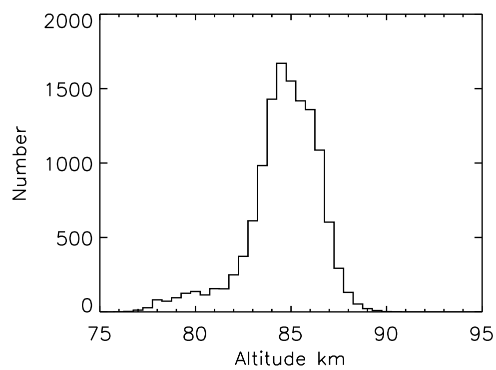

Figure 4. Height distribution of identified PMSE echoes.

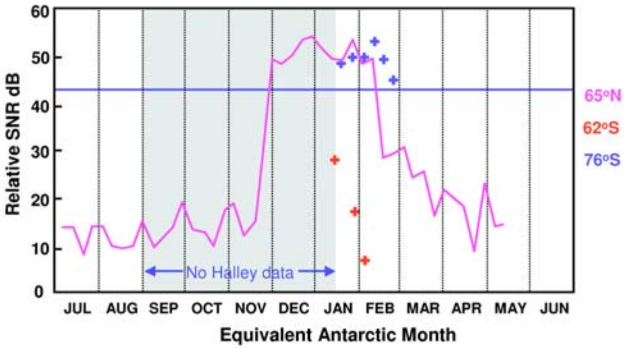

Figure 5. Comparison of the Halley PMSE signal to noise ratio (blue) with those previously published by *Woodman et al.* [1999, Figure 4] for 62°S (red) and 65°N (magenta). Baselines are adjusted to compensate for the different instrument configurations; the blue horizontal line represents the Halley 0 dB level.

season in Antarctica than in the Arctic. The last strong Halley PMSE were detected on 15 February 2004 followed by short-lived very weak PMSE on 17 and 19 February. Since then, through to winter solstice, there have been no instances of PMSE. Bearing in mind that the disappearance of PMSE echoes against the sky radio noise depends upon the upon the transmitted radar power at any particular site, the timing of the end of the Halley PMSE season probably occurs about a week before that reported in northern Europe at 78°N and 69°N latitude. The end of the PMSE season at Halley coincides almost simultaneously to that reported recently by *Morris et al.* [2004] from Davis (69°S), Antarctica.

[16] Power comparisons at different sites both between hemispheres and within the same hemisphere have produced confusing evidence. *Balsley et al.* [1993] found no PMSE at 62°S in 1993, but *Woodman et al.* [1999] found weak PMSE at the same site with the same instrument in 1994. *Woodman et al.* [1999] compared their southern hemisphere results with those from Poker Flat (65°N). Figure 5 compares that result with the Halley PMSE data. For this comparison, the Halley data have been processed in the same way as those of *Woodman et al.* [1999]. The mean echo power over each hour was first calculated and then the maximum and upper quartile of this mean value over each seven day period was derived. By including all data, regardless of whether PMSE had been identified or not, the result is a combined measure of echo power and of PMSE occurrence rate. Following the method of *Woodman et al.* [1999], the baseline for the Halley data has been shifted on the y-axis to account for the different instrument parameters. One advantage of using an upper quartile, rather than a mean, is that data below the level of the background sky noise can be included by number count even though the actual echo return level is unknown. The comparison suggests that the power of PMSE at Halley are almost identical to those at Poker Flat, contrary to Antarctic data from 62°S [*Woodman et al.*, 1999]. The effect of latitude on this comparison is open to question; northern hemisphere comparisons of PMSE with latitude [*Latteck et al.*, 2000; *Huaman et al.*, 2001; *Rapp and Lübken*, 2004] do not show any consistent variation with latitude.

[17] These preliminary results at 76°S are in agreement with the recent first observations at 69°S [*Morris et al.*, 2004] and together these tend to support the results of *Lübken et al.* [1999] who found Antarctic mesopause temperatures (68°S) to be just as cold in January as Arctic mesopause temperatures (69°N) in July. Further measurements are required from Antarctic sites at a range of latitudes. PMSE observations at Halley will continue through the full 2004–5 summer season for a more comprehensive comparison with northern hemisphere data.

[18] **Acknowledgment.** This research was funded by the U.K. Natural Environment Research Council.

References

Balsley, B. B., R. F. Woodman, M. Sarango, J. Urbina, R. Rodriguez, E. Ragaini, and J. Carey (1993), Southern hemisphere PMSE: Where are they?, *Geophys. Res. Lett.*, *20*, 1983–1985.

Bremer, J., P. Hoffmann, R. Latteck, and W. Singer (2003), Seasonal and long-term variations of PMSE from VHF radar observations at Andenes, Norway, *J. Geophys. Res.*, *108*(D8), 8438, doi:10.1029/2002JD002369.

Cho, J. Y. N., and M. C. Kelley (1993), Polar mesosphere summer radar echoes: Observations and current theories, *Rev. Geophys.*, *31*, 243–265.

Cho, J. Y. N., and J. Röttger (1997), An updated review of polar mesosphere summer echoes: Observation, theory, and their relationship to noctilucent clouds and subvisual aerosols, *J. Geophys. Res.*, *102*, 2001–2020.

Dowdy, A., R. A. Vincent, K. Igarashi, Y. Murayama, and D. J. Murphy (2001), A comparison of mean winds and gravity wave activity in the northern and southern polar MLT, *Geophys. Res. Lett.*, *28*, 1475–1478.

Grubb, R. N. (1979), The NOAA SEL HF radar system (ionospheric sounder), *NOAA Tech. Memo. ERL SEL-55*, Environ. Res. Lab., NOAA, Boulder, Colo.

Hervig, M. E., R. E. Thompson, M. McHugh, L. L. Gordley, J. M. Russell III, and M. E. Summers (2001), First confirmation that water ice is the primary component of mesospheric clouds, *Geophys. Res. Lett.*, *28*, 971–974.

Huaman, M. M., and B. B. Balsley (1999), Differences in near-mesopause summer winds, temperatures, and water vapor at northern and southern latitudes as possible causal factors for inter-hemispheric PMSE differences, *Geophys. Res. Lett*, *26*, 1529–1532.

Huaman, M. M., M. C. Kelley, W. F. Hocking, and R. F. Woodman (2001), Polar mesosphere summer echo studies at 51.5 MHz at Resolute Bay, Canada: Comparison with Poker Flat results, *Radio Sci.*, *36*, 1823–1837.

Jones, G. O. L., K. Charles, and M. J. Jarvis (1997), First mesospheric observations using an imaging Doppler interferometer adaptation of the dynasonde at Halley, Antarctica, *Radio Sci.*, *32*, 2109–2122.

Latteck, R., R. Rüster, W. Singer, J. Röttger, P. B. Chilson, and V. Barabash (2000), Comparison of polar mesosphere summer echoes observed with the ALWIN MST radar at 69°N, the SOUSY-Svalbard-radar at 78°N, and the ESRAD radar at 68°N in summer 1999, paper presented at Ninth International Workshop on Technical and Scientific Aspects of MST Radar, Sci. Comm. on Sol. Terr. Phys., Toulouse, France.

Lübken, F.-J., K. H. Fricke, and M. Langer (1996), Noctilucent clouds and the thermal structure near the Arctic mesopause in summer, *J. Geophys. Res.*, *101*, 9489–9508.

Lübken, F.-J., M. J. Jarvis, and G. O. L. Jones (1999), First in situ temperature measurements at the Antarctic summer mesopause, *Geophys. Res. Lett.*, *26*, 3581–3584.

Lübken, F., M. Zecha, J. Höffner, and J. Röttger (2004), Temperatures, polar mesosphere summer echoes, and noctilucent clouds over Spitsbergen (78°N), *J. Geophys. Res.*, *109*, D11203, doi:10.1029/2003JD004247.

Morris, R. J., D. J. Murphy, I. M. Reid, D. A. Holdsworth, and R. A. Vincent (2004), First polar mesosphere summer echoes observed at Davis, Antarctica (68.6°S), *Geophys. Res. Lett.*, *31*, L16111, doi:10.1029/2004GL020352.

Rapp, M., and F.-J. Lübken (2004), Polar mesosphere summer echoes (PMSE): Review of observations and current understanding, *Atmos. Chem. Phys.*, *4*, 2601–2633.

Rapp, M., F. Lübken, P. Hoffmann, R. Latteck, G. Baumgarten, and T. A. Blix (2003), PMSE dependence on aerosol charge number density and aerosol size, *J. Geophys. Res.*, *108*(D8), 8441, doi:10.1029/2002JD002650.

Rüster, R., J. Röttger, G. Schmidt, P. Czechowsky, and J. Klostermeyer (2001), Observations of mesospheric summer echoes at VHF in the polar cap region, *Geophys. Res. Lett.*, *28*, 1471–1474.

Siskind, D. E., S. D. Eckermann, J. P. McCormack, M. J. Alexander, and J. T. Bacmeister (2003), Hemispheric differences in the temperature of the summertime stratosphere and mesosphere, *J. Geophys. Res.*, *108*(D2), 4051, doi:10.1029/2002JD002095.

Woodman, R. F., B. B. Balsley, F. Aquino, L. Flores, E. Vazquez, M. Sarango, M. M. Huaman, and H. Soldi (1999), First observations of polar mesospheric summer echoes in Antarctica, *J. Geophys. Res.*, *104*, 22,577–22,590.

M. A. Clilverd, M. J. Jarvis, S. Rodwell, and M. C. Rose, British Antarctic Survey, Madingley Road, Cambridge CB3 0ET, UK. (m.jarvis@bas.ac.uk)