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Automatic weather stations in the Antarctic

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Between 1980 and 1982 a number of automatic weather stations was deployed in the Antarctic region by the Antarctic Division, Department of Science and Technology. Data from these platforms are processed via the ARGOS data collection and location system utilising satellites. Despite some initial problems, the stations have proved most successful with the longest running station having provided over 12 months data. This paper briefly describes the design and deployment of these observatories, compares data from AWS with that collected manually, and discusses the preliminary data received from the stations.

Introduction

Automatic weather observing stations (AWS) are an attractive proposition for increasing data coverage in the vast uninhabited regions of the Southern Ocean in general, and in Antarctic regions in particular. Automatic geophysical observatories have been used on the ice sheet previously by the Antarctic Division (Bird and Humphreys 1971) but these stations used on-site recording on magnetic tape whereas the weather stations described here utilise the (ARGOS) satellite data system. The present stations are principally designed for deployment on the ice sheet during glaciological traverses which regularly travel far inland, but they can also be used in other areas of interest. They have been built with a range of sensors, some at several levels. These, besides providing instrument redundancy, provide data useful for monitoring the surface energy exchanges peculiar to the ice sheet, and data necessary for modelling such phenomena as katabatic winds.

Description of AWS design and calibration

Three prototype AWS have been designed and built by the Antarctic Division, two for deployment on the Antarctic ice sheet and one for the sub-Antarctic Heard Island. The variables measured by the stations, the sensor types and their range and resolution are shown in Table 1.

The wind and air temperature sensors are mounted on a guyed mast (Fig. 1). The wind speed and direction are measured at a height of 4 m above the surface and the air temperature sensors are fitted with double mushroom shaped radiation shields which also allow natural ventilation. The surface temperature thermistor is buried in snow (initially at a depth of about 100 mm) near the base of the mast. A silicon solar cell array is mounted on the top of the mast, facing north at an inclination normal to the sun on the equinoxes. The output from this array is not presently used as a power source for the station but the integrated current output is recorded by the AWS to provide both a crude measure of incident solar radiation and as a test of the feasibility of incorporating solar charging in future stations.

The transmitter used is a Handar 621A which is ARGOS-TIROS-N compatible. The transmission frequency is 401.65 ± 1.2 kHz and the nominal power output is 3 watts. Data from the various sensors are relayed to a shift register and the contents of this register are circulated through the transmitter and transmitted every 200 seconds in 4 blocks of 32 binary bits. The contents of the shift register are updated every 16 transmissions; that is about every 53 minutes. The electronic components are all rated to at least -40°C and high reliability, lower power consumption integrated circuits are used throughout.

Fig. 1 **AWS during installation inland of Mawson. An anemometer, wind vane and temperature sensor are mounted 4 m above the surface with additional temperature sensors at 2 m and 1 m. The transmitter antenna (nearest the guy) and breather pipe for the batteries are downward from the mast.**

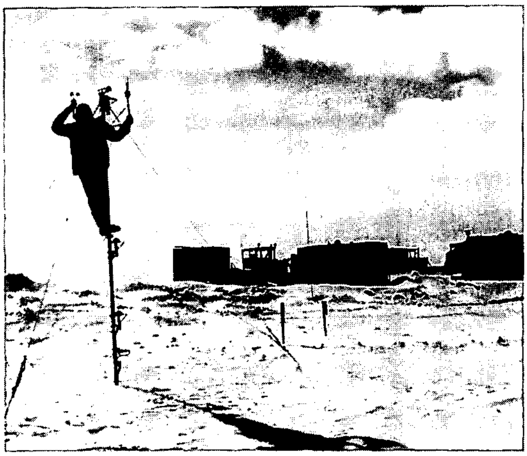


Table 1. Antarctic Division automatic weather stations.

A. Continental stations

Variable	Sensor	Resolution	Range
Air temperature at 4 m, 2m and 1m above surface	ITT F53D thermistors in integrating radiometric circuit	0.05 to 0.02°C	-60° to +10°C
Snow temperature	as above	as above	as above
Air pressure	'Solatron' NT 3082 vibrating cylinder	0.2 mb	660 to 860 mb or 860 to 1080 mb
Wind speed — average over the sampling period and peak speed in any 2 s interval during sample period	'Anderaa' 2593 cup anemometer	0.08 $m\ s^{-1}$ (average) 0.3 $m\cdot s^{-1}$ (peak)	0 to 60 $m\ s^{-1}$
Wind direction	'Anderaa' 2053 wind vane	1.5°	0° to 357°
Housekeeping sensors:			
Battery voltage	—	0.1 V	0 - 26 V
Internal temperature	AD590 Semi-conductor transducer	1.7°C	-60°C to 40°C
Solar cell output charge	Silicon solar cell array	0.06 Ah	15 Ah day^{-1}

B. Heard Island station
Similar to continental stations, excepting that there are temperature sensors only at 4 m and 1 m (no 2 m or surface temperature sensors) and the range of these sensors is +20°C to -20°C.

The total current consumption of the AWS is about 50 amp per year.

The transmitter, pressure transducer and electronics for the Antarctic AWS are in a box buried several metres below the snow surface. The antenna and small breather tube for the pressure transducer extend a metre above the snow surface (Fig. 1). Besides providing mechanical protection, burying the stations insulates them from short periods of severe cold. The transmitter box of the Heard Island AWS was placed on the surface near the mast.

The primary power source for the autostations is a bank of air-depolarised cells (22 V regulated to 13 V) of several hundred amp-hour capacity. The AWS deployed inland of Casey was provided with lead acid batteries as back up in case the air-depolarised cells should freeze. Back-up for the station deployed inland of Mawson is a 100 amp-hour, 13.5 V inorganic lithium battery. The batteries are also buried several metres under the snow in a separate box to the transmitter and electronics. A pipe extends from the battery box to about a metre above the surface to provide the air supply required for the air-depolarised cells.

The air and snow surface temperature sensors were calibrated against a standard platinum resistance thermometer. The absolute uncertainty in the calibration reaches a maximum of about ±0.15°C at the lower temperature extreme (-60°C). The differential error between the sensors in each station, however, is only about ±0.03°C because the sensors for each station were calibrated together in an arrangement which minimised the differential error. The electronics associated with each sensor are self-compensating for drift caused by temperature and time and do not contribute significant error.

Neither the anemometer nor the pressure transducer were calibrated by the Antarctic Division and the manufacturer's calibration was used for data reduction. However, the pressure transducer calibration was checked against a deadweight pressure standard for three different sensor temperatures and occasional checks of a group of pressure transducers against a digital aneroid barometer showed agreement to within 0.6 mb. The output from the pressure transducer is corrected for the temperature as measured inside the electronics box. The wind direction transducer was calibrated in the laboratory.

Additional calibration checks of the full AWS system are provided by the field comparisons and internal consistency of the data as discussed further below.

History of AWS deployment and operation

Three automatic weather stations have been deployed to date. The first station installed, Argos Platform 8580, was activated at Atlas Cove, Heard Island (53° 01'S, 75° 23'E) on 26 March 1980. This station only operated for 14 days before failing due to a design fault in the temperature sensor circuits. However, during its short life it gave data which were in excellent agreement with pressure and temperature data collected by a Bureau of Meteorology AWS at the same site (Allison and Morrissy 1981).

A second AWS (Platform 8560) was erected on the ice sheet inland of Casey station at (68° 24'S, 112° 10'E) on 11 October 1980. This site is 280 km from the coast and at an elevation of 1630 m. All sensors operated well until the 2 m temperature sensor failed on 23 March 1981 and the anemometer failed on 25 March 1981. Transmission from the station ceased on 30 April 1981 when the power supply was damaged during a manual check. Both the anemometer and the vane plastic housings were found to have cracked due to wind vibration at low temperature.

Platform 8561 was activited on 2 March 1981 about 20 m from the Bureau of Meteorology surface observation site at Mawson (67° 36'S, 62° 52'E). The anemometer on this station failed on 7 April 1981 and the mast was severely damaged during a blizzard on 14 July. A new mast was built, all sensors repaired, and the station was re-activated at an inland site (68° 39'S, 60° 33'E, 1850 m asl) on 4 January 1982. Here the station has operated continuously for over one year (still operating June 1983) at temperatures down to –53°C and wind gusts of up to 35 m s^{-1}. The wind direction and wind speed sensors have been intermittent for periods of up to 30 days at low temperatures and the latter appears to have failed completely after 11 months.

The major problems that have arisen with the three prototype stations have been with the wind sensors, which are operating at temperatures down to and beyond their design specifications, and with the structural design of the mast. The bodies of the wind sensors have cracked in the cold, anemometer cups have failed and both sensors have shown intermittent faults at low temperatures. Failures with wind sensors were also noted during 1975-76 trials of a US experimental AWS (Renard and Salinas 1977) but choice of sensors suitable for the extreme conditions experienced remains difficult. At the continually sub-zero inland temperatures, it is unlikely that icing will affect the anemometers but hoar frost deposition on the cups may affect the accuracy for short periods.

The first masts, made of welded aluminium tube, proved totally unsuitable at high wind loading. No failures have been experienced with the rebuilt steel masts and future AWS will use a steel, triangular section, lattice tower.

Data acquisition and reduction

At present data are not received from the stations in real time but as a magnetic tape from System Argos every month. System Argos does have the capability to relay the data in near-real time but some minor changes to the present data formatting of the Antarctic Division AWS would be required to feed these data into the Global Telecommunication System (GTS).

At Heard Island and the coastal Antarctic stations, 15 to 20 transmissions are received daily from the AWS. The inland stations, which are both at higher latitude and have an horizon unobstructed by local geographical features, are received 25 to 35 times daily. The satellite orbit geometry results in a data gap of up to six hours for the sub-Antarctic and coastal stations. The satellite orbit planes (which are at a constant angle to each other and the sun) intersect at a point at 82°S latitude and the longitude which represents local midnight at any time. This unfortunately leads to the data gap always occurring around local noon, and some caution must be exercised in interpreting daily mean temperatures determined from the station data. Similar data gaps do not occur with the higher latitude inland stations and data are received from these nearly every hour.

The AWS data format includes several null sensors, and a preliminary editing procedure rejects any pass for which a non-zero null sensor is recorded. Sensor calibrations are applied and the resultant raw data are stored in binary form. Magnetic tapes of the data in this form can be made available to interested researchers. Further data editing, both automatic and manual, is done as required. Standard data reduction presently includes the calculation of daily and three-hourly means of all variables (by time integration of the edited data) and the calculation of hourly group means for any selected period greater than ten days.

Comparison of AWS data with manually-observed data

For the 36-day period between 3 March and 7 April 1981 a AWS, with all sensors functional, operated within 20 m of the Bureau of Meteorology observation site at Mawson. Data collected by the AWS over this period have been compared with that observed manually. Manual observations are taken at the synoptic times 0000, 0300, 0600 GMT, etc. The pressure observations are made with a digital aneroid barometer (excepting for 1500, 1800 and 2100 when the observations are read from a barograph), temperature observations with a Fielden thermometer in a Stevenson screen, and wind observations with a Bendix Aerovane mounted about 10 m above the surface. Synoptic observations are only reported to a resolution of 0.1 mb, 1°C, 0.5 m s^{-1} (1 kn) and 16 compass points.

We first compared the synoptic observations with AWS data received by the satellite up to 53 minutes

Table 2. Statistics of the comparison of synoptic observations with AWS observations taken within 53 minutes of the synoptic observation time.

Period of comparison is 3 March to 7 April 1981.
(Wind direction comparison only between 7 March and 7 April)

		Pressure (mb)	Temperature (°C)	Wind speed (m s^{-1})	Wind direction (deg. T)
Number of obs (N)		122	127	108	114
Difference between AWS and synoptic observations	mean	0.01	- 0.2	- 0.8	4
	s.d.	0.42	0.6	1.0	17
	$\lvert t \rvert$	0.00	0.33	1.29	1.85
Linear regression	slope	1.01	1.01	1.02	0.68
	r	1.00	0.99	0.98	0.55
	F	61435	10025	2290	48

after the observation time. The AWS holds data in a buffer for up to 53 minutes and hence we are comparing data collected within 53 minutes either side of the synoptic time. The AWS data were edited to exclude obvious transmission errors.

The statistics of all such comparisons are shown in Table 2. The standard deviation of the difference between the AWS and synoptic data is less than the resolution of the reported synoptic data in the case of the temperature and wind speed, 0.4 mb for pressure, and 1 m s^{-1} for wind speed. The wind speed difference is consistent with the higher mounting of the Bendix Aerovane than the AWS anemometer. The Student-t parameter has been calculated for the difference in mean between the AWS data and the synoptic data, and the null hypothesis, that the mean value of each sample is the same, is significant at better than the 5 per cent level ($t<.96$) for all variables.

Also shown in Table 2 are the results of the linear regression fit to the pairs of synoptic and AWS data for each variable. The significance of the regression relationship can be tested using analysis of variance and the F statistic. The probability that the observed correlations will occur by chance is less than 1 per cent for pressure and temperature, and less than 2.5 per cent for wind speed.

Although the mean wind directions are in agreement, the correlation between individual wind direction observation is not good. This arises because of the high variability of wind direction and the different sampling used for the two observations. The wind directions reported from the synoptic observations are the mean over ten minutes; those measured by the AWS are instantaneous.

The data presented in Table 2 show the excellent agreement between the manually observed and AWS data for individual observations. However, we have previously noted that for an AWS on the coast of Antarctica we do not receive a uniform distribution of data over the day. The question remains, then, as to how well the AWS data can be used to estimate diurnal means when there may be a large period around noon when there are no observations. Hence we have compared the diurnal means calculated from the synoptic data (the arithmetic mean of 8 observations) and that calculated from the AWS data (time weighted for the randomly spaced observation times). The statistics of this comparison are presented in Table 3.

Although the difference between the two estimates of diurnal mean temperature is greater than between the means of the individual observations, the AWS data still provide a good estimate. The hypothesis that the means are the same is again statistically acceptable; the hypothesis is significant at greater than the 2 per cent level ($t<2.33$) for all variables except wind speed.

The comparison between the two observing methods was made around the equinox, when the diurnal ranges of temperature and katabatic wind speed are at their greatest. Hence we can expect the AWS to provide accurate estimates of all variables over the whole year.

Data from Antarctic automatic weather stations

Detailed analysis and discussion of the data from the AWS will be presented elsewhere and here we present only sufficient to illustrate the scope and accuracy of the data available. Further preliminary data from these stations are presented by Allison and Morrissy (1981).

Figure 2 shows the temperature and wind data from the AWS inland of Casey for the period 28 December 1980 (day 363) to 3 January 1981 (day 3). The diurnal temperature variation during this period is large and the wind speed shows a very strong diurnal katabatic cycle, from around 3 m s^{-1} near midnight to up to 9 m s^{-1} near midday (note that the time scale for Fig. 2 is GMT; local midday occurs around 0430 GMT). A surface inversion was almost always present at the site and this was considerably stronger during the night (a mean temperature difference between 2 m and 4 m of about +0.2°C)

Table 3. Comparison of mean value of manual observations with the mean of all AWS observations over the same period 3 March to 7 April 1981 (temp., press., wind speed) 7 March to 7 April 1981 (wind direction)

		Pressure (mb)	Temperature (°C)	Wind speed (m s^{-1})	Wind direction (deg. T)
Synoptic observations	mean	994.7	- 10.7	10.8	141
	s.d.	9.1	5.3	4.7	17
	N	288	288	288	256
AWS observations	mean	994.8	-11.2	9.8	144
	s.d.	9.2	5.4	4.6	18
	N	482	480	485	427
	$\lvert t \rvert$	0.15	1.25	2.90	2.15

Fig. 2 Temperature and wind data from the AWS inland of Casey (68° 24'S, 112° 10'E, 1630 m) for the period 28 December 1980 until 3 January 1981.

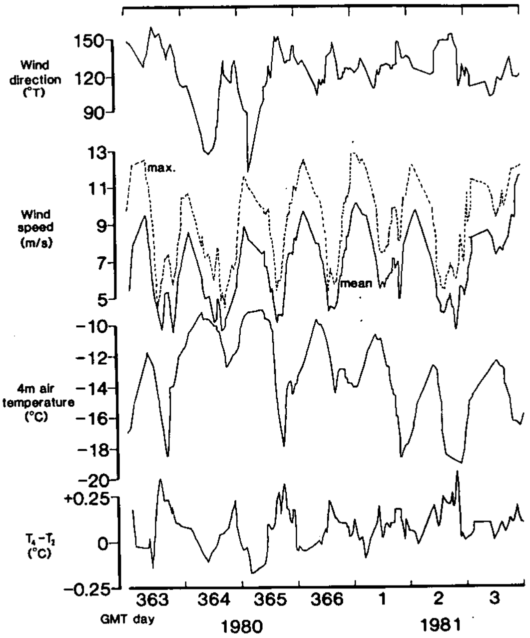
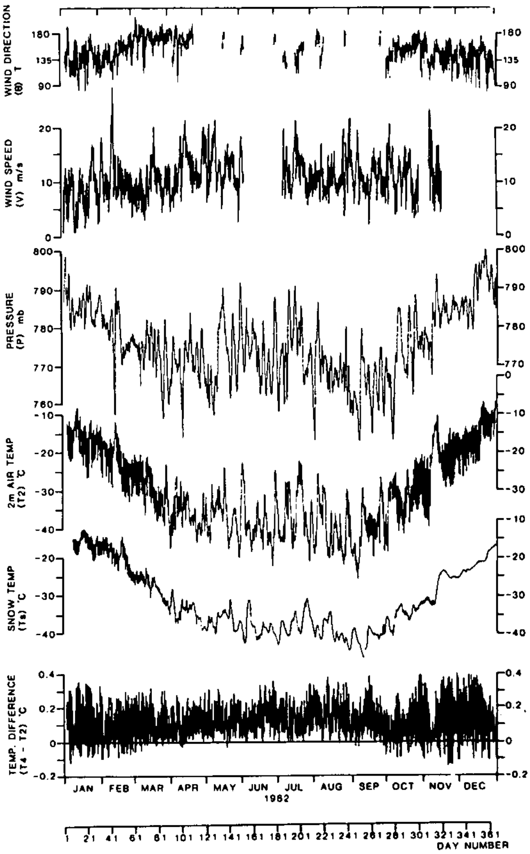


Fig. 3 Data from the AWS inland of Mawson (68° 39'S, 60° 33'E, 1850 m) for 1982.



than during the day (a mean temperature difference of less than +0.05 °C). The katabatic builds up as a result of the surface inversion developed by nocturnal radiational cooling, but the maximum wind speeds occur 8 to 12 hours after the minimum temperature. This is typical of the central plateau and contrasts with the steep coastal slopes of Antarctica, where the katabatic has a minimum speed around local noon and a maximum during the night (Mather and Miller 1967).

Figure 3 shows the complete data set from the station inland of Mawson for 1982. The traces for variables with a large diurnal cycle appear noisy because of the compacted time scale, but a number of features are clearly displayed in the figure. These include the seasonal variation of temperature, pressure and wind speed and the correlation between low pressure and high wind speed events. Also, the temperature difference between 4 m and 2 m shows a slight increase in inversion strength during winter and a decrease in the diurnal variability; the temperature gradient above the snow surface may be negative around noon in summer, but is very seldom negative in winter.

Conclusion

Despite some initial problems with the prototypes, the Antarctic Division automatic weather station is now a reliable system suitable for use in the Antarctic interior. The accuracy of the system has been proven from comparison of the data with manual observations, intercomparison of the results from two autostations, and the internal consistency of the data.

Automatic weather stations offer the potential for making a significant contribution to the study of Antarctic surface weather events and are being developed by a number of nations. In March 1982 more than 20 AWS were operating in the Antarctic including stations deployed by Australia, France, USSR and USA (Savage and Stearns 1981; Wendler and Poggi 1980). The deployment of numerous other stations is planned by these and other nations in the next few years.

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