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Portable Automated Mesonet II

FRED V. BROCK,* GEORGE H. SAUM AND STEVEN R. SEMMER

*National Center for Atmospheric Research** Boulder, CO 80307*

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ABSTRACT

The Portable Automated Mesonet II (PAM II) system was developed by NCAR to provide surface mesoscale data for the research needs of the atmospheric science community. The PAM system has 60 remote stations with planned growth to 300. In such a distributed system, data communication is a vital subsystem and, since it dictates some key system constraints, deserves special attention. The NOAA/NESDIS satellite, GOES, is used to link the remote stations to the base stations. This provides very wide areal coverage but limits the data rate.

Special attention was given to the design of the sensor subsystems to minimize the possibility for human error and to maintain the calibration in field conditions while using interchangeable modules. This was achieved by using a dedicated microprocessor in the psychrometer and the barometer. The microprocessor in the sensor modules controls the sensors, applies the individual calibration coefficients, and transmits the sensor data to the master data acquisition module.

The master base station collects the data, archives them and generates graphic displays of real-time or archived data for system control and scientific analysis. The field base stations provide real-time data for the user in the field environment.

1. Introduction

The National Center for Atmospheric Research (NCAR) designed and constructed the first Portable Automated Mesonet (PAM I) and operated it from 1976 through 1982. PAM I, as described by Brock and Govind (1977), was a computerized system that collected mesoscale meteorological data from a surface array of 30 stations and telemetered them by a line-of-sight UHF radio link to a central base station where they were archived and displayed. Each station measured wind speed and direction, air temperature, humidity, pressure, and rainfall. The data were averaged over one-minute segments and reported to the base station in one-minute intervals.

The PAM I system has been used in support of relatively short, intensive research investigations of mesoscale phenomena. These include thunderstorms, squall lines, tornadic storms, hail storms, downslope winds, air quality, the planetary boundary layer, wind shear, weather modification, and fog. For examples, see Cotton and George (1978) and Fujita and Wakimoto (1982).

In February 1981, NCAR sponsored a workshop where approximately 40 scientists reviewed plans for the next generation PAM system (PAM II) (Brock and Saum, 1983). The major motivation for designing a new system was to overcome the line-of-sight limitation imposed by direct radio telemetry. With an antenna height of 10 m at the remote stations and 50 m at the base station, the maximum size array for PAM I was approximately 50 km by 50 km. The array size limitation was eliminated by using the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite (GOES), which allows PAM II to cover more than just the small end of mesoscale phenomena. The workshop generally endorsed the PAM II plans and emphasized the following points:

(i) The wind sensors should be mounted at 10 m instead of the 4 m height used in PAM I. Generally for mesoscale work, the wind sensors should be as high as possible but 10 m is usually acceptable.

(ii) There should be at least 100 remote stations.

(iii) There is a need for two base stations; one being permanently located in Boulder, and the other being an easily transportable field base, both of which can receive data directly from the satellite. The latter is essential for real-time data displays in the field. The fixed base in Boulder is able to archive data from all stations.

(iv) There is a real need to maintain the high-time resolution of PAM I, e.g., 60 s averaging with 60 s reporting. However, for some applications, longer averaging periods and reporting intervals would be acceptable.

(v) The remote station design must accommodate special sensors and have facility for local processing of data from these sensors.

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* Now at the University of Oklahoma.

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2. Design goals

The specific design goals of the system were derived from our experience with PAM I and from the recommendations of the PAM II workshop. The key requirements are summarized below.

(i) *Portability.* The remote stations were designed to: minimize shipping weight and volume, require very little site preparation, minimize set-up time, and facilitate on-site maintenance by one person. The system is to be deployed in an area and in a pattern that is optimum for the phenomena under study.

(ii) *Flexibility.* The remote stations are equipped with a microprocessor that operates continuously with low-power consumption and is programmed in a high-level language. It is possible to easily add sensors and processing algorithms for those sensors.

(iii) *High performance.* Because the demands for short, intensive research programs are great, the system provides good time resolution, fast reporting for real-time analysis, and high accuracy sensors.

(iv) *Real-time displays.* Network data are displayed at the field site in a wide variety of graphic formats.

3. Communications requirements of PAM

The ideal communications system would be transparent to the user; it would impose no constraints on remote station location, frequency, reporting or the data rate, and the cost would not constrain the system design.

When data communications must span distances greater than about 30 to 50 km or if the meteorological phenomena to be studied dictates site selection, then a communication system with greater flexibility than was used in PAM I is needed. Such a system is available using earth satellite technology. In selecting a satellite system, access is one of the key considerations. The spacecraft transponder must be accessible from low-power and modest size antenna installations, and the spacecraft must be available to the full mesonet on a 24 hour a day basis. Only one satellite system currently satisfies all of these requirements. It is the GOES of the National Earth Satellite Data and Information Service (NESDIS) as described in a NOAA Technical Report (NOAA, 1979a). The GOES system is widely used by researchers and operations personnel involved in the collection of geophysical data.

Using the aforementioned criteria, we came to the following set of data transmission requirements:

(i) Placement of remote stations must be substantially independent of communications considerations.

(ii) The network should not have the logistical encumberance of a land based repeater.

(iii) Transmitter frequencies that can be easily changed in the field, and that are available on a nationwide basis must be used.

(iv) The transmission path must be free of multipath and propagation problems.

(v) The channel capacity must be large enough to permit transmission of standard meteorological parameters at least once every five minutes from a network of up to 100 stations.

(vi) Communications equipment must require no more than a minor part of the remote station's available power.

4. Communications design

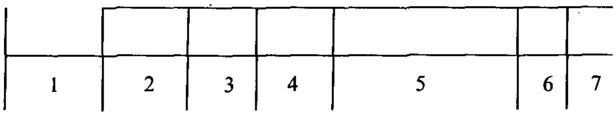
The rules for use of the GOES system specify a set of standards and an established protocol. These include transmission on the assigned channel, at the designated time, at the established rate of 100 baud, and with a ±60 degrees phase-shift-keyed Manchester encoded modulation.

The protocol NESDIS permitted NCAR to use is shown in Table 1.

In this protocol, the transmitter is required to transmit for 0.5 s to permit carrier acquisition by the demodulator's phase-lock loop circuit. Next, 0.48 s of alternating ones and zeroes are transmitted to permit bit synchronization in the demodulator. This is followed by the 15-bit Maximal Linear Sequence (MLS) code, a 31-bit coded address, the data message, and finally an end-of-transmission (EOT) character. The MLS code is a sequence of ones and zeroes with the number of ones equal to the number of zeroes within one count. The autocorrelation for this code for all values of phase shift is -1 except for the zero ± 1 bit phase shift region where the correlation varies linearly from -1 to 2^{n-1}. In the GOES system the MLS code is used for demodulator frame synchronization.

The 31-bit Bose, Ray-Chaudhuri, Hocquenghem (BCH) code is actually a 21/31-bit BCH code providing

TABLE 1. PAM II GOES transmission format. The data portion of the message comprises 19 bytes. The interstation gap is adjusted so that it is at least 0.5 s. The transmission time is on the integer second.



Interval	Activity	Used for
1	0.5 s unmodulated carrier	carrier acquisition
2	0.48 s alternating bits	bit synchronization
3	0.15 s 15 bits of MLS	frame sync.
4	0.31 s BCH address	platform address
5	1.52 s 19 bytes of data	sensor data
6	0.08 s EOT character	end of transmission
7	0.96 s interstation gap	
	Total = 4.0 s	
Data Byte:	P 1 X X X X X X	(P = Odd Parity)

for 2^{21} unique addresses defined in a NOAA technical memorandum (NOAA, 1979b). The ten remaining bits provide the means for error correction. In the code there are nine bits for user identification, two bits for priority, and ten bits for platform index. The last bit in the platform index is used to identify primary or secondary platform addresses. The priority field is used to tell whether the platform is operational, emergency or experimental in nature. The complete preamble takes 1.44 s to transmit at the 100 bits per second rate. This preamble is currently being used by data collection platforms operating in NESDIS' "random reporting" mode.

In the PAM II system 15 bytes of data are transmitted from six sensors, three bytes of engineering index and system status and one byte representing a check sum of the message. These 19 bytes of data contain eight bits, with bit eight as odd parity and bit seven always being a one. At 100 bits per second, 19 bytes take 1.52 s to transmit. The transmission is concluded with an American Standard Code for Information Interchange (ASCII) End of Transmission (EOT) character. Thus the total transmit time is 3.04 s. We allow a 0.96 s interstation gap bringing the time slot to 4.0 s per platform. Table 2 shows the format for the PAM II data message.

Since the stations transmit sequentially on the same channel, the clocks must maintain synchronization so that any given station is not allowed to drift by more than ±480 milliseconds. The oscillator error is at most $\pm 0.25\ \mu s\ s^{-1}$ over the temperature range of -40 to 60°C. Therefore the clock drift in the worst case would be 480 milliseconds in about 22.2 days and then the station would have to be resynchronized. Moreover, oscillator synchronization must be accomplished automatically; manual techniques employed in the past are not precise enough especially under field conditions. The scheme presently used in PAM II involves setting the station clock to National Bureau of Standards (NBS) time as received from the GOES "interrogate" channel (468.825 MHz or 468.8375 MHz). The transmit time is thus tied very accurately to Universal Coordinated Time (UTC) throughout the network. The remote station contains a "keep alive" battery that preserves the time settings and other instructions for a considerable length of time, and allows field deployment by persons who have limited technical experience with the system.

TABLE 2. PAM II data message.

Byte	Data
1	Engineering data index
2	Engineering data, least sig. byte (LSB)
3	Engineering data, most sig. byte (MSB)
4	Pressure, LSB
5	Pressure
6	Pressure, MSB
7	Air temperature, LSB
8	Air temperature, MSB
9	Wet-bulb temperature, LSB
10	Wet-bulb temperature, MSB
11	Rain, accumulative, LSB
12	Rain, accumulative, MSB
13	Avg. wind speed, V-component, LSB
14	Avg. wind speed, V-component, MSB
15	Avg. wind speed, U-component, LSB
16	Avg. wind speed, U-component, MSB
17	Max. wind speed, LSB
18	Max. wind speed, MSB
19	Checksum Byte

To ensure continued time synchronization throughout the network it has been proposed to add an NBS time code receiver to each remote station in the future. With such a receiver, the remote station could receive NBS time and resynchronize its clocks periodically; twice a day would be sufficient. Then all clocks in the network would be synchronized to within a few tens of milliseconds. Such a receiver would, however, greatly increase the cost of the remote station as well as affect its overall power consumption.

5. Communications hardware

Apart from the satellite and its large ground control network, the two main hardware components of the PAM II communication system are in the remote stations and in the base stations.

The remote station is built around the Handar 540 processor, controller and transmitter modules. To these modules we have added a data acquisition module developed at NCAR. We chose to make the division of commercially available and in-house developed modules in this manner to take advantage of the experience of Handar and their NESDIS certified controller and transmitter. A photograph of the remote station is shown in Fig. 1 and a block diagram in Fig. 2. We now have 60 stations in the inventory.

The base station consists of commercially procured modules. We built the station to permit reception of the GOES visible and infrared spin scan radiometer atmospheric sounder (VISSR/VAS) and weather facsimile (WEFAX) transmissions, as well as the data collection platform (DCP) signals. Sufficient hardware is in place to monitor any combination of three GOES simultaneously. Figure 3 shows a photograph of this installation. With a 4.5 m antenna and an 85 K preamplifier, the base station exhibits an antenna–low noise amplifier gain over temperature G/T of 12.6 dB K^{-1}. This is adequate for receiving downlink signals from a satellite transponder loaded with 75 simultaneous platform transmissions while maintaining a 1×10^{-6} bit error rate.

DCP demodulators are units obtained from Telcom that were modified by NCAR to permit computer control of channel selection. In our installation, four demodulators are housed in one chassis. We selected a

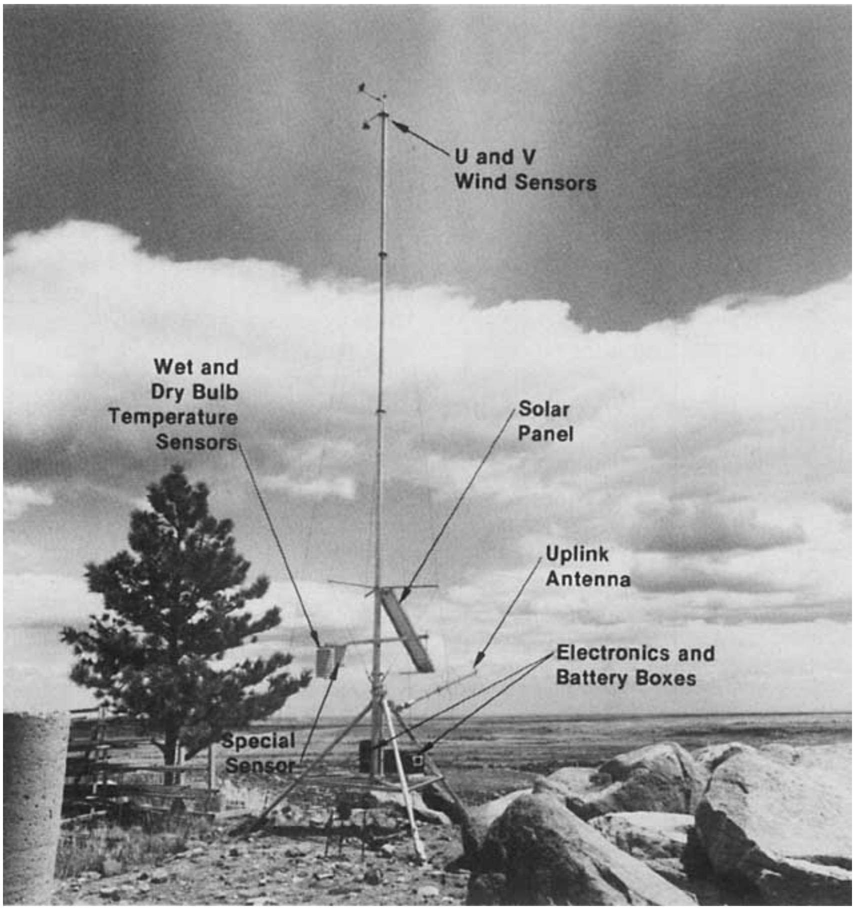


FIG. 1. Photograph of a remote station.

"standard" (STD) bus, National Semiconductor Corporation (NSC) 800 microprocessor for the demodulator control system. The control system can service up to eight demodulators, programming their synthesizers and collecting data. The data are passed off to a Digital Equipment PDP-11/23 host machine and eventually to a VAX 11/780. All components of the base station except the Digital Equipment hardware are backed up by an interruptable power source. A photograph of the Boulder base station is shown in Fig. 4.

6. Remote station design

The key elements of the remote station, in addition to the communications equipment, are the mast assembly, sensors, sensor interfaces and data processing elements, and the power system.

The mast assembly was given special attention because of the requirements for minimizing shipping weight and volume, for access to relatively remote sites, and for easy access to the wind sensors that must be mounted at 10 m. A mast hinged to a tripod base satisfies these requirements and allows for two people to lower the mast for servicing the wind sensors without special equipment. Refer to Fig. 1.

During the process of selecting sensors, the decision was made to provide a microprocessor for each individual sensor. This led to the design of the integrated sensor concept (Pike et al., 1983).

Two of the sensors, the tipping bucket raingage and the propeller anemometer, are commercially available. In the raingage a magnetic reed switch is activated each time the rain bucket tips. An accumulated count is maintained and passed on to the data processing module.

The horizontal wind vector is sensed by two orthogonal propeller anemometers. The propellers are oriented to the north and east; the direction alignment can be verified and corrected with the mast in the erect position. Data samples are averaged over a one-second period. Due to the non-cosine response of the propeller blades, a correction is applied to the raw data and then they are passed on to the data processing module.

The psychrometer was selected as the humidity sensor in PAM I because, like McKay (1978), and Stigter and Welgraven (1976), we found it to be relatively inexpensive, easy to maintain, and it has well-known er-

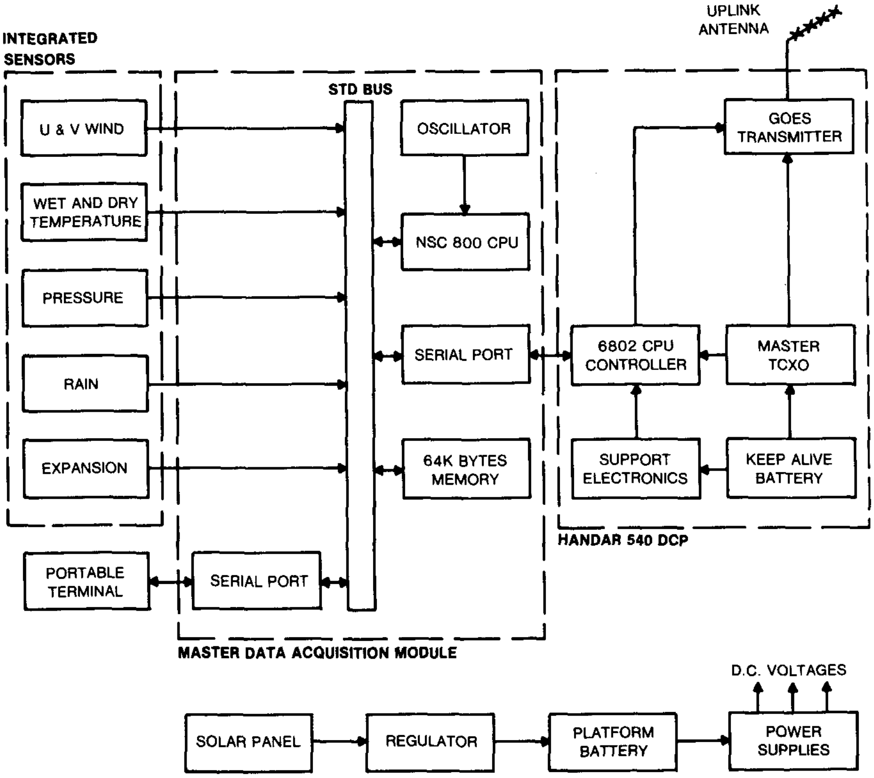


FIG. 2. Block diagram of a remote station.

ror sources. Many of our applications demand the best possible humidity measurements. Most of our research programs are in the spring or summer seasons. We are continuing evaluation of nonaqueous humidity sensors for application in cold weather programs. Low-power, continuous operation devices have not been available commercially, but have been used in agriculture by Munro (1980), and others. The psychrometer designed in PAM I proved to be very satisfactory. We were able to cope with the sources of error discussed by Tanner (1972), and Wexler (1970). The PAM II model was based on the existing design and we integrated the electronics to improve the overall performance. Other people have reported psychrometers with integrated electronics, Nantou (1979), and with microprocessors,

FIG. 3. Photograph of the fixed receiving site at Boulder.

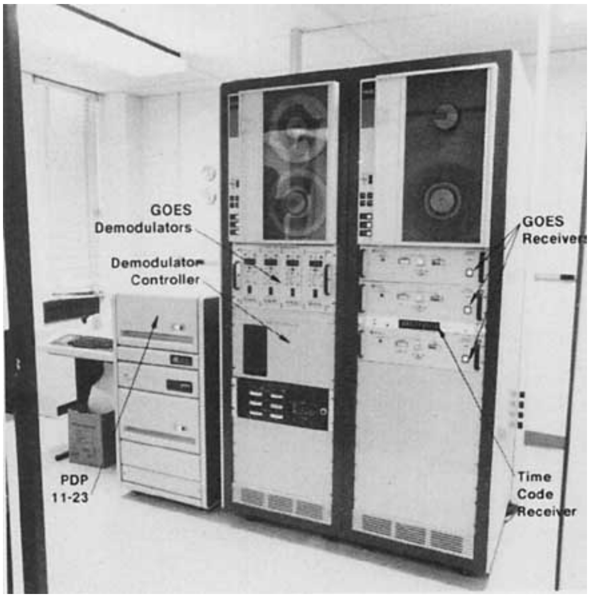


FIG. 4. Photograph of Boulder Base Station receivers and demodulators.

Nantou and Suzuki (1981), and Fisher et al. (1981). We extended these developments to meet our needs.

The psychrometer must have wet- and dry-bulb temperature transducers that have closely matched characteristics, and it must maintain high accuracy over a wide temperature range. The electronics are subjected to ambient temperature excursions and consequently exhibit gain and bias changes which must be accounted for. The psychrometer must have low power consumption and must be capable of continuous operation. The operating temperature range is −30° to 50°C even though the wet bulb is not useful below freezing.

Figure 5 shows the radiation shield and the internal components of the psychrometer. The temperature transducers are aspirated by a blower with a ventilation rate of 4.0 m s^{-1}. Wicking for the wet bulb is provided by a dual reservoir system. The larger reservoir replenishes the lower reservoir as water is wicked to the wet bulb. In dry climates, this system lasts for approximately two weeks. The system described up to this point has been in use in the PAM I system for seven years and has proven to be effective.

As shown in Fig. 5 the microcomputer for the psychrometer is mounted at the top of the enclosure. Figure 6 shows a block diagram of the psychrometer electronics. A reference voltage is applied to a bridge circuit, wherein voltages related to the transducer resistances together with reference resistor voltages are multiplexed to an analog to digital converter under the control of the microprocessor. The reference voltage is then turned off to save power. The microprocessor computes normalized dry- and wet-bulb values using

$$D_N = (D - R_L)/(R_H - R_L)$$
$$W_N = (W - R_L)/(R_H - R_L) \qquad (1)$$

where R_L and R_H are the low and high reference values, and D and W are the raw dry- and wet-bulb voltages. The corrected temperatures are calculated from

$$T = A_0 + A_1 D_N + A_2 D_N^2$$
$$T_W = A_3 + A_4 W_N + A_5 W_n^2 \qquad (2)$$

where the coefficients are computed from a calibration run and stored in an onboard electrically alterable read only memory. These temperatures are passed to the host system and then the microprocessor is shut down until time to take another sample.

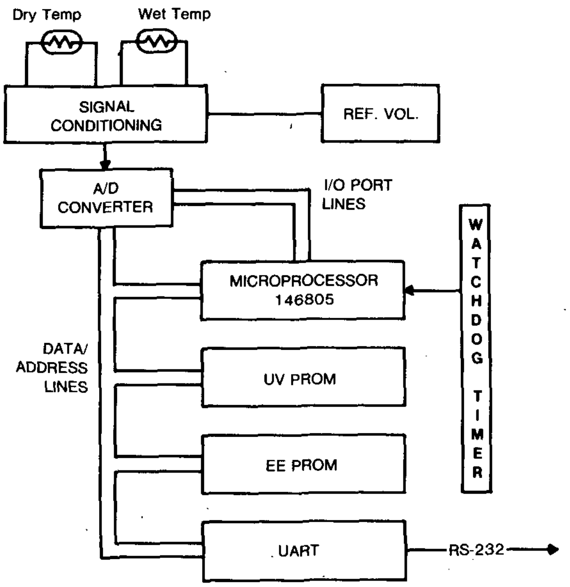


FIG. 6. Psychrometer electronics block diagram.

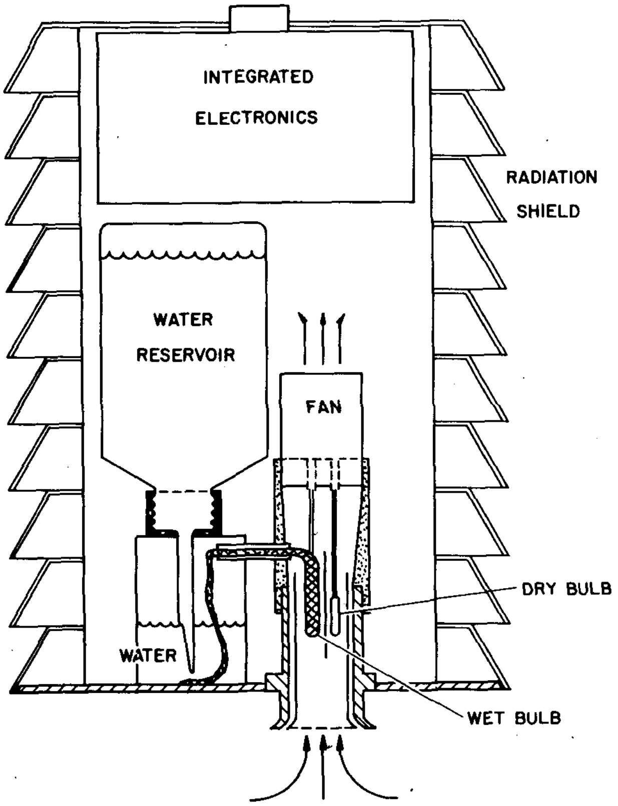


FIG. 5. Psychrometer schematic.

The transducers are platinum resistance thermometers (PRT). The PRT resistance is 500 ohms at 0°C and has a slope of 1.925 ohms/°C. The PRT was chosen for this application because it is stable, available in a convenient package, and reasonably linear. The PRT sensors are operated in a bridge circuit as shown in Fig. 7. The sensor leg of the bridge is actually four separate legs, only one of which is switched into the circuit at a time. The four legs are for the dry-bulb PRT, the wet-bulb PRT, a low-reference resistor, and a high-reference resistor. The normalization step eliminates the bridge voltage and the gain of the amplifier so that these parameters only need to be stable for the period of time required to make the four measurements. It is not necessary to know their values precisely. The analog-to-digital converter is a low-power device

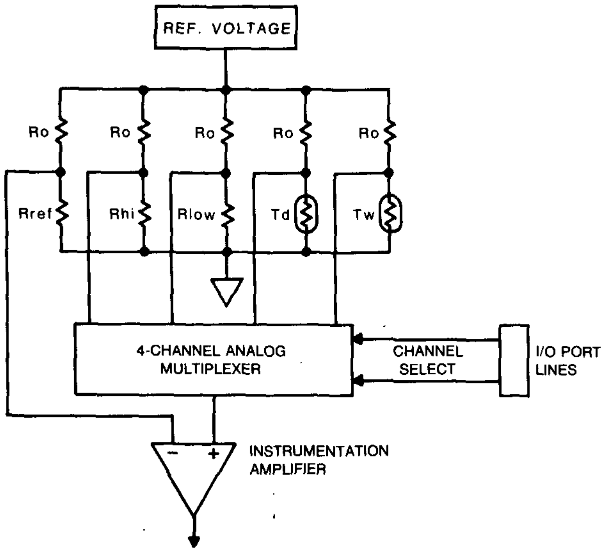


FIG. 7. Psychrometer bridge circuit.

providing 12 bits plus sign. The psychrometer specifications are summarized in Table 3.

NCAR has a pressure standard (Pike, 1984) and has been involved in developing pressure sensors since 1975. The goal has been to develop an absolute pressure sensor with high sensitivity and reasonable accuracy that will work over the range of 60 to 110 kPa and from −30 to 50°C. PAM has been deployed from an elevation of 9 to 3960 m and has experienced the above temperature range.

TABLE 3. Summary of psychrometer specifications.

Physical	
Dimensions	0.24 m diameter by 0.33 m high
Weight without water	3 kg
Water reservoir capacity	0.6 l
Radiation shields	louvered plates for direct solar double walled intake tube
Aspiration	
Ventilation rate	$4\ \mathrm{m\ s^{-1}}$
Wind effect	enhances ventilation
Sensors	
Type	platinum resistance, 500 ohms @ 0°C
Wick	GSA #2, treated
Electronics	
Processor	Motorola MC146805
Data memory, RAM	112 bytes internal to processor
Program memory, PROM	2048 bytes
Coefficient memory, nonvolatile RAM	64 by 4 bits
Communications	RS232, serial, 1200 Baud
Reporting interval	10 s
Resolution	0.025°C
Inaccuracy	0.25°C
Power consumption	
Blower	250 mW
Electronics	250 mW
Total Operating Power	500 mW from 12 volts, unregulated

A block diagram of the pressure sensor is shown in Fig. 8. The signal generating electronics, shown above the microprocessor, generate frequencies that are related to the capacitance of the pressure sensor, the resistance of the temperature sensor, and the capacitance of each reference. The microprocessor makes the sensor/reference selection and obtains a number proportional to the period of the frequency generated by that element. The four period measurements of pressure, temperature, low reference, and high reference are calculated into pressure, and sent to the host system. The barometer uses operating firmware stored in PROM. The firmware contains an auto-restart feature which works in conjunction with the watch dog timer forcing the microprocessor to execute the algorithm systematically.

The aneroid pressure transducer is a design used previously, Pike and Bargen (1976), and is shown schematically in Fig. 9. It is currently being produced in an improved version by Atmospheric Instrumentation Research, Inc. (A.I.R.). The capacitance at one atmosphere is approximately 19 pF, and it exhibits a typical sensitivity of about 0.08 pF/kPa. The capsule temperature coefficient is near 0.01 kPa/°C. The temperature transducer is a common bead thermistor, which has sufficient accuracy for the application.

The most critical measurement in the system is the measurement of the pressure transducer capacitance. We monitor a reference capacitor at each end of the sensor capacitance range to establish reference points. These capacitors are inexpensive NPO disc ceramic devices. Similar capacitors were used for several years as references in our calibration laboratory, and repeated calibration by the NBS showed them to have excellent stability. The reference timing resistor is a low temperature coefficient metal film resistor of high stability.

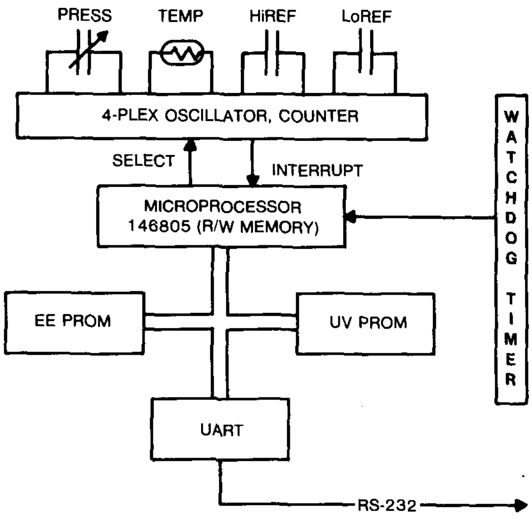


FIG. 8. Pressure sensor block diagram.

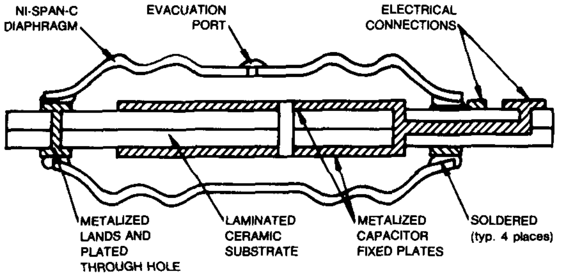


FIG. 9. Pressure sensor transducer.

The 4-Plex oscillator is a design developed at NCAR and tested for a period of over a year for long-term stability. The error level indicated is in the few tenths millibar per year range. The circuit is implemented with Compatible Metal Oxide Semiconductor (CMOS) logic gates using a 3-gate "delay" configuration and CMOS analog switches to select the active element by logic level signals. The oscillator frequencies are counted in a binary counter of hardware selectable length. This permits scaling the number to the microcomputer requirements.

The normalized pressure P_N and temperature T_N are calculated from the measured periods just as in the psychrometer Eq. (1). The observed temperature effect is a combination of temperature coefficients in the aneroid sensor and in various electronic components including the reference capacitors. The resultant temperature effect is quite irregular and difficult to model so the pressure is calculated using

$$P = A_0 + A_1P_N + A_2P_N^2 + A_3P_N^3 + A_4T_N \quad (3)$$

which is fitted over segments of the temperature range with different sets of coefficients for each segment. Up to seven segments are used, as needed, when the coefficients are calculated.

The standard deviation of the measurement error over the above ranges is 40 Pa, which represents a very good fit. The resolution, at 2 Pa, is much greater than the accuracy. Transient events in the time series, such as gravity waves propagating across the network, can be detected. Table 4 is a summary of the pressure sensor characteristics.

The data processing module is based on the NSC 800 microprocessor as noted above. This machine executes Z80 software and because we are providing sufficient memory, up to 65 536 bytes can be programmed in FORTRAN. This makes it relatively easy to implement special algorithms for processing data at the remote station. The implementation of special algorithms is essential because of the special demands of research programs, the need to accommodate new and sometimes unique sensors, and the communication bandwidth restrictions.

The remote station uses solar panels as the primary power source with two levels of battery storage. The first level is a large battery that can carry the entire remote station overnight and through periods of reduced insolation. The second level is a small battery intended to preserve the time base and certain operating parameters while the station is being moved. The average power consumption of the remote station is about 3 W.

7. Base station design

In addition to the base station shown in Figs. 3 and 4, we have a transportable, field base station. Both base stations provide roughly the same capability. The fixed base at Boulder, Colorado, can monitor any three GOES simultaneously allowing us to deploy stations over an extremely wide geographical area. The fixed base feeds the PAM data into the Research Data Support System (RDSS) that has powerful graphics capabilities and can merge surface network data with radar, rawinsonde, satellite and aircraft data. This base is also the primary system for data archiving since it can monitor transmissions from all of the GOES satellites.

The field base is mounted in a trailer with a portable 4.5 m antenna restricting it to monitoring only one satellite at a time. It acts as a redundant data acquisition system for the stations illuminating the chosen satellite. Its primary function is to provide real-time data to the project headquarters. In addition to the communications equipment, which is similar to that in the fixed base, it has a computer responsible for data acquisition and management and provides interactive graphics displays for the user. The latter capability can be remotely located to the project operational headquarters and uses phone lines for data transmission, if necessary.

Some samples of the real-time graphics products are shown in Fig. 10. These displays were available in real-time at the field base in Project PreSTORM in Oklahoma and Kansas in 1985. They show data at 0600 CDT 27 May 1985 when a squall line was pushing south towards the network. The network comprised 42 stations, but only 40 are shown. These are spaced at approximately 50 km intervals in a 5 by 8 grid. Figure 10a shows the station locations along with the wind vector, the air temperature and the dew point at each station. Figures 10b and 10c show the regular grid

TABLE 4. Summary of pressure sensor characteristics.

Transducer	
Type	Aneroid capsule, Nispan C
Range	60 to 110 kPa, −30 to 50°C
Resolution	2 Pa
Inaccuracy	40 PA rms error
Reporting interval	30 s
Electronics	
Processor	Motorola MC146805
Data memory, RAM	112 bytes, internal to processor
Program memory, PROM	2048 bytes
Coefficient memory nonvolatile RAM	64 by 4 bits
Communications	RS232, serial, 1200 Baud
Power	180 mW @ 12 volts, unregulated

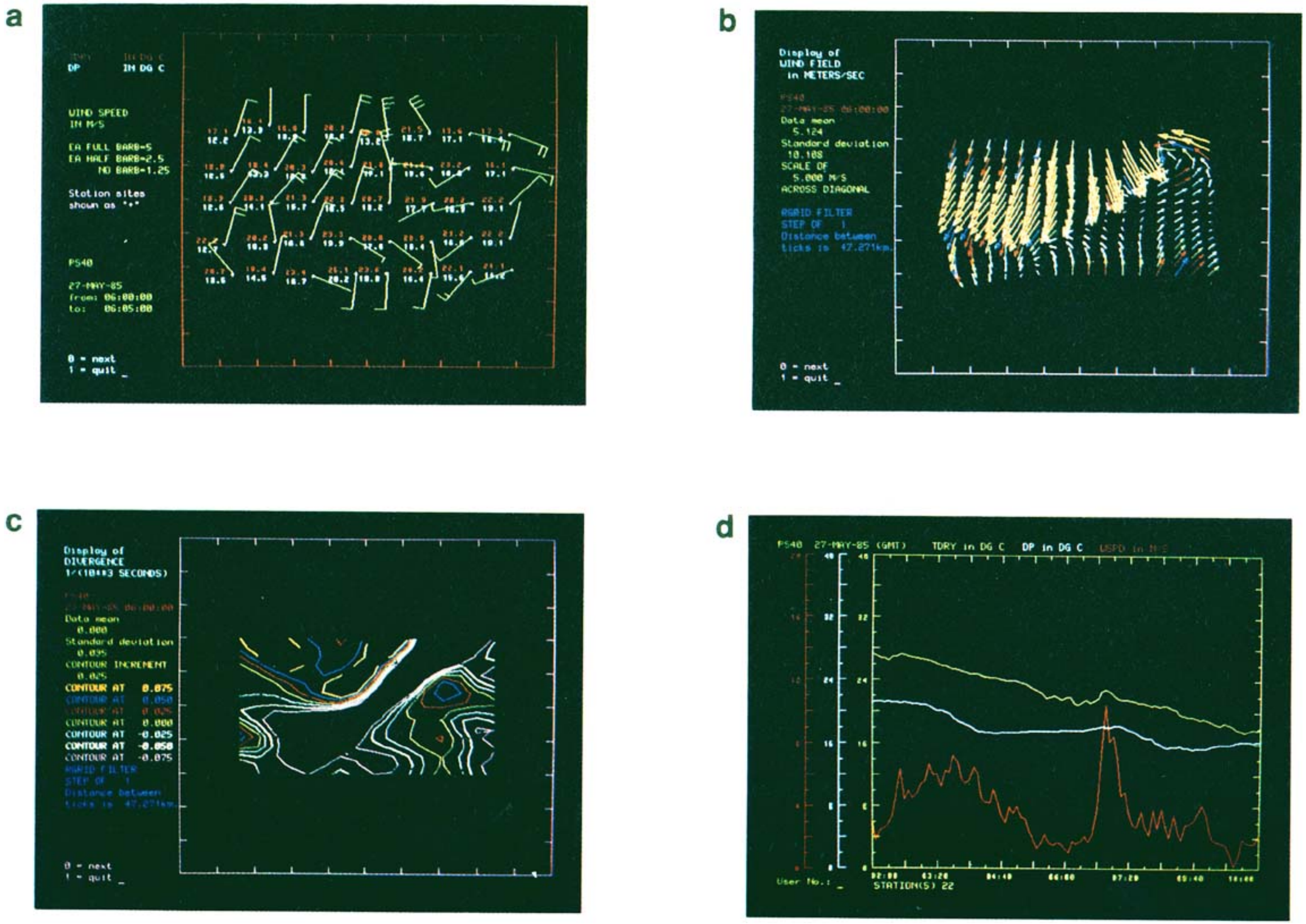


FIG. 10. Real-time PAM data displays. Clockwise starting at the upper left is (a) the station plot showing the wind vectors, (b) the regular grid analyzed wind field, (c) the regular grid divergence and (d) a time series plot. In (a) the 5 by 8 grid of station locations is shown which has approximately a 50 km spacing. In (b) and (c) a regular 16 by 16 grid is used for the analysis. The time plot in (d) shows the dry-bulb temperature and the dew point with a 0–40°C scale and the wind speed with a 0–20 m s^{-1} scale. The time interval is from 0200 to 1000 CDT.

analysis of the wind field and the divergence, respectively. The procedures used to obtain the 16 by 16 regular grid from the somewhat irregular 5 by 8 station grid were described by Wilson and Carpenter (1983). Figure 10d shows the time plot of the dry-bulb temperature, the dewpoint and the wind speed at station 22 which is near the center of the network.

8. Future prospects

When the base stations are completed the development effort will shift to even greater emphasis on sensor development. There are many possibilities for new sensors. The power, cost, and portability restrictions are severe, but can be relaxed for a subset comprising only a few stations. Some stations could be equipped with active or passive remote sensors to profile thermodynamic properties of planetary boundary layer. The remote station processor would be used to compress the data before transmission. The flexibility of PAM II encourages smaller and/or simultaneous projects which were impossible with PAM I.

We have seen how special demands are put upon the GOES system by the need for high-time resolution and shortened reporting intervals. To meet these needs the GOES system must accommodate changes in format and permit greater throughput of data. Higher time resolution can be obtained by using an NBS time receiver at the platform for time synchronization to a far greater precision than is now available in data collection platforms. This technique will enable us to pack more stations onto a given channel.

Another technique which holds promise for packing stations more closely is one or more of the new, sophisticated modulation formats. For example, the present frequency and channel allocation scheme of GOES assigns 1500 Hz of bandwidth to transmit data at the rate of 100 bits per second. New modulation schemes described by Spilker (1977), such as multiple-level phase-shift keying or minimum-shift keying will permit the transmission of data at bit rates in excess of the channel bandwidth. Perhaps the concept of channelization should be abandoned and a spread spectrum transmission (Dixon, 1976) format used by all platforms accessing the satellite on a purely random basis. Spread spectrum modulation offers an interesting alternative to both the channelization and address assignment philosophy. This should be explored thoroughly so that the national resource represented by the GOES satellite system can be more fully utilized.

The entire PAM II system is evolving to benefit from the experience of the initial field projects. The software in the base station for generating the real-time displays is changing rapidly to take advantage of the user recommendations and new display technology. Each new project brings demands for special displays and increased computing capability.

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