Meteor burst telemetry in hydrologic data acquisition

ARTHUR G. CROOK, Consulting Hydrologist
A.G. Crook Company
15058 N.W. Oakmont Loop
Beaverton, Oregon 97006, USA

DONALD SYTSMA, General Manager
Meteor Communications Corporation
22419 72nd Ave. South
Kent, Washington 98032, USA

ABSTRACT

The technology that allows transmission of VHF radio signals via meteor trails has been recognized for many years. However, it was not until microprocessor-based communication equipment was developed that the technique became a viable option for data telemetry.

In 1976, the U.S. Department of Agriculture awarded a contract for installation of a large meteor burst data acquisition system. This system, called SNOTEL, was the first operational use of meteor burst. The system collects daily data on a variety of parameters; the data are collected from high mountain regions of the western United States and are used principally to forecast seasonal snowmelt runoff (which contributes up to 75 percent of the western United States' water supply). Water managers also use the data to regulate reservoirs, analyze flood potential, and for numerous other purposes.

Numerous other meteor burst systems have been established since the initial SNOTEL effort, the majority of which have been for military applications. This paper presents a significant sample of non-military systems used for collection and processing of hydrologic data, and discusses the characteristics of meteor burst as compared to VHF, UHF, microwave, and satellite systems.

INTRODUCTION

Meteors are space rubble - leftovers from the development of our universe or residue from a passing comet. Their size and makeup is variable. Meteors are constantly being pulled into our atmosphere by the earth's gravity. As they burn, they produce an ionized trail of gasses in the upper atmosphere, which reflect or reradiate radio signals. These "meteor trails" are being used throughout the world to send messages long distances (up to 1920 km) without the use of communications satellites or repeaters.

The earliest known study of meteor trail propagation of radio signals began in the 1930s. The technique of using these trails for communication can be attributed to ham radio operators who, under certain conditions, found themselves talking to someone hundreds of miles farther than normally possible on VHF frequencies.

Research on meteor burst continued into the 1950s when the National Bureau of Standards, Stanford Research Institute, North Atlantic Treaty Organization, and the Canadian Defense Research Board all built systems to evaluate the technique (Vancil, 1984). However, it wasn't until high speed
microprocessor-based computer equipment came into use that meteor burst communications became a functional reality in data acquisition projects.

**METEOR BURST THEORY**

Meteor burst telemetry uses the billions of dust-size meteors that enter the earth's atmosphere daily. As each particle enters the atmosphere, it burns, producing an ionized trail of gasses in a zone 80 to 120 km above the earth's surface.

These trails diffuse rapidly, usually disappearing within seconds. During their brief existence, however, they will either reflect or reradiate radio signals, particularly those in the low end of the VHF range, from 40 to 100 MHz. The height of these trails allows radio communications from a transmitter to be received as far as 1920 km from the source (fig.1).

![FIG.1 Meteor burst communications system](image)

Meteors are divided into two classes: shower and sporadic. Shower meteors are groups of particles all moving with the same velocity in well-defined orbits around the sun. These meteors account for only a small fraction of meteors entering the earth's atmosphere, but can significantly enhance the performance of meteor burst systems when they occur.

Sporadic meteors move in random orbits around the sun. Most meteors used in radio work are in this class. Although their random entry points make them less predictable than shower meteors, certain characteristics are known. Intersection of their orbits with the earth's orbit is most frequent in August and least frequent in February, at a ratio of about 4:1 due to the tilt of the earth's axis. The forward motion of the earth sweeps about four times more meteors into the atmosphere in the morning than during the
evening, resulting in a significant diurnal variation in available meteor trails (fig.2).

![Message rate as a function of time](image)

**FIG.2** Message rate as a function of time

The ionized trail of gasses is composed of positively charged ions and free electrons. Typical trails are about 25 km long with a radius of about one meter. The electrons either reflect or reradiate radio waves, depending on the density of the trail. Low electron line densities (underdense trails) result in reradiation of radio signals. High electron line densities (overdense trails) reflect radio signals.

Signals from underdense trails, which are the most common, rise to an initial peak volume in a few hundred microseconds, then typically decay exponentially within a period from a few milliseconds to a few seconds. There are no distinctive patterns associated with overdense trails, except they usually reach higher amplitudes than underdense trails and last longer.

Other means of propagation offered the typical meteor burst system are airplane reflections, sporadic E, and ground wave. Airplane reflections can be utilized for short range (approximately 100 miles) communications. These reflections usually last many seconds, and are characterized by a great deal of signal fading.

Sporadic E is an ionization phenomenon that occurs in the "E" layer of the atmosphere, from 100 to 125 km above the earth's surface. This ionization leads to continuous sky wave conditions, where stations can communicate on a continuous basis. Since sporadic E occurs rarely, it is impossible to predict. However, it does occur more frequently in June and July in the mid-latitudes.

Remote Stations in close proximity to a Master Station can be reached via either line-of-sight or ground wave radio signals. Curvature of the earth and terrain features generally limit ground wave communication to about 160 km, although this type of propagation has been observed to extend up to 240 km from the Master Station.
Beyond the ground wave signal (200 - 240 km), the number of messages per unit of time that can be expected is a function of the amount of "common sky" between stations. The common sky is less at closer distances, increases to its maximum in the range of 800 to 1,280 km, and then reduces with distances beyond 1,280 km. The maximum length of a single-hop link is about 1920 km, a distance determined by the height of the meteor trail and the curvature of the earth (Leader, 1974) (fig.3).

![Ground Wave Message Rate vs Distance](https://example.com/fig3.png)

**FIG.3** Message rate as a function of distance

**Meteor Burst Communication Systems**

Meteor burst communication systems (MBCS) consist of two types of terminals: Master Stations and Remote Stations.

Master Stations are the controlling elements in a meteor burst network, and can communicate with hundreds of Remote Stations. The Master Stations process collected data, and control the dissemination of the data.

Remote Stations can be either message communications or data collection units. They are small units that can easily be installed in remote locations. Remote Stations can communicate with other Remote Stations through the Master Station, but they cannot communicate directly with each other.

The Remote Data Terminals, a specific type of Remote Station discussed in this report, are solar or battery powered, and collect data directly from up to 40 sensors. The primary purpose of these terminals is to collect data, although short messages can also be transmitted.

**Meteor Burst as an Alternative in Hydrologic Data Acquisition**

At about the time meteor burst telemetry became a viable alternative in data acquisition, satellites were gaining popularity in the same application. Prior to that time data had been telemetered generally by telephone or line-of-sight radio (VHF, UHF, or microwave frequencies). These techniques all require extensive land based facilities; i.e., telephone poles and wires, or numerous repeater stations. Most data acquisition projects are
set-up either to retrieve information from remote areas (which have space restriction), or for access to critical gauges during storms or floods (when facilities are most likely to be damaged). Users have enthusiastically welcomed any alternative technology which eliminates costly and vulnerable mountain-top repeaters and land lines.

Meteor burst and satellite communications, while similar with respect to the elimination of repeaters, are quite different in many respects. Polar orbiting satellites pass within reach of their data sites every few hours, and communicate with their sites only at those times. Geostationary satellites are constantly in view of their data sites, but typically require the sites to transmit at fixed times. This type of system eliminates the need for a receiver at the data site, but also precludes optional unscheduled polling and bidirectional communications. For example, many of the data sites reporting through the GOES satellite are in a self-timed mode, transmitting during a discrete two minute window. Consequently, the throughput of data from this network of sites is 30 sites per hour per channel. Heavily used satellites have channel management problems, as the operators attempt to strike a balance between allocation of channels and rate of data retrieval.

Meteor burst data systems are comprised of data sites which respond to interrogations from one or more Master Stations. In contrast to satellites, the reporting schedule is determined by the user, and can be as frequent as desired, rather than scheduled for a specific time slot. In addition, short alphanumeric messages can be sent bidirectionally from the Master Station to the Remote Station or from the Remote Station to the Master Station, which constitutes a dual purpose use of the facilities - message communications as well as data acquisition. The availability of meteor trails is subject neither to the economic nor political decision process, since the trails occur naturally as a perpetual feature of the universe.

**METEOR BURST TELEMETRY IN USE**

**SNOTEL System - USA**
The SNOTEL system transmitted its first data from a remote site in the Cascade mountain range of Oregon to its two Master Stations near Boise, Idaho and Ogden, Utah in April of 1977. By October of 1980 there were 465 operational Remote Stations. The system has grown steadily, with a current count of about 540 Remote Stations.

Nearly all of the Remote Stations are located in forested, heavy-snow accumulation areas. They report water equivalent of the snowpack; precipitation catch in a storage gauge; air temperature; and the previous 24 hours maximum, minimum, and average temperature. A few special locations are equipped with other sensors, including tipping bucket precipitation; stream gauge height; wind speed and direction; relative humidity; soil moisture and soil temperature. Newly designed Remote Stations also transmit important information on site electronics conditions each day.

SNOTEL Remote Stations are interrogated by two Master Stations which, in turn, forward the data reports to a central computer facility. Project managers screen, edit, and retrieve data from the central location. Daily reports are received from 95 to 97 percent of the Remote Stations. Besides data reports, maintenance statistics generated by each Remote Station allow service personnel to evaluate the behavior and operational integrity of the Remote Station.
Data acquired by the SNOTEL system are used primarily to predict seasonal water supplies in a region of the western United States which is characterized by drastic variations in seasonal streamflow. Approximately 500 streamflow points are forecast several times each spring, prior to the snowmelt runoff season.

Hydrograph simulation models rely on the daily data, and some forecasts are updated throughout the season. Reservoir operations, hydroelectrical power generation, and flood hazard evaluation are other examples of the uses currently being made of SNOTEL data.

SNOTEL system reliability is continuously monitored by compiling statistics on several performance characteristics. These performance indicators have been discussed in previous works (Crook et al., 1987; Crook, 1985). In summary, the percentage of Remote Stations responding to each of the daily system-wide polls has steadily improved as maintenance personnel become more skillful and as they discover and rectify problems created by some inadequate practices on the part of the installation contractor. Failure of a site to report is attributed to inadequate battery power or component malfunction rather than absence of adequate meteor trails. Additional improvement has been gained by implementing new, higher performance hardware. In 1981 an average of 82.29 percent of all Remote Stations answered each daily poll within the required three hours. In 1986 the percentage was 95.44, with a range from 92.5 percent during February to 97.1 percent in June.

Another measure of performance is the time lag between the Master Stations' request for data and the Remote Station's response. This statistic is referred to as the average wait time, and appears to range between 4.5 minutes and 8.5 minutes, based on a monthly average of all 540 sites taken during the daily poll.

Alaska Meteor Burst Communication System (AMBCS) - USA

Following on the heels of the SNOTEL system, an interagency group procured a similar system to operate in Alaska. Included in the original user group were the Soil Conservation Service, National Weather Service, Army Corps of Engineers, Bureau of Land Management, and U.S. Geological Survey. Their system was installed in 1978, and consists of a single Master Station in Anchorage and 68 Remote Stations, including some Remote Stations within the Arctic Circle.

The system is dual-purpose, as it telemeters hydrometeorological data, and also provides alphanumeric communications with mobile survey and fire suppression crews. The system-wide polling of sites differs from SNOTEL in that AMBCS polls all sites each hour. The Master Station automatically sends all Remote Station responses to each participating user via common carrier and/or dedicated phone lines. Each agency does its own data retrieval and verification and data base management.

Data collected via the AMBCS is primarily snow water equivalent, precipitation, temperature, and wind speed direction and passage. These data are used for a wide variety of purposes: flood hazard assessment and warning; streamflow forecasting; hydroelectric project evaluation and design; snowpack effects on wildlife winter range; snow avalanche assessment and hazard warning; and fisheries management.

Comprehensive performance statistics are not readily available for the AMBCS, but limited and periodic samplings of the system operations indicates that performance is equivalent to SNOTEL's record.
A system of 255 Remote meteor burst data collection and alphanumeric communication stations is being installed along the Nile River in the Arab Republic of Egypt. The project is controlled by two Master Stations – one at the Delta Barrage, a short distance north of Cairo, and the other at Aswan. A large number of the data sites are clustered in the Nile River Delta region, with a significant number distributed along the river plain between Aswan and Cairo. The Remote Stations are located at barrages, first order irrigation canal intakes (where water is diverted directly from the river), and major pumping plants.

Most Remote Stations will sense and telemeter water level data: 143 sites will monitor the river and first order canal levels; 38 will monitor drainage pumping plants; 8 will report lake and reservoir levels; and 17 will measure ground water levels. At some of the data sites meteorological instruments and evaporation pans will be installed. These data will be used to drive the reservoir, river flow, and irrigation system operations models used by the Ministry of Irrigation to allocate and distribute the nation's water resources.

The NRIDCS will provide a much more sophisticated message sending capability than either SNOTEL or AMBCS. At 18 administrative regions along the Nile – referred to as directorates – communications terminals will be used to intercept and monitor data reports from the Remote Stations. These terminals will also be used to send and receive river status and control messages, using packet store-and-forward technique. Messages can also be sent from and received by the Remote Stations and Master Stations.

Consequently, messages of variable length can be sent from or to any point in the system. This will allow both maintenance and operational personnel to exchange information rapidly, and invites the use of meteor burst communications for control functions as well as data acquisition.

This multipath communications system will require that the Master Stations periodically interrogate all sites. When a message is queued for transmission, it will then be sent as soon as the Master Station's signal is received. This operation can then be readily adapted to Remote Station sensor data criteria checking and event reporting. System problems can then be discovered more quickly and actions taken to mitigate the effects of the malfunction or natural hazard.

An additional 300 Remote Stations are planned to be installed at second and third-order canal structures. This second phase of the NRIDCS is expected to be implemented as soon as the first phase is completed, in mid-1988. The feasibility of automating and controlling certain irrigation structure operations via the meteor burst system will be evaluated as a part of Phase Two.

A limited performance test of the system was conducted in early 1987. Fifteen Remote Stations and one Master Station were run in the operational configuration for 30 days, and their responses analyzed. Ten of the Remote Stations were within ground wave (line-of-sight) distance to the Master Station, and five were far enough away to operate in the meteor burst mode. Each was interrogated every two hours. All sites responded to all polls for the thirty days. All ground wave sites responded within the required two hours, and 97.7 percent of the meteor burst reports were received within the two hours. The aggregate response success rate was 99.2 percent, as compared to the contract specified minimum acceptable figure of 95 percent.
Argentina Systems

In Argentina, two systems have been installed for monitoring snow water equivalent, stream gauge height, and various other parameters. A third system has just been delivered.

The first of these systems, Agua Y Energia Electrica, has been operational for one year, and employs one Master Station and seven Remote Stations. The primary purpose of the network is to measure the water equivalent of the snowpack in the Andes. This system is currently operating at 100% efficiency, with an average wait time of approximately 10 minutes.

A second system, for Instituto Nacional de Cientia Y Tecnica Hidricas (INCYTH) is just coming online, and consists of one Master Station and eight Remote Stations. This system measures a variety of parameters, including rainfall, water evaporation, wind direction, wind speed, barometric pressure, humidity, temperature, and solar radiation. Each Remote Station collects data from its sensors once per minute; calculates the standard deviation and the minimum, average, and maximum values where applicable; and transmits hourly reports to the Master Station.

The latest system, for the Ministerio De Obras Serv. Publicos Y Vivenda, is equipped with a Host Computer at the Master Station for monitoring incoming data. The Host Computer has special alert warning software that can rapidly detect and report problems. One of the seven Remote Stations comprising this network will be located in Antarctica, on the Larsen peninsula, approximately 1,000 miles south of Ushuaia.

The Larsen Remote Station will be enclosed in a massive, heavily insulated enclosure which will protect the station against the severe environmental conditions of Antarctica.

Danjiangkou System (DJK) - China

The Danjiangkou network, implemented in May 1987, and now fully operational, consists of one Master Station and five Remote Stations. Two of the five are Remote Data Collection Stations; the other three are line-of-sight, low-power, transmit-only Remote Stations, and they are linked to the Master Station by a Relay Station. The network is designed for flood warning, although irrigation information can also be monitored. The Remote Stations are equipped with sensors to measure rainfall, water depth, and/or water flow.

The Master Station is situated at the east end of the Danjiangkou Reservoir. The two full-power Remotes are located in mountainous areas; they communicate with the Master Station via meteor burst, transmitting collected sensor data when polled by the Master Station. The three line-of-sight Remotes are all located along tributaries that are behind a mountain ridge; they transmit at user-selectable intervals, communicating only with the Relay Station on top of the ridge. The Relay Station transmits the collected sensor data to the Master Station.

CONCLUSIONS

Meteor burst appears to be a viable alternative to other hydrologic data acquisition systems, such as satellites, line-of-sight radio, and telephones. Meteor burst communications systems do not require extensive land-based facilities, neither do they suffer from resource allocation
problems. Meteor burst communications systems offer the user more control over collection of data, and can easily be installed in remote locations.

SNOTEL and AMBCS have demonstrated the reliability of meteor burst technology in hydrological data acquisition as an alternative to conventional line-of-sight or satellite systems. In 1986 the 540 Remote Stations in the SNOTEL system responded to the daily three hour poll at a 95.4 percent reliability rate. Recent new performance data indicate that an average wait time of 6.5 minutes can be expected between interrogation of the Remote Stations and their replies. In comparison, a GOES satellite based network of 540 self-timed sites would require six channels to retrieve all the sites in three hours, and the average wait time would be 90 minutes. Current applications of meteor burst show that systems can be installed in any environment and in the most remote locations. Data, messages, and event-actuated alarms and reports can be interchanged throughout these systems, allowing for maximum flexibility.

REFERENCES


