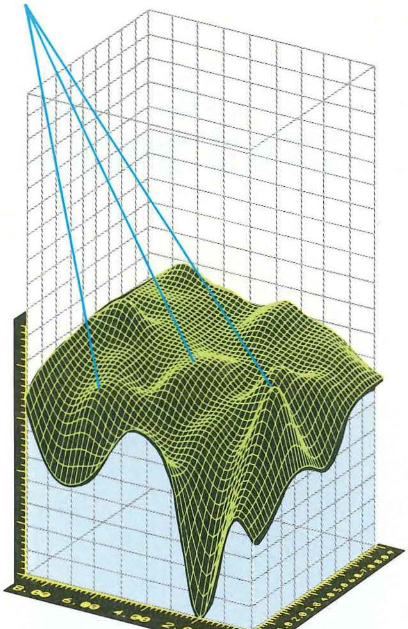

RINEX: The Receiver-Independent Exchange Format

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The survey in the January 1994 issue of GPS World *listed some 50 manufacturers of GPS receivers. Most of these manufacturers use their own proprietary formats for recording or outputting the measurements made by their equipment. This babel of formats could have been a problem for surveyors, geodesists, geophysicists, and others doing postprocessed GPS surveying who wanted to combine data from receivers made by different manufacturers. Luckily, a small group of such users had the foresight several years ago to propose a receiver-independent format for storing GPS data — RINEX. This format has been adopted as the* lingua franca *of GPS postprocessing software, and most manufacturers now offer a facility for providing data from their receivers in this format. This month, one of the authors of RINEX, Dr. Werner Gurtner of the University of Berne's Astronomical Institute, outlines the evolution of the format, its inherent philosophy, and the structure of its files.*

"Innovation" is a regular column in GPS World *featuring discussions on recent advances in GPS technology and its applications as well as on the fundamentals of GPS positioning. The column is coordinated by Richard Langley and Alfred Kleusberg of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick. We appreciate receiving your comments as well as suggested topics for future columns.*

Most of the high-precision GPS applications in geodesy and surveying involve postprocessing of the data collected by two or more receivers in a differential mode. Postprocessing means that the data must be stored and transferred to a computer after collection for processing some time later. In differential processing, the data simultaneously collected by two or more receivers are processed to determine the relative or differential receiver coordinates. Usually one of the receivers (actually, its antenna) is placed on a survey marker whose coordinates are precisely known in a well-defined coordinate system, so that the coordinates of the other receivers can be expressed in the same system.

Although all the geodetic-quality receivers on the market measure the same basic GPS observables (pseudorange and carrier phase on one or two frequencies), all the manufacturers have developed their own file formats for data storage and optimized them for their particular receiver with provisions for including additional engineering and auxiliary data. To save storage space and to increase data-handling efficiency, most of these formats use some kind of binary representation. (See the sidebar on this page for a brief, general discussion of computer file formats.) The postprocessing software specially developed for a receiver by a manufacturer and usually sold in a package with the receiver knows exactly how to read and interpret these original data files.

There is a potential problem, however, when we try to use one manufacturer's software to process the data from another manufacturer's receiver. The program is immediately faced with a variety of format, data, and file types. Additional problems can arise if the (binary) data are processed on computer platforms with different operating systems (such as DOS, Unix, and VMS), which typically use different internal number representations.

There are two solutions to this problem. Either we develop front-end software programs to interpret and convert the raw data for each receiver type, or we define a unique data exchange format and provide software to convert the raw data into this exchange format. With the latter option, a postprocessing program can readily interpret data from any receiver type, provided it accepts the exchange format as one of its data input formats.

The first solution has the advantage of being independent of any external interventions. It does not require coordination among

Binary and Text Files

Binary files, unlike text files, are not intended to be understood directly by computer users. These files store information using binary numbers — the native language of computers. Binary files are used to store executable computer programs and data that will be read directly into programs. Text files, usually coded using the American Standard Code for Information Exchange (ASCII — pronounced "as-kee") and therefore often called ASCII files, are usually meant to be read by computer users but can also be used for storing data that will be read by a program. Almost all computers, regardless of make, can read standard ASCII files.

The ASCII alphabet is a 7-bit code consisting of $2^7 = 128$ characters, representing all the letters (upper and lower case) of the English alphabet, the numbers 0 through 9, some special printable characters such as the ampersand, and control characters used for controlling the actions of a computer or a peripheral device. Developers of computer-operating systems have extended the standard 7-bit ASCII alphabet to various (usually incompatible) 8-bit alphabets that include special symbols and characters from foreign alphabets. Although the standard ASCII character format allows files to be shared among different kinds of computers, there is a penalty to pay. Such files tend to be much larger than their binary counterparts. The number −123.4567, for example, typically requires 4 bytes (each byte consisting of 8 bits) if stored in binary fashion, but 9 bytes (one for each character) if stored in ASCII format. — R.B.L.

receiver manufacturers, software developers, and users as long as all necessary information for the interpretation of the raw data is available to the software. However, it does not solve the problems associated with the transfer of binary data to different platforms, and it heavily depends on precise (and up-to-date) knowledge of the various raw data file formats used by different manufacturers. Furthermore, this approach is uneconomical in that the same or similar developments have to be carried out for each postprocessing program.

The second solution shifts the responsibility of data conversion to only a handful of programs. Basically, we need only one conversion program per receiver type (or rather one per raw data format). In the ideal case, it's the receiver manufacturer who makes the conversion program available. But there is one important obstacle to this solution: we have to agree upon the common data exchange format!

BACKGROUND

Geodesists, in particular, have been keenly interested in combining data from receivers produced by different manufacturers, and by the late 1980s, different groups of us had developed four data exchange formats to enable such combinations:

- The FICA (Floating Integer Character ASCII) format was developed by the Applied Research Laboratory of the University of Texas, Austin. This format basically maintained all the information found in the raw receiver data files, but it also provided computer-independent access to character, integer, *and* binary data.
- The ARGO (Automatic Reformatting GPS Observations) format was developed by the U.S. National Geodetic Survey (NGS) to distribute tracking data collected by various receiver types within CIGNET (the Cooperative International GPS Network). It contained only the information absolutely necessary for processing the data and did not allow for new data types or for the inclusion of auxiliary information, such as station descriptions (names, antenna heights, and so on). It was defined as an ASCII format, and as such it made moving from one system to another easy.
- An ASCII exchange format was developed by the Geodetic Survey of Canada for internal use.
- The RINEX (Receiver-Independent Exchange) format, a draft version of an exchange format developed at the Astronomical Institute of the University of Berne, was to be used for the exchange of data among the institutions participating in EUREF — the large GPS campaign to establish a pan-European high-accuracy geodetic reference network — in May 1989, involving about 60 receivers from four different manufacturers.

The authors of these formats, including myself, met during the Fifth International Geodetic Symposium on Satellite Positioning in Las Cruces, New Mexico, in March 1989, to discuss the differences among the formats and to try to agree on a single recommended format. Fortunately, we concluded an agreement quickly and presented it at a data format workshop held during the symposium.

The proposed common exchange format basically follows the draft RINEX format with a few modifications. Those attending the workshop accepted the format — dubbed RINEX Version 1 — and it became the recommended format within the geodetic community.

More workshop discussions on data format were held a few months later, in August 1989 at the General Meeting of the International Association of Geodesy in Edinburgh, United Kingdom, and again the following year, in September 1990, at the Second International Symposium on Precise Positioning with GPS, in Ottawa, Canada. From those discussions, Version 2 of RINEX emerged. It facilitates the inclusion of rapid static and kinematic data and includes other minor improvements.

The latest change to RINEX was discussed at the International GPS Service for Geodynamics (IGS) meeting in Berne, Switzerland, in March 1993, and it was subsequently distributed to all interested parties. It only concerns the proper flagging of the data collected under antispoofing (AS) and is in fact such a small change that it does not justify the generation of a new version.

In the meantime most manufacturers of geodetic GPS receivers, and some others as well, offer programs to convert the data from their receivers into RINEX Version 2. Many manufacturer-supplied postprocessing program packages also contain options to process data given in the RINEX format. In addition, some more general, research-oriented GPS program systems (such as the Bernese) contain conversion modules for various receiver types.

After this short historical overview, we now turn to the basic philosophy behind the RINEX exchange format.

THE FORMAT

A data exchange format should have a number of requisite characteristics, including:

- easy portability between different computer operating systems
- easy readability by software and users alike
- minimum-size storage files
- easy expandability to absorb new observation types
- access to all site-dependent information within each file for easy differential postprocessing
- no redundancy
- information limited to that needed for processing (that is, not an archive format)
- omission of formatting provisions for real-time data transmission (that is, checks for transmission errors and special synchronization information are unnecessary).

The RINEX pure-text (ASCII) format meets all of these conditions except for the third. Smaller-size files could certainly be obtained by selecting binary formats, and such files could shrink even more using differential (incremental) algorithms — but only at the expense of the first two requirements, portability and readability. We judged these factors to be more important than size minimization, especially given that there are many compression/decompression routines available that can easily reduce the storage size or data transmission time of text files by a factor of three or more. The size of an average RINEX observation file containing the uninterrupted data from one station, at a 30-second sampling interval, for a whole day ends up being about 1.5–2 megabytes, which can be compressed down to about 500–600 kilobytes. To allow easy inspection of the file contents on a computer screen, the maximum line (record) length of the text files was restricted to 80 characters.

To date, three different RINEX file types have been defined:

- observation files
- broadcast navigation message files
- meteorological data files.

Each file basically consists of a header section, with information describing the file contents and information that remains constant for the whole file (such as file type, station name, observation types to follow, approximate station position, antenna height, and so on) and a section containing the actual data. RINEX Version 2 also permits additional header records to be inserted into the data section. Such records can account, say, for changes in the station information during data collection (such as occurs for rapid static surveys and kinematic data).

To further improve visual readability, in columns 61–80, each header record contains a textual descriptor of the contents of the record. This descriptor is part of the format and as such is exactly defined. It also allows (within certain limitations) a free ordering of the header records within the header section. The Version 2 header section ends with an "END OF HEADER" record.

The RINEX format definition also contains recommendations for naming the different files (see Figure 1).

RINEX Observation Files. Most geodetic postprocessing software for GPS data uses a well-defined set of observables (see "The GPS Observables," *GPS World,* April 1993, for further details):

- the *carrier-phase measurement* on one or both carriers (actually a measurement of the phase of the beat signal generated by combining one of the received carriers of the satellite signal with a receiver-generated monochromatic reference signal)
- the *pseudorange (code) measurement,* equivalent to the difference between the time of reception (expressed in the time frame of the receiver clock) and the time of transmission (expressed in the time frame of the satellite clock) of a code transition in the satellite signal
- the actual *time of observation* of the above quantities, expressed either in the time frame of the satellite clock at signal transmission or in the time frame of the receiver clock at signal reception.

It is important to define precisely the meanings of the observables in RINEX observation files so that they can be properly interpreted by the processing software.

Most receivers store the time of observation in received-signal receiver time — valid for both code and phase observations. These receivers also synchronize the observation times of the simultaneously tracked satellites so that the observations for all satellites are made at the same instant. Because the clock in each receiver is essentially free-running, the true observation times may differ from receiver to receiver. But the differences will in general be less than one millisecond, because all geodetic receivers synchronize their clocks to true GPS Time to this level or better in order to help eliminate the effect of selective availability in differenced data. (For a discussion of satellite and receiver clocks and the various time scales used in GPS, see "Time, Clocks, and GPS," *GPS World,* November/December 1991.)

It is important to define precisely the meanings of the observables in RINEX observation files so that they can be properly interpreted by the processing software. The following definitions have been adopted:

- *Time.* The time of the measurement is the receiver time of the received signals. It is identical for phase and code and for all satellites simultaneously observed. It is expressed in the GPS time frame — not in Coordinated Universal Time (UTC).
- *Pseudorange.* The pseudorange *(PR)* is the difference between the receiver clock time at signal reception and the satellite clock

File type	ASCII file	Compressed file Unix	VMS	DOS
Observation File	ssssdddf.yyO	ssssdddf.yyO.Z	ssssdddf.yyO_Z	ssssdddf.yyY
Navigation File	ssssdddf.yyN	ssssdddf.yyN.Z	ssssdddf.yyN_Z	ssssdddf.yyX
Met Data File	ssssdddf.yyM	ssssdddf.yyM.Z	ssssdddf.yyM_Z	ssssdddf.yyW

Key to Figure I:
ssss: 4-character station code
ddd : day of the year of the first record
f : file sequence number within the day
yy : year

Figure 1. Recommended naming conventions for the three RINEX file types are shown above. The conventions for compressed files are platform dependent.

```
    2                 OBSERVATION DATA    G (GPS)                RINEX VERSION / TYPE
TRRINEXO V2.3.4 LH  L+T                   07-APR-94 00:42        PGM / RUN BY / DATE
Zimmerwald LT88                                                  COMMENT
ZIMM                                                             MARKER NAME
LOGST/COMPAQ        L+T                                          OBSERVER / AGENCY
2691                TRIMBLE 4000SSE        5.68                  REC # / TYPE / VERS
67905               4000ST L1/L2 GEOD                            ANT # / TYPE
  4331297.2640   567555.5480  4633133.8904                       APPROX POSITION XYZ
        0.0000        0.0000        0.0000                       ANTENNA: DELTA H/E/N
    1     1                                                      WAVELENGTH FACT L1/2
    5    C1    L1    L2    P2    P1                              # / TYPES OF OBSERV
   30                                                            INTERVAL
  1994     4     6     0     1   30.000000                       TIME OF FIRST OBS
                                                                 END OF HEADER
 94  4  6  0  1 30.0000000  0  8 29  2  1 31 25  7 15 14
  23734665.672    -5202516.134 5  -3946701.99046  23734662.3674
  24818676.758       31634.756 5
  23897306.945     3652408.601 6   2957592.98846  23897305.2814
  24422240.859    13087773.974 5  10316673.22246  24422238.9844
  24861950.883    -1292690.523 5   -131987.20146  24861950.4494
  22693648.602    -8726376.425 6  -6644038.11147  22693646.6334
  20281211.250   -14289330.419 8 -11044112.52949  20281210.5124
  20850344.086   -15892124.748 7 -12280932.15549  20850342.3054
 94  4  6  0  2  0.0000000  0  8 29  2  1 31 25  7 15 14
  23718574.414    -5287077.516 6  -4012593.96546  23718571.5314
  24835140.453      118156.671 4
  23918043.766     3761380.550 6   3042506.20046  23918041.9844
  24448484.891    13225687.753 5  10424138.50546  24448481.4344
  24852859.758    -1340473.462 5   -169220.63246  24852858.2344
  22684725.992    -8773263.781 6  -6680573.70447  22684725.0554
  20288847.508   -14249203.099 8 -11012844.48749  20288846.7584
  20847228.758   -15908493.673 7 -12293687.15849  20847227.8324
                                . . .
```

Figure 2. The first part of a RINEX observation file is shown above. The data in this file were collected by a dual-frequency receiver at the University of Berne's Zimmerwald Observatory on April 6, 1994. Note that blanks appear for P1 observations as all the data shown are from Block II satellites with antispoofing in effect.

time at signal transmission and as such differs from the signal travel time by the receiver and satellite clock offsets from GPS system time:

$$\text{PR(sec)} = \text{travel time} + \text{receiver clock offset} - \text{satellite clock offset}$$

or, in units of distance:

$$\text{PR(m)} = \text{electromagnetic range} + c \times (\text{receiver clock offset} - \text{satellite clock offset})$$

where c is the speed of light.

The pseudorange is stored in the RINEX files in units of meters. The RINEX format accepts the three specific pseudorange observations: C1 (based on C/A-code measurements on the L1 frequency) and P1 and P2 (based on P-code measurements on L1 and L2, respectively). Some receivers don't collect pseudorange observations on the L2 frequency under AS; instead, they determine the ionospheric delay difference between the two Y-code (encrypted) signals (Y2−Y1) using a correlation technique. In this case, the RINEX converter may generate synthetic P2 observations using the C/A-code observations and this Y2−Y1 ionospheric delay difference. Such observations are appropriately flagged as AS-affected.

■ *Phase.* The phase observation *(L)* is the carrier phase (or actually the phase of a beat frequency signal) continuously measured in cycles of the carrier wavelength for either the L1 or L2 carrier. (Half-cycle data collected by squaring-type receivers must be converted into whole cycles and appropriately flagged by the wavelength factor in the header section of the file.) The phase must be expressed in the same sense as the pseudorange (that is, an increase in the pseudorange implies an increase in the phase value, which is opposite to the integrated Doppler count). The RINEX format designates the phase observables as L1 and L2. Some early-generation GPS receivers stored only the fractional parts of the phase observations or ambiguous pseudoranges, and code and phase were not necessarily observed at the same instant. The conversion software therefore had to manipulate the data to a certain extent before the actual reformatting could be carried out.

■ *Doppler.* To allow special processing software to make use of the Doppler frequency measured by some receivers, the optional observables D1 and D2 have also been defined. These observables, if present in a RINEX file, are expressed in Hertz.

None of the observables in a RINEX file must be corrected for external biases like atmospheric refraction or satellite clock offsets.

If the receiver or the converter software adjusts the measurements using real-time–derived receiver clock offsets, *dT(rcvr),* the consistency of the three basic quantities of phase, pseudorange, and time must be maintained. This requires that the receiver clock correction be applied to all three observables:

$$\mathrm{L_i\,(corr) = L_i\,(rcvr) - freq_i \times dT(rcvr)}$$
$$\mathrm{PR_i(corr) = PR_i(rcvr) - c \times dT(rcvr)}$$
$$\mathrm{Time(corr) = Time(rcvr) - dT(rcvr)}$$

where the subscript i indicates the carrier (1 = L1, 2 = L2) and $freq_i$ is the frequency of carrier i.

Although the format of each element in the observation file has been exactly defined, the number of the observables and the order in which they appear in the observation records can be adjusted to match the properties of the receiver. Thus we need to reserve space in the records only for those observation types that are actually generated by the receiver, and we can achieve a substantial reduction in the file size because most computer systems allow for variable record lengths. The list of the observation types and their order in the records are defined in the header section of the file.

Each RINEX observation file usually contains the data collected by one receiver at one station during one session. Version 2 of the format also allows files to hold all the data collected in sequence by a roving receiver during rapid static or kinematic surveys. The first part of a RINEX-formatted observation file is shown in Figure 2.

RINEX Navigation Message Files. The navigation message file contains the orbit data for the satellites tracked, satellite clock parameters, information on the health of the satellites, and the expected accuracy of the pseudorange measurements. The file contains all the navigation messages collected by a GPS receiver during a certain time period (usually for the same session covered by the corresponding observation file). To simplify postprocessing and to increase temporal coverage, a composite file containing all (nonredundant) messages collected during the session by all receivers in a campaign can be created.

The file header section optionally may contain some additional data from the navigation message, such as the parameters of the single-frequency ionospheric delay model and correction terms relating GPS Time to UTC.

```
     2              NAVIGATION DATA                         RINEX VERSION / TYPE
TRRINEXN V2.5 LH    L+T / AIUB          07-APR-94 00:53     PGM / RUN BY / DATE
Zimmerwald LT88                                             COMMENT
                                                            END OF HEADER
29 94  4  6  2  0  0.0 0.114352442324E-04 0.454747350886E-12 0.000000000000E+00
    0.500000000000E+01 0.461562500000E+02 0.465019369923E-08 0.268278611498E+01
    0.233389437199E-05 0.504723004997E-02 0.878237187862E-05 0.515370262527E+04
    0.266400000000E+06 0.465661287308E-07 0.145517086011E+00-0.465661287308E-07
    0.954467795998E+00 0.204968750000E+03-0.183352377861E+01-0.800819071614E-08
    0.260367988229E-09 0.100000000000E+01 0.743000000000E+03 0.000000000000E+00
    0.320000000000E+02 0.000000000000E+00-0.931322574615E-09 0.500000000000E+01
    0.259200000000E+06 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
 1 94  4  6  2  0  0.0-0.162012875080E-04-0.216004991671E-11 0.000000000000E+00
    0.236000000000E+03 0.507812500000E+02 0.470126725522E-08-0.244763561108E+01
    0.255368649960E-05 0.353195995558E-02 0.833906233311E-05 0.515371101761E+04
    0.266400000000E+06 0.130385160446E-06 0.188545523895E+00 0.111758708954E-07
    0.955632498227E+00 0.219000000000E+03-0.117514318047E+01-0.807462205471E-08
    0.214651798252E-09 0.100000000000E+01 0.743000000000E+03 0.000000000000E+00
    0.320000000000E+02 0.000000000000E+00 0.139698386192E-08 0.492000000000E+03
    0.259200000000E+06 0.000000000000E+00 0.000000000000E+00 0.000000000000E+00
                                    . . .
```

Figure 3. The first part of a RINEX navigation message file is shown above. The data shown are for satellites PRN 29 and PRN 1 at 02:00 UTC on April 6, 1994.

```
     1              METEOROLOGICAL DATA                     RINEX VERSION / TYPE
XL:MET_BATCH        AST.INST. BERNE     06-APR-94 00:00     PGM / RUN BY / DATE
HAENNI MET.SENSOR                                           COMMENT
ZIMMERWALD                                                  MARKER NAME
     3    PR    TD    HR                                    # / TYPES OF OBSERV

 94  4  6  0  0 10  907.3    -0.7   83.6
 94  4  6  0 30 10  907.0    -0.8   81.7
 94  4  6  1  0 10  906.8    -0.6   76.5
 94  4  6  1 30 12  906.8    -0.6   82.8
 94  4  6  2  0 12  906.6    -1.1   95.1
 94  4  6  2 30 11  906.1    -1.1   99.3
 94  4  6  3  0 12  905.9    -0.9   94.8
 94  4  6  3 30 10  905.7    -0.9   94.4
 94  4  6  4  0 10  905.3    -1.5   99.1
 94  4  6  4 30 10  905.2    -1.8   99.8
 94  4  6  5  0 11  905.0    -1.9   99.2
 94  4  6  5 30 12  904.9    -1.9   99.6
                                    . . .
```

Figure 4. The first part of a RINEX meteorological data file with measurements of surface pressure, temperature, and relative humidity at Zimmerwald Observatory on April 6, 1994, at half-hourly intervals.

A large part of the navigation message file format is based on the NGS ARGO format. The first part of a navigation file is shown in Figure 3.

RINEX Meteorological Data Files. A simple RINEX format has also been defined to simplify the exchange and processing of meteorological data collected at observation sites. It follows the same principles used for the definition of the RINEX observation files. The data appearing in the files include time-tagged, calibrated surface values of barometric pressure in millibars; the dry air temperature in degrees Celsius; relative humidity in percent; and (optionally) the zenith wet tropospheric path delay in millimeters, obtained from water vapor radiometer data. Each file contains the data collected at one site for a certain time period. Figure 4 shows the first part of a meteorological data file.

CURRENT AND FUTURE STATUS

Discussions on the definition and further improvement of the RINEX format have taken place mainly at large, international, scientific GPS symposia. The promulgation of the format definitions was assured through the symposia proceedings, through publications of the International Association of Geodesy, and by direct contact between the format authors and receiver and software manufacturers.

In the last two years, the International GPS Service for Geodynamics, a worldwide Navstar satellite tracking service (see "Geodynamics: Tracking Satellites to Monitor Global Change," by Gerhard Beutler, Peter Morgan, and Ruth E. Neilan, *GPS World,* February 1993), has become one of the most important user communities for the exchange and use of (compressed) RINEX files. The tracking data from more than 40 global, permanently operating GPS stations are automatically collected and redistributed through computer networks, processed for precise orbit determination, and made available to interested parties. As mentioned earlier, the latest changes to the RINEX format were proposed at the 1993 IGS meeting in Berne.

A number of small changes to the format will be implemented in the very near future. These concern mixed GPS/GLONASS observation files, the definition of the time system used by GLONASS, the possibility of explicitly defining sampling rates smaller than one Hertz, additional parameters in the navigation file, and the formal introduction of a file format for GLONASS navigation messages. The appointment of an organization responsible for the "official" maintenance of the RINEX format is still an open issue.

Additional information on the evolution of the RINEX format can be found in "Summary of the Workshop on GPS Exchange Formats," by Alan Evans, in the *Proceedings of the Fifth International Geodetic Symposium on Satellite Systems,* held in Las Cruces, New Mexico, in March 1989; and "The RINEX Format: Current Status, Future Developments," by Werner Gurtner and Gerald Mader in the *Proceedings of the Second International Symposium on Precise Positioning with the Global Positioning System,* held in Ottawa, Canada, in September 1990. The current RINEX file definitions can be found in the IGS Central Bureau Information System (CBIS). Access to CBIS is by means of anonymous ftp (file transfer protocol) through the Internet. The node address is sideshow.jpl.nasa.gov, and the designation of the file is /igscb/data/format/rinex2.txt. More information about IGS and CBIS can be obtained by sending an e-mail message to igscb@cobra.jpl.nasa.gov or by fax to (818) 393-6686. ■