Data Requirements for Motion Pictures and Single Pictures

Pictures and figures are used in publications. Many families now have camcorders to take motion pictures. There are many cases in the sciences where the use of motion pictures permits people to grasp a meaning that they would otherwise miss. In the computing and graphics industries some of the digital graphics capability is starting to come together. Developing the technology and methods to handle the large data volumes associated with the digital graphics has been a problem. It is worth briefly looking at the status of this capability.

1. Data Volume for a Digital Movie

How much data is in a movie? A typical movie runs for 135 minutes. The data flow needed is large, even after the data is compressed:

- 3500 kilobits/sec for full motion video (after compression is used)
- A sound track uses 384 kbits/sec and movie producers wanted three of these for three languages.
- A subtitle track takes 10 kbps, and producers wanted four of these for more languages.

This total data rate is 4692 kbits/sec which gives about 4.5 GB for the whole movie (this volume is about seven of today's CD-ROMs).

The data volume for a motion picture is extremely high if the data are not compressed. Consider a picture of 800 x 600 resolution. Also suppose that 24 bits are used to define the color and intensity for each pixel. A motion picture requires 30 frames per second or else the picture may appear jumpy (I am a bit puzzled because people used to say that 24 frames/sec were OK). Anyway, the data rate for this resolution and a rate of 30 fps would be 345.6 megabits per second, which also gives about 100 times more data volume than people are planning for a video disc. Data compression explains this. Methods such as MPEG - 2 have been developed that can compress the picture to use much less data while changing the picture quality very little. The methods take advantage of the fact that neighboring pixels often have the same color and that things do not change too rapidly with time. It is a great technical achievement to be able to decompress the data stream fast enough to present a good movie.

The movie industry wants to be able to distribute movies for home use on CD-ROMs and not on VCR tapes. By fall 1996 this may start to happen. Present CD-ROMs hold up to 680 MB. This is not enough to store a movie. In mid 1995, people worked very hard to merge two standards to define a new CD-ROM called DVD (digital video). The new standard calls for two layers of recording on one side of a disc. One layer holds 4.7 GB of data and with two layers, the total on one side is 8.5 GB. Since these are both on one side, there is no need to flip the disc.

From Computer Shopper (March 96), p 180, by Alfred Poor
2. Handling Lower Grade Video

People want to provide video clips in CD-ROM's and still keep the data volume under control. Suppose that they use 320 x 240 pixels per picture, they only use 15 bits of data for color instead of 24, and settle for a jumpy 15 fps instead of 30. Even this lower quality still needs 2.16 MB of data for each second. Therefore, compression is still necessary. There are several schemes to compress the data such as Indeo, Cap'n Crunch, and Cinepak. MPEG could be used, but very few computers have MPEG hardware to decode pictures yet, and the rest of the people are unlikely to upgrade their PC's. Therefore, people use software decompression. "Motion Pixels" is another one of these methods. A resolution of 320 x 240 pixels is good only for about a 1/4 screen picture. This software ($299) can also interpolate pixels to produce a full screen video, and it can interpolate for twice the frames to produce smoother video motion.

From Computer Shopper (April 1996), p 203, by Alfred Poor


Everyone is familiar with the camcorders that have become very popular to take home movies. Although the generation of equipment in use may have digital features, they store the data in an analog format (not digital). VHS and 8 mm formats deliver 240 horizontal lines of resolution; super VHS and Hi 8 give 400-plus lines. Digital video gives 500, which gives even better image quality than video laser disks. The data is stored on digital form which means that people can edit the video and make copies of copies without losing quality. The white speckles of "snow" in home video is caused by video noise. The picture color, clarity, stability and lack of noise for digital video are far better than what people have been used to--and the sound is great too. Three of these video cameras are now on the market--for about $3000 (still too expensive for big sales). The cameras have built-in data compression to control the data volume. The problems are the camera cost, the tape cost ($12), and there are no digital VCR's yet. Not all the camcorders have a digital output, so don't count on the benefits of good digital copies as yet. Hopefully, these problems will gradually be solved. The author predicts that before very long it will be as hard to find an analog camcorder as it is to find a vinyl LP record. (Based on Popular Photography, April 1996, p 48 - 50 by Elinor Stecker-Orel)


These cameras have arrays of little photocells that are something like the receptor cells in an eye. The resolution is still poorer than 35 mm film and they cost more than a 35 mm camera, but the pictures are actually becoming very interesting. They are very useful for a number of tasks. Look for articles that show how pictures from various cameras compare for a given color scene. Some articles are:

1) In PC Magazine, Feb 6, 1996; Very good comparisons by Grotta & Grotta
2) In Computer Life, Feb 1996; Shows pictures of a barn and fall tree colors using the same six cameras listed in Table 1.
3) In *Popular Photography*, April 1996: Shows pictures and blowups to help show resolution (by M. McNamara). Two of the best are Apple & Kodak.

**TABLE 1. The lowest priced set of digital color cameras in early 1996.**

<table>
<thead>
<tr>
<th>MODEL</th>
<th>LIST</th>
<th>RESOL.</th>
<th>STOR. HI</th>
<th>PIX. STD.</th>
<th>AMOUNT OF MEMORY (MB)</th>
<th>RATIO COMPRESS (HI QUAL)</th>
<th>DOWNLOAD TIME ONE PICTURE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apple Quick Take 150</td>
<td>$739.00</td>
<td>640 x 480</td>
<td>16 32</td>
<td>1</td>
<td>14.7</td>
<td>9 sec.</td>
<td></td>
</tr>
<tr>
<td>Casio QV - 10</td>
<td>$995.00</td>
<td>480 x 240</td>
<td>96 96</td>
<td>2</td>
<td>16.6</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Chinon ES - 3000</td>
<td>$1,095.00</td>
<td>640 x 480 or 320 x 240</td>
<td>5 40</td>
<td>1</td>
<td>4.6</td>
<td>48</td>
<td></td>
</tr>
<tr>
<td>Dycom 10 - C</td>
<td>$999.00</td>
<td>640 x 480 or 320 x 240</td>
<td>5 40</td>
<td>1</td>
<td>4.6</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>Kodak</td>
<td>$995.00</td>
<td>756 x 504</td>
<td>48 96</td>
<td>4</td>
<td>13.7</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Fotoman Pixtura</td>
<td>$949.00</td>
<td>768 x 512 or 384 x 256</td>
<td>48 144</td>
<td>4</td>
<td>14.2</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

Some of these cameras have street prices of $500 to $750. They say that a 640 x 480 picture can be printed up to a size of about 3.2 x 2.4 inches without showing resolution effects. The gains in quality have been rapid over the past two years. All six cameras listed in Table 1 use 24 bit color. This means that they use 8 bits (256 levels) for each of the primary colors. These cameras have about 400,000 pixels in a picture compared with about 17 million in a 35 mm film picture.

The Chinon ES - 1000 digital camera captures 501 by 370 pixels. It stores 8 images and costs $499. It weighs 4.2 ounces (a March 1996 ad). The Casio QV - 10 sells for $629, and the Chinon ES - 3000 sells for $799 in a March 1996 ad (both are shown in Table 1). The new Epson color camera sells for $499 and uses a resolution of 640 by 480 pixels (a new Mar 1996 ad).
5. High End Digital Cameras (April 1996)

The cameras below have a higher resolution (and higher price) than the $500 - $800 cameras for the consumer market. As in all the digital SLR cameras they tested, the user can take the smaller compressed files to the computer and only decompress them as needed.

<table>
<thead>
<tr>
<th>CAMERA</th>
<th>RESOLUTION</th>
<th>PIXELS (10^6)</th>
<th>PRICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kodak EOS DCS 5c</td>
<td>1012 x 1524</td>
<td>1.54</td>
<td>$11,995</td>
</tr>
<tr>
<td>Minolta RD - 175</td>
<td>1146 x 1528</td>
<td>1.75</td>
<td>$9,995</td>
</tr>
<tr>
<td>Fujix DS 505</td>
<td>1000 x 1280</td>
<td>1.28</td>
<td>$12,780</td>
</tr>
<tr>
<td>Kodak DCS 460</td>
<td>2036 x 3060</td>
<td>6.23</td>
<td>$27,995</td>
</tr>
</tbody>
</table>

What is the equivalent resolution of a 35 mm film picture? The film area is 24 mm x 36 mm. The resolution of the film is equivalent to about 70 pixels per mm on the film (or 1680 x 2520) or 4.23 million pixels. Using 3 bytes (24 bits) each for an RGB color pixel, it would take 12.70 Mbytes to store this picture (Based on Popular Photography, April 1996, p 70 - 73, M. McNamara).

Note that the Kodak DCS 460 has 6.23 m pixels, which would require 18.7 Mbytes to store. This is about the information density that Kodak assigns to a 35 mm slide.

Polaroid announced a new digital camera in Mar 1996. It is the PDC 2000, which also uses 24-bit color. The resolution is 1600 x 1200 pixels. The article says that the images are not compressed. A model that only connects to a computer sells for $2995 (list), and two models that store pictures are $3695 and $4995. They note that these prices are less than the competitors. It is true; see the list of prices above. (From Investors Business Daily, March 12, 1996 --some garbles in article)

6. Home Pictures and 35mm Slides on CD-ROM:

For a few years Kodak has offered a service to scan a 35 mm picture (gives about 18 Mbytes) and compress this to 6 Mbytes. Then 100 of these pictures (600 MB) are put onto a CD-ROM that the customer can take home to view on computer or TV screens, in addition to having the prints. The resolution of the pictures on the CD-ROM is 2048 x 3072 pixels. This is higher than necessary to view on a computer or TV screen, but it allows one to zoom in on part of the picture. The CD-ROM also has the same pictures in a low resolution (128 x 192 pixels) for "thumbnail" indicies to decide what pictures you want, and at a mid resolution for normal viewing.
Big Datasets Are Different

Big datasets have special properties; their size means that they should have some special attention in order to ensure that computer timing is okay, data volume is constrained, cost is constrained, and that volume and cost does not prevent data use.

1. Large and small datasets are different

Large and small datasets have different properties in data systems, and there should be a separate focus on each. There are examples of data systems that deliver even 25,000 modest size files of data per week at low cost. For large datasets, there should be a special analysis to determine the best methods to handle the data so that data flows are good, and costs are controlled. There is text information about these problems.

The tendency to just treat small and large datasets equally in data system planning should be avoided. Some organizations already work with big datasets. The comparison of methods and costs with a selection of other data systems is essential for learning from experience and avoiding excessive costs.

2. Many DAACs and PIs need basic data

There are two choices to let DAACs and PIs use data:

- Move data to them
- Let them compute at a central place (under present plans, access to lots of basic data is hard).

3. Data subset selection

There are two main approaches to extract subsets. It may be necessary to extract subsets in order to provide users with useful amounts of data.

- Automatic within a big system (as in EOSDIS). Will the timing be okay?
- Use data select modules that operate on big data streams (case 2 will probably have better timing and less complexity).

4. For EOS, all basic data is 200 GB/day

A volume of 200 GB/day is a lot of data. Can we move it and process it?

- Using 6250 tapes, this is 15 cartridges per day.
- Using 1996 technology, this is 10 media cartridges per day.
- Using simple compression, this is 3 cartridges per day (or 100 per year).
5. The ability to copy very large datasets is better than people think

If we use 1996 technology, the cost to make 10 copies of 200 TB per year is about $3M per year.

- This cost is much, much lower than people realize.
- We are not using technical opportunities to move large datasets and control costs.

6. Big datasets; two ways to handle them

I am not aware of a special focus within EOSDIS to make sure that the big data flows will work well. I think that the following comparison is probably accurate.

<table>
<thead>
<tr>
<th>Present EOSDIS</th>
<th>Another approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data must be loaded into the system</td>
<td>No need for system load</td>
</tr>
<tr>
<td>Use a standard format</td>
<td>Use a local format, if better</td>
</tr>
<tr>
<td>Data paths may have timing trouble</td>
<td>Clean and fast data paths</td>
</tr>
<tr>
<td>Software is complex</td>
<td>Much less software</td>
</tr>
<tr>
<td>These methods are risky</td>
<td>These methods will work</td>
</tr>
<tr>
<td>Can have bad cost problems</td>
<td>Cost is quite low</td>
</tr>
<tr>
<td>Little or no experience for large datasets</td>
<td>There is experience with this approach</td>
</tr>
<tr>
<td>Are locked into methods</td>
<td>Are not locked into big systems</td>
</tr>
</tbody>
</table>

7. The 10-year global-scale problem

There are many cases where we need reliable data for variables over a 10- to 30-year period, or more. We need to make sure that our data plans support these projects. Such work can be prevented if there is an excessive amount of data to cope with.

- Handling the 10-year problem is necessary for success.
- Products must periodically be recalculated using new algorithms.
- In many cases, full data resolution is not necessary (as in ISCCP).
  - So we can define a sampled subset with 1% to 10% of full volume.
  - It is easy to make copies of this subset.
  - This reduced dataset (still primary data) will often meet 80% to 90% of the science needs.

(This is not handled well in present plans. A special focus on how to handle big datasets is needed.)
8. The ISCCP project (cloud climate)

This project uses data from a polar orbiter and 3 or 4 geosynchronous satellites. Data subsets were selected that have been very useful.

- All basic data is about 8000 GB per year (22 GB/day).
- ISCCP B3 data is 20 GB per year, 3 hour, 25-km resolution. This is used for cloud calculations.
- ISCCP B1 is 80 GB per year, 3 hour, 8-km resolution. This is more data but it could be used for cloud calculations.
- ISCCP is now for the period Jul 1983-95.
Methods to Handle Large Datasets

Some datasets are very large. We will discuss some of the issues of handling these datasets and give some examples of the experience with coping with datasets that are very big.

Three short papers follow this one:

a. Procedures to Handle High Rate Data (Sep 1994)

The main point is that we should be willing to break any rules to achieve timing that works and data volume that is reasonable.

b. Cost to Archive and Copy Large Datasets (Jun 1995)

This includes some technical information which shows that it should be possible to achieve lower costs to copy large datasets than first seemed possible.

c. New Weather Radars for the U.S.; the Data (Sep 1995)

An example of where NOAA plans to copy 114 Tbytes of radar data each year at a cost of $451,000.

1. Reprocess the GOES Data

The University of Wisconsin has an archive of GOES geosynchronous satellite data for 1978-95. The volume is now over 130 Tbytes. This is one of the largest digital archives in the U.S., and was captured at an amazingly low cost.

Bretherton's group would like to reprocess all of this archive to derive new products. About 1993-94 they developed a plan to use 10 to 18 fast workstations to accomplish this. Under this plan, they would read through the entire archive once each year to develop one or more products. They planned to do this for a cost of under $2 million per year.

A note: they first have to go through the archive to remove a few glitches and put it onto new media. With 1993 technology, I thought that the plan to process all of the data in a year was optimistic, but it was close to achievable then, and is more certain now.
Cost to Archive and Copy Large Datasets

Some datasets are very large. They need to be archived, and a few copies may be needed for use at other locations. We will present some tentative information about costs to show that costs can be constrained more than is sometimes realized. One purpose of this note is to compare the 1970s cost of archiving large amounts of satellite data with the cost of using new technology that will be available in 1996.

1. University of Wisconsin Saves Satellite Data

The University of Wisconsin has one of the largest digital data archives anyplace, and it was prepared at modest cost. Their archive of GOES satellite data for 1978 through 1991 (14 years) has a volume of 125 Tbytes.

One GOES satellite had an average data rate of about 1 mbit/sec. Each U.S. GOES satellite produced about 3.8 Tbytes of data per year and there were often two GOES satellites in operation. They started saving the data about 1973, when ordinary half-inch tape technology was 1600 BPI density, with 40 MB on a tape. This standard technology for 1973 was not practical to use for such a large dataset at affordable costs. They used Sony recorders that could put 2.5 GB on a tape with the first technology and later 5 GB. The error rate was poor, but it was okay for this data.

Their cost was about $100,000 per year to save all this data, and this paid for recorders, media, and students to change tapes each 6 or 12 hours. The cost could be this low because there was technical expertise available who could help when problems happened. Note that $100K per 8 Tbytes is a cost of $12.50 per Gbyte, which is an amazingly good price, especially for those early years.

2. Saving High-volume Satellite Data in 1996

Consider an example of a process to save high-volume satellite data in 1996 and make 10 copies for use elsewhere. Two main hardware options for 1996 are available:

- Use Exabyte or DLT drives and an automated library that holds 40 to 100 tapes
  - The cost is about $30K to $70K, so use $50K for the drives and library.
  - One cartridge will hold 20 or 30 Gbytes (without compression), and cost about $20. So the media cost is about $800 per Tbyte.
  - The data rate is 3 to 5 Mbytes/sec using this technology

- Or use new IBM drive technology and a small library
  - For about 3 drives and a library of a few hundred cartridges, the cost is about $150K to $190K, so use $170 K.
  - A cartridge holds 10 Gbytes, not counting compression.
  - The data rate is about 9 Mbytes/sec.
Using these technologies we will assume that a steady 3.5 Mbytes/sec can be achieved on one drive. Compare this with the University of Wisconsin in the 1970s and 1980s when they recorded 1 mbit/sec from each of 2 satellites (on two tapes). This new gear can handle data 28 times faster, the error rate is much much better, and students aren't needed to change tapes often. So it appears that the 3.5 Mbytes/sec rate (110 Tbytes a year) could be handled at perhaps around $150K per year, if some experts are on call. How much would it cost to make copies?

- Assume that media costs are $80,000 per 100 Tbytes (or $800K for 10 copies).

- Each hardware station to make a copy (of 100 Tbytes) would probably have a capital and operating cost of about $50K per year. For 10 units, this would be $500K per year.

- Depending on the degree of automation, a staff in the range of 2 to 5 people may be needed to make this happen.

- Perhaps the huge dataset (100 new Tbytes each year) can be archived for around $200K a year and 10 copies made for around $1.7M a year (doesn't count overheads). The costs need to be scaled more precisely.

Then we also have to make sure that a few experts are available and account for overheads. The purpose of these arguments is to come up with some ballpark costs to handle a huge data stream. The costs can be controlled more than many people realize.

It is good to have the data in a proper time order. Quite often, satellite datasets are not in proper time order. It is costly to take out-of-order data and make it right. This issue should be thought about during planning.

In 7 or 8 years, the archive will need to be copied to new media if it is going to be saved for long-term archives. This activity will have a cost.

For some large datasets a sampled archive should be prepared that has perhaps about 6% or 1% of the original volume. This archive would be much easier to copy for many users.

3. A Paper

Jenne has a paper (Handling Large Datasets, 1993) that has more information. Other papers are also available.
Procedures to Handle High-Rate Data

The data from the EOS-A satellite was planned to be about 72 TB per year (July 1991 plan). This is an average continuous data rate of 2.26 MB/s (or 18.1 Mbit/s). Some of the burst rates would be higher than this. The average rates from the Aster instrument alone (89.6 GB/day) will be 1.04 MB/s.

1. How to handle high-rate data

To handle very high rate data (such as 100 Mbit/s), recorder drives are needed that are expensive. The experience of the Alaskan SAR facility is described in "Handling Large Datasets" (Jenne, 1993). It appears that many data rates in EOS are low enough that they can be handled by lower cost drives now becoming available (see Attachment 1). However, we have to worry about peak data rates (vs. average data rates), and the real data rate through a tape drive (vs. the rated speeds). Some guidelines for handling large datasets are:

- Store the data in compact formats; don't do anything that blows up the volume.
- Don't put slow software in the data path.
- If any standards hurt data volume or speed, ignore the standards.
- Handle large chunks of data and keep the data movement clean and fast.
- Don't use random accesses to small amounts of data.
- Error protection is good; try to keep error protection on blocks of data (checksums).
- Use simple, fast data access programs to unpack the data.

Is it likely that EOSDIS and related data planning will follow the above rules and stay out of trouble? At this point it is likely that several of these rules will be broken. This can cause plenty of trouble. There are some people in Hughes and NASA with the right kind of experience.

Table 1 shows much of the technology available to handle big data flows. The new IBM NTP technology looks like it will be very good, and the cost of the tape drives is very affordable. NTP uses the same size and shape of cartridge as the 3480 and 3490 line of drives. Attachment 1 has information about the new NTP drive and a new drive from Storage Tek.

2. How to move large datasets long distances

How should we move data from point A to point B at a distance? The main options often are to use networks or tapes. For large datasets it may be cheaper and faster to use tapes. We have to explore the tradeoffs and timing requirements to determine what is sensible.

- Do U.S. data planning activities strongly consider the cost and benefits to determine which approach will be used to move data? No, the U.S. approach is usually to plan to use networks and to ignore the cost tradeoffs. Europeans are more likely to consider the costs.
Table 1. Selected Technologies to Handle Large Datasets
A brief history is included. The compression column shows whether the tape drive has built-in compression.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Year</th>
<th>Compression</th>
<th>Tape Capacity</th>
<th>Data Rate (burst)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Half-inch tapes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/2&quot;, 150 IPS, 1600 BPI</td>
<td>1972</td>
<td>No</td>
<td>40 MB</td>
<td>240 kB/s</td>
</tr>
<tr>
<td>1/2&quot; tapes, 6250 BPI</td>
<td>1980</td>
<td>No</td>
<td>135 MB</td>
<td>1.2 MB/s, or slower</td>
</tr>
<tr>
<td>IBM 3480 and 3490 tape drives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3480</td>
<td>1985</td>
<td>No</td>
<td>200 MB</td>
<td>3 MB/s</td>
</tr>
<tr>
<td>3480 (Sep 1989)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3490 (Jul 1991)</td>
<td></td>
<td>Yes</td>
<td>460 MB</td>
<td>3 MB/s</td>
</tr>
<tr>
<td>3490 long tape (Sep 1992)</td>
<td></td>
<td>Yes</td>
<td>900 MB</td>
<td>3 MB/s</td>
</tr>
<tr>
<td>IBM NTP tape drives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NTP (Fall 1994)</td>
<td></td>
<td>Yes</td>
<td>10 GB</td>
<td>9 MB/s</td>
</tr>
<tr>
<td>Exabyte tape drives</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exabyte (1988)</td>
<td></td>
<td>No</td>
<td>2.3 GB</td>
<td>246 kB/s</td>
</tr>
<tr>
<td>Exabyte 8505C (Sep 1992)</td>
<td></td>
<td>Yes</td>
<td>5.0 GB</td>
<td>500 kB/s</td>
</tr>
<tr>
<td>Exabyte Mammoth (e Oct 1995)</td>
<td></td>
<td>Yes</td>
<td>20 GB</td>
<td>3.0 MB/s</td>
</tr>
</tbody>
</table>
New Weather Radars for the US; the Data

The National Weather Service is in the process of installing NexRad radars to cover the U.S. These radars are going in at the rate of 4 per month. By Aug 1995, 67 radars had been commissioned and 40 to 50 were recording data. The data recorders mainly went in during Apr and May 1995.

The radar network will grow to 150 radars. All of these will record raw scan data (Level 2), and 115 of them will record the Level 3 data (grids of precipitation, etc.). These radars output a lot of data (116 Tbytes each year).

1. **An Outline of the Task at NCDC**

   When all of the radars are sending data, we will see that NCDC-Asheville will receive about 30,000 Exabyte tapes a year (with 114 Tbytes of data) plus 2800 disks per year. There will be an additional 1.66 Tbytes of Level 3 data each year from the disks. They plan to make a copy of all this data at a cost of $451,000 per year which includes workstations, operators, media, etc. This is a total copy cost (including media) of only about $4 per Gbyte which is very good, even where a massive job gives the advantage of mass production. Up until Sep 1995, NCDC had received a total of 4000 to 5000 tapes from the radars.

2. **The Data**

   a. **The radar scan data.** Each radar will send NCDC-Asheville about 200 tapes a year. Each tape could hold nearly 5 Gbytes (without compression). Now a program cuts recording off too soon, and the tapes average 3.8 GB each.

      - So NCDC will get (200 tapes/yr)(150 radars)(3.8 GB). This is about 114 Tbytes of data each year.

   b. **The Level 3 grid data.** There will be 2 disks per month of Level 3 data for 115 stations. This is a much smaller volume of data. The disks are 5.25 inches in diameter. Each disk holds up to 660 MB. We will use 600 MB as an average. There will be about 1.66 Tbytes of this data each year from 115 radars.

3. **The Task for NCDC**

   NCDC copies the original Exabyte tapes from the radars, keeps the copy, and sends the original tapes to Oklahoma. NCDC also copies Level 3 data from the disks.

4. **Using Workstations for the Copy**

   Asheville now has five workstations for this job (IBM 6000 series). They will get four more. Each workstation handles six tape drives to make three copies at the same time.
To copy one tape to one tape takes an average of 3.8 hours (1 Gbyte per hour). To copy three tapes to three tapes takes an average of 4.5 hours.

There will be two or three operators on a shift to do this work, running 24 hours a day and 5 days a week.

Asheville will use 72 Exabyte tape drives, the 8505 model. This includes spare drives. They figure that one drive will last 8 months (at 100% use) before needing to be refurbished.

The array of 150 radars will send a total of 30,000 Exabyte tapes during a year. NCDC has to buy the tapes for the tape copy (the tapes now cost $13 each). This gives a total tape media cost of $390,000 per year when all radars start sending data. We will see that this budget will be reduced by using compression.

Asheville is worried whether problems in the SCSI controllers may slow them down too much. Sometimes they have 60% of a copy job done when the workstation locks up and they have to start over. People still are not sure where the exact problem is.

5. Use of Compression

The 8505 Exabyte drive includes compression. When NCDC uses that feature, they find that they get surprisingly good compression with this type of data (38 Gbytes can be put onto a 5-Gbyte tape). They are going to start copying 5 inputs to 1 output to reduce media and handling costs (about 18 Gbytes on a tape).

6. The Budget

For FY 1996 the total costs for this project at NCDC are estimated at $486,000. In 1997 and later, when all the radars are going, NCDC previously estimated costs of $649,000 each year. By taking advantage of compression, the new cost estimate for these years is $451,000 each year.

Conclusion: This is an example of a project that moves a huge amount of data. Good plans were established to set up procedures to accomplish the task. Dick Davis at NCDC is the project manager, and deserves a lot of credit for using a clean system design to do the job well, and which strongly constrains the budget.

Question: When did the archives for any one radar start and continue in a consistent way?
Projects that Handle Large Volumes of Data

There are several projects in the US that handle large amounts of data. In order to help scale necessary costs to handle data from EOS satellites in NASA, we will give a few examples below. Since projects are different, we should not expect that the cost per unit volume of data would be the same. However, the examples should help us to ask the right questions. In some projects, huge amounts of data are being handled for relatively modest amounts of money.

- The hardware cost over a 3 year period to store 275 Tbytes of data in a silo (robot retrieval) is about $1.4 million ($500 K per year). This technology uses tapes that each hold 50 Gbytes. The cost of the media is $1500 per terabyte. (Written June 1997)

1. Task to copy 100 Tbytes of weather radar data each year.

NCDC (Asheville) is now copying 100 Tbytes of weather radar data per year at a cost of $800,000 per year. (Written June 1997)

Update Jan 2000: The rate of data collection is far from perfect. Not all data are delivered. They do collect about 56 Tbytes a year. Hardware can give 8-to-1 compression. Software can give 15-to-1 compression. So these methods may reduce 56 Tbytes per year to about 4.0 Tbytes per year. There is now technology so that 4.0 Tbytes will fit on about 80 tapes.

2. The amount of NASA primary EOS data coming down will be under 100 Tbytes per year. A lot of data products will be calculated. The tasks will be big.
   - We have to be careful about people blaming a lot of their huge costs on big data volume. It is still true that volume is important.

3. Plan to handle GOES data, 210 Tbytes (written June 97). Work done at University of Wisconsin. (Process 210 Tbytes for $2.2m plus $800K for media. Do this task over three years.) This information is from Bob Fox, Univ of Wisc.

The University of Wisconsin has done an excellent job of capturing GOES satellite data from 1979-on, at a low cost. The data needs to be copied to new tapes, and calibrations and navigation should be improved. NOAA has typically paid them $80,000 to $100,000 per year to capture and archive about 5 to 15 Tbytes each year. The cost can only be this low because some other experts are available to give help and advice when necessary.

The University of Wisconsin has proposed a project to be done over five years (now do it in three years). They hope to copy all of the data (210 Tbytes) to new media, work on calibrations, do a better navigation, and deliver a copy of the data to NCDC. The data is for three months in 1974, 5-satellites in 1979 (FGGE), and all of 1980 through 1996 (for GOES satellites); written in n1997.

They have recently figured out a way to do this job over three years, starting in 1997, for a lower total cost of $2.2m (the April 1997 estimate was $2.8 million). There will be an additional $800K for media costs (for two copies). NOAA is providing $750K to start this project. There will be several fast workstations and operators on duty 24 hours per day and five days per week.

The group at the University of Wisconsin deserves several gold stars for their huge contributions to the USA, done at a very low cost. Without their superior capability, we would not have an archive of GOES data from 1979-on.
An update in Dec 1999: As of Oct 1999, the U of Wisc’s total archive volume was 257.1 Tbytes. They are using software compression that will reduce this total volume by a factor of 2 to about 128 Tbytes for archive storage. But first, the old tapes have to be copied and the data has to be improved. Their expertise is very good and their costs are much better than most. But it is still hard to line up funds for this essential work.

4. Satellite data archiving systems at NCDC, Asheville (November 1997). This information was from Rob Quayle (NOAA, NCDC) in November 1997.
   a. Geostationary Satellite Archiving System (GSAS for GOES). Data volume is about 20 TB/yr for primary & the same for backup on IBM 3590 tape cassettes (10 Gbytes each). Development costs were about $1M. Operating costs are about $350K/yr, with most of the work done at University of Wisconsin.
   b. POES (NOAA Polar Orbiting Satellites): Data volume is only about 1 to 2 TB/yr. Development costs unknown. Operating costs are about $200K/yr with work done by NOAA.

5. The NOAA satellite active archive. This unit is located at Suitland, MD. During 1999, it is making good progress in establishing the archives of:
   a. TOVS satellite sounder data (Oct 1978 – on)
      The volume of TOVS is about 1.7 times one satellite when two satellites are up. With two satellites, the volume is about 55 Gbytes per year. A second TOVS satellite started early (Jun 27, 1979). The total volume of this primary TOVS data for Nov 78 through Mar 1992 (13.4 years) at NCAR is 631 Gbytes. The total volume for Nov 1978 through 1999 (21.2 years) at NOAA SAA will be about 1060 Gbytes.
   b. NOAA global 4 km, 5 channel GAC scanner data (Oct 1978 – on). The volume of GAC was about 237 Gbytes per year when 2 satellites were up in the early 1980s. I think that the archive had data for about 1.3 satellites. Perhaps the total archive for Oct 78 – Dec 99 (21.2 yrs) will be about 5000 Gbytes. But perhaps data for more than 1.3 satellites is in the archive for later years.
   c. Some of the 1 km NOAA AVHRR data
   d. USAF DMSP meteorological satellite data for 1991 – on. And they have some earlier tapes.
      Staff for Satellite Active Archive. This unit has 2 government people and 12 contractors (14 total). There are also two people in another group who maintain the mass storage device (they use part of it).

      Total archive data volume at NOAA SAA: By Dec 1999 they had about 10 Tbytes on the mass store. By mid-2000 they will probably have 13 to 15 Tbytes.

6. How much would it cost to handle Landsat-7 and Aster data?

The EROS data center (of USGS) has many years of experience in handling Landsat type data. Aster also is scene-oriented data that fits with this same experience. They at EROS figure that if they were to do all of the work for these instruments themselves (independent of the NASA ECS contract), then it would cost about $2m or $3m to set up systems for Landsat-7 and Aster and probably about $1m per year to operate them for both satellites. Landsat-7 will be launched about mid-April 1999. Even in 1997 – 98, there was work on backup systems to handle these data, independent of the large core ECS contract. The EDC DAAC at EROS said (in Aug 1998) they could have gotten ready for launch, even if they did not have help from the ECS contract.
Summary:

- There was an option to use established methods at the EROS center (they look for simplicity, proper technology, and good costs)
- Set up systems for Landsat and Aster data (this costs $2m or $3m)
- Operate the data system in production for these two sensors: around $1m per year. Perhaps this is a little low.
- Total cost: Over a 6-year period, the total cost for system development and operations would be about $1.5m per year.
- This assumes independence from ECS contract
- The volume of primary Landsat-7 data is 50.4 Tbytes per year. Primary Aster data is 32.7 Tbytes per year. The cost projections are certainly attractive for a project that needs to handle 83.1 Tbytes per year.
- But they were not allowed to use their own methods.

7. Handle all data from the TRMM rain satellite

The data from the TRMM rain satellite is being handled by the NASA Goddard DAAC. They archive the data and calculate the data products (precipitation, etc.) The cost of this work is under $1m per year.

Note 1: These examples help tell us how much it costs to move data out of storage, do a few calculations, and copy it to new storage media. Appropriate methods to handle large datasets are being used. Many of these examples do not include the cost to generate a lot of data products. That costs more money.

Note 2: The hardware costs in EOSDIS are only about 15% of the total budget according to information received. The hardware costs are affected by the data volume.
Table 1. Data volume from selected EOS missions

The volume of data from various EOS missions is given for each day and each year. We note that only a few instruments give large data volumes. The data rates given are the average rates (Mbits/sec).

<table>
<thead>
<tr>
<th></th>
<th>Data Rate (Mbps)</th>
<th>Data/Day</th>
<th>Data/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. TRMM, tropical rainfall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.016</td>
<td>173 MB/d</td>
<td>63 GB/y</td>
</tr>
<tr>
<td></td>
<td>Instruments TM1 (microwave)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>VIRS (visible, IR), LIS (lightning),</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CERES (radiation)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. EOS AM-1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MODIS</td>
<td>17.626</td>
<td>190.4 GB/d</td>
<td>69,520 GB/y</td>
</tr>
<tr>
<td>MISR</td>
<td>6.2 Mbps (average)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASTER</td>
<td>3.3 Mbps (average)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MOPITT</td>
<td>8.3 Mbps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CERES</td>
<td>25 Kbps (pollution)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 Kbps (for 2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Landsat-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12.778</td>
<td>138.0 GB/d</td>
<td>50,371 GB/y</td>
</tr>
<tr>
<td>4. Radar ALT series (altimeter) (Doris, AMR, S Salt)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.0016</td>
<td>18 MB/d</td>
<td>6.3 GB/y</td>
</tr>
<tr>
<td></td>
<td>* Launch 9/99</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* Launch 9/2004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. EOS ocean color</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.347</td>
<td>3.7 GB/d</td>
<td>1,369 GB/y</td>
</tr>
<tr>
<td></td>
<td>This has 8 channels and a resolution of 1.1 km and 4.5 km (global cover)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Laser ALT series</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.150</td>
<td>1.6 GB/d</td>
<td>592 GB/y</td>
</tr>
<tr>
<td>7. Sage III Strato aerosols, gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>100 Kbps for 24 min/day</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sage III is being built</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* fly it on the Russian Meteor 3M, launch Aug 1988</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* fly it on the space shuttle, Feb 2001</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>* Similar older data starts 1978</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1. Data volume from selected EOS missions (Cont.)

<table>
<thead>
<tr>
<th></th>
<th>Data Rate (Mbps)</th>
<th>Data/Day</th>
<th>Data/Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>8. EOS Chem-1</td>
<td>3.404</td>
<td>36.8 GB/d</td>
<td>13,428 GB/y</td>
</tr>
<tr>
<td>MLS (100 Kbps), HIRDLES (50 Kbps), ODUS (50 Kbps?), TES (~3.2 Mbps)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Notes: (1) TES can make both Limb and Nadir observations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(2) 788 GB/y from three instruments and rest from TES.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Sounders for PM series</td>
<td>1.45</td>
<td>15.7 GB/d</td>
<td>5,720 GB/y</td>
</tr>
<tr>
<td>AIRS</td>
<td>1.44 Mbps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMSU</td>
<td>3.2 Kbps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MHS</td>
<td>4.2 Kbps</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Data from EOS mission with lower data rates

We will see that the amounts of data for the instruments with lower data rates are small enough that it will be fairly easy to move the data to individual PIs or to work groups.

One example is data from the altimeter missions. There have already been several missions (Seasat, Geosat, and Topex). The world needs precise data for ocean sea level. Some wave data are also included in this set. Data are sensed at 10/sec under the satellite path. The main output data for PIs who are experts on this type of data is a dataset sampled at 1/sec, plus correction terms for the path through the atmosphere. Grids of sea level are also prepared. All of these data have a reasonable volume and have usually been distributed on CD-ROMs. That is also a good model for the future.

5. Mountains of data and limited research use?

The history of large data flows from satellites is that the U.S. spends a lot of money to capture the data, perhaps use it for operations, and then put it into an archive. Then the data sits in the archive because it is too expensive or too difficult for a PI or a work group to obtain a copy. There is a big danger that we will have this same problem with the big datasets of EOS data. A few days of data can be used by a PI, but a few years of data cannot be used.

There are a couple of ways to approach this problem. One is to at least position copies of the data at two or three places around the country, such as at NCAR and Goddard, where a lot of PIs can access it from the local mass store. However, the only way to really solve the problem is to develop methods to handle and move large amounts of data at costs that are low, so that the costs are not a burden on either the PI or the government. But we have to remember that some of the data flows are so large that they will not be trivial to handle.
The Big Problems of Using Huge Datasets

Members of our EOS project have stated a need to process huge amounts of EOS data. We need to take a harder look at these issues. How much data do we really need? Are there ways to sample parts of the data in order to reduce the volume? There are examples of some large data streams that are now being handled. Some examples are given that can be compared with EOS data flows.

Members of our EOS research project are saying that we want 1000 Gbytes per day of data from NASA, and that we will give back 300 Gbytes per day of products. This is a lot of data (handling 475 Tbytes a year), and I doubt if people have thought about what it means to handle the data or to process it. Attachment 1 has a table which shows that all of the primary data from the EOS-A platform has a volume of 195 Gbytes per day; therefore, we are requesting 5 times more than all of the primary data volume. What does our request of 1000 Gbytes per day include?

I will give only a little information to help scale the problem now. Our EOS group should discuss our needs for data and the technical constraints when we get together. New technology is helping, but these data flows are still huge.

1. **Keep large data flows fast and clean**

   With large data flows, it is very important to keep the flows fast and clean. The data will usually need dedicated paths. Any disk buffers used would probably fill up so fast that they would not work.

   - The general strategy is to move the data to a tape as directly and quickly as possible.

   - The data should be in a compact, fast format; not in a standard format that probably does not meet these requirements.

2. **Some issues for handling large datasets**

   It is helpful to consider some of the issues that should be analyzed in dealing with large datasets.

   - Is the format efficient in terms of volume and speed?
   - Is a sampled dataset needed for the global scale, 10-year problem, with reprocessing practical?
   - Do some products have modest volume so that most potential users can handle them?
   - Is it better to move the data to the users, or let the users compute on the data elsewhere?
   - Have the costs of a few options been approximated?
3. The NCAR mass store

Some information about the NCAR mass store is given so that readers can compare these amounts of data and data flows at NCAR with some of the numbers for EOS data.

The mass store (MSS) had 2 Tbytes in Sep 1986, now it has about 53 Tbytes (Figure 1). The Cray Y-MP8/64 (8 processors) arrived at NCAR in May 1990. It has 2.8 times the processing power of the previous Cray X-MP48 (4 processors). A year after it came, the rate of archiving data increased a lot (Figure 1). The daily data flow on it (reads and writes) is about 250 Gbytes a day (Figure 2). The MSS has a lot of tape drives, disks, and parallel paths. It is now struggling to keep up with the data flows caused by increases in computer power. Figure 2 gives the total rate of data flows to and from the MSS. Figures 3 and 4 break this into reads and writes.

The present mass store is based on IBM cartridge tape ("square tape") technology. The previous NCAR mass store used TBM technology—based on big (15 pound) round tapes that each held 5 Gbytes. From Jan to Jun 1986 all data was moved to the small (3480) cartridge tapes, where each tape held about 200 MB. These tapes have amazingly good (low) error rates. By 1991, space was becoming a problem; in Sep 1991, NCAR started the migration of data to the new double-density cartridges. Each cartridge held about 400 MB (but really held about 500 MB of user data because of compression). The data migration was completed 2 years later in Sep 1993.

The NCAR mass store costs a lot of money. For large data flows, it is possible to reduce costs by dedicating equipment to these specific tasks.

4. Receiving reanalysis data at NCAR

One year of NMC/NCAR reanalysis data comes to NCAR on 144 cartridges (with a total of 54 Gbytes of data). When we receive a year of data, we have jobs always waiting to import data. During fall 1994, it usually took 10 days to import a year of data (54 GB). During Feb and Mar 1995, the typical time to ingest 54 GB is about 20 days because NCAR has more Cray horsepower, which causes higher data flows that compete with these jobs.

- NMC can accomplish a year of analyses in a month (data output 54 Gbytes).
- Resolution is T62 with 28 levels.
- It is taking NCAR 10 to 24 days to import a year (54 GB) of data.
- Compare this with our EOS statements to receive 1000 GB a day from NASA and send 300 GB back. Wow!
- The NCAR data import methods would have to be changed in order to handle high rate inputs.

5. University of Wisconsin saves GOES data; a success story

The University of Wisconsin has saved all GOES satellite data for many years by being smarter than the average bear, and controlling costs. For many years they read and saved all
GOES geosynchronous data from one or two satellites. One GOES has a steady rate of about 1 mbit/sec (the new GOES gives more data).

- One GOES (1 mbit/sec) gives about 8000 Gbytes of data per year (about 22 Gbytes a day). Their archive of GOES data has data for 1978-present.

- University of Wisconsin set up dedicated equipment to handle this data stream in a sensible way.

- They could buy tapes and operate the system for a cost of about $120K per year (this was a great achievement).

- In 1994 the University of Wisconsin had one of the largest digital archives in the U.S. (over 125 Tbytes). They have figured out ways to read all of the data and make new calculations at very attractive costs (see "Handling Large Datasets," Jenne, 1993).

6. **Set up an archive system in 1996**

Newer technology will be available in 1996 that will help a lot. One cartridge will hold about 10 to 20 Gbytes (use 70 tapes per Tbyte). By developing fast and easy compression for selected huge datasets, this could be improved even more.

- Drives will mainly range from 3 MB/sec to 8 MB/sec in 1996. We will assume that it is rather easy to handle a steady flow of 1 Mbyte/sec (86 GB/day or 32 TB a year).

- Probably 3 MB/sec is also fairly easy (259 GB/day, or 95 TB a year).

- There are also faster (and more expensive) drives.

- To process the data, it also has to go into a computer, and 30% of the volume has to come back out. The computer would have to keep up with these fast data flows.

7. **Are there opportunities to sample some of the data streams?**

For some research problems it is useful to define a data sampling method. In this case, it may be possible to obtain full resolution data for short periods of time; and sampled, global data all the time.

In the mid 1970s, it was recognized that global cloud information was very important. An international cloud program (ISCCP) was started later. The relevant data were from several satellites with a total volume of about 8 Tbytes a year. From about 1976-80 there were discussions about how to reduce the volume.

- Some people wanted no more volume than 320 Mbytes/year (40 tapes, 1600 bpi, over a 5-year period). This seemed too restrictive to me. However, the idea of an archive with
reduced volume that can satisfy 90% of the science and permit 10- to 20-year studies makes a lot of sense.

- For many climate problems, it must be practical to process (and reprocess) 10 to 30 years of data.

- We finally defined a 8-km/3-hour archive of about 70 Gbytes a year for ISCCP. My goal was to have data that was primary enough that we didn't sharply constrain future research. This was achieved.

- And we defined a further sampled archive of about 13 Gbytes a year (25 km/3 hour). All ISCCP processing is still using this archive, which makes it very practical to reprocess 10 years of data. In the mid 1980s, I thought that people would move to the higher resolution archive (8 km/3 hour) by 1988-92, but it has not happened.

- The archives started Jul 1983 (now the archives have 11.7 years of data).

- GISS is now reprocessing all of the data using a better ISCCP algorithm for clouds. Rossoew will also calculate surface radiation components.

8. **Controlling costs with large data flows**

I believe that it is important to control the costs of large data flows. We have talked about how the data flows should be kept fast and clean. A key problem is that people may just mix the high-volume data in with all other data on a mass store, without doing the specialized analyses that are necessary to achieve good data flows and cost control. A few of the biggest data flows need special treatment. A few groups in the world handle very large datasets. There should always be some studies that document their methods, experience, and costs to help guide future planning. I have put some of this information into "Handling Large Datasets."

The analysis needs to consider two things: (1) ways to keep the costs down for a given volume, and (2) ways to reduce the volume using good formats, possible easy compression, and perhaps sampling strategies.

9. **A few related texts**

To handle large datasets we need to know about storage hardware, computer options, costs, etc. Additional information about these subjects is in the following texts:

- Some Data Storage Options (11 Apr 1995)
- Some Comparisons of Fast Computer CPUs (12 Apr 1995)
- Use Mail or Communication Lines for Data (12 Apr 1995)
- Handling Large Datasets (Jenne, 3 Mar 1993, 27 pp). This text includes examples such as the Fairbanks SAR Facility, handling NEXRAD radars and the experience of the University of Wisconsin, and it has more cost information.

-end-

- 4 -
Figure 1. Total data (terabytes) on the NCAR mass store. The rate of increase in archives was about 3.5 Tbytes per year to 1991. The new Cray Y-MP8 arrived at NCAR in May 1990 and a Y-MP2 arrived in June 1991. Later, the archive rate increased to about 9.5 Tbytes per year.
Figure 2. Total user data moved on the NCAR mass store
Figure 3. Volume of data reads on the NCAR mass store

Figure 4. Volume of data writes on the NCAR mass store
Volume of EOS Data

The volume of EOS data is high, but this fact is primarily driven by data from a few sensors. The handling and use of high-volume data requires a special analysis in order to control costs and to ensure that the required processing of the data is practical. The requirements specification of July 15, 1991, for the EOSDIS core system on EOS-A gave average data rates for the 15 core instruments as follows. The Hiris instrument (like Landsat) had already been deleted.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Data from Spacecraft (Gbytes/day)</th>
<th>Total Data for Archive (Gbytes/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRS</td>
<td>21.60</td>
<td>85.72</td>
</tr>
<tr>
<td>ASTER</td>
<td>89.64</td>
<td>380.65</td>
</tr>
<tr>
<td>Modis-N</td>
<td>58.32</td>
<td>284.06</td>
</tr>
<tr>
<td>Modis-T</td>
<td>16.20</td>
<td>101.18</td>
</tr>
<tr>
<td>Other 11 instruments</td>
<td>9.27</td>
<td>22.08</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>195.03</strong></td>
<td><strong>873.69</strong></td>
</tr>
</tbody>
</table>

These daily rates of data give 71 Terabytes per year from the sensors and 319 Terabytes per year, total. The total data volume is a lot higher than the spacecraft data, because NASA usually assumed two more versions of all of the basic data. This much redundancy usually is not necessary. Also some data volume is increased markedly by the choice of formats.
User Access to Large Datasets from NCAR

We will describe how users can obtain access to the datasets at NCAR. The focus will be on the larger datasets. Except for a few restricted datasets (i.e., data from ECMWF and the UK Meteorological Office), the datasets are open for anyone to use. We are trying to keep the data in the public domain, and without restrictions (this has been a struggle).

The datasets are almost always put onto the NCAR mass store. Then anyone with permission to use the NCAR computers can access the data. This includes about 450 users at NCAR and about 600 in the university community. The computing is free if the university user has an NSF grant. In general, people from NOAA or NASA would have to pay computer charges for this type of access.

Many users want to use data on their home computer. This includes people who can use the NCAR computers and people who do not have permission to use NCAR computers for no charge. Data Support has charges for data and these charges are generally low enough that they do not retard data access. However, costs are a factor for large datasets and we will discuss them next.

NCAR's normal charges to send data are about $750 per Gbyte. From other archives, we usually have to pay charges much higher than this. On big datasets we give a volume discount so that the cost is $450 per Gbyte. For large datasets, this still leads to costs that are not affordable for most users. Starting Jan 1995, we have designated a few datasets to be in a new category of bulk charges. These charges are $50 per Gbyte for direct copies of data for reanalysis, NMC Eta model (GCIP), and some satellite data for TOGA COARE. At this low cost, we do not do data selections.

For some large datasets we will probably make a master copy on a media such as Exabyte tapes, and then just duplicate the tapes. A 5-Gbyte Exabyte tape can now be duplicated commercially for a cost under $100. CD-ROM technology has been excellent because the main work is to prepare the data and to prepare access software. Then a master tape can be made for $1200, and copies are only $2 each. A CD-ROM can hold 660 MB, and new versions will increase this to 3 to 5 Gbytes. We cannot duplicate tapes as cheaply as CD-ROMs, but some of the same concepts still apply.

1. Some of the larger datasets at NCAR

NCAR Data Support now has over 440 datasets. We will list some of the larger datasets, with the rate of adding data. Other listings show the total time periods that are available.

<table>
<thead>
<tr>
<th>Dataset</th>
<th>Gbytes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMC analyses and forecasts</td>
<td>11</td>
</tr>
<tr>
<td>NMC mesoscale</td>
<td>1.8</td>
</tr>
<tr>
<td>New NMC mesoscale, start Apr 1995</td>
<td>90</td>
</tr>
<tr>
<td>NMC surface and upper air global observations</td>
<td>3.7</td>
</tr>
<tr>
<td>All data from NMC/NCAR reanalysis</td>
<td>477</td>
</tr>
</tbody>
</table>
(53 Gbytes/yr; do 9 years each year)  
ECMWF analyses (at T106 resolution)  
3-hourly ISCCP clouds  
TOVS basic satellite data  
NOAA 4-km GAC (some years)  
Meteosat from CSU (not solid)  
Wentz SSMI product tapes (orbits and monthly)  

<table>
<thead>
<tr>
<th>Gbytes/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.2</td>
</tr>
<tr>
<td>2.6</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>321</td>
</tr>
<tr>
<td>220</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

When people talk about obtaining 1000 Gbytes/day (365,000 Gbytes/yr) of EOS data, it is clear that the EOS numbers are much much bigger than the above list (which is already giving problems for data distribution).

Consider three reasonably large data streams. Table 1 shows the cost for 1 year of data, given several prices per gigabyte. Better cost analyses must be done so that we have a better knowledge of the actual real costs.

Table 1. Cost for a year of data at given prices

<table>
<thead>
<tr>
<th>Cost of Data</th>
<th>NMC Analyses (11 GB/yr)</th>
<th>TOVS (50 GB/yr)</th>
<th>EOS (1000 GB/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$750/GB</td>
<td>$8250</td>
<td>$37,500</td>
<td>$274M</td>
</tr>
<tr>
<td>450/GB</td>
<td>4950</td>
<td>22,500</td>
<td>164M</td>
</tr>
<tr>
<td>50/GB</td>
<td>550</td>
<td>2,500</td>
<td>18.3M</td>
</tr>
<tr>
<td>10/GB</td>
<td>110</td>
<td>500</td>
<td>3.7 M</td>
</tr>
</tbody>
</table>

2. Purchase cost of a few large datasets

We give the cost to purchase a few large datasets, during about 1988-94. The costs are summarized in Table 2.

a. Obtain TOVS data for Pathfinder. In Jun 1992, NASA made an agreement with NOAA to obtain an update of TOVS data for Oct 1989 to Mar 1992 (2.5 years). NASA paid NOAA $189,880 for the data ($92 per tape). The volume was about 52.8 GB/year, or 132 Gbytes for the period. This cost was $1439 per Gbyte.

b. Jim Tucker (NASA) buys 4-km GAC data from NOAA. During about 1988-93 Tucker worked out a special discounted price where he paid NOAA about $140,000 for each year of GAC data (about 307 Gbytes a year).

c. TOVS soundings. The set of TOVS 2.5 data has cloud-cleared radiances and soundings. In Jun 1993, NCDC (NOAA) kindly gave us a deal to obtain the data at half price. The data went from Jan 1979 to early Jan 1993, less many missing periods that added up to 14 months. The total volume was about 21 Gbytes. NCAR and ECMWF shared the half-price cost of $31,096. It turned out that a NOAA research set had a
much better date order and fewer gaps, so it was the prime set and we got some gap fillers from the NCDC set.

Table 2. Summary of some data costs

<table>
<thead>
<tr>
<th>Date</th>
<th>Dataset</th>
<th>Years of Data</th>
<th>Total Volume</th>
<th>Cost</th>
<th>Cost/GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun 1992</td>
<td>TOVS for Pathfinder</td>
<td>2.5</td>
<td>132 GB</td>
<td>$189,880 total</td>
<td>$1440</td>
</tr>
<tr>
<td>1988-93</td>
<td>NOAA 4-km GAC</td>
<td>5</td>
<td>307 GB/yr</td>
<td>$140,000/yr</td>
<td>$ 456</td>
</tr>
<tr>
<td>Jun 1993</td>
<td>NOAA 2.5° TOVS</td>
<td>13</td>
<td>21 GB</td>
<td>$ 31,096 total</td>
<td>$1481 (half price)</td>
</tr>
</tbody>
</table>

3. Total cost to handle data

To prepare a dataset, we often spend a considerable amount of time to check for mechanical data bugs and to get the data in the right order. Documentation and archiving all have costs. In addition, it takes time to fill data orders and to answer questions. We try to keep the overheads low. The costs to prepare datasets are not passed on to the users.
Some Problems to Distribute Large Datasets

Roy Jenne
18 May 1999

The problem of the cost to distribute large datasets:

Consider the data at model resolution that will come to us from the Maps model at FSL in Boulder. The volume is about 35 Gbytes per year from this set. The FSL group wants us to handle distribution so that they do not have to do it. But they hope that people could obtain a year of data for perhaps $100. They worry about a $30 per Gbyte charge. We have been working to reduce the cost to send data. For certain large data sets we offer a "bulk rate" to send data (if no data selection is needed besides time and file name). The recent charges for large datasets have been as follows:

<table>
<thead>
<tr>
<th></th>
<th>Ordinary Charges</th>
<th>Bulk Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Sep 1998</td>
<td>~$450 per GB</td>
<td>$50 per GB</td>
</tr>
<tr>
<td>Sep 1998 &amp; Later</td>
<td>~$300 per GB</td>
<td>$30 per GB</td>
</tr>
</tbody>
</table>

What can we still do to reduce these costs? Small tapes are holding more data and their data rates are increasing. But we are usually constrained to choose a technology where people can buy a tape drive for about $1000 to $2500 rather than $6000 or $40,000. Also, the tape drive needs to be common enough that it will serve other purposes for the user who buys it to read our data. We will usually offer 2 or 3 different tape technology options.

One possible activity to help reduce costs would be to develop some master tapes that have 15 to 50 Gbytes of data on them. A version of these could be held off-line, and copied off-line. Some notes are:

a. It should not be too hard to build a master tape.
b. What should be the charge to copy a tape off-line? If it has 30 GB, can it be copied for $150 ($5 per GB) or $300 ($10 each)?
c. Are there still commercial places that will copy a tape? At what price?
d. Note: The number of copies needed may be small; therefore it is hard to use mass production to reduce costs.

Some examples of other charges to buy data:

1. 1993: NCAR and ECMWF bought 2.5° TOVS from NCDC data. For ~1980 – 1994 (~20 GB). A half-price deal from NCDC: $30,000 for 20 GB
   Price: $1500 per GB (half-price)

2. Jan 1999: NCAR bought 3 datasets of analyses For 1998 from ECMWF. The data was half-price Because of a data exchange. The cost was £6075. ($10,328) for 10.22 Gbytes.
   Price: $1022 per GB (half-price)
Handling Large Datasets

Some large datasets are already being processed, and it is useful to learn from the experiences of these efforts. It has been common to hear statements (especially from 1987-1992) that new measuring systems would soon drown us with data compared with existing systems, and that the budgets for data must increase enormously. Such claims need to be strongly tempered by a comparison of costs for various projects. This description of projects and analysis of technical opportunities to handle large datasets efficiently has been prepared to help readers scale their own processing tasks.

First we will review the progress that has been made in making large datasets available for general use. Then we will discuss some of the procedures and costs that should be considered in planning for large amounts of data. A series of examples where large datasets are being handled is given, starting with item 12.

1. Data Systems over the Past 20 Years

There has been considerable progress in making digital data more readily available. An overview of many years of data progress and data methods is given in Jenne, 1988. It has been interesting to observe many different ideas about scientific data systems as they have popped up in the last 20 years. There have been enormous improvements in our ability to handle data. For example, the world’s satellite sounder data (VTPR) was from NOAA satellites for the period Dec 1972 - Mar 1979. There was global coverage, twice a day, with eight IR channels. This sounds like a lot of data, and in a sense it is. The data was on 1150 tapes as late as 1983. With better blocking and higher density tapes (half-inch, 6250 BPI), the same data now fits on 48 tapes. Let us see the progression:

- 1150 tapes for NOAA satellite VTPR soundings in 1983 (6.4 years of data).
- All data were copied to 48 tapes (120 Mbytes each), about 1983. The total volume is 5.516 Gbytes.
- In 1991, the data would fit on 13 cartridges, each with 430 Mbytes.
- In 1991, the data would all fit onto 2 Exabyte tapes (rated at 5000 Mbytes, with no compress option).

This is only one example of a dataset that was too big for general use in the early 1980s, but which is very easy to handle now.

2. Process Large Sets of Observed Data

Some experience has been gradually built up for handling large datasets. In the Data Support Section (DSS) of NCAR, a considerable amount of our time goes to preparing large datasets that have individual observations, often with global coverage and covering many years of time. Some sets of satellite data that are much larger have also been processed. The Alaskan SAR facility is now processing large amounts of SAR data from the European ERS-1 satellite. We need to learn from all of these projects. The requirements that are often useful for handling these large projects are:
• Very compact formats, but still usually simple

• Variable length data capability

• Checksum control so there are no undetected mechanical errors

• Absolute volume control (so that a human or hardware error can't lose data).

• Data flow methods that permit very fast data paths, and fast sorts when needed (that use the 7-way sort-merge methods). Don't put slow software in the path of the data flow.

• Control of the format so that all needed variables and flags can be included. In this process, we cannot afford the time to coordinate with 100 other groups. It takes a lot of coordination as it is, and the results would be hurt by letting all of the world's format questions get mixed up with the science.

What are some of these projects at NCAR?

When the above methods are used, the data will be more secure, and the amount of manpower needed to process the data will be strongly reduced. Some of the datasets involved are as follows:

• COADS project: prepare the world's ship and buoy data, from 1854-on, in cooperation with NOAA (ERL and NCDC).

• World aircraft data: prepare data for 1950-on for reanalysis.

• World rawinsondes. Prepare data for 1948-on. This includes data from GTS (telecom in real time), as well as data from the archives of many countries.

• World surface land synoptic data. Prepare data for 1967-on for use in reanalysis. Also add earlier data.

• Also handle satellite TOVS sounder data from NOAA, and 4 km, global GAC scanner data for many years. The volume of GAC is about 255 Gbytes per year.

3. How Data Handling Was Simplified on Satellites

It is usually possible to separate the levels of detail when organizing data, in order to obtain a simpler data system that does not sacrifice efficiency. To illustrate this point, I will give an example from the first set of NASA-EOS data panel meetings in 1986. There are often five to nine different sensors on one satellite. The data is usually stored on the satellite tape recorder and read out once each orbit. In the first JPL designs in earlier years, there was a specified data structure from each of the sensors. Later designs produced a great simplification; a uniform blocking structure was designed so that it could accept logical records from any of the sensors at any time. The front of each logical record identified the instrument of origin and the
destination on the earth. The big simplification was that the tape recorder system, satellite readouts, and most ground systems did not have to know anything about the internal format of the data. They just move the data and store it. Notice that with this design, satellite instruments can be added or subtracted and internal formats may change. It does not matter to the data system. This sort of data packaging structure is what I advocate in this paper.

Successful mass storage systems are also designed on the principle that the system does not have to know anything about the format of data within a file. Packet switching on networks follows this same principle. When the format knowledge is needed, it is handled by other software. Some mass storage systems have been implemented so that the migration of data from one type of media to another can be fully automated, and with error detection built in. This protects the data and saves a lot of human time.

Data systems should be implemented so that they have standards to block variable length logical records of data. Other software will know how to handle the format of the data. We do not expect that there will be one standard format for all data.

4. The Data Railroad

To process large amounts of data, it is important to be able to move it rapidly to and from I/O devices such as tapes and disks. This means that the data flow should be as serial as possible so that the timing is not dominated by the relatively slow access times of devices. We can think of the process as being like trains moving across the country, each with about 100 cars. A lot of produce can be moved in a short time, at low cost, if we keep all the cars moving.

Consider the process of loading and unloading cars in the train. In some cases we might do this using mass production methods that quickly load one car of coal at a time. In other cases, we have more detailed work to do. In this case we move one car to a siding to do detailed work on that car. Let us suppose that the one car is like a few records in a big file of data that we want to use to prepare some graphics. The method is that we extract these records from the file and operate on them. We do not want to slow down fast data paths, in order to operate on small amounts of data.

If the nature of the overall task is that we need to process large amounts of data, then a whole-train approach is needed. We have to move the data in large blocks or files. With modestly large datasets, it is reasonable to select somewhat smaller entities of data if needed: these are logical records. One of these records might be a satellite scan line or an analyzed field. The process must be organized so that we do not have a disk access for each record, or it will be slow. Data base approaches that index down to each number are not appropriate for handling large datasets. However, it is still possible to get each number by operating on the logical records.

5. Run Control Automation

The Data Support group of NCAR has developed methods of run control automation so that we can accomplish large data development tasks with limited staff. The methods automate the submission of thousands of jobs, tell the program where to find data inputs, and keep absolute
control over report counts and data volume. Thus, no data can be lost without our knowing it. All the data are under checksum control. Examples are methods used for handling the data flow for the COADS project (collect all world ship reports), and methods used to save 1500 Gbytes of satellite data.

When we started the COADS ship project in 1982, we figured that more than 5,000 job submissions would be required. There is no way to do this manually, avoid human errors, and check systematically for machine errors. Therefore, these methods for automating the tasks were developed.

6. The Meaning of Access Time

When people handle large sets of data, it seems common to focus on the data transfer rates of channels and storage devices without enough attention given to access times. The usual time needed to mount a tape of data and find a dataset is over 60 seconds, even using a robot. The typical access time for a hard disk is now about 20 milliseconds. The difference between the two is a factor of 3000. If the average data rate is important, the amount of data read must increase, with the access time. Any scheme that randomly accesses small amounts of data will fail to have a significant data rate. When tapes (or disk platters) have to be mounted, it helps to have more tape drives to give parallel data paths.

Even good display systems must get this timing right. I know of one system (NEONS) that uses the Empress DBMS to access reports. It does not index down to each number or even to each report. It brings in a batch of reports at once, and it has the timing right.

This timing struck home to me about 1975 when using the CDC 7600 computer. The access time on the disks was 50 ms. I was thinking of indexing more deeply than would have been wise. It turned out that the program could sort through 150,000 words (1.2 Mbytes) and extract needed data during the time of one disk access.

7. How areDatasets Used?

Data are used in several different ways. The categories of use of data are:

1. Large batch computing jobs
2. Personal browse
3. System browse and display

Data Support (DSS) at NCAR has concentrated on doing a good job with No. 1, a reasonable job with No. 2, and we make the data available for other groups to support No. 3.

Groups at the University of Wisconsin, University of Maryland, Unidata and others concentrate on doing No. 3. It has to be possible to insert data into various systems for browse and display. We are now using the University of Maryland GrADS system that has data manipulation functions and display. This is a good system in which care was taken to make data importing very easy.
I have been in several meetings where scientists say: "please give us the data so that we can do our own thing." This is often interpreted by data people as meaning bigger and better display systems. The PI really means that he/she wants easy access to the data to use for calculations, or to use in display routines that the PI chooses (item No. 1 and No. 2 above).

It often amuses me that people use the high data rates of EOS to justify big data systems, and then design data systems that are not appropriate for handling large volumes of data. One of our problems in national data activities is that some groups focus so strongly on item No. 3 (display) that they ignore the need for 1 and 2, or try to force their methods on 1 and 2 so that these tasks cannot be done as easily or efficiently.

It is still true that there is a real need for graphics and applications of many types. Some of this capability will be developed within our scientific community. Some will be commercial software. It should be fairly easy for the user to match up the data with software that he/she chooses.

8. **What is Needed to Keep Data for 50 Years?**

We will review what approaches are needed for important datasets to survive for 50 years. Data structures should be simple enough that maintaining the read software is easy. The data should be under error control and volume control. It should be possible to fully automate the process of migrating the data to new media. Then people only have to monitor the process of migration, not do all of the work. With the normal heavy use of people for this task, the costs are high and errors occur. For large datasets, it is essential that the data flows be kept fast and "clean" without excessive software overhead and certainly not a lot of random accesses, where each access only retrieves small amounts of data.

The data should be packaged so that keeping track of each dataset is like keeping track of a book, and not like keeping track of each sentence in a book. People using the dataset in 50 years must find all of the important information and auxiliary data that they need. The information must be in 2 to 4 levels of detail or it will be too hard to use.

With packaged data, it often is reasonable to define a special lower cost for people who just buy the whole package that has whole blocks of data. This is the way that CD-ROMs are now priced. I am proposing that we use a similar strategy for some of our larger datasets that could be put on media, such as Exabyte tapes that hold 5000 Mbytes.

9. **Volume of Data and the Media Used**

When the data volume becomes high, the media costs have to be monitored closely. There are options for magnetic media where the costs are now much better than for optical disk options (Table 1), and the data rates are better. The difference is that we may have to wait 2.5 minutes for a tape to be mounted. But with a large archive, we would also have to wait for an optical disk to be mounted. Since a given 200 Mbytes of a large dataset often is used only once each three years (or less), a wait of a few minutes is not unreasonable.
10. The Cost of Media to Save Data

For small datasets, the cost of the media to save data usually is not an important part of total costs. For large datasets, media costs often become very expensive. We are fortunate that the cost of media has decreased sharply since 1960. A few of these costs are given in Table 1 below.

<table>
<thead>
<tr>
<th>Date</th>
<th>Media Type</th>
<th>Effective Capacity (Mbytes)</th>
<th>Media Cost per Gbyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960</td>
<td>556 BPI tape, $14, 14 MB</td>
<td>12</td>
<td>$1200</td>
</tr>
<tr>
<td>1980</td>
<td>6250 BPI tape, $10, 150 MB</td>
<td>125</td>
<td>80</td>
</tr>
<tr>
<td>2/86</td>
<td>IBM 3480 tape cartridge, $14, 200 MB</td>
<td>174</td>
<td>81</td>
</tr>
<tr>
<td>9/89</td>
<td>3480, $5 each, 230 MB</td>
<td>200</td>
<td>25</td>
</tr>
<tr>
<td>8/92</td>
<td>3490, $5 each, 460 MB</td>
<td>420</td>
<td>12</td>
</tr>
</tbody>
</table>

**Metrum VHS Tapes**

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Cost per GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>5,000</td>
<td>4.0</td>
</tr>
<tr>
<td>1991</td>
<td>14,100</td>
<td>1.42</td>
</tr>
<tr>
<td>1993</td>
<td>19,200</td>
<td>1.15</td>
</tr>
</tbody>
</table>

**Exabyte Tapes (8 mm)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Cost per GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>2,100</td>
<td>6.66</td>
</tr>
<tr>
<td>1991</td>
<td>4,700</td>
<td>3.00</td>
</tr>
</tbody>
</table>

**DEC Tapes (0.5 inch)**

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Cost per GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>9,500</td>
<td>3.10</td>
</tr>
</tbody>
</table>

**Sony Optical Disks**

<table>
<thead>
<tr>
<th>Year</th>
<th>Capacity</th>
<th>Cost per GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>2,900</td>
<td>93</td>
</tr>
<tr>
<td>1990</td>
<td>6,100</td>
<td>44</td>
</tr>
</tbody>
</table>

*Note:* Metrum, Exabyte and DEC prices are approximate for top-quality tapes, in volume orders.

11. Cost to Save Data for 16 Years

Since either the media wears out, or the read devices are no longer available, data has to be migrated to new media each 8 years. We will consider the cost of this process. Since a given portion of most large datasets is used once each 2.5 years (or less), it is important to design systems that keep the storage costs low. Table 2 summarizes the cost. Media costs and data rates improve with time. This makes it possible to save the data for a long time at acceptable costs. I will assume that the media costs are about 30% of the cost to write the data the first time (if low-cost tape technology is used). When the data are copied, the original slower media have to be read but the output is easier and cheaper than the first time.
Table 2. Cost to Copy and Save Data

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original</strong></td>
<td></td>
</tr>
<tr>
<td>Cost to save a year</td>
<td>$ \ n</td>
</tr>
<tr>
<td>of data the first</td>
<td></td>
</tr>
<tr>
<td>time (media is 30%)</td>
<td></td>
</tr>
<tr>
<td><strong>Years 2-8</strong></td>
<td></td>
</tr>
<tr>
<td>• Cost to save all</td>
<td>$.15 \ n</td>
</tr>
<tr>
<td>latest 8 years of</td>
<td></td>
</tr>
<tr>
<td>data on shelves</td>
<td></td>
</tr>
<tr>
<td>• Cost to copy data</td>
<td>$.6 \ n</td>
</tr>
<tr>
<td>in 8 years</td>
<td></td>
</tr>
<tr>
<td><strong>Years 9-16</strong></td>
<td></td>
</tr>
<tr>
<td>• Cost to store data</td>
<td>$.03 \ n</td>
</tr>
<tr>
<td>9-16 years old</td>
<td></td>
</tr>
<tr>
<td>• Cost to copy data</td>
<td>$.15 \ n</td>
</tr>
<tr>
<td>in 16 years</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL:</strong></td>
<td>~$2.0 \ n</td>
</tr>
<tr>
<td>(Annual cost for</td>
<td></td>
</tr>
<tr>
<td>data 0 to 16 years</td>
<td></td>
</tr>
<tr>
<td>old)</td>
<td></td>
</tr>
</tbody>
</table>

Items 12 to 21 that follow have a good deal of detail about the handling of several very large datasets. Some of the information is summarized from item 22 to the end, so please feel free to skip some of the details if you wish.

12. Handle Large Satellite Datasets

The data volume from U.S.-GOES geosynchronous satellites is large. We will now consider the cost of using storage technology to save a continuous data stream that averages about 3 Mbit/sec (375 Kbytes/sec). The data volume is then about 12,000 Gbytes per year. One GOES geosynchronous satellite that takes full earth-disk pictures each half hour has an average data rate of over 1 Mbit/sec. We will discuss a system to save data from two GOES satellites plus some other data. Assume we need to save 12,000 Gbytes per year. We find that there are technical opportunities to accomplish this at surprisingly low costs.

Since about 1973, the University of Wisconsin has been saving all data from the one or two operational GOES satellites. Each satellite produces about 3800 Gbytes of data per year. Their total archive (University of Wisconsin) for 1978 through 1991 (14 years) has about 125,000 Gbytes of data. It would have been too expensive for them to use ordinary magnetic tape technology, so they got inventive. They recorded the signal on special Sony tapes. At first a tape would only hold 6 hours of data from one satellite. By 1984 they could put 12 hours on one tape that cost $26 (about 5 Gbytes of data).

The media cost was therefore about $19,000 per satellite each year. The error rate was about 1 in 10^6. This error rate is acceptable (barely) for this kind of data but not for ordinary mass storage. The tape recorders cost about $25,000 each. For a cost of well under $100,000 per
year, Wisconsin could pay for the media and tape recorders, and hire students to change the tapes. They saved an average of about 6900 Gbytes of data per year; this is a lot of data. The University holds one of the nation’s largest archives of data.

In a paper about data storage (Jenne, 1993 draft), we discussed mass storage options with excellent error rates, and very low media costs. These could be used to build a new version of the University of Wisconsin system that would automate the search for a given satellite scene. It should be possible to use this new equipment to keep hardware and media costs under $100K per year to save a continuous 3 to 5 Mbit/second data stream, about 12 Tbytes per year. The media cost for 12 Tbytes of new Honeywell tape is only $14,000. This is a large volume of data (equivalent to 96,000 half-inch tapes)! Again, note the cost; about $100,000 per year for saving about 12 Tbytes of data each year. It can be this cheap because technical expertise is available for consulting at Wisconsin, and because cost is a factor when systems are planned.

For example, the following data could all be saved, which is well under 12 Tbytes/year, even with two GOES satellites.

<table>
<thead>
<tr>
<th>Satellite</th>
<th>All data/year (10^9 bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One US-GOES (IR, visible ea. 30 min)</td>
<td>3190</td>
</tr>
<tr>
<td>Meteosat (Europe)</td>
<td>461</td>
</tr>
<tr>
<td>GMS (Japan)</td>
<td>621</td>
</tr>
<tr>
<td>Global TOVS sounders (avg. 1.8 satellite)</td>
<td>40</td>
</tr>
<tr>
<td>Global 4 km (5 channel), GAC data, (avg. 1.2 satellites), from AVHRR</td>
<td>256</td>
</tr>
</tbody>
</table>

Some useful subsets of satellite data have a much lower volume than the total data stream. For example, the volume of sampled three-hour/8 km archive from a GOES satellite is about 13 Gbytes per year, compared with 3190 Gbytes for all GOES data as given above. A subset with even fewer samples (3-hour/24-30 km) is being used to derive clouds for the International Satellite Cloud Climatology Program (ISCCP), as described in Rossow and Schiffer (1991) and Schiffer and Rosson (1985).

What does it cost for a PI to obtain satellite data? Even with a discount of about 25% it now (1990) costs about $140,000 to obtain one year of GAC data from a data center (256 Gbytes). Note that GAC data has only 8% of the volume of data from one GOES satellite. At the same cost per Gbyte, a year of GOES data would cost $1.75 million. There are technical opportunities to radically reduce the costs to save and transfer data. Will the U.S. develop and use these methods? After reading the present tea leaves, I believe it will go 70-30 against using these methods, but they may slowly appear anyway.

13. Saving Data from NEXRAD Weather Radars (Jun. 1992)

If the U.S. does archive all of the NEXRAD radar data, the archive will be very large. We will describe a proposal to do this at a lower cost than most people have believed is possible. Dick Davis at NCDC told me about the Asheville plans to archive NEXRAD data. Some radars have been installed (starting in early 1992); all of them should be in place by 1996. If
all of the data were saved (from 159 radars), NCDC/Asheville would receive about 18,000 Exabyte tapes each year. About 8800 Exabyte tape-drive-hours per month would be needed to copy the data. Dick figures that six IBM RISC workstations and 36 Exabyte drives (probably about $180,000 of hardware) would be needed for the work. Their estimate of the total cost assumes 3 shifts per day and 5 days per week. He assumed that they would receive about 18,000 Exabyte tapes per year from the radars, each with 4.7 Gbytes. Dick noted that one video-quality Exabyte tape costs about $7; tapes with "data quality" standards cost $20, at best. He assumed that they could purchase data-quality tapes for $15 each, in quantity lots. He said that no one could tell him whether the cheaper video-quality tapes would be adequate for this task. There have been questions about how many years Exabyte tapes will last. My reading of the evidence is that if temperature and humidity are controlled, the life of the tapes should be quite good. Sony recently developed a new tape preparation process for which accelerated aging tests show that the life should be very good. In any case, the data has to be copied to new media about each 8 years, if we want to save it.

The total estimate of $600,000 per year to do this work at NCDC is a very good price. The task is to copy and inventory 18,000 tapes with dense data each year. If tapes cost $15 each, the media cost for 18,000 tapes is $270,000 per year. The tapes for one year contain about 80.5 Tbytes of data. This is a lot of data! NCDC is coordinating this archiving task with the Oklahoma NEXRAD group led by Tim Crum.

We will see below that there is a compression option that can decrease the radar data volume by a factor of four. In this case, only about 5000 blank tapes per year would be needed; these tapes would cost $75,000 each year instead of the $270,000 above. Another large saving with compression is that the effective data rates are much faster; therefore, the number of tape-drive hours needed each month will drop sharply.

What data rate is necessary to read the 18,000 Exabyte tapes per year that have 80.5 TB of data? If the read is active 70% of the time, it turns out that the average rate is 3.65 Mbytes/sec (or 29.2 Mbit/sec). This is fast; NCDC plans to accomplish it by using a number of low-cost drives that run in parallel. This is only the read of the data; an equivalent data rate will be needed to write the data to new tapes. Compression can reduce these problems.

There is a "standard format" for radar data. Apparently it adds so much header information to the front of each scan line that it increases the total data by a factor of four. This is absolutely insane for a large dataset. In 1991, I was asked if this standard format should be used. The answer was: "Absolutely not!"

We have seen that NEXRAD will produce 80.5 Tbytes each year. It is interesting to compare this data rate with the data flow planned from the various satellite sensors on EOS-A, to fly about 1998. The sensor data from the EOS-A satellite(s) will be about 71.2 Tbytes per year. This does not include products made later.

An update of NEXRAD information (Feb 1993):

About 400 Exabyte tapes with radar data have been generated; Asheville will start copying these tapes. With many radars in 1996, Asheville could get up to 22,000 tapes per year (4.7
Gbytes each, with no compression). Some experiments have been done with compression; it appears that about 2 to 1 compression can be achieved on this data. The budget to set up equipment at NCDC and to copy and inventory data in 1993 is $271,300. The top quality blank Exabyte tapes cost $14.10 each when purchased in quantity.

14. Opportunities for Data Compression on NEXRAD (Jun. 1992)

With the high volume of radar data (80 Tbytes per year), we should determine whether there are any significant gains that could be attained by compression. Only simple and fast methods should be considered. Any saving of data volume means less data to handle, store, and move.

The basic (Level II) radar data is in 8-bit bytes. When there is no rain, the signal should be low. When there is clear air, the data often will not have good winds beyond about 25 km. This means that compression could save much volume.

Rich Murnan (at the radar center in Oklahoma) talked about the compression that will soon be available for the Exabyte drives. They are finding (Feb 1993) that about 2 to 1 compression can be achieved on this radar data:

- A 5-Gbyte tape (compressed) should then hold almost 10 Gbytes of radar data (before compression), on average.

- Since compression is at the storage device level, all of the data still has to flow over the channel. We need more fast, low-cost methods to compress data in memory.

- The data rate from Exabyte drives is 500 Kbyte/sec. At this rate (and 70% overall efficiency), it takes 3.7 hours to read the 4.7 Gbytes from one tape. If the data is compressed 2 to 1, the effective data rate for uncompressed data is much higher.

Rich Murnan (Oklahoma), Dave Kitts (NCAR), and I had a phone conversation (May 1992) about Exabyte tape reliability, Murnan’s tape experiments, and the experience of Fermi Lab. (Kitts says that Fermi has about 4096 Exabyte drives). Murnan will check on the experience with Exabyte drives at Fermi. Dave Kitts is a key storage expert at NCAR. Murnan’s phone number is 405-366-6510.

15. Data Rates from EOS Satellites

There has been a lot of talk and planning about the large amounts of data expected from NASA’s Earth Observing system (EOS) satellite instruments.

The Jul 1991 requirements specification for the EOSDIS Core System gave daily data rates for the 15 instruments of EOS-A as follows:
<table>
<thead>
<tr>
<th>Instrument</th>
<th>Data from Spacecraft (Gbytes/day)</th>
<th>Total Data for Archive (Gbytes/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AIRS</td>
<td>21.60</td>
<td>85.72</td>
</tr>
<tr>
<td>ASTER</td>
<td>89.64</td>
<td>380.65</td>
</tr>
<tr>
<td>MODIS-N</td>
<td>58.32</td>
<td>284.06</td>
</tr>
<tr>
<td>MODIS-T</td>
<td>16.20</td>
<td>101.18</td>
</tr>
<tr>
<td>Other 11 instruments</td>
<td>9.27</td>
<td>22.08</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>195.03</strong></td>
<td><strong>873.69</strong></td>
</tr>
<tr>
<td>Annual rate</td>
<td><strong>71.19</strong></td>
<td><strong>318.90</strong></td>
</tr>
</tbody>
</table>

The volume of the total EOS archive in the above table is much higher than the volume of data from the satellite, because NASA usually assumed that two more versions of all of the basic data are archived. And each of these versions is in a format that increases the volume of the basic satellite data by about 46%. Some volume increase is probably necessary to include location data. An increase of this amount usually is not necessary when handling high-rate data.

During the course of planning for EOS, a lot has changed including the satellites, sensors, and data rates. Following is a little of the history of the cost for EOSDIS:

- **1986:** The EOS data system was described as probably costing $500-$800 million to set up and $80 million per year to operate. (This was from a NASA briefing to a NAS panel.)

- **1990-1991:** NASA had many groups of PIs analyze data rates, and brought them under quite good control. Unfortunately, some sensors had to be dropped because of budgets.

- **Sep 1991:** The GAO report about EOS, dated Sept. 18, 1991, said that the planned EOSDIS budget was $3.6 to $4.0 billion through the year 2000. During the period 1990-1991, I generally heard NASA people refer to the cost as being $4 to $5 billion.

- **Feb 1992:** The newer GAO report about EOSDIS says that the cost will be $3 billion.

- **Aug 17, 1992:** The Federal Computer Week’s headline was "NASA delays EOSDIS, Demands Cost Reality." The article said "NASA has delayed the award of the $3 billion Earth Observing System Data and Information System until the two bidders provide more realistic cost proposals." NASA was worried that the bids were too low and that there would be budget overruns.
• Sep 30, 1992: The EOSDIS award went to Hughes ($685 million for 1993 through 2003). "A NASA spokesman said that the cost of the database system is estimated at $2 to $2.5 billion." (Wall Street Journal). The costs in addition to the $685 million were not described.


There are a few cases where data is received from a satellite instrument (or other source) at a very high rate. The recording device must be able to accept data at this high rate or data will be lost. One storage unit that will accomplish this is built by Ampex. It will accept data at rates from zero up to 107 Mbit/second (13.38 Mbyte/sec). It is in use at the SAR facility in Fairbanks, Alaska.

The data cartridge holds 47.5 Gbytes of data. A tape is 1 inch wide and 1800 feet long. The size of the tape cassette is 10.5 inches x 6.5 x 1.65 inches. One cartridge can hold one hour of data input at 107 Mbit/second, or 107 hours of data input at 1 Mbit/second, etc. Nine blank cartridge costs about $300. This is a good price! The data error rate is about 1 in $10^9$ bits on the same drive; across drives it is about 1 in $10^7$ bits. Some error correction bits are used to achieve these error rates. These error rates are too big for use as general mass storage media.

The European satellite (ERS-1) with a synthetic aperture radar (SAR) sensor was launched in mid-1991. The data rate from the satellite will be 105 Mbit/second. The data swaths usually cover an earth area about 100 km wide with a resolution of about 12.5 meters. The data will be used to gather detailed information about polar ice, for ocean waves, and other needs. One receiving station is at the Alaska SAR facility, at the University of Alaska, Fairbanks. It can receive data for a region about 4000 km in radius. They have had two of the Ampex recorders since spring 1989. The cost for the two was about $280,000 (valid Jun. 1991).

The Alaskan facility planned to record up to 10 minutes of SAR data per day, using a scheduled sampling pattern. This represents data for about 4000 km of the satellite tracks each day. Six days of data (10 minutes/day) will fit on one cartridge that costs about $34. However, the SAR facility in Alaska was actually recording 55 minutes of data each day (in 1992), which is much more than planned. Alaska is archiving 13.5 Tbytes of SAR data each year.

Let us compare these media costs for SAR with the cost of other mass storage media. Since Aug 1991, NCAR has been using double density 3480 cartridges that can actually hold about 430 Mbytes each (or a little more with the compression that is built in). The cartridges cost $5 each. The media costs are $12,000 per Tbyte, compared to $725 per Tbyte for the Alaskan tapes and $1150 for Metrum tapes (19.5 Gbytes each).

The facility in Fairbanks is used to collect high-rate data from both European and Japanese satellites, archive the data, and also send the data back to those countries. Those centers locate their tape recorders in Fairbanks, data is put onto tapes, and the tapes are mailed to Europe and Japan. This is a low-cost method to move large amounts of data that do not have to be viewed in real time. More information about the processing of SAR data will be given later.
A few other readout stations also record SAR data. We will next see that Europe is processing about 48 Tbytes of SAR data each year.

17. Budgets to Handle Satellite Data in Europe

The budget for satellite operations and to handle satellite data during 1992 through 1998 in Europe is 180 million ECU (about $220 million). This is a cost of about $32 million per year. This cost includes ground operations for the satellites; bringing the data to the ground; putting the data into archives making inventories, and giving user support. It includes some QC on the data. About 200 people are involved in this effort.

Under this program, Europe now handles ERS-1 data; the satellite was launched about Jul 1991. Europe will handle Landsat-6, Radarsat, Seawifs, and other birds to come. They figure that their budgets are about one-fifth of those in the U.S. for similar work. This statement may be an overstatement because the U.S. costs appear to have come down. These budgets in Europe do not include other spending to obtain basic data from the above archive, to do research, or to generate data products within individual countries in Europe. This information is from Gerhard Triebning from Europe (6 May 1992).

Most of the data volume from the ERS-1 satellite is from the synthetic aperture radar instrument (SAR). Europe obtains SAR data from four readout stations. One SAR readout station is in Alaska. From Aug 1991 through Apr 1992, Europe obtained 300,000 scenes of SAR data, each 120 Mbytes. This is 36 Tbytes of data for a 9-month period. SAR data dominates the volume; all of the other sensors on ERS-1 probably add only another 10%. The annual volume of data from ERS-1 is therefore about as follows:

- 48 Tbytes of SAR data each year
- 5 Tbytes of everything else

18. Processing of SAR Data in Alaska (Nov 1992)

SAR data is high-resolution synthetic aperture radar data that can be used to study a variety of earth processes, including sea ice coverage, sea ice drift, and ocean waves. The data rate from the satellite is very high, but the period each day for collection is limited. Data were produced in 1978 by Seasat. Now the ERS-1 (Europe) and JRS-1 (Japan) satellites are providing this high rate data. The resolution from each satellite is about 10 m and the swath width is about 75 to 100 km. Ice products are produced that have a lower resolution.

Data from ERS-1 is received at the rate of 105 Mbit/sec (or 0.788 Gbytes/minute). The Alaskan SAR (ASF) facility receives both real-time JRS-1 data and data from the tape recorder simultaneously for a combined rate of 120 Mbit/sec. The facility at Fairbanks archives all of the basic data and also sends copies to Europe and Japan. Table 3 has information about the SAR data received in Alaska.
Table 3. Information about SAR Data

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Data Started</th>
<th>Swath Width</th>
<th>Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS-1</td>
<td>Aug 1991</td>
<td>100 km</td>
<td>105 Mbit/sec</td>
</tr>
<tr>
<td>JRS-1</td>
<td>20 May 1992</td>
<td>75 km</td>
<td>60 Mbit/s (real time)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60 Mbit/s (tape recorder)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Period</th>
<th>Average Data</th>
<th>Data Volume (Gbytes/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ERS-1</td>
<td>1 Sep 91 - 30 Sep 92</td>
<td>36.0</td>
<td>10,360</td>
</tr>
<tr>
<td>JRS-1</td>
<td>20 May 92 - 30 Sep 92</td>
<td>19.1</td>
<td>3,130</td>
</tr>
</tbody>
</table>

Note: For high rate data, one measure of quantity is often the minutes per day of data collection.

JPL built a special purpose pipeline computer to handle the processing; this computer can produce 4 Gflops. There are lots of fast Fourier transforms to do; a UNIX station controls it. Alaska is processing about 30% of the Japanese data and 44% of ERS-1 data. This amount keeps the computer busy. Tom George at Fairbanks says that ASF is receiving 4 to 10 times more data than was originally planned. In response to this situation, ASF has transitioned to a user-driven processing scheme. They are continuing to develop ways that will make the processing more efficient, so that more data can be processed.

18.1 One Scene of Original ERS-1 SAR Data

We will give the volume of sensor data and products for one scene of ERS-1 data (a box 100 km on a side). The swath from ERS-1 data is 100 km wide, and a long swath is split into scenes, each 100 km long. It takes about 15 seconds for the satellite to move 100 km. Since the data rate is 105 Mbit/sec, the volume of basic signal data for one scene is 196.9 megabytes. The main product that is calculated is a grid of 8-bit pixels, spaced 12.5 meters apart (this is called "30-meter resolution"). The low-resolution product has pixels spaced 100 m apart. The pixel spacing and data volume is summarized in Table 4. Also they noted that about 12% of the data that they thought may have been taken does not appear in storage.

Table 4. Volume of Data in One ERS-1 Scene, 100 km square

<table>
<thead>
<tr>
<th>Data Type</th>
<th>Pixel</th>
<th>&quot;Resolution&quot;</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor data</td>
<td>--</td>
<td>--</td>
<td>196.9 MB</td>
</tr>
<tr>
<td>The 30 m product</td>
<td>12.5 m</td>
<td>30 m</td>
<td>64.1 MB</td>
</tr>
<tr>
<td>Low-resolution product</td>
<td>100 m</td>
<td>240 m</td>
<td>1.1 MB</td>
</tr>
</tbody>
</table>

The facility also calculates selected ice products such as the movement of pack-ice (derived from pairs of images 3 days apart), and the type of ice.
An engineering team at JPL developed the processing system which is run by the ASF staff in Alaska, who monitor the output. There are about 15 members in the JPL team, led by Jeff Hilland. Now they are designing systems for a RADAR SAT (Canadian) that will be launched in Jan 1995. It will include a wide-swath mode, 500 km wide. Hilland provided part of the above information.

18.2 Operations in Alaska

The staff of the Alaskan SAR Facility (ASF) in Fairbanks has increased to 30 FTE to handle operations, archives, data distribution and management for SAR reception and processing. The total budget is about $3 million per year and includes salaries, media costs, tasks like antenna maintenance, etc. This budget does not include the JPL contribution to the SAR project. We have seen that the basic SAR data volume is about 13.5 Tbytes per year; a backup tape copy is also kept. There are also about 2.2 Tbytes of products per year. In summary, they handle a lot of data. This information was from Tom George, ASF (Phone: 907-474-7621)

19. Parallel Methods to Move Data and Compute (University of Wisconsin)

Consider the problem of some airlines that need to move 30,000 passengers across the Atlantic Ocean every day. They could either use a few airplanes that are extremely fast so that many roundtrips could be made each day or they could use more planes that are slower to do the same job. Some of the the slower planes also hold many more passengers than the supersonic planes. The decision on aircraft is made on the basis of what kinds of planes are available, the fuel use, and other costs.

The need for lots of computing often presents similar choices to the aircraft example. To accomplish several computing tasks, we can use either one very fast computer or several slower ones. To move large amounts of data, we can either use one very fast data channel, or several slower channels. Economics should play a strong part in the analysis of the choices. We have discussed the NCDC use of these parallel methods (and Exabyte tapes) to plan for handling NEXRAD radar data. Now we will consider the Wisconsin plans to process large amounts of satellite data.

The University of Wisconsin wants to process 120 Tbytes of data each year. They presented a plan at the Jan 1992 AMS meeting in Atlanta. They have a very large archive of satellite data: $1.2 \times 10^{14}$ bytes of data on 26,000 video cassette tapes. The data spans the period from early 1978 through 1991. They have a goal (which may be too ambitious) to process all of the data once each year. This means that the input data rate must average about 4.2 Mbytes/sec for 22-hour days during the year. They think that a computer processing rate of 1 Gflop will be needed. They want to achieve this with 17 separate processing units (each 60 Mflops), and where each unit costs about $20,000 to $40,000. The input data rate would need to be about 0.25 Mbytes/sec (equals 2.0 Mbit/sec) for each computer, which should be easy to achieve. The market may not be quite there as yet for these capabilities and costs, but it is getting close (written Jan 1992). This would be an investment of under $700,000 for an incredible amount of both computing power and data flow. In Aug 1992, J.T. Young (University of Wisconsin) told me that they will need only 12 computers (not 17), because
they find it less costly to plan for three shifts each day, instead of two shifts. I doubt that the $700,000 (or less) covers all of the hardware costs, but the goal could be relaxed some too. Note that $700,000 for hardware is the investment cost; the associated annual hardware cost would probably be around $250,000. The nature of this processing problem is that it can be divided up between many separate computers. Each can work on a different month of data.

This processing task is similar to the desire to run 15 or 20 different climate model experiments simultaneously. They could each be run on separate computers in a configuration like the above.

20. Put Planetary Data onto CD-ROMs at JPL

In this example, we show how JPL uses CD-ROMs to distribute significant volumes of planetary data. They include data compression to control costs and to effectively increase the data rates when reading the CD-ROMs.

JPL has produced about 23 CD-ROMs (as of Sept. 1991). The Magellan flight to Venus sampled data from about Aug 1990 to Sept. 1991 and it continues. About 42 discs of data will be ready by Dec 1991. Later, a total of about 200 Magellan discs will have been made. About 40 Mars discs are being produced. The present total inventory of about 23 discs will grow to about 125 by the end of 1992 and 425 by the end of 1993. So far, the discs contain largely the raw image data (compressed) that PIs have requested. Later on, some of the cleaned-up raw data and mosaic pictures will also be included.

Let us review some of the JPL technology. The grey scale of the typical planetary image data is in 9 bits for early satellites, 8 bits for Voyager, and 7 bits for Viking. The volume of an uncompressed Voyager scene is 640,000 bytes, and 1,300,000 bytes for Viking. Their compression routines average 3.5 to 1 for Voyager and 3.0 to 1 for Viking. The compression does not lose information. All data is under checksum protection and they “are very glad for this.” It has saved the day when problems appeared. They implement decompression and browse in a simple way. Many users have contributed software. There is a lot of free image programs that work well. Mike Martin (JPL) told about a NIH (Institute of Health) free image program that does wonders on a Mac (valid Sep 1991). There is software for VAX, PC, SUN, and Mac.

Because of compression, the stored volume is only about a third of the basic data. Even after compression, they will have about 35 discs from Voyager and 35 from Viking. The compression dropped total costs so that they could afford the program to put the data onto CD-ROMs.

The vision at JPL is that by the year 2000, they will have produced about 1000 CD-ROMs. These will contain all of the JPL data. Assume that JPL puts an average of 650 Mbytes of data on a CD-ROM. This is equivalent to about 2100 Mbytes before compression. Therefore, 1000 CD-ROMs will hold 2.1 Tbytes of uncompressed data. This information is from Mike Martin, JPL (818) 306-6038, Sept. 1991. Mike maintains a text about the JPL CD-ROMs, and includes other discs also.
The volume of one CD-ROM in a plastic case is about 179 cubic centimeters. Therefore, 1000 of these could be stacked in a box 60 cm x 60 cm x 50 cm. That is an impressive density of data!

The volume of this planetary data (2.1 Tbytes) is low, compared to some of the datasets that we have discussed. But this is still a lot of data. When datasets become large, we need to look at storage costs and the cost of data movement very carefully.

21. Large Datasets of Analyses for the Atmosphere

NCAR has relatively large archives of analyses from a number of centers including NMC, ECMWF, U.S. Navy, Australia, and Berlin. Most of these datasets have a resolution of about 300 km and are hemispheric or global in coverage. Usually the atmospheric analyses are available twice per day. There typically are analyses for 12 to 18 levels. During the past few years we have been obtaining advanced analysis products from NMC and ECMWF. These products have more variables and often the resolution is much higher (about 100 km).

The volume of analyses is high enough that it is hard to send users all of the data they might like at a low price, and where data access is still very easy. The volume of the sets of NMC advanced analyses is now about 23 Gbytes per year (this would fit onto 185 of the ordinary high-density half-inch tapes). The model resolution is now 18 levels and T126 (about 105 km spacing). The goal is for a PI to be able to afford data easily and to process 10 or 20 years of such analyses. If the person can do the calculations at NCAR, the task is already easy, but the steps needed to make it easy on his own computer are more difficult. We are working on a strategy to make this come closer to reality. Note that the volume of the dataset is small compared with our other examples.


We have considered several large datasets. We will now summarize the data volume and the data flow rates. Comparisons will be made with the amount of data on the NCAR mass store.

- All of the radar data from 159 NEXRAD radars would have a volume of 80.5 Tbytes each year. (But it may compress by a factor of 4 to 1.) We noted that if data reading is active 70% of the time, then a read rate of 3.65 Mbytes/sec is needed to accomplish this tape copy task. Since many tape drives are used to copy the data, the data rate needed on each drive is reasonably low.

- The GOES satellite data at the University of Wisconsin has about 120 Tbytes for 1978 through 1991, which is about 14 years of data (average of 8.6 Tbytes per year). J.T. Young at the University of Wisconsin said that they compress GOES data to send it over communication lines to remote McIdas display systems. They get 4 to 1 compression. So far, they have not considered compressing the data in the archive. Such decisions depend on the time needed to compress and decompress data relative to other costs. To process 120 Tbytes/year, the data rate must average 3.8 Mbytes/sec. By using about 12 data channels running in parallel, the data rate from each tape drive does not have to be very high.

-17-
• Data from EOS-A spacecraft (planned for about 1998)

The data rate from the satellites will be about 71.2 Tbytes per year (2.26 Mbytes/sec). This is a lot of data.

• SAR data from the European ERS-1 satellite

This data has been received in Europe since Aug 1991. The data is coming down at the rate of about 48 Tbytes per year (1.52 Mbytes/sec, average).

• SAR data archiving in Alaska

The Alaskan SAR facility is archiving data at the rate of about 13.5 Tbytes per year (plus backup), processing data and deriving products.

• Data on the NCAR mass store

About 80% of the data on the NCAR mass store is from major models, and the rest is from observed data. The total volume on the mass store has grown as follows:

<table>
<thead>
<tr>
<th>Date</th>
<th>Total Volume (in Tbytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 Aug 1985</td>
<td>1.65</td>
</tr>
<tr>
<td>12 Aug 1990</td>
<td>14.43</td>
</tr>
<tr>
<td>30 Mar 1992</td>
<td>24.08</td>
</tr>
<tr>
<td>3 Aug 1992</td>
<td>27.27</td>
</tr>
</tbody>
</table>

In 1992 the rate of increase at NCAR is about 7 Tbytes per year. This rate will increase as more computing power is added.

The data rate between the main supercomputers at NCAR and their external mass storage has increased with time. The data rate includes both the data read and data written:

<table>
<thead>
<tr>
<th>Date</th>
<th>Main Computers at NCAR</th>
<th>Power (Cray-1A)</th>
<th>Data Flow per day (Gbytes)</th>
<th>Flow Rate (Mbyte/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984-1985</td>
<td>2 Cray 1-As</td>
<td>2.0</td>
<td>11.9</td>
<td>0.14</td>
</tr>
<tr>
<td>1987-1988</td>
<td>X-MP48</td>
<td>8.3</td>
<td>40</td>
<td>0.46</td>
</tr>
<tr>
<td>1989</td>
<td>X-MP48</td>
<td>8.2</td>
<td>70</td>
<td>0.81</td>
</tr>
<tr>
<td>1991</td>
<td>Y-MP8, 64</td>
<td>20.1</td>
<td>115</td>
<td>1.34</td>
</tr>
</tbody>
</table>

• Advanced analyses from NMC

The volume of data is about 23 Gbytes per year (only 0.023 Tbytes) during 1991-1992. This looks small compared to the SAR volume, but it is still a lot of volume to work with. It is the same as 184 high-density tapes per year, but only 5 Exabyte tapes.

-18-
23. D2 Storage Devices (High Performance)

The D2 tapes are new storage devices that can now be purchased, but the cost is high. There are standards set by the military. There will be about three manufactures. Some characteristics are:

- A D2 small cartridge holds 25 Gbytes of data. The tape is 19 mm wide. A cartridge that holds 25 Gbytes has tape 300 meters long.

- A D2 cartridge will cost $25-$50 (We will use $35). A cost of $35 gives a media cost of $1.43 per Gbyte. This is similar to the cost of Exabyte media.

- The data speed is 15 Mbytes/second; this is very fast, but it still would take 28 minutes to read all 25 Gbytes of data. The search speed for a dataset is 300 inches per second.

- The end-to-end search time on a tape is about 110 seconds (average search time 55 seconds).

- The error rate should be as good as for a 3480 drive (very good).

- A drive costs $200K, list price (Aug 1992); perhaps this will come down to $100K later.

- Jerry Wade, Metrum Company, said (in Jun. 1990) that this is a very difficult technology to develop, and that it will be at least two years before production units are ready. He was right.

24. Future Tape Drive Options

It is likely that by early 1994, there will be cartridges on the market that will hold 15-25 Gbytes, with data rates of about 10-20 Mbytes/second. Some of these probably will use standard tape cartridges about the size of a 3480 cartridge, and use half-inch tape that is not expensive. The associated tape drives will cost about $100K to $115K each. It is hard to build a cost-effective storage system if the tape drives cost this much, but the prices may come down later.

25. Mass Storage Concepts for Data

The future needs for migrating data should be considered when plans are developed to store quantities of data. The present media will become obsolete, and therefore, the data must be copied to new media. Also, whole files of data, or subsets, will need to be extracted for others to use. This will often require that the data be placed on different media. The process of copying existing files to new media can be made relatively simple if proper mass storage concepts are followed.

For proper use of media, several datasets should often be stored on one piece of media, such as a tape, CD-ROM, or floppy disk. The data blocking and storage procedures should be
implemented so that it is easy to move all datasets or a selection of datasets to new media. It should not be required to know anything about the actual data or its format in order to accomplish this file transfer. It is desirable for each storage block of data to include a checksum. This permits the user to check for any errors that occur in any data path or storage device. It also helps to diagnose hardware failures so that they can be fixed.

The principle of not needing to know anything about the actual data or its format when doing a file transfer is very important. This permits automated recopy of archives, movement to new media and tight error control. The cost is also much lower than when a person worries about all the details (and makes mistakes).

- In the U.S., it appears to me that these concepts for storage typically are not followed. This results in many more problems, higher costs, and data loss.

26. Changes in the Cost of Technology

We have seen that the cost of computing has decreased markedly. We will now summarize the cost of both computing and storage media over time. The prices are in current dollars at the given dates. Because of inflation, the real changes are even more dramatic.

<table>
<thead>
<tr>
<th></th>
<th>1964</th>
<th>1974</th>
<th>1991</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Computing investment cost per Mflop</td>
<td>$15,000,000</td>
<td>$1,400,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>b. Storage media cost per gigabyte</td>
<td>$1400 (in 1960)</td>
<td>374</td>
<td>$2-12</td>
</tr>
</tbody>
</table>

The rapid decrease in cost means that improvements in technology have given us an opportunity to make more calculations, handle more data and still manage costs.

27. Cost of Handling High Rate Data, A Summary

The cost of a unit amount of computing capability has decreased by a factor of about 350 since 1974. The cost of storage media (per unit of data) has decreased by a factor of about 40 in the same period (see Table 1). This should give us an opportunity to control costs if we wish to. Some costs that I have been told are:

- 1978-1992: About $100,000 per year has been used to archive about 8 Tbytes of satellite data per year at the University of Wisconsin (usually about 2 Mbit/sec); this includes media and archive costs. Research costs are much more than this.

- Cost to copy, inventory, and save 80.5 Tbytes of radar data per year from new Weather Service radars: NCDC (Asheville) thinks that by using Exabyte technology, they can hold these costs down to $600,000 per year. This is a very good price, even amazing, compared to other datasets. This is the equivalent of a 20 Mbit/sec data stream (2.5
Mbytes/sec). There are options for data compression that could reduce the cost still more. (I guess that all of this data will not actually be saved.)

- Handle data from European satellites (about 53 Tbytes per year): $32 million per year

- If $3 billion were spent for EOSDIS for 1993 through 2000, it implies that data budgets would become about $350 million per year. This includes the work needed to prepare a number of products. This is the same as the annual cost of 10 NMCs, 25 Ashevelles, etc. This appears to be too expensive, and the price seems to be coming down. This is where budget breakdowns and comparisons are needed. Comparisons should be made with past U.S. missions, similar present missions, and with foreign projects. An update: In Sep 1992, the Hughes contract was accepted for data work through 2003, and the cost is $685 million.

- NASA has set up eight distributed archive centers. These centers will later phase into the EOSDIS contract. The budget for all of these centers in 1991-1992 was about $19 million per year, which is a very good price.

- High satellite data costs are often ascribed to high volume. I have given a simplified view, but these examples help to define the level of cost control that is possible if modern technology is used in the right way.

28. Some Comparative Budgets

I made a table (in 1991) of some of the budgets around the country. Now I cannot find the list quickly, but a few of the numbers from NOAA were roughly as follows:

- GFDL $15 million per year (Research Center); this includes a Cray Y-MP-8 computer.
- NMC $35 million per year (Forecast Center), includes Hurricane Center and Severe Storm Center
- NCDC, Asheville $16 million per year (Data Center)

29. Data Backups

If data backup copies are needed, or if it is desirable to have access to large datasets in two or three locations, it is often easiest (and much cheaper) to make the copies in parallel, rather than reading the whole archive to make each copy.

30. Prepare Useful Data for Multiyear Climate Research

It is essential that we have data that gives information about long-term climate change. There is a tendency to increase the sampling resolution in time and space more than is necessary to accomplish this goal. Then we drown people with data, so that it becomes difficult or impossible to carry out long period research, with global coverage.

There are two ways to tackle this problem. We can either make certain that we prepare a medium resolution archive from high-rate instruments, or we can design instruments where
the sampling makes sense for long-period studies. One nice example is the GAC 4-km (5-channel) data from the NOAA satellite series, Nov 1978-1993. The global 4-km archive covers the world and the volume is 255 Gbytes per year. The associated 1-km AVHRR data (16 times the volume) is only saved part of the time, and it can be read out locally on ground receivers that anyone can install.

A good example of the subsetting of large satellite datasets is the ISCCP world cloud program that will be discussed next.

31. Satellite Data for World Cloud Research (ISCCP)

During 1976-1980 it was recognized that data for more cloud research was needed, and plans were developed to start a world program. Data from five or six satellites were needed to study clouds. The total volume of basic data was about 8 Tbytes per year. Sampled subsets of data were defined to make it practical to calculate global clouds every 3 hours of every day. The meeting that made a final determination of data plans was in Hungary in 1981. Data collection started on 1 Jul 1983; the ISCCP program still continues (now 1993). One sampled radiances archive has data each 3 hours, with a resolution of about 10 km (volume about 75 Gbytes per year). A version (B3) with fewer samples (30 km, 3 hours) has been used for the calculations of clouds for ISCCP (volume about 14 Gbytes per year).

32. Blue Sky Approach to Systems

Sometimes our methods of planning systems lead to unreasonable costs. An example of this was the planning to replace the Seasat satellite, an excellent satellite that cost $75 million and was launched in 1978. It failed after 100 days and a replacement was badly needed. A replacement was planned in 1980 and cost $1.0 billion, but it could not be funded. A replacement was planned in 1985-1986 and cost about $1.35 billion, but it could not be funded. Frustration! We lost needed data because of our poor planning.

Assume that we involve scientists who know each sensor well, and ask them for far-reaching specifications of space and time resolution for the next generation of sensors. Then if we separately ask communications and data systems people for their most ambitious goals, we will end up with satellites that cost 3 to 10 times more than the previous generation. And this is in spite of the fact that developments in technology give us the opportunity to both get much more data and control costs. If Congress is too "stingy" to pay for what we ask for, the temptation is to blame the government rather than our planning. There is hope; I have noticed that most PIs are good at helping to achieve reasonable sensor specification if they are involved in a feedback loop that considers data volume and cost.

33. Volume of Data and the Cost for Users

The cost of data for users (1987-1992) has usually been about $100 for a 6250 BPI tape (125 Mbytes). Actually, the tapes often are not blocked well, nor are they full, so typical costs are $100 to $400 per 125 Mbytes of data. Using the lower cost of $100, let us determine the cost for a user to obtain 1 Tbyte of data:
• The cost for one Tbyte of data (at $100 per 125 Mbytes) is $800,000. This means that users can not afford to buy very much of the data from the new sensors.

However, we have seen that there are methods and technical options to reduce the real cost of delivering data, if we choose to use them.

34. Water Cost and Drought in California

It is useful to compare data costs with water costs. When drought hits in California, there is often a move to decrease the amount of water used; then the water department gets less money. The result is that the water department increases the cost of water in order to maintain the staff that they already have. I have noticed that private businesses also do this, but it is harder to raise prices in a competitive market. This is just a remark about the way that organizations behave, the binds that they are in, and how they try to respond to the trouble.

Data has some similarities. There are costs to gather and prepare the data. For scientific data, the number of requests are significant, but are not very high. This means that with tight budgets, the temptation to use better technology that would drop your income is not high. A lower income could mean that you do not have the money to develop datasets. The main answer is to use technology and sensible planning to help control real costs. I do not want to leave the impression that more technology will always reduce costs; unfortunately, technology is often used in ways that will increase costs.

35. Large Datasets and Formats

In 1991-1992 there has been a bandwagon effect that would have the U.S. adopting certain standard formats for all scientific data. Since the word "standard" sounds good, and since there are always skillful proponents, it is easy to get a bandwagon effect without a careful analysis of the issues. I am hoping that these issues can still be sorted out in time, before real trouble starts. The actual outlook for achieving a good analysis in time to impact plans is fairly pessimistic. The indiscriminate use of a number of proposed formats would take many of our large-volume datasets and do the following:

• increase the volume by 50% to 200% for no good reason
• increase storage and data movement costs
• slow down the data processing
• often make life harder for users

There are ways around these problems that can achieve better data systems. I have a text "Readings About Data Formats (Jenne, Oct 1992) that discusses these format issues.

There have been easy options for a PI to put data into a format. It should be considered a big "no-no" to propose data systems that make this task a lot more difficult.
36. Ease of Use

I do not think that our data community has done a good enough job for the users in delivering a real "ease of use" access to data. A lot of money is now being spent on new data systems, but it appears that "ease of use" could easily get worse instead of better.

Some aspects of ease of use are tied to format questions. Under any proposed format system, it should be as easy to put data into a format as it is to write out data in a character format. Ditto for reading. The reports I have seen about new data systems say that these systems are not even close to meeting these goals.

If a person in Kenya has a PC, any reasonable data plan should make it possible for that scientist to easily read in some data--without loading a huge software system, and without studying thick manuals. Plans are not going in this direction. Some clippings about the "ease-of-use" problems are available from NCAR.

37. Size Distribution of Datasets

Many discussions about datasets emphasize the large volume of data. People start to forget that most datasets are middle-sized, small, or very small. Some datasets can be sent to users on floppy disks, which hold 1.4 Mbytes each. The CD-ROM that holds 660 Mbytes is a convenient media to distribute many datasets. Table 5 shows the distribution of size in the main archives at NCAR.

<table>
<thead>
<tr>
<th>Dataset Size (Gbytes)</th>
<th>Number of Datasets</th>
<th>Approx. Volume (Gbytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over 16 (large inputs)</td>
<td>6</td>
<td>1660</td>
</tr>
<tr>
<td>6 - 16</td>
<td>5</td>
<td>500</td>
</tr>
<tr>
<td>1 - 5.9</td>
<td>18</td>
<td>180</td>
</tr>
<tr>
<td>Under 1</td>
<td>45</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>210</td>
<td>40</td>
</tr>
<tr>
<td>TOTAL ~280</td>
<td>~2500</td>
<td></td>
</tr>
</tbody>
</table>

38. Time to Read or Write Data (4 Mar 1993)

It is useful to determine the approximate amount of time needed to read in a dataset.

When magnetic media are used for data storage, it takes time to locate the media and to mount it in a tape drive. Then it usually takes about 60 to 110 seconds to load the tape and find a particular dataset on the media. To determine how long it takes to read the data in a dataset, use the column "data rate per minute" in Table 1. There are differences in error rates in the hardware in Table 1 that are important but which will not be discussed here; see the technology paper (Jenne, 1993).
It is interesting to compare the data density on film with that on digital media. Consider a 36-exposure role of 35-mm color film. Kodak says that the equivalent digital volume of one color slide picture is about 18 megabytes. This gives 648 Mbytes on a roll of film that has a volume of only about 18 cm³. The density is therefore about 36 Mbytes per cm³. When a 35-mm color picture is stored in digital form, it can be compressed to about 6 Mbytes with almost no loss of quality.

**Table 1. Some Characteristics of Storage Systems**

The "real capacity" column shows how much data will actually fit on one tape cartridge. The "approximate data rate" gives the burst data rate of the device. The "data rate per minute" assumes an efficiency factor of about 60%. The data density applies to a tape cartridge; it does not include space between cartridges.

<table>
<thead>
<tr>
<th></th>
<th>Real Capacity (Gbytes)</th>
<th>Media Cost per Gbyte</th>
<th>Approx Data Rate (Mbyte/sec)</th>
<th>Data Rate Per Minute (real) (Mbytes)</th>
<th>Cost of Drive ($1000s)</th>
<th>Data Density (Mbyte/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBM 3490 cartridges</td>
<td>0.42</td>
<td>$12.00</td>
<td>3</td>
<td>95</td>
<td>$15</td>
<td>1.2</td>
</tr>
<tr>
<td>$5 each, 460 Mbytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metrum VHS Tape</td>
<td>19.2</td>
<td>$1.15</td>
<td>2</td>
<td>72</td>
<td>$40</td>
<td>40</td>
</tr>
<tr>
<td>$22, 19.56 Gbytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exabyte 8 mm tapes</td>
<td>4.7</td>
<td>$3.00</td>
<td>0.5</td>
<td>18</td>
<td>$3</td>
<td>52</td>
</tr>
<tr>
<td>$14, 5 Gbytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ampex at Alaska SAR</td>
<td>46.0</td>
<td>$0.75</td>
<td>fast</td>
<td>1165</td>
<td>$140</td>
<td>25</td>
</tr>
<tr>
<td>$34, 47.5 Gbytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In 1994, 1/2-inch tape</td>
<td>14.0</td>
<td>$0.7</td>
<td>5-10</td>
<td>335</td>
<td>$110</td>
<td>41</td>
</tr>
<tr>
<td>$10, 15 Gbytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In 1993, DEC drive</td>
<td>9.5</td>
<td>$3.1</td>
<td>1.5</td>
<td>60</td>
<td>$9</td>
<td>35</td>
</tr>
<tr>
<td>$29, 10 Gbytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

39. **Will Data be Distributed on Bulk Media or Networks?**

Distribution of scientific data on CD-ROMs started in mid-1987 and has become very popular. The technology also inspires CD-ROM producers to remove the last bugs from the data and to make data access easy for users. A practical amount of data for a CD-ROM is about 660 Mbytes. For some datasets that seem a little large for CD-ROMs (and with fewer users), we could also use Exabyte tapes in a similar way. A CD-ROM drive costs only $300-$500 compared with $1500 to $3000 for DAT and Exabyte drives. DAT tapes usually hold up to 1300 Mbytes, and Exabyte tapes hold up to 5000 Mbytes.
At the Terabyte Workshop sponsored by NOAA and MITRE on 16-18 Sep 1992, I was asked whether the future would see data distribution on media such as CD-ROMs and tapes, or would networks become the dominant method? Both will be used. Even with a network, a user has to do something with the data when it comes in, and this usually means that it is written to a hard disk or to a tape. With a CD-ROM the data are already on a hard disc. Browsing from a CD-ROM can be done with 300 ms access times, without requiring tape mounts back at a data center. Networks are becoming quite popular for data transfer. On the better networks, typical real data rates are now 7 to 10 Kbytes/sec, and practical dataset sizes are up to 5 to 20 Mbytes.

At this time, all we can say is that both methods of data transfer will be used. The mix will be decided by convenience, CD-ROM costs, and network costs.

40. Related Texts That may be Useful

Several other texts are available from NCAR that may be useful for people interested in the subject of large datasets:

- Computing Power from PCs to Supers (Sep 1992, draft)
- Technology for Data Transfer and Storage (~Nov 1992, draft)
- Readings About Data Formats (Oct 1992)
- Selected Data Information Available from NCAR (Jan 1993)

41. Conclusions

The level of hype about handling large sets of data has been very high in the U.S. We have presented a series of examples where groups in the U.S. and Europe are actually saving large datasets. It is not easy to work with huge amounts of data, but a careful choice of technology can control costs much more than is usually thought.

To save data for 50 years, it must be easy to migrate data to new media; there must be good error control. There also has to be an overall simplicity of design so that formats and software are not big future problems. The data has to be packaged so that keeping track of each dataset is like keeping track of a book, and not like keeping track of each sentence in the book.
References

Jenne, R.L., Sep 1992 draft: Computing Power from PCs to Supers. NCAR, Boulder, CO; about 80 pp

Jenne, R.L., Feb 1993 draft: Technology for Data Transfer and Storage, NCAR; about 70 pp

Jenne, R.L., Oct 1992 draft: Readings About Data Formats, NCAR; about 70 pp


- End -
30 April 1980, revised

LARGE DATA SETS - CONDENSED DATA SETS

Roy L. Jenne

To meet the needs for climate applications and research, many parameters of the climate system must be monitored and analyzed over long periods of time. For the very large data sets, often involving hundreds or thousands of magnetic tapes (if the data are even saved) this presents severe problems. Data that are buried in archives with very high volume are useless to most projects. We will consider several aspects of the large data set problem, which may give some guidance for the definition of lower volume subsets of data.

These comments stem from the difficulty that groups have in using appropriate data because of high data volume, with its associated high cost and time demands. They also stem from the experiences of many organizations in finding that after making one set of calculations from a large data base, reasons arise for making similar or additional calculations again. These experiences suggest steps that can be taken during the planning for the processing and structuring of data sets which will help us avoid many of the problems.

Data sets can be thought of in several size categories:

a. When data for a project or a year will fit on just a few magnetic tapes (300 million bits each at 1600 BPI), we know that the volume won't significantly retard the use of the data. For such low volume data, we should concentrate on data completeness and data quality. Data digitization and manual checking often is very expensive; it costs about $70,000 to keypunch data (500,000 punched cards) that will fit on one tape. It only costs about $50 to provide a user with a copy of a tape.

b. The next data volume category is about 15 to 150 tapes. Many projects can still stand the costs of using the
data (about $50 per tape for making copies or for using the data on large in-house computers), but a number of useful projects start getting cut off. Attention should be paid to defining data subsets and different levels of data so that most projects can obtain most of the information from the data without having to use all of it.

c. The next volume category is about 150 - 2000 tapes. The larger projects and organizations can still handle the problems, but unless careful attention is given to preparing subsets of data and to the data organization for access, much of the information may never be used.

Some projects need all data for only a few days. Thus, this time selection is a natural data subset that may be of reasonable volume. Other projects that require data for long time periods need other types of data subsets.

d. Important data sets of 2000 - 10,000 tapes are well within our national resources to save when necessary but demand even more care to define different data levels having much less volume, and to develop low cost storage and access strategies.

e. For higher data volumes, it is unlikely that we could afford the time or cost to process all of the data for a long-term climate project. Thus it is important to define useful reduced-volume archives that can be prepared "on the fly" while the data are being processed for other purposes.

Selected access to high volume data can be provided by using lower cost technology (with higher error rates) to store the data. This can
provide the capability to examine special cases in delayed time. The University of Wisconsin "Soumi" recorder is an example. It can hold 5.5 hours of full resolution GOES satellite data on a cassette tape costing $16. This tape, thus, stores 246 x 10^8 bits.

Examples of data rates and volumes are:

1000 bits/sec is 3.16 x 10^{10} bits/yr (105 ordinary tapes)
1,000,000 bits/sec is 3.16 x 10^{13} (105,000 tapes)

An ordinary magnetic tape (costing $12) will hold about 3 x 10^8 bits recorded at 1600 BPI. The data rate from one GOES satellite is 1.7 megabits and is active 73% of the time. Table 1 shows information about data volume related to resolution. Note that nearly 5000 whole-earth grids will fit on one tape if the resolution is 250 Km and if only 8 bits per data point are needed.

Over the next 5 years we will probably see an improvement in computer data processing costs, storage capability, and running time by a factor of about 3. Thus, we should stretch ourselves somewhat to archive what is necessary. The sensors with very high data rates give us major archive problems. For other data, the problems are well within our technological capacities and can be easily solved if we use appropriate strategies.

In some cases, it may be appropriate to let a computer in the satellite calculate the statistics, and only send these down. However, many choices of statistics mask out much of the information. Also, high resolution data is needed for many purposes such as land and cloud pictures, cloud drift, winds, etc.

We will now consider several aspects of the data problem.

1. Need for Basic Data and for Several Levels of Data

Some projects may read 1000 tapes of satellite data that contain information for a 2 or 3 year period. The data often has problems; many cases are found where the radiances are bad for a few scans, where the date on the tape files is wrong, or the location is incorrect. In a project, each of these hurdles must be overcome, but often the basic data set is not cleaned up, nor is a data set saved that allows one to easily make the corrections. It may also be found that the transfer functions from
radiance to desired parameters were bad, or at least could be improved. The project may call for averages for a week or a month at 500 Km resolution; it may then be found that a higher resolution in space and time is needed. Thus, the project must start from scratch - if there is time or money to do it again.

We, therefore, must plan to make it as easy as possible to correct our mistakes, apply new procedures, use the data to calculate other parameters, or make a new synthesis that combines several types of input data such as satellite data and ground based data. This indicates a need to consider several levels of data sets in the archive along with supporting data:

a. Cleaned-up basic data
b. Data set showing any additional corrections needed in the basic data.

c. Compacted data set showing the best knowledge of satellite navigation.

 d. Lower resolution radiance data, not time averaged: About 250 km resolution or less (often 50 - 100 km). These intermediate sized data sets should allow most projects to obtain much of the information without going back to the basic data. They include averages, histograms, and samples of data. Note that changing the resolution from 1km to 100km reduces the volume by a factor of 10,000 if other things are equal.

e. A small selection of data sets with lower resolution such as weekly or monthly averages.

We shouldn't spend a lot of time trying to anticipate every possible data presentation that may be needed, such as averages, maps, or cross-sections in time and space. We should make a selection of composites and also attempt to choose the intermediate sized data sets so that they permit the calculation of a variety of lower resolution products without going back to the basic archives.
2. Save Inputs to Analyses

Analyses of stratospheric conditions are made that use rawinsonde data, rocketsondes, and radiance data from satellite channels. The analysis methods (including the amount of smoothing) often change with time. It is usually easy to save the analysis inputs that will permit a relatively easy recalculation of the analyses at a later time. The new calculations might include better, more uniform procedures. Additional or improved data inputs might also be available to use for the delayed analyses.

For example, five years of the satellite radiances for input to stratospheric analyses could be saved on one or two magnetic tapes if averages of the several channels were saved for each 200-300km along the orbit. Because such inputs haven't been saved, about 1000 tapes would have to be processed in order to obtain the necessary data for a new stratospheric analysis. When a satellite is measuring relatively continuous parameters (such as atmospheric temperature in the cloud-free stratosphere), some sample averaging of the radiances can often be done with little loss of information. In fact, because of the noise in each sample, the average may be a better estimate than any one sample.

3. Condensed Data for Cloud and Land Surface Studies

To obtain required information about cloud conditions and the heat balance, we can use average radiances with a resolution of 100-300km, but also need some information about the statistics. We could just save the standard deviation, etc. However, it is possible to save histograms of radiances that contain much additional information, and yet still are of a manageable volume. Table 2 shows an example of possible archives, and data volume from a SMS satellite, which sees a ground area of about 100° Latitude by 100° Longitude.

We prefer the histograms and radiance samples to cloud statistics because the histograms can be used for other purposes, and also we can then reprocess the histograms to obtain clouds using new methods. Some of the new analyses may also use other data inputs. The histograms can also be used for snow cover, land surface changes, and perhaps rainfall from cumulus clouds.

4. Data Sets of Land Surface Conditions

Information about land use, soil types, topography, vegetation, etc. are often gathered for very small areas. This can lead to very high data
volumes. Many studies only need averages for somewhat larger regions, such as 10-50km. A frequency distribution that shows the portion of the larger area covered by the different categories is even more useful than a simple average.

5. Other High Volume Data Sets

There are other large sets of conventional data and of satellite data. The formats should usually be inspected for possible volume compaction. To permit easy access, some data subsets may be necessary. Examples of subsets are: (1) a selection of stations from a much larger data set, (2) division of data into regions, (3) division by data types, (4) time series of station data and the same data in "synoptic order" (all data for one day together). Even mass-storage devices do not permit requests for data in both time series (station) order and in synoptic order to be economically serviced from a single data set.

6. Volume Analyses on Large Data Sets

Often the data structures that are used to store data require more volume than is necessary. It is, therefore, useful to make a quick estimate of the data volume necessary to contain all of the data samples. The volume of satellite data in an experiment can be easily checked by estimating the hours of data available. Knowing the samples per hour and the bits needed for each sample, the total data volume can then be easily calculated. This should match the actual volume, if a reasonable overhead is allowed. When this data volume analysis is done, one often finds either format problems, or many tapes that have very little data.
Table 1. Data volume for a single grid that uniformly covers the earth. The data volume assumes 8 bits per grid point. The earth's area is $5.10 \times 10^8$ km$^2$.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Points</th>
<th># Tapes</th>
<th>Time to Read</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 Km</td>
<td>$8.16 \times 10^3$</td>
<td>.0002</td>
<td>.065 sec</td>
</tr>
<tr>
<td>100 Km</td>
<td>$5.10 \times 10^4$</td>
<td>.0014</td>
<td>.408 sec</td>
</tr>
<tr>
<td>25 Km</td>
<td>$8.16 \times 10^5$</td>
<td>.022</td>
<td>6.53 sec</td>
</tr>
<tr>
<td>1 Km</td>
<td>$5.10 \times 10^8$</td>
<td>13.6</td>
<td>68 min</td>
</tr>
<tr>
<td>.1 Km</td>
<td>$5.10 \times 10^{10}$</td>
<td>1360.</td>
<td>113 hr</td>
</tr>
</tbody>
</table>

Table 2. NOAA has started a 3-hourly archive which has the data as in line a. Compared to raw data, this has only 1/6 of the data times, and 1/64 of the data samples each time. The other three proposed data sets are relatively low in volume and would meet a number of user needs. The IR histograms resolve the temperature to 2°C (83 levels, each with 6 bits to count the fraction of events). The visible histograms have 16 levels, 6 bits each. Each histogram should include an 8-bit mean of the region. Any average must be properly prepared to preserve the average flux. Note: one 800 BPI tape holds about $10^8$ bits, a 1600 BPI tape about $2.8 \times 10^8$ bits.

In some cases, the satellite data producers may be able to prepare these condensed data sets as by-products of other operations.

<table>
<thead>
<tr>
<th>Type</th>
<th>Space Resolution</th>
<th>Time Resolution</th>
<th>Bits Each Grids</th>
<th>Bits Per Day</th>
<th>Bits Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Average</td>
<td>8 km</td>
<td>3 hr</td>
<td>8</td>
<td>8 BIR, 5 vis.</td>
</tr>
<tr>
<td>b</td>
<td>Average</td>
<td>100 km</td>
<td>1 hr</td>
<td>8</td>
<td>24 IR, 12 VIS</td>
</tr>
<tr>
<td>c</td>
<td>IR histogram</td>
<td>250</td>
<td>3 hr</td>
<td>500</td>
<td>8 IR</td>
</tr>
<tr>
<td>d</td>
<td>Vis. histogram</td>
<td>250</td>
<td>3 hr</td>
<td>100</td>
<td>5 Vis.</td>
</tr>
</tbody>
</table>
Table 3. The relative volumes of different archives and summaries of satellite data is shown. A 1600 BPI tape holds 300 million bits.

In the 100 deg. lat. by 100 deg long. view of a synchronous satellite there are 1975 "boxes", each 250 x 250 km² (column on right below). If there are 1000 bits per "box", (right column) then 151 pictures of synchronous satellite data will fit on one tape. For one grid each 3 hours, there would be 19 days per tape.

For global coverage (8160 equal area boxes), 36 days (grids) will fit on a tape.

<table>
<thead>
<tr>
<th>Approx No. Points</th>
<th>Bits in area 250 x 250 km²</th>
<th>IR temp.</th>
<th>IR temp. Packing factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 km resolution</td>
<td></td>
<td>.5°C</td>
<td>500,000</td>
</tr>
<tr>
<td>8 km</td>
<td></td>
<td>&quot;</td>
<td>8,000</td>
</tr>
<tr>
<td>24 km</td>
<td></td>
<td>&quot;</td>
<td>800</td>
</tr>
<tr>
<td>100 km</td>
<td></td>
<td>&quot;</td>
<td>50</td>
</tr>
</tbody>
</table>

2. One dimensional histograms

<table>
<thead>
<tr>
<th>Level</th>
<th>IR hist.</th>
<th>Vis hist.</th>
<th>Cumulative IR</th>
<th>Cumulative Vis</th>
</tr>
</thead>
<tbody>
<tr>
<td>83</td>
<td>83 x 20</td>
<td>83 x 20</td>
<td>83 x 20</td>
<td>83 x 20</td>
</tr>
<tr>
<td>16</td>
<td>16 x 8</td>
<td>16 x 8</td>
<td>16 x 8</td>
<td>16 x 8</td>
</tr>
<tr>
<td>5 steps</td>
<td>5 steps</td>
<td>5 steps</td>
<td>5 steps</td>
<td>5 steps</td>
</tr>
</tbody>
</table>

3. Two dimen. histograms

<table>
<thead>
<tr>
<th>IR</th>
<th>Vis</th>
<th>Area</th>
<th>Bits/box</th>
<th>Grids/tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>6</td>
<td>8</td>
<td>3150</td>
<td>1450</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>8</td>
<td>3500</td>
<td>1200</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>8</td>
<td>1200</td>
<td>560</td>
</tr>
<tr>
<td>8</td>
<td>3</td>
<td>8</td>
<td>640</td>
<td>240</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>8</td>
<td>380</td>
<td>110</td>
</tr>
</tbody>
</table>

NOTES:

a. To use the data in rainfall studies, one needs a resolution of at least 1/3° lat (37 km) and prefers data each 3 hr., and temperature resolution to at least 2°C.

b. Consider an archive of 6 km data each 3 hours over Colorado (290 x 380 mi). About 286,000 km² area. Save 8 IR and 5 vis grids per day. Use 8 bits/point. This gives 640 days/tape.

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If there are 1000 bits in a 250 km box (right column above), then one tape holds 300,000 boxes (at 1600 B P I).

<table>
<thead>
<tr>
<th>Area</th>
<th>Bits/box</th>
<th>Grids/tape</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975 boxes</td>
<td>1000</td>
<td>151</td>
</tr>
<tr>
<td>8160 boxes</td>
<td>1000</td>
<td>36.76</td>
</tr>
<tr>
<td>4.6 boxes</td>
<td>8000</td>
<td>8150</td>
</tr>
</tbody>
</table>