Papers About Handling Large Datasets
(Roy Jenne, 29 Jan 2001)

For many years, people have pushed technology to gather larger and larger sets of weather/climate data from satellites, radars, and other observing systems. Much less thought is given to how users can gain access to necessary amounts of the data at an affordable cost for the users. Even less attention is given to how we can achieve real costs for data management that are low enough that they do not undermine the science goals.

- This bundle has 11 papers
- And a total of 126 pages in documents (plus 3 pages up front)

1. Managing Large Datasets for Efficiency and Ease-of-Use (RJ, 7 Dec 1992, 16 p)

   This is a set of slides that I presented to a conference at NASA Goddard. The purpose was to outline an overall philosophy and a set of methods to handle the data. It was also given to try to head off some methods that cause trouble.

2. Handling Terabyte Datasets (RJ, Sep 1992, 28 p)

   This is a set of 27 briefing slides presented at a major US interagency conference in 1992.
   - These give a lot of information about data management in general, with a focus on big datasets.
   - I encourage people to look at these slides.

   There was a lot of worry in NOAA and NASA about how to handle very large datasets. And there were plans to deliver some very large datasets to the archives. People wondered about the nature of the problem of handling large datasets.

   I was invited to give a talk at a large “Terabyte” data conference, held about Sep 1992 (probably about 120 to 160 people there). These slides trace a history of some data handling ideas (many of which were not good). For large datasets, it is possible to use a focused approach that delivers good results at attractive costs. There are also approaches that lead to overly complex systems, slower data flows, and high costs.


   This paper was given at a NOAA data workshop in 1981. It is also published in a NOAA proceedings.

4. Data Requirements for Motion Pictures and Single Pictures (RJ, 3 Apr 1996, 4 p) - start Part 2

   The data volume to store pictures is very high. Compression technology to control the volume has been very successful.

5. Big Datasets are Different (RJ, 5 Oct 1995, 10 p)

   This has 3 pages in the cover document. It was written to help understand the data problems of EOSDIS. This includes other short papers:
   a. Methods to handle large datasets (RJ, 5 Oct 1995, 1 p)
   b. Cost to archive and copy large datasets (RJ, 5 Oct 1995, 2 p)
   c. Procedures to handle high-rate data (RJ, 12 Sep 1994, 2 p)
   d. New weather radars for the US; the data (RJ, 1 Sep 1995, 2 p)
6. Projects that Handle Large Volumes of Data (RJ, Jan 2000, 5 p)

- This text briefly reviews some of the good projects around the USA to handle large amounts of data.
- It lists data rates from the NASA satellites in the EOS program. The big ones are 69.5 TBytes/year from EOS AM-1; 50.4 TBytes/year from Landsat-7, 5.7 TB/year from sounders, and 13.4 TB/year from EOS Chem-1. This is data from the satellites. To this we have to add data products.

PLEASE READ ABOUT THESE GOOD PROJECTS.

7. The Big Problems of Using Huge Datasets (RJ, 13 Apr 1995, 8 p)

When I go to the planning meetings for EOSDIS, it seems that a lot of the planning is like a conventional data server for comparatively small amounts of data. This set of ideas will lead to trouble for large datasets. We need to see people analyzing the data flows and data volume to see what really makes sense. This does not happen in committees (or in centralized rules), but a few people know how to do it.

There is another problem in the typical thinking of big projects. They generate tons of data at a cost of millions of dollars. Often the thinking is poor about how users will gain access to the 1 to 5% of the data that will meet 95% of research needs for reasonable real cost and reasonable data handling trouble.

8. Users Access to Large Datasets from NCAR (RJ, 14 Apr 1995, 3 p)

9. Some Problems to Distribute Large Datasets (RJ, 18 May 1999, 1 p)

If users are going to be able to afford to obtain and use large datasets, the cost must be affordable. Many data organizations still charge $500 to $1000 per GByte (or much more) to deliver data. It is necessary to use procedures that directly take advantage of the enormous gains in technology. This paper shows that we (at NCAR) are delivering large datasets for $30 per GByte.

10. Handling Large Datasets (RJ, 3 Mar 1993, 27 p)

There is a lot of talk and worry about handling large datasets. People are not sure (especially in NASA and NOAA) how to do it. People want budgets of zillions of dollars to do it. This paper was written to try to add perspective, to get a better focus on how to it, and to head off the need for excessive budgets (but it is hard to be successful in all these goals).

Suppose the good planning is done and the cost to copy data on to media is about n dollars ($n). The data will have to be copied again to new media in 5-8 years, and again in 9-16 years. What is the total cost of this process over 1000 years if it is done well? It appears that the total cost will converge to $2n, but only if the methods are very good.

This paper also discusses the handling of various large datasets around the US. Costs are often given.

11. Large Datasets—Condensed Datasets (RJ, 30 Apr 1980, 8 p)

During 1976 – 80, it was recognized that the world needed a dataset that could be used to study clouds and climate on the global scale. This led to the ISCCP project (International Satellite Cloud Climate Project).
During about 1976 – 80, there was a debate about how to prepare a condensed global coverage dataset of satellite data (from 4 or 6 geosynchronous satellites, and 1 or 2 polar orbiters). The much smaller dataset would be used to study global clouds and radiation. All of the basic satellite data would be about 20 TBytes per year. This is a lot of data over the 10 or 20 years needed. Using 1980s technology, it was impossible to handle and process these amounts of data.

Some people wanted a goal for the condensed dataset of 40 tapes (1600 bpi) for 5 years. This would be only 1.6 GBytes in 5 years. Technology was already good enough to readily store and share much more data than this. So in the international planning, we increased the data volume saved, but we kept the spirit of having a useful international dataset that could be accessed. Routine data preparation by several countries started in July 1983. And it continues in year 2001.

This paper talks about the range of data problems that are more general than just the ISCCP cloud climate project.
Managing Large Datasets for Efficiency and Ease of Use

- Overview of Use of Data
- Format Needs for Different Tasks
- What Users Need
  - What Users Get
- Comments on Formats
  - Format Complexity
  - Status of Archives
- Handling Large Datasets
THE DATA
- Should not be owned by any of the other systems.

Build things
- Design a car
- Optimize airplane

Land Surface
- Process topography
- Use GIS systems

Meterology
- Models
- obs
- GrADS (display)
- Gempak (display)

Paleoclimate
- Models
- Observations
- Displays

Oceanography
- Models
- obs
- Neons (display)

Agriculture
- Model wheat growth
- Model irrigation and salt
- Corn borer problems

Planets
- Model the science
- Fly by them visually

Publishing

Spreadsheets

Other Disciplines

What glue holds all this together?
Format Needs for Different Tasks

• Format needs for processing data
  — Sort and shuffle data
  — Add more variables when necessary

• Needs for large datasets
  — Efficiency
  — Maybe compression
  — Maybe variable length
  — Error protection

• Needs for 50-year archive
  — Data is separate from software
  — Ability to accept old format
  — Error protection
  — Some sense of simplicity

• Needs for display and manipulation systems
  — Feed data to various programs

• Needs for user of data
  — Simple
  — Low learning time
  — Low cost
  — Efficiency for large datasets

• General format needs
  — Put data into simple data package structures
  — Error protection
  — Variable length permitted
  — Permit either character or binary structures
  — Enough flexibility for data producer

Roy Jenne
23 Nov 1992
** Plans are that users see this data path for user data access

We should do this
Formats

Types

1. Character formats
   - String of characters
   - Rules for making numbers from characters

2. Binary formats
   - String of bits
   - Rules to make numbers from sets of bits
   - Mix of binary numbers and characters

Most formats

- Rules are put into user programs
- Rules are mostly external to the data

Common formats

- Rules are included with the data
- Complexity is high
- Needed features are not available
Different Formats

Two Methods
- Define common format and convert all data
- Apply a descriptor to an existing simple format
  - permits more flexibility
  - this approach will probably expand

What Happens in Common Formats?
- Data is a series of numbers
- Data description tells how the numbers are stored
- File: [Description] [Reports]

Data Description Contents
- What does a number measure (temperature, pressure, soil type)?
- What sort of number is it?
  - (8-bit binary, 32-bit floating point, 5-bit binary)
  - Characters: text, numbers I5, F7.2, etc.
- Present descriptions are not very flexible

Roy Jenne
7 Dec 1992
# Format Complexity

**Level of Complexity**

<table>
<thead>
<tr>
<th>Format Type</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Character format</td>
<td>Usually very simple</td>
</tr>
<tr>
<td>Packed binary</td>
<td>A little more complex</td>
</tr>
<tr>
<td>Common format</td>
<td>Complex</td>
</tr>
</tbody>
</table>

*Question:* What level of complexity does the user see?
Some Comments on Formats

- **Goddard CDF (common data format)**
  - Started about 1980
  - Now about the third version

- **NetCDF at UCAR**
  - Started from ideas of CDF

- **HDF (hierarchical data format)**
  - Started at the University of Illinois about 1988

- **For above three**
  - Size of number is 8, 16, 32, and 64 bits

- **WMO BUFR and GRIB formats**
  - Weather and ocean centers are starting to use these formats
  - The size of the number can be 1, 3, 15 bits, etc., as desired

- **Many other "standard" formats**

- **Most standard formats are not flexible enough now**
  - and they come with thick manuals
  - and often do not have needed features

- **There are other ways to approach formats**

- **See text about formats (Oct 1992 version)**
  - Users are being forgotten

Roy Jenne
23 Nov 1992
Formats for EOS DIS

Changes during Jan 1991 - Nov 1992:

<table>
<thead>
<tr>
<th></th>
<th>Jan 1991</th>
<th>Nov 1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is the new format in archives?</td>
<td>Yes</td>
<td>Usually No</td>
</tr>
<tr>
<td>Is it used in big computing projects?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Is the format given to users?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

New changes for late 1992:

- Data in several complex formats is entering the general archives. EOS DIS uses HDF
- Now they say that HDF will be used for products, not for basic data
  - But some products are also big datasets

Roy Jenne
7 Dec 1992
What Users Need

Ease of Use
  • It has to be
    "As easy as ASCII"
  • Otherwise: it is not a viable system

Direct Access to Data
  • Easy to just obtain some numbers
  • Most key science is done by personal calculations

Ability to Adapt to Other Simple Formats
  • Otherwise: we have a big brother system

For Applications and Displays
  • Easy to get data into them
  • Users will choose their own software

For Large Datasets
  • Need control of data volume
  • Need clean data paths

Roy Jenne
23 Nov 1992
What Users Get

- Thick manuals
- Three days to load systems
  — We failed in 2.5 days
- Two days to learn procedures
Status of Archives

- Archives mainly have simple character and binary formats

- Some more complex binary formats have arrived during 1989-1992

- Now there are many complex common formats
  - This data is starting to enter archives in 1992
  - Archive maintenance will be a problem
  - User access will be a problem

Roy Jenne
7 Dec 1992
Important for Data

- Main granule is a logical record
  - Such as a satellite scan line
  - A rawinsonde
  - An analyzed field
- Keep data in blocking structure for variable length reports
  - Blocks are fixed length
  - Short or long records can be handled
  - Structures like Cray-block or IBM VBS
- Keep checksums on data
  - Protects the data
  - Helps to find hardware problems
  - Checksums can be on the blocks, not records
- Design for fast serial processing
  - For most large datasets
  - But permit small-scale accessor
- To unpack the data
  - Have an access program for fast access
  - Prepare description of data format, automated

Roy Jenne
7 Dec 1992
Methods to Handle Large Datasets

- Plan archives for rapid data flow
  - Not random access to very small amounts of data
  - Don't put cumbersome software in the data path

- Include error control

- Keep the data compact
  - Use efficient formats
  - Consider simple data compression
    - Maybe reduce volume by a factor of 3 or 4

- Use automation for data access

- Keep it simple

Roy Jenne
7 Dec 1992
Some Large Archives

1. GOES, etc., data at the University of Wisconsin
   - 1978 - 1991
   - 125 Tbytes (about 6 to 12 TB per year)

2. All data now on NCAR mass store
   - Valid March 1992
   - 25 Tbytes (increasing at 7 TB per year)

3. SAR from ERS-1
   - Started in mid-1991
   - Rate of 48 Tbytes a year
   - Rate of 11 Tbytes a year for Alaska

4. NEXRAD radars (159 of them by 1996)
   - All scan data would be 80.5 Tbytes a year
     — Same as 644,000 tapes (half-inch, 6250)
   - NCDC can copy the 17,500 Exabyte tapes per year for $600,000
     — A big job; a good price
     — But data will compress 4:1 (to about 20 TB/yr)
     — The Universal radar format would increase the 80.5 Tbytes by a factor of 4.5

5. See Handling Large Datasets (Sep 1992)

Roy Jenne
23 Nov 1992
# Getting Large Datasets to Users

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Years</th>
<th>Volume (in GB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NMC (2.5°)</td>
<td>14.6</td>
<td>15</td>
</tr>
<tr>
<td>NMC adv. anal. (~1°)</td>
<td>1.0</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Satellite Data</th>
<th>Years</th>
<th>Volume (in GB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOVS sounders</td>
<td>10.9</td>
<td>497</td>
</tr>
<tr>
<td>World GAC (4 km)</td>
<td>4.0</td>
<td>1,022</td>
</tr>
<tr>
<td>GOES basic</td>
<td>12.0</td>
<td>120,000</td>
</tr>
<tr>
<td>GOES (8 km, 3 hr)</td>
<td>6.5</td>
<td>58</td>
</tr>
</tbody>
</table>

Typical costs for data on tape
- Now $700 per GB
- Less 30% on big orders

Could we lower the cost for large datasets?
- Maybe use Exabyte tapes
- One tape holds 4.5 GB
- Could we sell copies for $100?
  - This is only $22 per GB
  - Equivalent to $2.80 per 6250 tape
  - Is this price possible?

Roy Jenne
7 Dec 1992
Handling Terabyte Datasets

- Data at NCAR
  - Large satellite datasets at NCAR
  - Advanced analyses from centers
  - Size distribution of datasets

Some large data projects
- Reanalysis, COADS, etc.

- Changes in cost of technology
  - media costs, 1960-1992

- How are datasets used?
  Cost of technology

- Some huge datasets (volume, cost)
  - GOES data at University of Wisconsin
  - NEXRAD data
  - EOS satellites
  - European satellites

- The Seasat example of costs

- Formats

- Packaged data

Talk for the Big Terabyte

Roy Jenne
16 Sep 1992

NCAR Scientific Computing Division
Supercomputing • Communications • Data
Early Satellite Soundings

- VTPR, 8 IR channel, global
- Dec. 1972 - Mar. 1979, 6.4 years
- Still on 1150 tapes in 1983
- Copied to 48 tapes at NCAR, 1983
- Total volume 5.5 Gbytes
- Could copy to 2 Exabyte tapes

Note: various other datasets have a similar history
Data at NCAR

350 Datasets; two million MB

Earth elevation
Wetlands data
Vegetation types

World observations
• Some from 1750
• 50,000 obs/day from 1967

World ships from 1854

Analyses
• Daily N. Hem. pressure from 1899
• Many upper air fields from 1945

Atlantic Ocean Climate: 400,000 years

cattle population
methane emissions
**Data Support at NCAR**

- **NCAR handles many phone calls and requests**
  - Data for research on many subjects

- **Reanalysis Project**
  - Prepare world surface and upper air data (very big task)
  - Starting year: 1945, 1950, or 1958
  - NCAR is preparing data (with help)
  - NMC, ECMWF, and University of Maryland will do global analyses

- **CD-ROM Project**
  - Started Sep 1991
  - Prepare several datasets on CD-ROMs

- **Assessment Studies**
  - Provide climate model data
  - Changes of crops, forests, rivers when climate changes

- **Kuwait Fires Project**
  - Prepare data for mideast for 1991

- **NCAR is called an "active" research archive**
  - Coupled tightly to the science
  - Data for atmosphere, ocean, stratosphere, soils, etc.
Coverage of NMC raobs and piballs for a week in 1982. NCAR archives of these data start March 1962 and became global in June 1966. Data receipt has gradually improved compared with the early years.
Advanced Analyses, NMC and ECMWF (All fields are global)

### NMC Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Start</th>
<th>Day</th>
<th>Form</th>
<th>Resolution</th>
<th>Volume Per Year (in MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global 2.5°</td>
<td>1976</td>
<td>2X</td>
<td>Grid</td>
<td>2.5°</td>
<td>1038</td>
</tr>
<tr>
<td>Sigma levels</td>
<td>Sep '90</td>
<td>4X</td>
<td>Spec</td>
<td>T80, T126</td>
<td>7030</td>
</tr>
<tr>
<td>Flux</td>
<td>Mar '90</td>
<td>4X</td>
<td>Grid</td>
<td>T80, T126</td>
<td>3898</td>
</tr>
<tr>
<td>10-day forecast</td>
<td>Jan '90</td>
<td>1X</td>
<td>Spec</td>
<td>R30</td>
<td>3231</td>
</tr>
</tbody>
</table>

### ECMWF Data

<table>
<thead>
<tr>
<th>Type</th>
<th>Start</th>
<th>Day</th>
<th>Level</th>
<th>Form</th>
<th>Resolution</th>
<th>Volume Per Year (in MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global 2.5°</td>
<td>1980</td>
<td>2X</td>
<td>7</td>
<td>Grid</td>
<td>2.5°</td>
<td>~300</td>
</tr>
<tr>
<td>Basic consolidated</td>
<td>1985</td>
<td>2X</td>
<td>14</td>
<td>Grid</td>
<td>2.5°</td>
<td>1486</td>
</tr>
<tr>
<td>Advanced UA</td>
<td>1985</td>
<td>4X</td>
<td>14</td>
<td>Spec</td>
<td>T106</td>
<td>3339</td>
</tr>
<tr>
<td>Advanced surface (flux)</td>
<td>1985</td>
<td>4X</td>
<td>--</td>
<td>Grid</td>
<td>T106</td>
<td>2706</td>
</tr>
<tr>
<td>Supplementary (flux, rad)</td>
<td>1985</td>
<td>2X*</td>
<td>--</td>
<td>Grid</td>
<td>T106</td>
<td>602</td>
</tr>
</tbody>
</table>

* Starts Jan. 1990 (2X sampling was not good)

### Resolution

<table>
<thead>
<tr>
<th>Type</th>
<th>Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5°</td>
<td>About 275 km</td>
</tr>
<tr>
<td>T80</td>
<td>1.48°(164 km)</td>
</tr>
<tr>
<td>T106</td>
<td>1.125°(125 km)</td>
</tr>
<tr>
<td>T126</td>
<td>0.94°(104 km)</td>
</tr>
</tbody>
</table>

Roy Jenne  
20 Jul 1992
All Observed Data at NCAR (obs and analyses)
- About 380 datasets
- Add 20 each year

Size Distribution
- Biggest six datasets (1660 Gbytes)
  1022 GB  33
  497     32
  58      18
- Data in all of archive

<table>
<thead>
<tr>
<th>Dataset Size (GB)</th>
<th># Datasets</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>16+ GB (large inputs)</td>
<td>6</td>
<td>1660 GB</td>
</tr>
<tr>
<td>6 - 16 GB</td>
<td>5</td>
<td>~500</td>
</tr>
<tr>
<td>1 - 5.9</td>
<td>45</td>
<td>~180</td>
</tr>
<tr>
<td>under 1</td>
<td>~210</td>
<td>~100</td>
</tr>
<tr>
<td>Total Volume</td>
<td></td>
<td>~2500</td>
</tr>
</tbody>
</table>

R. Jenne/NCAR
April 1991
HOW ARE DATASETS USED

- Large batch computing jobs
  - Data flow is important
  - Ease of use is critical
- Personal browse
  - Use routines like NCAR graphics
- System browse
  - Use data in image analysis routines
  - Unidata graphics
  - GIS systems, spreadsheets, etc.
Data Issues

History of Claims, Often Not Good

• Common Formats 1971-1976
  — None were like the 1988-1992 versions

• No need for data in two sort orders, use pointers and random access 1974-1979

• DBMS is the only way 1977-1981

• Keep all data on-line 1975-1985

• Must never use binary data 1977-1984

• Only use communications, not tape 1984-1986

• We need integrated datasets 1974-1982

• Interoperable data systems 1986-on

• Common formats, a new push 1991-1992

References

— Discussion of Above:
  Data Management Methods: Data for Europe - 1988
— Principles for Data Management:
  See WCP-19 - 1982
— Troubles that Users See:
  Meteorological Data Processing - 1978
— For Questions:
  Guidelines for Data Processing - Oct. 1985

Roy Jenne
Sept. 1992
Cost of Technology

- Costs have decreased:

<table>
<thead>
<tr>
<th></th>
<th>1964</th>
<th>1974</th>
<th>1991</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer cost per Mflop</td>
<td>$15M</td>
<td>$1,400,000</td>
<td>$4,000</td>
</tr>
<tr>
<td>Storage media cost per Gbyte</td>
<td>$1200</td>
<td>$374</td>
<td>$2 to 12</td>
</tr>
</tbody>
</table>

- What can happen:
  - Define cadillacs that work like Edsels
  - Escalate costs

- We have an opportunity to:
  - Save more data
  - And control costs

Roy Jenne
Sept. 1992
## Archive Media Costs

<table>
<thead>
<tr>
<th>Date</th>
<th>Type Description</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>1972</td>
<td>1600 BPI tape ($14), 42 MB</td>
<td>37.5</td>
<td>374</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>2/87</td>
<td>3480, $10.50 ea.</td>
<td>174</td>
<td>60.5</td>
</tr>
<tr>
<td>9/89</td>
<td>3480, $5.00 ea., 230 MB</td>
<td>200</td>
<td>25</td>
</tr>
<tr>
<td>8/92</td>
<td>3490, $5.00 ea., 460 MB</td>
<td>420</td>
<td>12</td>
</tr>
</tbody>
</table>

**Metrum VHS Tapes**

<table>
<thead>
<tr>
<th>Date</th>
<th>Capacity (GB)</th>
<th>Price ($/GB)</th>
<th>Capacity (Mbytes)</th>
<th>Cost Per Gbyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>$10.50, 5.2 GB</td>
<td>2.1</td>
<td>5,000</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>$10.00, 14.4 GB</td>
<td>0.71</td>
<td>14,100</td>
<td></td>
</tr>
</tbody>
</table>

**Exabyte Tapes (8 mm)**

<table>
<thead>
<tr>
<th>Date</th>
<th>Capacity (GB)</th>
<th>Price ($/GB)</th>
<th>Capacity (Mbytes)</th>
<th>Cost Per Gbyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>1988</td>
<td>$7, 2.3 GB</td>
<td>3.33</td>
<td>2,100</td>
<td></td>
</tr>
<tr>
<td>1991</td>
<td>$7, 5.0 GB</td>
<td>1.49</td>
<td>4,700</td>
<td></td>
</tr>
</tbody>
</table>

**Sony Optical Tapes**

<table>
<thead>
<tr>
<th>Date</th>
<th>Capacity (GB)</th>
<th>Price ($/GB)</th>
<th>Capacity (Mbytes)</th>
<th>Cost Per Gbyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>$270, 3.2 GB</td>
<td>93</td>
<td>2,900</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>$270, 6.4 GB</td>
<td>44</td>
<td>6,100</td>
<td></td>
</tr>
</tbody>
</table>
# TAPE MEDIA COMPARISON

<table>
<thead>
<tr>
<th></th>
<th>PRESENT CAPACITY</th>
<th>EXPECTED 1995 CAPACITY</th>
<th>TRANSFER RATE</th>
<th>EXPECTED 1995 TRANSFER RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAT</td>
<td>2GB</td>
<td>16GB</td>
<td>187KB/Sec.</td>
<td>456KB/Sec.</td>
</tr>
<tr>
<td>QIC</td>
<td>2.1GB</td>
<td>35GB</td>
<td>600KB/Sec.</td>
<td>600KB/Sec.</td>
</tr>
<tr>
<td>8mm</td>
<td>5GB</td>
<td>10GB</td>
<td>500KB/Sec.</td>
<td>1MB/Sec.</td>
</tr>
<tr>
<td>Half-Inch Cartridge</td>
<td>6GB</td>
<td>20GB</td>
<td>800KB/Sec.</td>
<td>1.5MB/Sec.</td>
</tr>
<tr>
<td>3480</td>
<td>220MB</td>
<td>1.2GB</td>
<td>3MB/Sec.</td>
<td>3MB/Sec.</td>
</tr>
</tbody>
</table>

Source: Archive, Exabyte
Some Large Datasets

1. University of Wisconsin satellite data
   • Now 120 Tbytes in archive
   • About 8 Tbytes per year
   • Cost $100,000 per year

2. Handle 12 Tbytes per year
   • Media costs $9000 to $20,000
   • Fast, automated search
   • Good error rates
   • Cost about $100,000 per year
     — And consultants to use

3. Save data from NEXRAD Weather Radars
   • Save data from 159 radars
   • 80.5 Tbytes/year, on 18,000 Exabyte tapes
   • Cost to copy and inventory tapes (at NCDC)
     — $600,000 per year
     — Includes $270,000 for media
   • Can compress data 4 to 1
     — Reduces costs more

Roy Jenne
Sept. 1992
Some Large Datasets  
(Cont'd)

4. Data from EOS-A satellites  
   • 71.2 Tbytes per year  
   • Also make products  
   • Cost is $3 billion for 1993 through 2000

5. Europe handles satellite data  
   • ERS-1 and other satellites  
   • Run satellite operations, and make archives  
     — Cost $32 million per year  
     — For 1992-1998  
   • 53 Tbytes per year (ERS-1)  
     — 48 of this is SAR  
     — Data rate is 1.5 Mbytes/sec

6. Data on NCAR Mass Store

<table>
<thead>
<tr>
<th>Tbytes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 1985</td>
<td>1.6</td>
</tr>
<tr>
<td>Aug 1990</td>
<td>14.4</td>
</tr>
<tr>
<td>Aug 1992</td>
<td>27.3</td>
</tr>
</tbody>
</table>

• Mass store data rate  
  — 1991 data rate: 1.5 Mbytes/sec  

Roy Jenne  
Sept. 1992
# Meaning of Access Time

<table>
<thead>
<tr>
<th>Device</th>
<th>Access Time</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 sec</td>
<td>tapes</td>
<td>3000</td>
</tr>
<tr>
<td>20 ms</td>
<td>disks</td>
<td></td>
</tr>
<tr>
<td>20 ns</td>
<td>memory</td>
<td>1000</td>
</tr>
</tbody>
</table>

- If data rate is important:
  - Amount of data read must increase with access time
  - More tape drives are needed to get parallel paths

- Remember
  - One robot silo
    - Maximum of 130 tapes per hour
Seasat Satellite Saga

- Seasat was launched in 1978
  - Nice bunch of sensors for ocean work
  - Cost about $75 million
  - Only lasted 100 days
  - Replacement badly needed

- Replacement was planned in 1980
  - Cost $1 billion
  - Could not be funded

- Replacement was planned about 1986
  - Cost $1.3 billion
  - Could not be funded

Note:
- Technology gets cheaper with time
- But planned costs are much more expensive

Roy Jenne
Sept. 1992
Data Handling Methods

- Run control automation
  - Automate 1000's of tasks
  - Protect against errors

- Separate the levels of detail
  - Good file management
  - Fast handling of logical records
  - Easy ways to use each number

- Use good mass storage principles
  - Mainly manages files
  - Can copy data to a new media when necessary
    - Fully automated
User friendly; the complexity of systems

- Be obvious -

And all the rules boil down to one thing: Be obvious. A machine should be designed so that customers can look at it, understand it, and figure out how to use it—quickly. Forget manuals. Industrial designers and manufacturers have discovered that there is an inverse ratio between the reading needed to learn how to operate a product and the use of that product.

Personal Workstations or Hobbled PCs?

Are PCs getting too big, powerful, and complex?

Surprising
Complexity

Or is the PC industry thinking too small about ways new technology can empower users?

Usability Should Really Mean Never Having to Say You're Sorry
Data

- Are we making it easier?
  - We can
  - But we may not

- A person in Kenya has a PC
  - Can they easily read the data?
  - Not with many proposed systems

- Big datasets, how much use?
  - For many large datasets
    - One use each 2.5 years
  - Recent data are usually used more
  - But the costs may be driven by old data

Roy Jenne
Sept. 1992
Format Issues

- Complexity of the format
- Time needed to format data
- Efficiency
- Volume of data in the format
- Is the data easy to use in 50 years?

Some Questions About a Format System

- Does it handle variable length data easily?
- Is there error protection?
- Can both character and binary data be handled?

The User Interface

- Is bulk data access easy and efficient?
- Time needed to format and unpack data
- Time needed to understand and load software
- Many users want "native formats"
- The principle should be
  "As Easy as ASCII"

Roy Jenne
20 Jul 1992
Two Issues

1. Don't let old software drive costs
   - Keep basic data access software simple
   - Keep archive formats simple

2. Don't let old data drive costs
   - Cost to save a year of data the first time
     — media is 30%
     Years 2-8
     - Cost to save all latest 8 years of data $0.15 n
     - Cost to copy data in 8 years $0.7 n
   - Cost to store data 9-16 years old $0.03 n
   - Cost to copy data in 16 years $0.15 n

Total
Annual costs for data 0 to 16 years old ~$2.1 n

Assumes
- Data resolution increases with time (more data)
- Media costs decrease
- Data rates improve
- Storage volume per MB decreases with time

Roy Jenne
Sept. 1992
Packaged Data

- We write books
- We organize datasets on CD-ROMs
- A similar idea is needed for larger datasets
  - A whole period could be on some Exabyte tapes
  - Just copy the tape--no selection
  - A special low price

Data Layout

- Blocked scan lines
- Checksum control
- Perhaps some compression
- Keep sensible, logical records together
  * such as scan lines

Roy Jenne
Sept. 1992
Cost Curves

- We need more projects to gather data
- Need to control costs on each one

So,

- For a cost effective solution, try to determine point A
- Often the plans are at point B
- Cost per unit output
  
  The cost curve goes to point D if cost per unit output is included
Satellite Data on CD-ROMs
(Some Options)

Consider two windows for Geosynchronous Satellite:

- Full disk
- Region of US 48 states

<table>
<thead>
<tr>
<th>Area</th>
<th>Sample Time</th>
<th>Space Sample</th>
<th># Chan</th>
<th>Volume Per Year</th>
<th>CD-ROMs Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. All GOES data</td>
<td>0.5 hr</td>
<td>1 km</td>
<td>2</td>
<td>3500 GB</td>
<td>5400</td>
</tr>
<tr>
<td>2. Full disk</td>
<td>3.0 hr</td>
<td>25 km</td>
<td>2</td>
<td>1500 MB</td>
<td>2.3</td>
</tr>
<tr>
<td>3. US ($10^7\text{ km}^2$)</td>
<td>1.0 hr</td>
<td>8 km</td>
<td>2</td>
<td>2800 MB</td>
<td>4.3</td>
</tr>
</tbody>
</table>

A possible initiative:

- Prepare #2 and #3 above on CD-ROMs
Selected Publications

- Computing Power from PCs to Supers (Sep. 1992, draft)
- Technology for Data Transfer and Storage (~Nov. 1992, draft)
- Handling Large Datasets (Aug. 1992)
- Data to Verify Climate Models (Apr. 1991)
- Readings About Data Formats (Aug. 1992)
- List of Publications

Roy Jenne
10 Sep 1992
List of docs taken to Tenabyte Workshop
Sep 1992

10 Handling Large Datasets
10 User Friendly; the Complexity of Systems
10 Datasets @ NCAR; Brief list & Volume
3 Computing Power from PCs to Supers
2 Reading A bout Data Format
2 Technology for Data Transfer & Storage

30 Formats for Data; Can the fight ever end?

Number of copies to take

Note: I took copies of these papers to put on a table at the meeting.
-Roy Pearce
15 January 1981

Strategies to Develop and Access
Large Sets of Scientific Data

Roy L. Jenne

This paper was presented at a marine
geology and geophysics data workshop, "Frontiers
in Data Storage Retrieval and Display." Sponsored
by the National Geophysical and Solar Terrestrial
Data Center, with support by the National Science
Foundation. 6-7 November 1980.

Jenne, R. L., 1981: Strategies to Develop and Access Large Sets of
Scientific Data. Workshop Nov 1980, "Frontiers in Data Storage
Retrieval and Display." Proceedings by NGSDC, NOAA, Boulder,
Colorado. PP 5-11.
15 November 1980

Strategies to Develop and Access Large Sets of Scientific Data

Roy L. Jenne
National Center for Atmospheric Research*

Most of the scientific disciplines face similar problems in the preparation of data sets. Data are needed for both relatively small scale problems and for all the earth. Some data sets have large enough volumes that they are difficult and expensive to use. Therefore, careful attention must be given to the way the data are structured, to formats, and to data subsets to minimize problems where possible. The strategies for managing and accessing the data will be considered. The costs for processing and archiving data are included to help clarify which hardware and processing strategies will reduce costs.

The data Support Section at NCAR has over 100 different data sets, many with various subsets. They vary in volume from one tape to several hundred. Our data are now on several thousand tapes, and some are on the mass storage system. We have millions of analyses, each usually with 1000 to 4000 grid points. There are even more millions of observations. One data set contains a total of about 30 million reports each year from 9000 major weather stations around the world. Other thousands of tapes contain model output, radar data, etc.

In the fields of meteorology and physical oceanography, there are hundreds of tapes of data that we would like to be able to easily obtain from other organizations when necessary. Fortunately, it is usually rather easy to exchange data sets that have been properly prepared.

*The National Center for Atmospheric Research is sponsored by the National Science Foundation.
The process of getting most national and global data sets prepared for easy access and exchange has been slow, but progress has been made. Data sets with very high volumes give special problems. We are involved in discussions about some of the larger sets of satellite data held elsewhere (or not saved) so that appropriate data strategies can be developed.

Data Needs

Data needs usually cover a wide range of space and time scales. For local flash flood forecasts, we need radar or rain gage data each few kilometers, but for many problems, a sampling or average each 70 to 300 Km is sufficient. For frost forecasts, or solar energy availability in a valley, detailed data may be necessary. For most purposes the data doesn't need to be as dense. For most studies of climate-economic effects such as wheat yields, the exact location and size of each field isn't needed, but the total land area of wheat fields in a 100 Km box is necessary.

Both basic and derived data are necessary. The basic data are necessary to permit better analyses or different types of synthesis, but the results of credible data synthesis steps should be saved. Sometimes analyses are only saved in chart form. Usually a digital version should also be made available so that it can be used in many ways without going through a costly digitizing step. All possible statistics don't have to be planned at the start of a project; primary attention should be given to planning for data sets and subsets from which a large variety of outputs could be easily produced.

Data Volume and Formats

Some data sets have such high volumes that special attention must be given to compact formats and to data subsets. Sometimes a laboratory with a 1000 or 10,000 tape data set doesn't feel like they have a problem, because they have a good computer and sufficient staff to cope with the few data sets in which they specialize. However, other groups would like to obtain much of the information in the data without dedicating most of their resources and time to using it. And they need both basic data and
the processed data. The main emphasis for compaction and subsets should be given to those sets with volume more than about 100 tapes. When data are kept on-line, compaction deserves even more emphasis because of the high cost of on-line storage.

Some examples of high volume data are data from meteorological radars, gust probe data on aircraft, and many satellites. The volume from geostationary satellites is shown in Table 1. The average data rate from the US GOES satellite is 1 million bits/per second. Note that saving all GOES data would take 70 tapes (6250 BPI) per day which can be cut to 36 tapes without loss of information. This can be cut to 91 tapes per year by saving data only each 3 hours (instead of half hourly) and saving data each 9 Km instead of 1 Km. Most of the projects needing data can be satisfied from this heavily sampled archive that has .0036 the original volume. Other planned archives are histograms and averages for 250 Km areas; these have very low volumes.

Some factors concerning formats that deserve analysis are:

- Are all variables saved at the same time or space frequency even when it is not necessary?
- Is there more location and housekeeping data than observed data?
- Does each data element use 6 to 60 bits when 4 to 16 might be enough?
- Are variable length reports saved in fixed length blocks?
- Are data written on tape in short unblocked records?
- Are too many data types integrated into one data stream?
- Is the volume of quality control information high compared to the data?
- Does the grid mapping method have an excessive number of points?

The question often arises as to whether the primitive, first level archive can be thrown away. Sometimes this is decided by momentary economics or poor decisions which are regretted later. Usually archives are needed on either side of difficult or non-reversible data transformations
but there are cases where the initial process is straightforward (though often messy) enough that the initial archive doesn't need to be kept.' An example is the voltages and instrument corrections from which radiosonde temperature versus height soundings of the atmosphere are derived.

Relatively simple methods for using binary packing, variable length blocking, etc. (and using such data on other machines) are described in Jenne and Joseph, 1974.

When people become aware of data volume savings that can be obtained by applying binary packing techniques, they sometimes go overboard and spend a lot of time and effort to squeeze out the last binary bit. This can lead to comments such as "He (she) is more interested in saving the last bit (or microsecond) than getting the job done." Thus, it is hoped that formats for both character and binary packed data be kept as simple as is consistent with both hardware and programming efficiency.

Management of Large Scientific Data Sets

It is generally not reasonable or cost effective to try to provide access to scientific data sets with near instant turn-around. A typical portion of a large data set is used very infrequently. Sometimes a researcher may obtain a copy of a large data set for use elsewhere, or make calculations from the whole set at NCAR. Then the data may sit unused for many months. Instead of using all of a large set, many projects only require a portion of the data such as:

- Most data for a few days, months, or years
- A selection of analyses for a time period
- Data for only a few stations from a large data set having many stations in time-series order.
The use of model output data follows a similar pattern. A set of data is typically summarized soon after it is created and then it may sit idle for months before new questions arise.

Instant turn-around is not necessary for these jobs. It is important to keep costs down so that useful data jobs are not "priced out of the market". If the storage of much of the data off-line helps to reduce costs, (See Table 3) then this should be done. It must still be a relatively simple task to bring the data back on-line.

When a data set is in active use, it may remain in use for several days.

In most cases a file management system is needed, not a full DBMS. Jenne and Joseph, 1978, outline the considerations regarding use of data pointer systems in data access. The access times for disks and mass stores are such that data block sizes must be large to obtain reasonable average data transfer rates. This means that full random access to small reports is not permitted by the hardware. Thus, the files needed to be structured so that most users see a file that is as nearly serial as possible.

Usually system functions have a high overhead. For example, at the National Climatic Center a test was run to load 16,000 daily weather observations, about 60 characters each. It took 8 hours on the DMS-1100 system on the Univac. Since there are 133,000,000 observations in this data set, it would take about 8 years to load it (.2 seconds each and even much worse if the data are not presorted). Since this is not acceptable, they want to experiment with System 2000. This system inverts down to the element; it is also understood to be intensive on overhead, but hopefully it will give better timing. It has been noted that system timing may be acceptable on a small subset of data, but gets much worse as the volume increases. Experiences with some systems lead to comments such as "If we had used the approach of method Y or system X, we would need a CRAY (fast computer) just to keep up".
Costs for Processing and Archiving Data

The archives to support cloud studies will be approximately as in Table 2. They are included to give some feeling for data volumes that can be associated with the cost information that will be presented. One 6250 BPI tape holds $10^9$ bits.

Table 3 shows the annual cost to archive data both on-line and off-line. Note that the on-line costs for disks or mass-storage systems become extremely high with large amounts of data. It also becomes expensive to copy an archive once. Sometimes some of the copy costs can be reduced by using a mini-computer associated with a mass storage system and thus not ascending the data to the large computer. It should also be noted that many data sets are small enough that they are inexpensive to manage, especially if they are usually off-line.

Table 4 shows costs for individual storage and processing components. It is from Jenne (1980), which contains additional information on computer component costs, data rates, and mass storage data flow. The CPU cost is based on the CPU time needed to pass the data through the system without a significant number of special calculations. The cost of hardware maintenance, operations, and software support is not significantly included in the on-line costs. The off-line costs don't include the costs of mounting tapes or keeping track of the archive.

To store large amounts of satellite data the University of Wisconsin has adapted a standard Soni tape recorder (Cost $25,000 each). Students change a tape each 6 hours. The yearly cost for saving data from one satellite ($3.2 \times 10^{13}$ bits) is about $90,000. The cost with 6250 BPI tapes would be $775,000, but then a mini-computer could reduce the volume giving a cost of about $250,000. The Soni recorder has poorer error rates than a tape, probably one error in $10^6$ bits. The recorder looks to the program just like a satellite when it is read. Tapes that are 5 or 6 years old are getting hard to read, especially if they have been used several times.
In figuring the costs of computing, it is good to consider capacity factors as is done in the economic evaluation of production facilities. For example, a windmill that generates electricity may be rated at 2 Kilowatts, but only operate at this rate 10% of the time. The cost of the delivered energy is the total kilowatt-hours produced per year divided by the annual capital costs (including interest), the maintenance costs, and the operating costs. A similar analysis is needed for each major part of a computer system. On-line storage of seldom-used data represents a low capacity factor and thus high costs. A computer, disk channel, or tape drive that is seldom used usually has a high cost per unit of use. Thus, we should avoid obtaining excess equipment or using expensive methods that aren't necessary, because the unit costs may become so high that many worthwhile projects are cut off.

The cost of developing software systems is often high. After a system is developed, changes are usually necessary. Then the person making the changes must determine where the changes should be made, and what the adverse interactions might be. This is often hard even for the person who designed the system and very difficult for others. This is one reason that so often a new beautiful system is designed to replace the poor inadequate system which was the beautiful system of yesterday. And often this approach may be best because of the cost of understanding a previous system. But simpler, more modular approaches are often overlooked.

Table 5 lists some of the costs associated with getting a useful result for a computer.
References:


Table 1. Data from Geostationary Satellites. Note that saving all data from one GOES satellite would take 9149 tapes/year (6250 BPI) for visible data but only 25 tapes when the data is sampled each 8 Km. The data volume includes several percent for overhead.

<table>
<thead>
<tr>
<th></th>
<th>ESA</th>
<th>GMS</th>
<th>GOES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meteosat</td>
<td>Japan</td>
<td>USA</td>
</tr>
<tr>
<td>Spin scan</td>
<td>100 RPM</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>No. of steps</td>
<td>2500</td>
<td>2500</td>
<td>1820</td>
</tr>
<tr>
<td>Visible resolution (Km)</td>
<td>2.5</td>
<td>1.25</td>
<td>.9</td>
</tr>
<tr>
<td>IR resolution (Km)</td>
<td>5</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Water vapor resolution (Km)</td>
<td>5</td>
<td>35</td>
<td>21(E-W)x25(N-S)</td>
</tr>
<tr>
<td>Visible resolution (μm)</td>
<td>65 μm</td>
<td>24</td>
<td>21</td>
</tr>
<tr>
<td>Angle between vis spots (E-W)</td>
<td>62.5 μm</td>
<td>140</td>
<td>250x250</td>
</tr>
<tr>
<td>IR resolution (μm)</td>
<td>140 μm</td>
<td>48</td>
<td>84</td>
</tr>
<tr>
<td>Angle between IR spots</td>
<td>125 μm</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Wave Length Vis IR</td>
<td>4.1-11 μm</td>
<td>.5-.75</td>
<td>.55-.75</td>
</tr>
<tr>
<td>Wave Length Vis IR</td>
<td>10.5-12.5 μm</td>
<td>same</td>
<td>same</td>
</tr>
<tr>
<td>Vis samples in scan line</td>
<td>5000</td>
<td>13376</td>
<td>15292</td>
</tr>
<tr>
<td>Vis lines in picture</td>
<td>5000</td>
<td>10000</td>
<td>14560</td>
</tr>
<tr>
<td>IR spots in scan line</td>
<td>2500</td>
<td>6688</td>
<td>27283</td>
</tr>
<tr>
<td>IR lines</td>
<td>2500</td>
<td>2500</td>
<td>1820</td>
</tr>
<tr>
<td>Vis Bits/picture (6 bit spot)</td>
<td>1.58 x 10^8</td>
<td>8.12 x 10^8</td>
<td>13.9 x 10^8</td>
</tr>
<tr>
<td>IR Bits/picture (8, 9, 9 bit spots)</td>
<td>5.26 x 10^7</td>
<td>1.57 x 10^8</td>
<td>6.51 x 10^7</td>
</tr>
</tbody>
</table>

Data from Satellite each day

| Vis Bits/day (6 bit) (10^9) | 7.57 (48p) | 11.4 (14P)* | 66.7 (48P) |
| IR Bits/day (8, 9, 9 bit) (10^9) | 2.52 (48p) | 2.20 (14P) | 3.12 (48 P) |

Cut vis at dark line, drop IR overlap each year

| Vis Bits/day (6 bit) (10^9) | 3.79 (48p) | 5.69 (14P) | 33.4 (48P) |
| IR Bits/day (8 bit) (10^9) | 2.52 (48p) | .98 (14p)(5 Km) | 1.39 (48P) (9Km) |

Cut most space data (25%) each year

| Vis Bits/year (6 bit) (10^9) | 1037 (48p) | 1558 (14p) | 9149 (48P) year |
| IR Bit/year (8 bit) (10^9) | 691 (48p) | 268 (14p) | 381 (48P) |

3-Hourly spots each 8 to 10 Km

| Vis Bits/year (6 bit) (10^9) | 13 (8P) | 15 (8p) | 25 (8P) |
| IR Bits/year (8 bit) (10^9) | 31 (8P) | 40 (8p) | 66 (8P) |
| Points each vis, IR picture | .75 (1250x1250) | .75 (1672x1250) | .75 (1912x1820) |

*(14p) means 14 pictures/day

Note: A 1600 BPI tape holds \( 3 \times 10^9 \) bits
A 6250 BPI tape holds \( 1.0 \times 10^9 \) bits
A U. Wisc. recorder tape holds \( 22.3 \times 10^9 \) bits
<table>
<thead>
<tr>
<th></th>
<th>Tapes now</th>
<th>Planned tapes (6250)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old surface synop</td>
<td>~1901-1965</td>
<td>1414</td>
</tr>
<tr>
<td>Sfc synop from teletype</td>
<td>1965-1980</td>
<td>400 to 2500</td>
</tr>
<tr>
<td>Ship log data</td>
<td>1850-on</td>
<td>500+</td>
</tr>
<tr>
<td><strong>Scanners</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOAA SR grids (20 Km)</td>
<td>Jan 73-Mar 78</td>
<td>2600</td>
</tr>
<tr>
<td>TIROS 4 Km (ea 8 Km)</td>
<td>21 Oct 78-on</td>
<td>5800/yr</td>
</tr>
<tr>
<td>NASA SR (N4, 5, 6, 7)</td>
<td>Apr 1970-on(breaks)</td>
<td>8700/yr</td>
</tr>
<tr>
<td>DMSP (6 Km spot ea 12 Km)</td>
<td>none</td>
<td></td>
</tr>
<tr>
<td><strong>Geosynchronous</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Each US GOES (8 Km)</td>
<td>FGGE on</td>
<td>(\frac{\text{all orig}}{9530/yr})</td>
</tr>
<tr>
<td>ESA Meteosat (10 Km)</td>
<td>FGGE on (break)</td>
<td>(\frac{\text{all orig}}{1728/yr})</td>
</tr>
<tr>
<td>GMS Japan (10 Km)</td>
<td>FGGE on</td>
<td>(\frac{\text{all orig}}{1826/yr})</td>
</tr>
<tr>
<td><strong>Sounders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VTPR</td>
<td>Nov 72-Jan 79</td>
<td>1130</td>
</tr>
<tr>
<td>TIROS (all chan, 250 Km)</td>
<td>Nov 78-on</td>
<td>50 /yr</td>
</tr>
<tr>
<td>TIROS (all spots, 4 chan)</td>
<td>Nov 78-on</td>
<td>610 /yr</td>
</tr>
<tr>
<td><strong>Clouds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-D neph (only do this now)</td>
<td>1971-1980</td>
<td>11460</td>
</tr>
<tr>
<td></td>
<td>10 boxes, 1978-80</td>
<td>360</td>
</tr>
</tbody>
</table>

*The geosynchronous satellite now has much more volume than this.
**Only 2 channels.
TABLE 3. Data archive and copy costs. The full maintenance and people costs are not included in the archive costs. Note that a steady 1 megabit rate for a year is $3.16 \times 10^{13}$ bits per year.

<table>
<thead>
<tr>
<th>Tapes (6250 BPI)</th>
<th>offline cost/year (6250-tapes)</th>
<th>on-line disk cost/year</th>
<th>copy archive once</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>$10^{10}$</td>
<td>$0.20</td>
<td>$5,000</td>
</tr>
<tr>
<td>100</td>
<td>$10^{11}$</td>
<td>200</td>
<td>50,000</td>
</tr>
<tr>
<td>1000</td>
<td>$10^{12}$</td>
<td>2000</td>
<td>500,000</td>
</tr>
<tr>
<td>10,000</td>
<td>$10^{13}$</td>
<td>20,000</td>
<td>5,000,000</td>
</tr>
<tr>
<td>100,000</td>
<td>$10^{14}$</td>
<td>200,000</td>
<td>50,000,000</td>
</tr>
</tbody>
</table>

*These costs would be about $730 using our TBM mass store, and ascending and descending the data. Costs using 1600 BPI tape are about 3 times the 6250 BPI costs.

On-line mass storage costs are high.
Table 4. Data storage and processing costs. The cost is given for both on-line and off-line storage. The costs generally assumed a hardware lifetime of 5 to 6 years. The processing costs are optimistically low because inexpensive rates on a fast computer (CDC-7600) were used.

<table>
<thead>
<tr>
<th></th>
<th>Cost/yr per $10^{10}$ bits</th>
<th>I/O and Computing costs for $10^{10}$ bits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>on-line hardware storage costs</td>
<td>off-line costs media and storage</td>
</tr>
<tr>
<td>(no maintenance)</td>
<td>(minutes</td>
<td>minutes</td>
</tr>
<tr>
<td>1600 BPI tapes</td>
<td>170,000</td>
<td>$66*</td>
</tr>
<tr>
<td>6250 BPI tapes</td>
<td>51,000</td>
<td>20</td>
</tr>
<tr>
<td>Auto tape Library</td>
<td>835</td>
<td>20</td>
</tr>
<tr>
<td>(2000 tapes-6250 BPI)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disk packs (300 mbytes)</td>
<td>36,000</td>
<td>1000+</td>
</tr>
<tr>
<td>Large disks (2400 mbytes)</td>
<td>E4,700</td>
<td>-----</td>
</tr>
<tr>
<td>TBM mass store</td>
<td>7,600</td>
<td>29</td>
</tr>
<tr>
<td>Optical disk</td>
<td>E3,600</td>
<td>E2</td>
</tr>
<tr>
<td>Core disk transfer</td>
<td>-----</td>
<td>-----</td>
</tr>
</tbody>
</table>

*These costs assume relatively full tapes. If tapes average only 25% full, multiply these costs by 4.

In the table, E means estimated.
Table 5. Costs associated with getting a useful result from a computer.

Applied Programmer Costs:

- Time to learn to use the computing system
- Time to write and check the program
- Time to run the program (portion of hardware and software costs)

Costs of Using the Hardware:

- Cost to buy it
- Cost to maintain hardware
- Cost to operate hardware; people, energy, etc.
- Floor space

Cost of Using the Software:

- Cost to develop software system at plant
- Cost to develop local software
- Cost to understand and maintain software

Next Level of Software Costs:

- Cost to document system
- Cost to teach courses about the system
- Cost to write utility programs
- Cost to provide consulting help about system

Cost of Managing the Hardware and Software System
Workshop Reflections by Roy Jenne, NCAR*

It seems to me that the workshop was very effective in helping each data group to benefit from the data strategies of other groups and to hear about the good or bad results from different methods that have been tried.

Most of the data sets that were considered at the workshop were small in volume; they would fit on one to several magnetic tapes. The characteristics of use of the many geophysical data sets probably vary markedly. A few are used quite often and others are idle for long periods between use. An overall data strategy should encourage different approaches depending on data set size and how the data set is used. It is not reasonable or cost effective to model all data access systems after an airline reservation system. If the frequency of data access is relatively low and/or the data volume is high, a more batch oriented file system will be best.

In the on-line data systems, it may be easy to forget that a secure copy of the data, usually off-line, is also necessary. This copy should be in a well structured format that can be easily (and inexpensively) copied for use at another installation, and it can serve as a backup. For most new data sets, the first priority (after meeting any real-time needs) should be to get it onto secure storage in a well structured file format. Different stages of quality control should follow; the first stage should ensure that mechanical details such as format, dates, and locations are correct.

*National Center for Atmospheric Research