# The Prototype Digital Weather Laboratory at Colorado State University

By
T.H. Vonder Haar, C.F. Shih, D.L. Randel, A. Meade, J.J. Toth, D.N. Allen and R.A. Pielke

CIRA and
Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

Colorado State University

Department of Atmospheric Science

Paper No. 397

# The Prototype Digital Weather Laboratory

# at Colorado State University

By

T. H. Vonder Haar, C. F. Shih,
D. L. Randel, A. Meade, J. J. Toth,
D. N. Allen, and R. A. Pielke

Cooperative Institute for Research
in the Atmosphere (CIRA)

and

Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado 80523

Atmospheric Science Paper No. 397

## ABSTRACT

A new weather laboratory for teaching and applied research has been developed at Colorado State University. The laboratory uses DEC Workstations and also hosts various microcomputers via a Local Area Network to interface with the CIRA computer system shared by the Department of Atmospheric Science. This computer system centers on a cluster of VAX 700-class computers and includes several user-interactive subsystems, such as the Interactive Research Imaging System (IRIS), Direct Readout Satellite Earth Station (DRSES), and a weather display system (using GEMPAK). Through direct communication lines, the VAX 700-class computer cluster is linked to the main frame computers of CSU, NCAR and NOAA/ERL. Since our computer system has such broad interface with other computer systems, a unique feature of our new weather laboratory is its capability to provide not only current weather data but also realtime satellite, radar, mesonet and profiler data. Examples of the products of the new weather laboratory are presented. Options and trade offs encountered in the design of the new weather laboratory are discussed. [The present paper is a revision of one with the same title presented at the AMS Second International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology (IIPS) in Miami, Florida, January 13-17, 1986, and published in the Preprint Volume of that conference.]

## Acknowledgements

Support for this prototype development has come from many sources. The staff of CIRA have participated under the auspices of NOAA contract NA85RAH05045. Some weather lab equipment was provided by the NSF, Atmospheric Sciences Section under grant ATM-8414813, and the Department of Atmospheric Science, Colorado State University has provided some direct support. We also have appreciated the assistance of scientists at PROFS, ERL, NOAA; UNIDATA, UCAR; and the discussions with faculty at the University of Illinois and the U.S. Naval Postgraduate School.

TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ACRONYMS

| | |
|---|---|
| AFOS | Automated Field Operations and Services |
| ASCII | American Standard Code for Information Interchange |
| CIRA | Cooperative Institute for Research in the Atmosphere |
| COMTAL | Comtal Vision One/20 Image Processing Workstation |
| DCS | Data Collection System |
| DCP | Data Collection Platform |
| DEC | Digital Equipment Corporation |
| DEC/VAX | Digital Equipment Corporation |
| DRSES | Direct Readout Satellite Earth Station |
| ERL | Environmental Research Laboratory |
| FAA604 | FAA weather service |
| FAX | Facsimile Data System |
| GEMPAK | General Meteorological Software Package |
| GEMPLT | General Meteorological Plotting Software Package |
| GOES | Geostationary Operational Environmental Satellite |
| IRIS | Interactive Research Imaging System |
| NASA | National Atmospheric and Space Administration |
| NMC | National Meteorological Center |
| NOAA | National Oceanic and Atmospheric Administration |
| NSF | National Science Foundation |
| NWS | National Weather Service |
| PRE-STORM | Preliminary Regional Experiment for STORM-Central |
| PROFILER | Ground-based Microwave System for Remote Sensing |
| PROFS | Program for Regional Observing and Forecasting Service |
| TAE | Transportable Applications Executive |

| | |
|---|---|
| UCAR | University Corporation for Atmospheric Research |
| UNIDATA | University Weather Data System |
| VAS | VISSR Atmospheric Scanner |
| VISSR | Visible Infrared Spin Scan Radiometer |

## 1. Introduction

Traditionally, the weather laboratory classroom has consisted of daily weather maps, teletype messages, and a video display system to use educational video programs. With today's advanced technology, various powerful mini computers and personal computer workstations, as well as graphical display devices, are available at a relatively low cost. The use of these systems has been pioneered for research applications. We are currently adopting them for use in the teaching weather laboratory.

Through the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University, we have contributed research (Vonder Haar, et al., 1982; Vonder Haar and Brubaker, 1981) related to the early development of the Prototype Regional Observational and Forecasting System (PROFS) (Beran and Little, 1979; Schlatter, et al., 1985). This system focused upon forecaster needs and helped formulate early ideas for the digital weather lab. Because of our participation in the planning for the UCAR/NSF UNIDATA project, our weather lab development is a very close complement to that project.

The new CSU digital weather laboratory will not only use the traditional weather data broadcasted by the National Weather Service (NWS), but also utilizes digital satellite images, remote data collection platforms, and radar data sets provided in real-time. Another important data source, the grid point model data produced by the National Meteorological Center, is also going to be available in the near future. Such combined usage of current as well as archived meteorological data through computer analysis/display software will help both education and student research projects in the atmospheric sciences. We note two specific improvements for educational purposes:

1) Using computer analysis/display software saves considerable time in contrast to manual plotting and analysis of weather maps. However, the individual interpretation and modification of the analyses are still retained. Thus, students learn more by spending the time saved in discussing the structure of weather systems and analyses of weather in real-time.

2) By testing various methodologies of displaying weather information, the students can obtain a better and more vivid kinesthetic feeling about weather. This is especially effective when results of weather analysis and numerical models are presented for intercomparison.

Student research projects also benefit from our new digital weather system. For example, to support the field experiments in atmospheric research (ranging from the study of cloud-radiation processes to mesoscale dynamics), it is very important to be able to display the current weather information in realtime in order to make effective and appropriate experiment decisions. Another aid to student and faculty research in the field is the use of weather lab capabilities for follow-up debriefing and selected processing of collected data. Using software modules implemented in our new weather laboratory, we display the results with great ease and reliability. Faculty and students who recently participated in the Oklahoma PRESTORM experiment used this capability to good advantage (Purdom, et al., 1985).

The CSU digital weather laboratory is linked to the CIRA and Department of Atmospheric Science research data and processing facilities via a Local Area Network (Ethernet) which transmits digital data at a rate of 10 mega bits per second. The Colorado Climate Center, adjacent to the Department, is also on the network. Thus, we plan for the weather lab to serve as a testbed for selected hardware/software developed in our larger research and extension activities.

## 2. System Design

Figure 1 illustrates the computer and data ingest system configuration supporting our new digital weather laboratory. Technical features of the VAX 11/750, VAX Workstation I and Ethernet are listed in Tables 1-3. Figures 2 and 3 are examples of the computer hardware system and the VAX workstations used in our new digital weather lab. Figure 4 demonstrates the capability of displaying products of our weather lab software on the COMTAL station. However, the weather lab is a distinct division of the larger CIRA research data collection and processing system. As shown in Figure 1, the main weather data ingest arrives through a commercial satellite downlink, which includes National Weather Service Facsimile (NWS FAX), NMC grid data, and FAA604 data. Additional weather data, such as PROFS mesonet, NWS radar, AFOS, as well as PROFILER data, are also available via direct links to NOAA, ERL. In conjunction with our Direct Readout Satellite Earth Station (DRSES), we collect real-time digital full-resolution GOES satellite data, which includes imager and sounder (e.g. VISSR, VAS) data as well as DCS/DCP data. Figure 1 shows that the system includes several special data ingest lines (both direct and dial-up), notably those to the PROFS, NCAR, the CSU University Computer Center facilities, and the Colorado Climate Center.

All data sets mentioned above are input in digital format, in either binary or ASCII codes. Because GEMPAK software uses packed binary data, these ASCII data sets are converted into a binary format. Currently, two decoder programs (one for surface data, and the other for upper air sounding data) are used as shown in Figure 5. Besides translating and packing the data from ASCII into binary format, these programs also do error checking to some extent. When there is an error in the translated data of a station, the specific station report for that hour is disregarded.

CURRENT COMPUTER SYSTEM CONFIGURATION DIAGRAM RELATED TO THE NEW DIGITAL WEATHER LABORATORY AT CSU

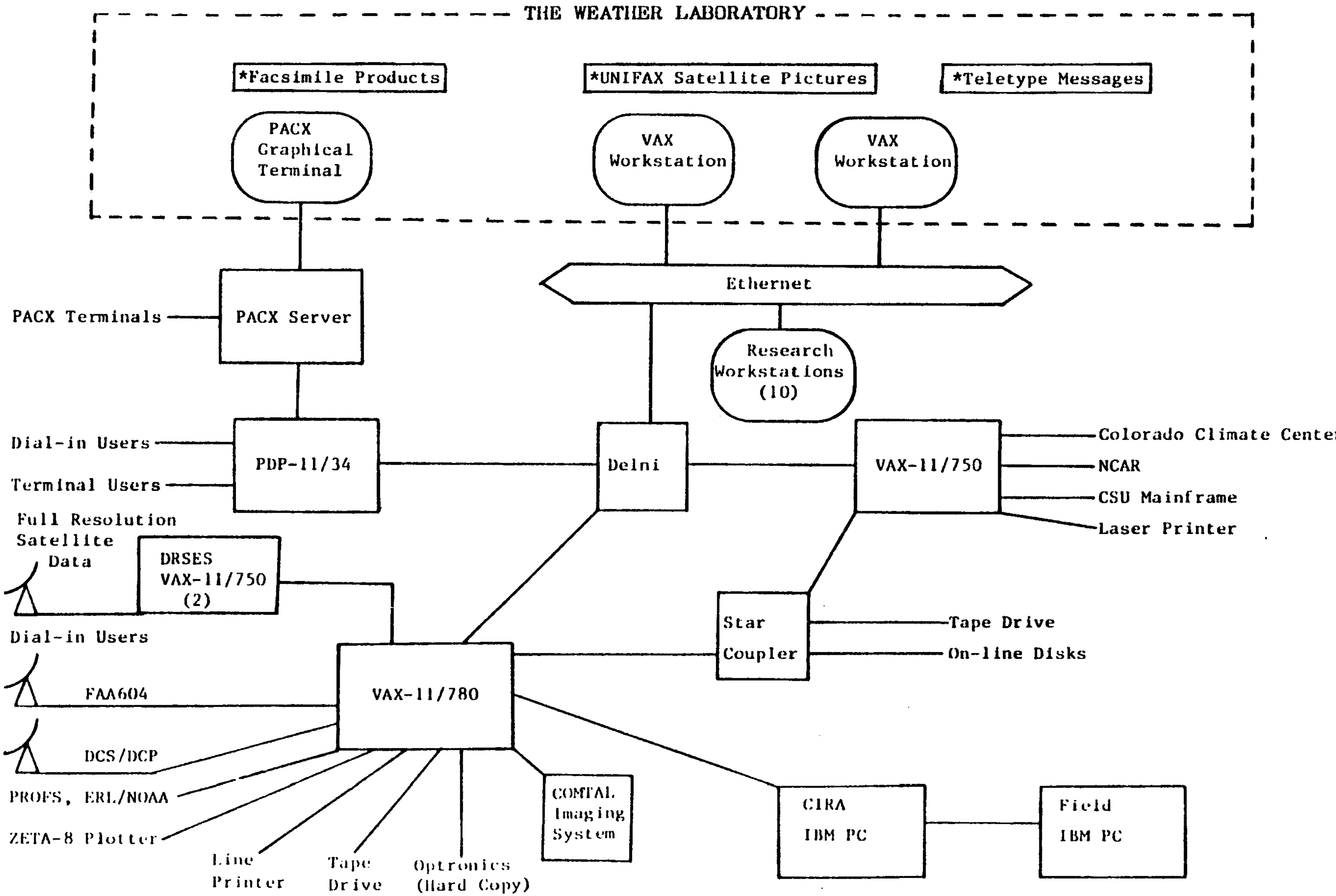


Figure 1. The computer and data ingest system configuration chart of the CSU new digital weather laboratory.

Table 1. Technical specifications of the host computer, VAX-11/750, of the Digital Weather Laboratory.

VAX-11/750

I. Hardware

A. DEC mini computer featuring 32 bit virtual memory.

B. 4 mega bytes of main memory.

C. Ethernet interface for networking.

D. Interface for clustering with two HSC-50 controllers supplying access to two 6250 BPI 125 IPS tape drives and 3.6 giga bytes of disk storage with an access rate of about 3.5 mega bytes per second.

II. Software

A. VMS operating system.

B. Fortran compiler.

C. DECNet software for data communications, using the Ethernet interface.

D. Pascal compiler.

E. VAX macro.

Table 2. Technical specifications of the VAX Workstation I used in the Digital Weather Laboratory.

VAX Workstation I

I. Hardware

A. Stand alone MicroVAX I micro computer featuring 32 bit virtual memory.

B. 2 mega bytes of main memory.

C. 1K x 2K bit-mapped video RAM area.

D. 19 inch non-interlaced monochrom monitor supporting a 960 by 864 format with a resolution of 78 pixels per inch.

E. One internal and one external 31 megabyte, 5 1/4 inch Winchester disks.

F. Dual 5 1/4 inch, 400 Kbyte floppy disks.

G. Ethernet interface for networking.

H. Mouse pointing device with 3 function buttons.

II. Software

A. MicroVMS operating system.

B. Fortran compiler.

C. DECNet software for data communications, using the Ethernet interface.

D. MicroVMS Workstation software supporting multiple window management.

E. GKS graphics programming interface.

F. VT-100 or VT-200 terminal emulation.

G. Tektronix 4014 terminal emulation.

Table 3. Technical specifications of the Ethernet, which connects the Digital Weather Laboratory and the CIRA research data collection and processing system.

Ethernet

Ethernet supplies data communications over a coxial cable. The speed of the Ethernet is 10 mega bytes per second. The Ethernet uses Digital DECNet software for communications.

Figure 2.

Examples of the computer hardware system supporting our new digital weather laboratory.

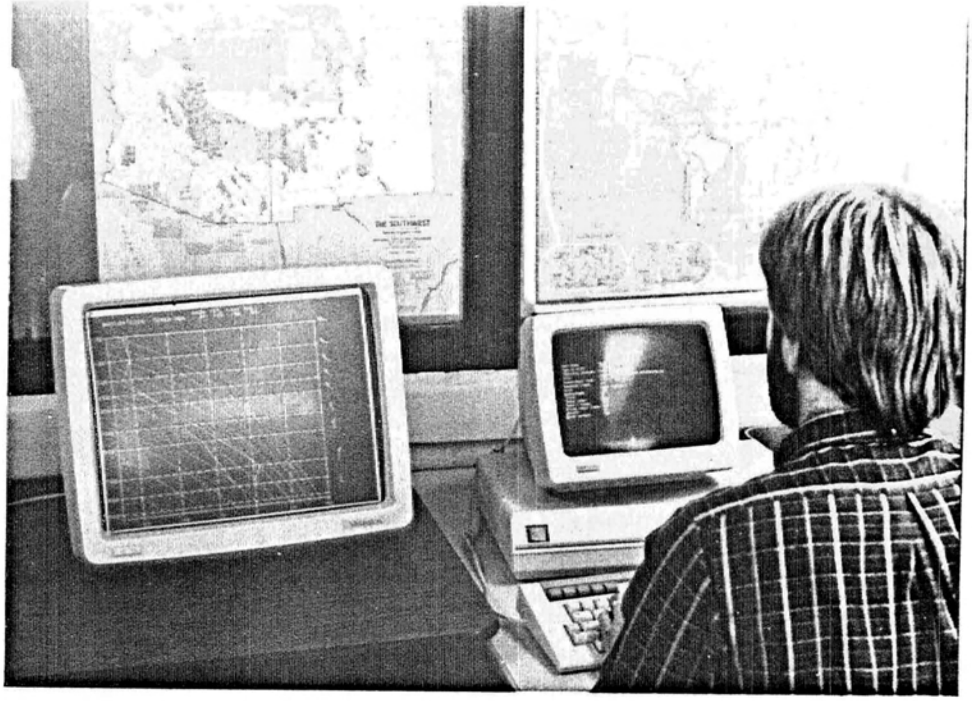

Figure 3.

The VAX workstation used in our new digital weather laboratory.

Figure 4.

The products of our weather lab software are displayed on the COMTAL Imaging System.

FAA604 DATA PROCESSING FLOW CHART

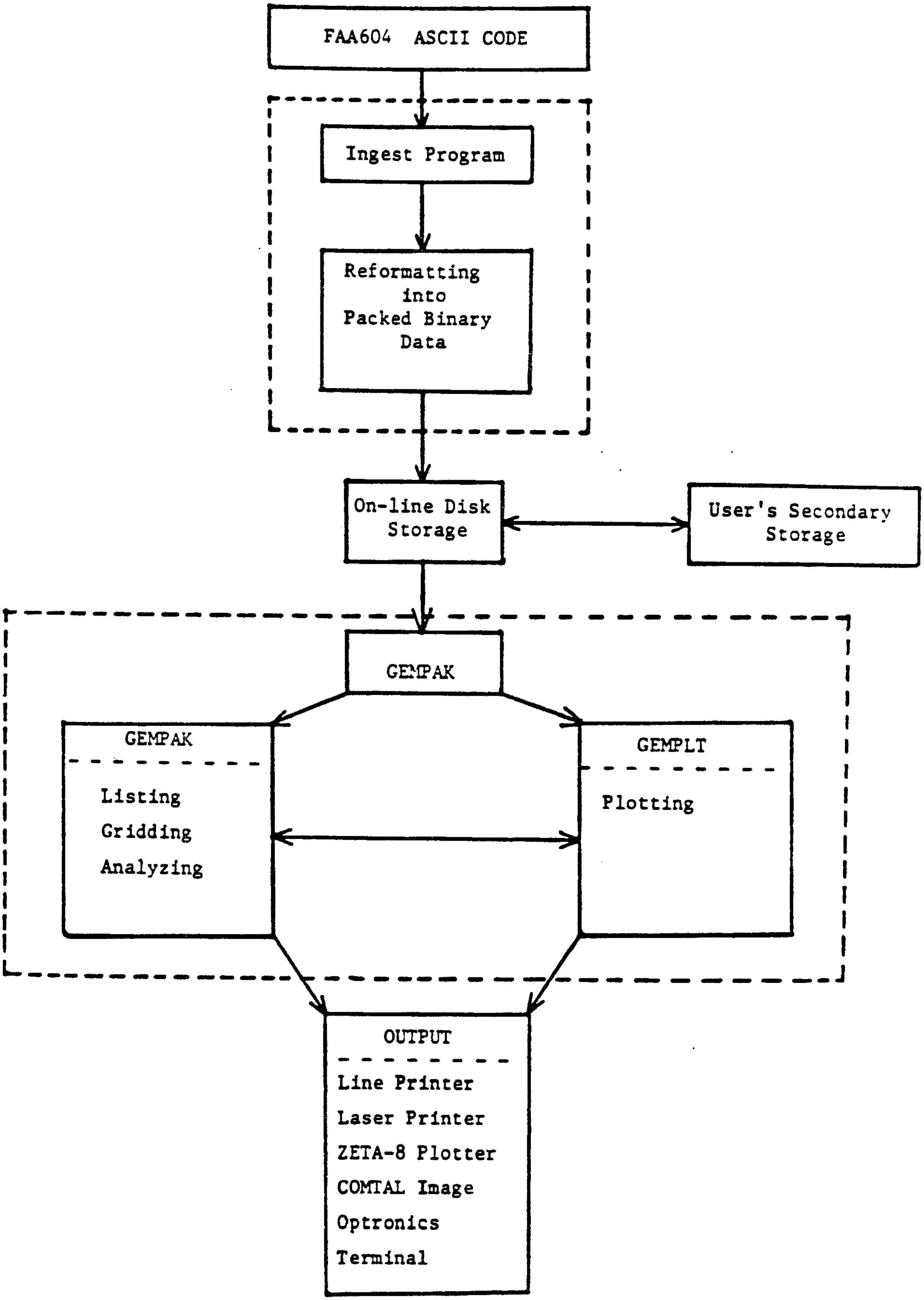


Figure 5. The flow chart of processing FAA604 data.

Through long collaboration with NASA's Goddard Space Flight Center (which also operates a large DEC/VAX-based system), we have obtained and use the Transportable Applications Executive (TAE) software system developed there (des Jardins, 1985). We have also adopted their GEMPAK and GEMPLT software which will be discussed in the next section. The software aspects of a digital weather lab are extensive and should not be underestimated.

## 3. Weather Lab Capability and Products

All new weather labs must face decisions regarding their software and hardware configurations. We recommend these be 'output oriented' with a prioritized list of output products matrixed against budget resources. However, some other important factors must also be considered. These include intra-university collaborations [e.g. with Electrical Engineering (as at CSU), Computer Science, etc.], as well as collaboration with other national groups in research data analysis. With all these factors considered, the CSU digital weather laboratory has emerged with specific definitions. We have chosen some developed software (e.g. NASA's) to fit the computer hardware. Hardware decisions were heavily influenced by our joint research work with Electrical Engineering. Thus, our weather lab has evolved from research origins. We expect many other university weather labs will also emerge from such a process, rather than arrive as a turnkey system.

Because of the features of the NASA GEMPAK software for display of weather data, and previous research experience with their Transportable Application Executive (TAE) menu, we decided to use GEMPAK for our weather laboratory. Four main advantages of using GEMPAK are:

1) <u>It is user friendly</u>.

Because GEMPAK is a menu-driven package, it is easy to use and well documented even for the first-time user. This feature certainly encourages the students to use the weather data, and has been applied successfully in a classroom environment in the Fall, 1985 and Spring, 1986 semesters (e.g. Figure 6 displays the surface observations over Colorado on December 23, 1985 at 1500 GMT; this display required less than a minute to complete and was available only a short time after 1500 GMT). Also, in each menu session a user can save the parameters entered in a parameter file for future use, and the parameters entered the last time are always saved. In this way, a user can always recall the parameters saved without memorizing them.

2) <u>The weather analysis options</u>.

As mentioned in the introduction, automated plotting and analysis saves considerable time. GEMPAK allows the option of merely plotting the data, ready for hand analysis as shown in Figure 6. But if desired, an automated analysis may be added to the data plot (Figure 7). Also notice that the GEMPAK software is flexible enough to accommodate local needs; we found it very easy to automatically add PROFS mesonet stations to the surface data set, such as Figures 6 and 7. Various indices exist for evaluating thunderstorm and severe weather potential; GEMPAK has subroutines to calculate them. For example, the total totals index, K index, and sweat index are included in the analysis section of GEMPAK. Although these calculations are performed using computer algorithms, the students still are taught how these indices are computed in order to use them correctly.

3) <u>Archiving weather data</u>.

Since GEMPAK uses a binary format for surface/sounding data, it is more economical to save weather data in this format. GEMPAK has input/output routines available, or users can simply invoke operating system routines to do this. Therefore, there is no difficulty in saving or restoring surface/sounding data.

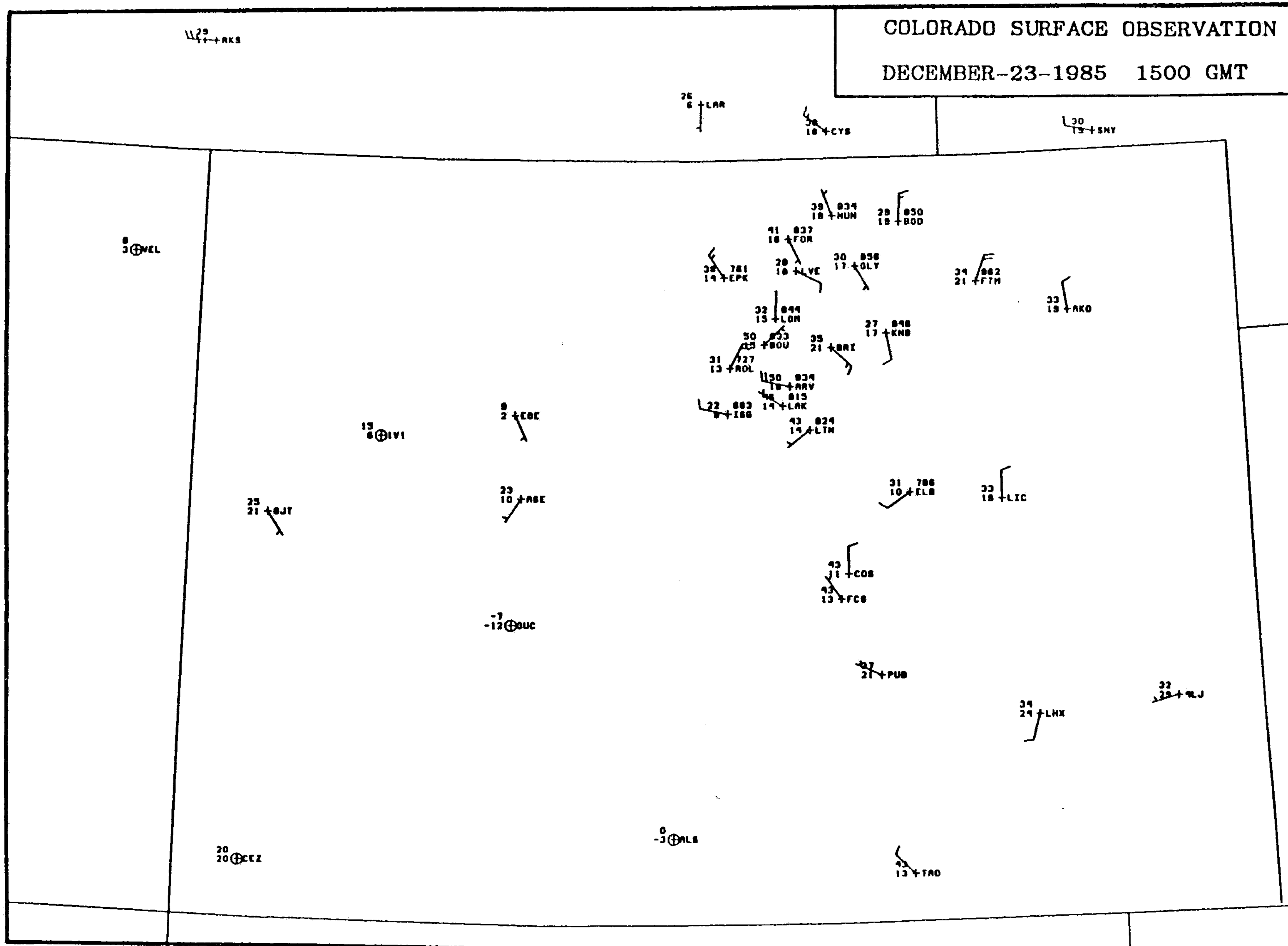


Figure 6. The surface weather map over Colorado on December 23, 1985 at 1500 GMT.

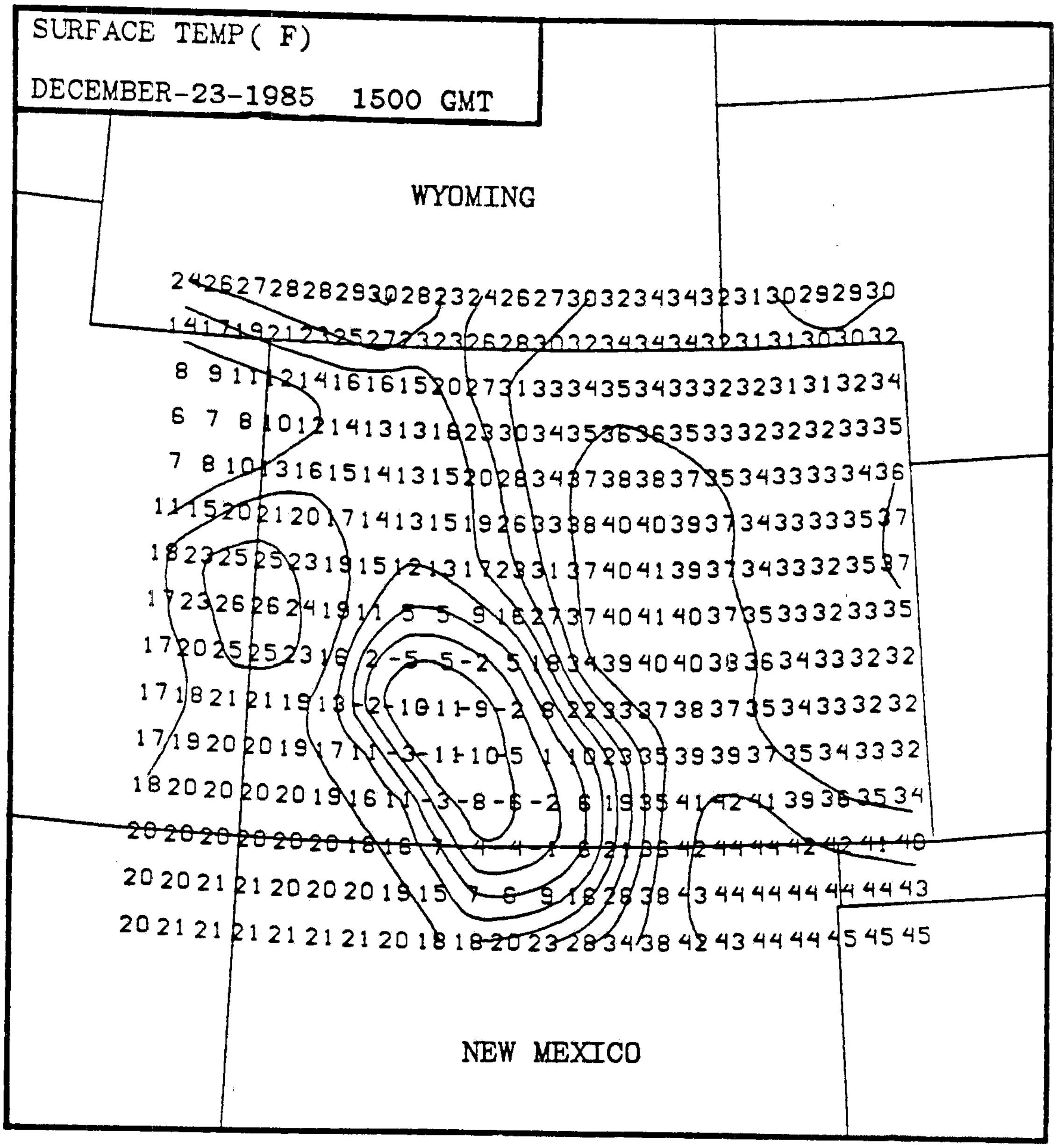


**Figure 7. Temperature analysis of Figure 6 using GEMPAK grid analysis software.**

4) Gridded data.

Because weather stations are not uniformly distributed, interpolation between stations is necessary in order to perform analyses or to be used for numerical model input data. In GEMPAK, there exist gridding routines which can generate grid data sets from original data. Using upper air sounding data over the U.S., for example, 500 mb temperature and geopotential analyses can be generated (Figure 8). Earth Radiation Budget Experiment (ERBE) data was applied to create the gridded analysis in Figure 9 using GEMPAK software. In addition to the above features, a new procurement will soon enable us to display the current weather data on a large 'screen wall' directly from the computer system. This new feature will make weather map discussions clear to a larger audience.

4. Discussion

Since monitoring the weather in real-time is one main objective of our weather laboratory, very large amounts of weather data need to be saved for use. We have experienced some difficulties in accurately maintaining the huge flow of data. For example, errors caused either by initial coding or during the transmission process could not be corrected or removed completely by our first decoder programs (e.g. see Figure 10). Between the initial coding errors and the transmission errors, we determined that the latter happen more often and vary with time in our weather data system.

As shown in Figure 1, our FAA604 data is collected via a satellite downlink. Ideally, if the receiving antenna was kept tuned and aligned to the broadcasting satellite the transmission errors would be minimized. However, our antenna points at the broadcasting geostationary satellite which drifts, and we do not continuously adjust its direction to be kept aligned with the satellite. To demonstrate the possible effects of transmission errors, we

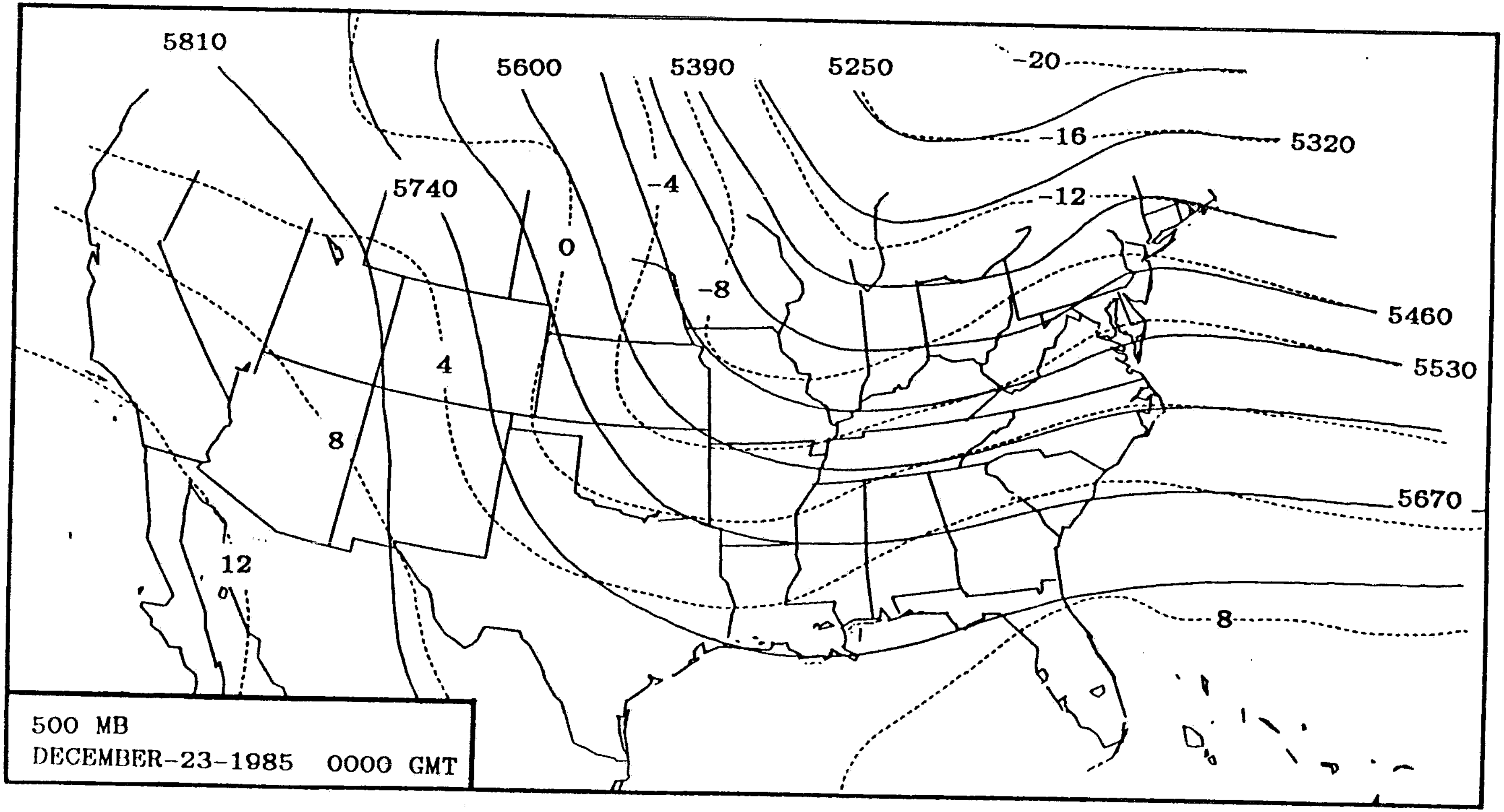


Figure 8. 500 mb temperature and geopotential analyses of the U.S. The solid lines are contours of geopotential height (in meters) and the dashed lines represent the isotherms (in °C).

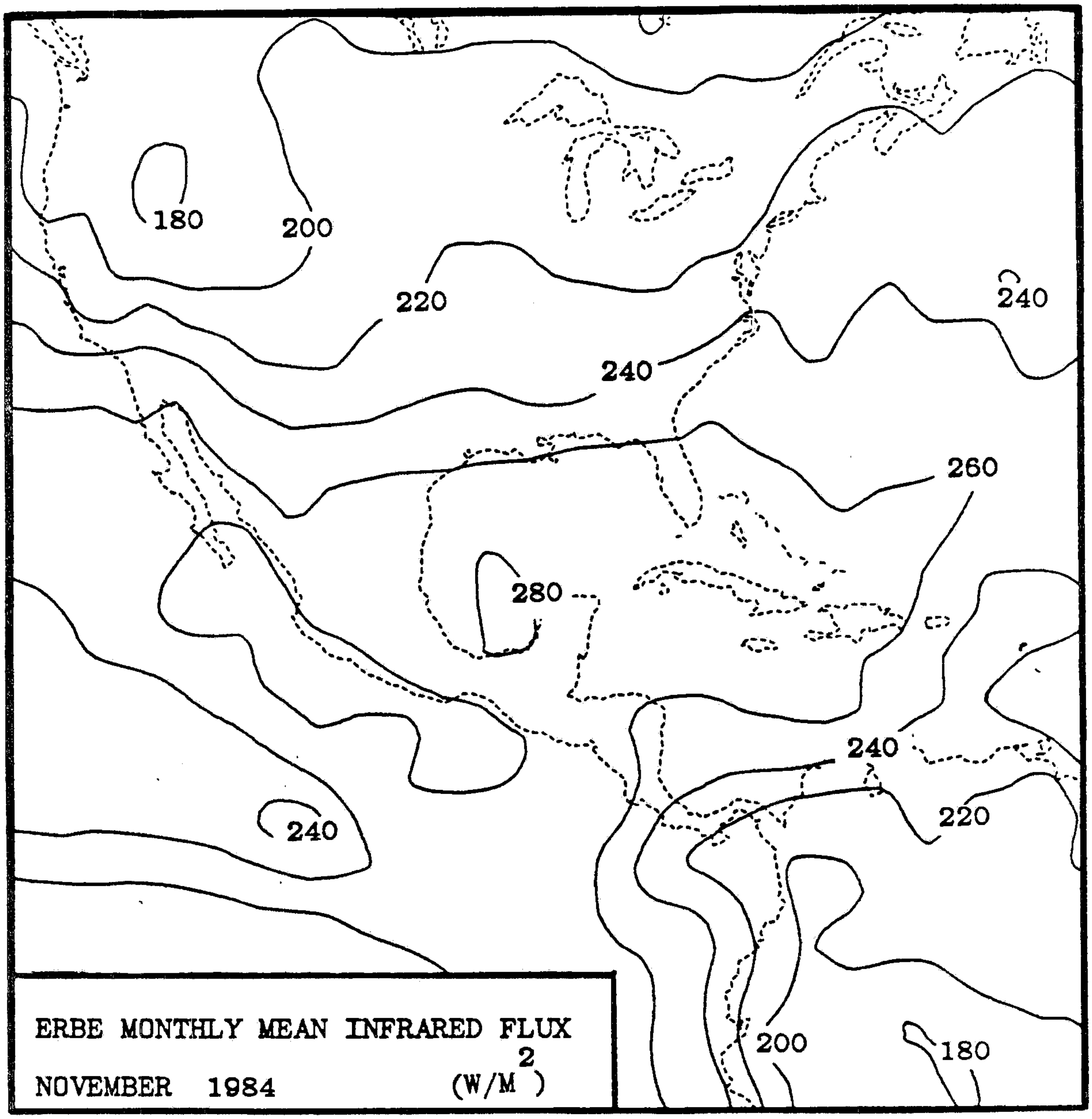


**Figure 9.** The November 1984 monthly mean map of outgoing infrared flux as measured by the ERBE satellite.

(a)

## FAA604 DATA (ORIGINAL)

```
04900333
     UW/US NORTH AMERICA 161257


72645 TTAA  66121 72645 99990 13324 29005 00132 ///// /////
 85363 15309 29522 70820 19711 280cpAk'525 35945 26554 40677   ←
 437// 27080 30865 547// 26594 25981 577// 27091 20124 543//
 27093 15308 541// 27082 10566 575// 26574 88278 571// 26593
 77196 27096 41732 51515 10164 00013 10194 30015 28533=


72655 TTAA  66121 72655 99983 19934 31005 00189 ///// /////
 85396 19356 32031 70833 22560 30544 50524 38558 30058 40675
 457// 29567 30862 539// 28570 25979 5dH5// 29067 20122 549//  ←
 6^
2[S
c 1530!
 .19}E/ 28560 10562 605// 28074 88263 561// 29066
 77280 28573 41107 51515 10164 00015 10194 32525 31040=
```

(b)

## GEMPAK LIST (DECODED FROM FAA604)

GRB 72645 Date/Time= 851216/1200 Latitude= 44.48 Longitude= -88.13

| PRES | HGHT | TEMP | DWPT | DRCT | SKNT | |
|---|---|---|---|---|---|---|
| 990.00 | 210.00 | -13.30 | -15.70 | 290.00 | 3.89 | |
| 850.00 | 1363.00 | -15.30 | -16.20 | 295.00 | 21.38 | |
| 700.00 | 2820.00 | -19.70 | -20.80 | 99999.00 | 99999.90 | ← |
| 400.00 | 6770.00 | -43.70 | -92.70 | 270.00 | 79.70 | |
| 300.00 | 8650.00 | -54.70 | -103.70 | 265.00 | 93.30 | |
| 250.00 | 19810.00 | -57.70 | -106.70 | 270.00 | 89.41 | |
| 200.00 | 11240.00 | -54.30 | -103.30 | 270.00 | 91.36 | |
| 150.00 | 13080.00 | -54.10 | -103.10 | 270.00 | 81.64 | |
| 100.00 | 15660.00 | -57.50 | -106.50 | 265.00 | 73.86 | |

STC 72655 Date/Time= 851216/1200 Latitude= 45.55 Longitude= -94.06

| PRES | HGHT | TEMP | DWPT | DRCT | SKNT | |
|---|---|---|---|---|---|---|
| 983.00 | 317.00 | -19.90 | -23.30 | 310.00 | 3.89 | |
| 850.00 | 1396.00 | -19.30 | -25.30 | 320.00 | 29.16 | |
| 700.00 | 2833.00 | -22.50 | -32.50 | 305.00 | 42.76 | |
| 500.00 | 5240.00 | -38.50 | -48.50 | 300.00 | 56.37 | |
| 400.00 | 6750.00 | -45.70 | -94.70 | 295.00 | 66.09 | |
| 300.00 | 8620.00 | -53.90 | -102.90 | 285.00 | 69.98 | |
| 250.00 | 19790.00 | 104.40 | 99.50 | 99999.00 | 99999.90 | ← |
| 200.00 | 11220.00 | -54.90 | -103.90 | 99999.00 | 99999.90 | |
| 150.00 | 12850.00 | -177.60 | -160.00 | 99999.00 | 99999.90 | |
| 100.00 | 15620.00 | -60.50 | -109.50 | 280.00 | 73.88 | |

Figure 10. Examples to show the effects of transmission errors in the FAA604 data (a) and the resulting GEMPAK lists (b). The arrows mark the lines containing transmission errors.

will show two examples in Figure 10. Figure 10a lists out the ingested FAA604 upper air sounding data for stations 72645 and 72655. Their decoded sounding data was listed in Figure 10b using GEMPAK routines. For station 72645, the errors started at the 700 mb wind data and ended at the 500 mb temperature measurement in FAA604 code (Figure 10a). After being decoded (Figure 10b), the 700 mb wind information of station 72645 was listed as missing and all information of 500 mb measurements was dropped. For station 72655, the errors started at the 250 mb temperature measurement (Figure 10a) but successfully passed through the error checking routines of the decoder program to give an abnormal warm temperature of 104.4$^{\circ}$C (Figure 10b). One way to solve such data error problems is to add an interactive checking procedure to the decoder program. However, this approach is unrealistic for very large-scale real-time operation at universities because of the continuous transmission of weather data. This difficulty may be eased by modifying the error checking procedure in the decoder program when a new type of error happens. Overall, a more complete error checking routine is desired. With our experience of using weather data via the satellite downlink method and knowing that UNIDATA is planning to use this method to distribute the weather data, the possible contamination caused by the transmission process is important to be considered.

Weather labs must also face the on-line storage problem. Every computer system has limits to its on-line disk storage capacity. Currently, all surface and upper air sounding data are kept on-line for a week.

Our digital weather lab has already been applied to several 'outside-the-classroom' uses. In summer 1985, there were field observations associated with the PRESTORM project, which focused on the study of mesoscale convective systems. FAA604 data was used to help make decisions concerning flight plans. At the same time, FAA604 data was saved for post analysis.

In Fall 1985, the weather forecast contest in our department gave a number of students, staff and faculty their first occasion to use the new weather lab.

Another application involves collaboration with UCAR, which has sponsored the initiation of the UNIDATA project to develop weather data distribution and analysis among universities in the near future (Fulker, 1985). In order to determine the hardware and software standards, various tests need to be performed as part of UNIDATA. Because of the various computer systems in our Local Area Network, we recognize the possible advantages of testing some portions of UNIDATA in our weather laboratory.

## 5. Summary

A new weather laboratory is being developed at the Department of Atmospheric Science at Colorado State University. Various weather data including FAA604, PROFS, PROFILER, and satellite data are available in digital format for analyses. Traditional facsimile, teletype, UNIFAX and GOES-TAP data are also available for laboratory usage. The software used in our weather laboratory is based on the GEMPAK system, which includes various subroutine modules written in FORTRAN 77. GEMPAK is easy to use to analyze either current data or past data stored on disk. It is planned that satellite data will be used in combination with traditional weather information. Since we have already completed classroom and outside-the-classroom use of our prototype digital weather laboratory, it provides an ideal testing site for the ongoing UNIDATA system.

## References

Beran, D. W., and C. G. Little, 1979: Prototype Regional Observing and Forecasting Service: From concept to implementation. National Weather Digest, vol. 4, no. 3, 2-5.

des Jardins, M. L., 1985: GEMPAK, a meteorological system for research and education. International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology. Los Angeles, California, January 7-11, 1985. American Meteorological Society, p. 313-319.

Fulker, D., 1985: UNIDATA - Results of Phase II. Seminar given at the Department of Atmospheric Science, CSU, Fort Collins, CO 80523.

Purdom, J. F. W., R. N. Green, J. F. Weaver, R. M. Zehr, and D. A. Lubich, 1985: Satellite data support to the pre-STORM operations center, May-June 1985. CIRA Paper No. 3, CIRA/CSU, Fort Collins, CO 80523. 75 pp.

Schlatter, T. W., P. Schultz, and J. M. Brown, 1985: Forecasting convection with the PROFS system: Comments on the Summer 1983 experiement. Bull. Amer. Meteor. Soc., 66, 802-809.

Vonder Haar, T. H., and T. A. Brubaker, 1981: Participation in the Prototype Regional Observing and Forecasting Service (PROFS) program. Final Report, CIRA/CSU, Fort Collins, CO 80523.

Vonder Haar, T. H., T. Brubaker, G. Smith, R. Wachtmann, L. Chorowski, M. Kruidenier, S. Naqui, M. Whitcomb, P. Horton, B. Plomondon, and D. N. Allen, 1982: Realtime processing and transmission of digital satellite imagry for use at a remote forecasting facility. National Weather Digest, vol. 7, no. 2, 32-37.