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CROSS SECTIONAL ANALYSES OF WIND SPEED AND RICHARDSON NUMBERS

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1. INTRODUCTION

An AFOS applications program is available that prepares extensive vertical analyses of individual rawinsonde reports (Jannuzzi, 1980). The two AFOS applications programs described here combine up to ten user-selected rawinsonde reports to produce objective vertical cross sectional analyses of wind speed and Richardson numbers. The programs also generate AFOS graphics products for display on a background isentropic cross section. The cross section can be produced by running another applications program (Gilhousen and Person, 1981).

The combined product, wind speeds and Richardson numbers superimposed on an isentropic cross section, will help forecasters locate areas of clear air turbulence, strong winds, and strong wind shears (see Cahir, et al., 1976).

2. METHODOLOGY AND SOFTWARE STRUCTURE

Fig. 1 illustrates the data flow and program relationships necessary to produce isentropic cross sections for AFOS display. The decoder program, TTBBD (Person and Gilhousen, 1981), is run first, and just once, on the available significant level (CCCSGLXXX) data. The cross section program, CRS (Person and Gilhousen, 1981), is run next. Fig. 2 shows an example of the AFOS display graphic (NMCGPHTM1) produced by CRS for the data date of 0000 GMT February 17, 1982. The isentropic cross section graphic (NMCGPHTM2) produced by CRS for the same date will be the background for the products of the wind speed and Richardson number programs, which are next to be run in the series of cross section programs.

The wind speed analysis program, WSANAL, and the Richardson number analysis program, RICHNO, both read the observed data processed by the cross section program, CRS. The station locations relative to the section are read from the CRS-produced file COEF.DT. The station data, composed of pressures, temperatures, dewpoints, winds, and elevation, are read from the file CRSRD.DT, also produced by CRS. To prepare another cross section for a different set of stations, the cross section program, CRS, must be rerun for the new combination of stations.

The analysis grid for WSANAL and RICHNO is the grid adopted in CRS. It is a vertical projection with the base near the ground. The vertical coordinate is linear in the natural logarithm of pressure extending from a pressure of 1050 mb at the base to 100 mb at the top. Horizontally, the coordinate is linear distance along the path of the cross section. Grid points are equally spaced in each coordinate direction.

A. Wind speed analysis program: WSANAL

After reading the observed data, WSANAL assigns each wind sounding to the nearest grid column in the section. In the columns with assigned data, the winds are linearly interpolated in height to grid points. Since the vertical coordinate of the section is the logarithm of pressure and the heights of the grid points are required for the interpolation, hydrostatics are used to find the heights.

Wind speeds for grid points in columns not having assigned soundings are determined by a distance weighted combination of grid point data from columns with assigned data. Speeds for grid points in the columns with assigned data for which vertical interpolation was not possible are also determined this way. The Cressman (1959) weight function,

$$W(d) = (D^2 - d^2)/(D^2 + d^2)$$

defines the weighting, where D is the limiting distance beyond which W is zero, and d is the separation between a grid point with interpolated data and the grid point without data. The influence area for W is elliptical with respect to a displayed cross section (see Fig. 3). The major axis is along the horizontal and the length of the axis is a function of the number of stations in the section. The length of the minor axis is set to two grid intervals. The selection of an elliptical influence area is motivated by the apparent larger correlation in the horizontal than in the vertical for winds. No attempt was made to define a ratio of the lengths of the axes that was representative of actual atmospheric structure. If no data are available within the influence area for a grid point, the length of the axes is doubled for that point. After all grid points have wind speeds, the grid values are smoothed with a simple 3 point filter. The filtering operation is performed first in one coordinate direction, then in the other, with the relative weighting 1-4-1. The boundary points are adjusted in only one direction -- along the boundary. The corners of the grid are not adjusted.

The output graphics product, NMCGPHTM3, is stored first on DPO. Then a call to FSTOR (from the BG.LB) is made to store the product into the AFOS database. An attempt is made to delete the copy of TM3 from DPO after the return from a successful call to FSTOR. However, if the file is in use as part of the call to FSTOR, the delete cannot be performed, and the file remains on DPO.

Fig. 3 shows an example of the isotachs produced by WSANAL on an isentropic cross section. The isotachs are labeled in small numerals at both sides of the cross section and at field maxima and minima.

The cross section shown in Fig. 3 runs from PIA (2532) to CHS (2208) and indicates a jet core of greater than 45 m/s over BNA (2327). There is also a secondary maximum centered over AHN (2311). The isentropes in the troposphere slope gently downward from SLO (2433) to AHN, showing a large scale weak frontal surface.

B. Richardson Number Analysis Programs: RICHNO and RIANAL

RICHNO calculates the Richardson number, defined as

$$Ri = \frac{g}{\bar{\Theta}} \frac{\Delta\Theta}{\Delta z} \Big/ \left(\frac{\Delta v}{\Delta z}\right)^2$$

where $\overline{\theta}$ is the average potential temperature in a layer, and $\Delta\theta$ and Δv are the differences in potential temperature and wind speed over a vertical increment Δz. The computed numbers are restricted to the interval 0 to 3.

The program assigns each sounding to the nearest grid column and calculates the wind shear over the reported height intervals. The potential temperature shear is calculated over the reported pressure intervals nearest to each wind interval. The Δz for the pressure intervals is determined hydrostatically. The Richardson numbers are calculated from these shears. Each number is given a vertical position in terms of a representative pressure for the height interval.

RICHNO then chains to RIANAL which maps the computed Richardson numbers to the cross section grid. Each number is assigned to the nearest vertical grid point. "Nearest" is judged by finding the smallest difference between the representative pressures defined in RICHNO and the grid point pressure. Values for grid points not having assigned data are determined the same way as in WSANAL -- a distance weighted combination of grid point data available after the vertical assignment step. Smoothing passes with a 1-4-1 filter, as in WSANAL, are made after all grid points have values. Also as in WSANAL, the output graphics product, NMCGPHTM4, is stored first on DPO, and then sent to the AFOS database via a call to FSTOR. The program attempts to delete TM4 from DPO if the call to FSTOR is made successfully. If the file is in use because of the call to FSTOR, the delete cannot be performed, and the file remains on DPO.

Cahir, et al. (1976) found that analyzed Richardson numbers less than 1.5 enclosed areas where aircraft reported moderate and severe turbulence. The Richardson number analysis produced by RICHNO differs slightly from Cahir's, so the critical value may be different. Fig. 4 shows a RICHNO analysis of Richardson number overlaid on an isentropic cross section. The computed values have been multiplied by 10 and contoured every 10 starting at 5, so that the Cahir critical value is less than 15.

The Richardson number contours in Fig. 4, shown on the same isentropic cross section as in Fig. 3, suggest two areas for turbulence. A small region at 300-mb over AHN (2311) and a region near 600-mb over BNA (2327) contain values less than 15. The values above 200-mb should be ignored (see Section 4).

Richardson numbers are very sensitive to the methods of calculation and the resolution of the upper air data (Dutton and Panofsky, 1970). Consequently, Richardson numbers, as calculated by RICHNO, have to be regarded as an approximation to a <u>large</u> scale number. This is because the vertical shears are calculated over depths of several hundred meters.

With these limitations in mind, the diagnostic value of the Richardson numbers in Fig. 4 is the indication of a higher likelihood of turbulence at 300-mb over AHN (Ri = 1.3) than at 300-mb over BNA (Ri = 2.7). Looking at just the wind speeds in Fig. 3, a forecaster may not have reached such a conclusion.

C. Graphical Contouring

Contouring for both WSANAL and RICHNO is done in subroutine CNTR3. It applies the same approach to contouring as CONTUR (Gilhousen, 1980), providing the added features of labeling the product and drawing the contours in the vicinity of cols.

3. PROCEDURES

A. WSANAL

The wind speed analysis program is initiated at the console by entering:

```
RUN:WSANAL TM3 N/I
```

where TM3 indicates the output file in the AFOS data base where the analysis will be stored under the heading NMCGPHTM3. The default is TM3 = T67. The optional I switch allows the contour interval to be set to N m/s. Default contour interval is 5.

The program executes in 15K words in about 1 minute, and requires as input the data sets COEF.DT and CRSRD.DT produced by CRS. The software structure and load line for WSANAL are given in Fig. 5.

B. RICHNO

The Richardson number analysis program is initiated at the console by entering:

```
RUN:RICHNO TM4
```

where TM4 is the AFOS output file name as part of NMCGPHTM4. The default value for TM4 is T68. The contour interval is set to 5 units beginning at 5; there is no option to change it.

RICHNO runs in 14K words and takes about 1 minute to execute. As with WSANAL, both COEF.DT and CRSRD.DT produced by CRS are required as input files. The software structure and load line for RICHNO are given in Fig. 6. RIANAL is initiated by a chaining call (FCHAN) from RICHNO. The structure and load line for RIANAL are shown in Fig. 7.

4. CAUTIONS

Because the analysis grid extends to 100 mb, occasionally exceeding the height of some rawinsonde reports, there may not be reliable analyses produced near the top of the cross section. Consequently, the primary utility of this product is within and slightly above the troposhere.

The critical values for the Richardson numbers produced by this analysis have not been determined. Forecaster experience will be the best guide until such determinations have been made.

5. REFERENCES

Cahir, J. J., J. Norman, W. Lottes, and J. Toth, 1976: New tools for forecasters: Real-time cross sections produced in the field. Bull. Amer. Meteor. Soc., 57, 1426-1433.

Cressman, G. P., 1959: An operational objective analysis system. Mon. Wea. Rev., 87, 367-374.

Dutton, J. A., and H. A. Panofsky, 1970: Clear air turbulence: A mystery may be unfolding. Science, 167, 937-944.

Gilhousen, D. B., 1980: "CONTUR"--A program to contour a field for GDM display. Unpublished manuscript, Integrated Systems Laboratory, National Weather Service, NOAA, U.S. Department of Commerce, 20 pp.

_____, and A. Person, 1981: Isentropic cross sections for AFOS. ISL Office Note 81-2, National Weather Service, NOAA, U.S. Department of Commerce, 13 pp.

Jannuzzi, J. A., 1980: RAOB plot and analysis routines. NOAA Western Region Computer Programs and Problems NWS WRCP-No. 8, NOAA, U.S. Department of Commerce, 43 pp.

Person, A. A., and D. B. Gilhousen, 1980: "An enhanced AFOS graphics library". Unpublished manuscript, Integrated Systems Laboratory, National Weather Service, NOAA, U.S. Department of Commerce, 9 pp.

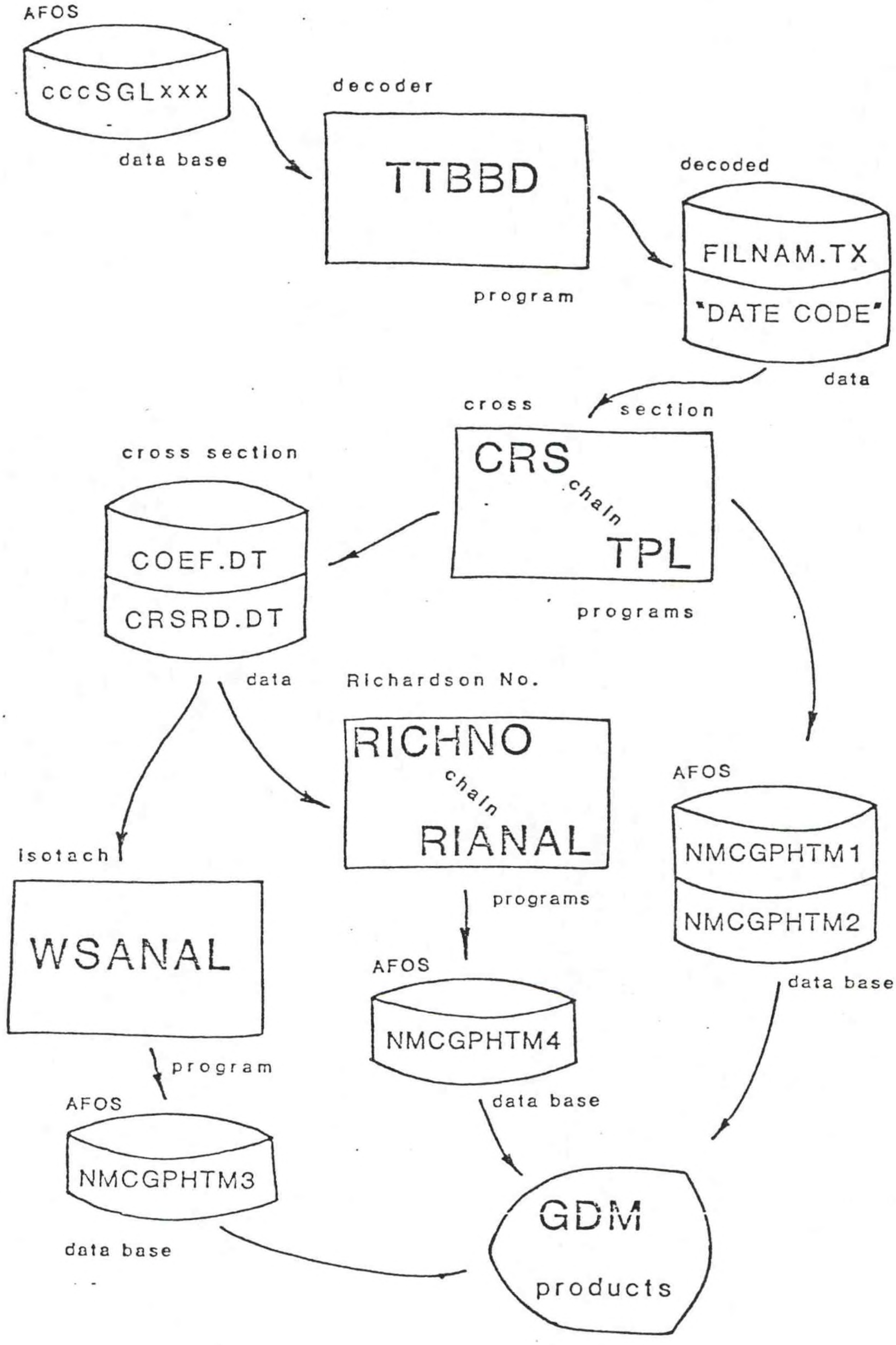


Figure 1. Data flow and program relationships for the programs in the cross section series. Program names are inside boxes. Disk and AFOS data sets are indicated by a disk platter symbol with the name of the set inside the symbol. The actual label for the decoded data, indicated by "Date code," is formed by TTBBD at runtime and stored in FILNAM.TX.

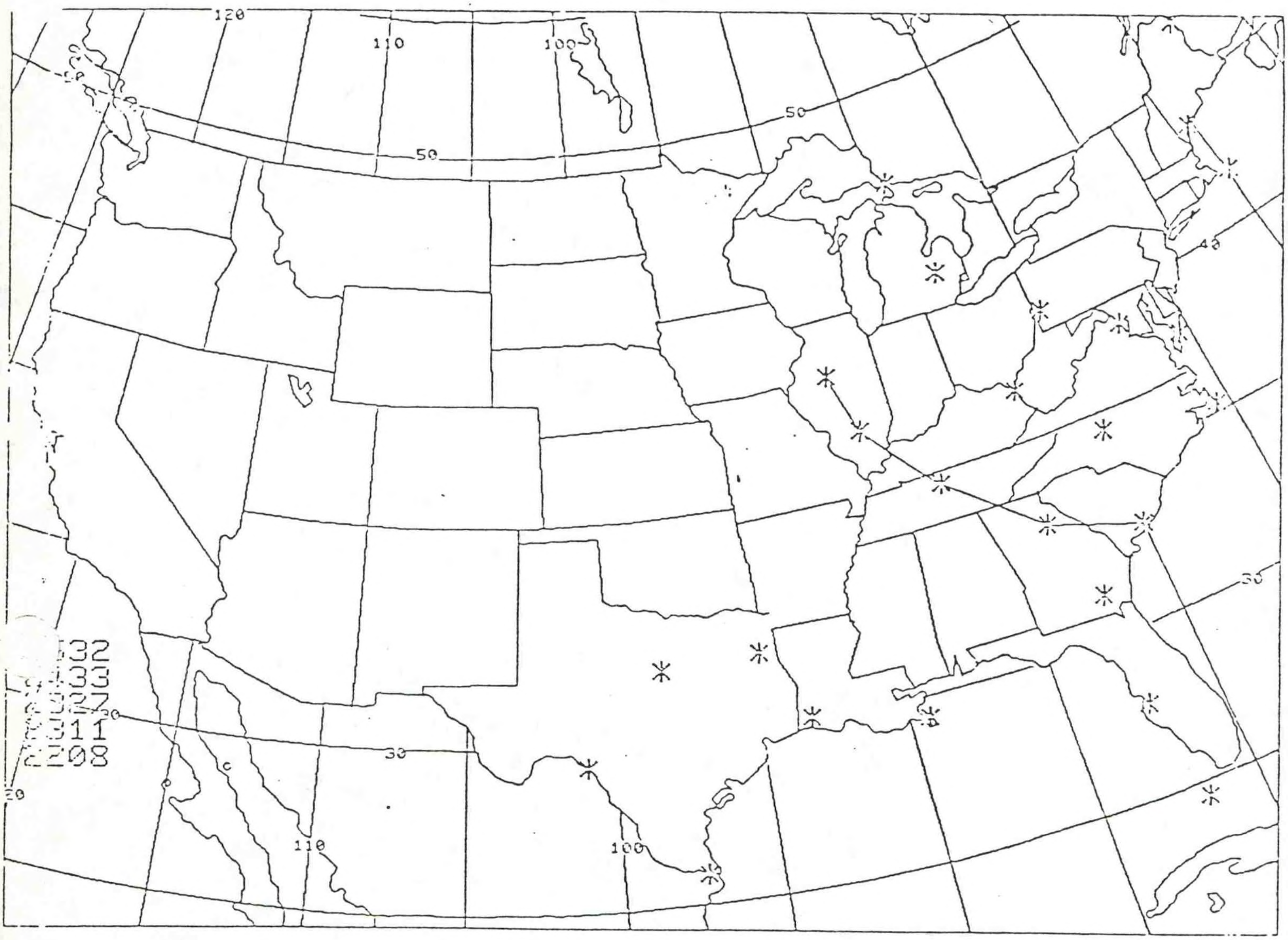


Figure 2. An example of the graphics product NMCGPHTM1, produced by CRS. The asterisks are plotted at observing sites from which significant level data are available. The line connecting the asterisks is the cross section path selected by the user. The WMO station numbers of the selected reports, prefixed by the digit from the WMO block code (2 = block 72), are plotted at the lower left.

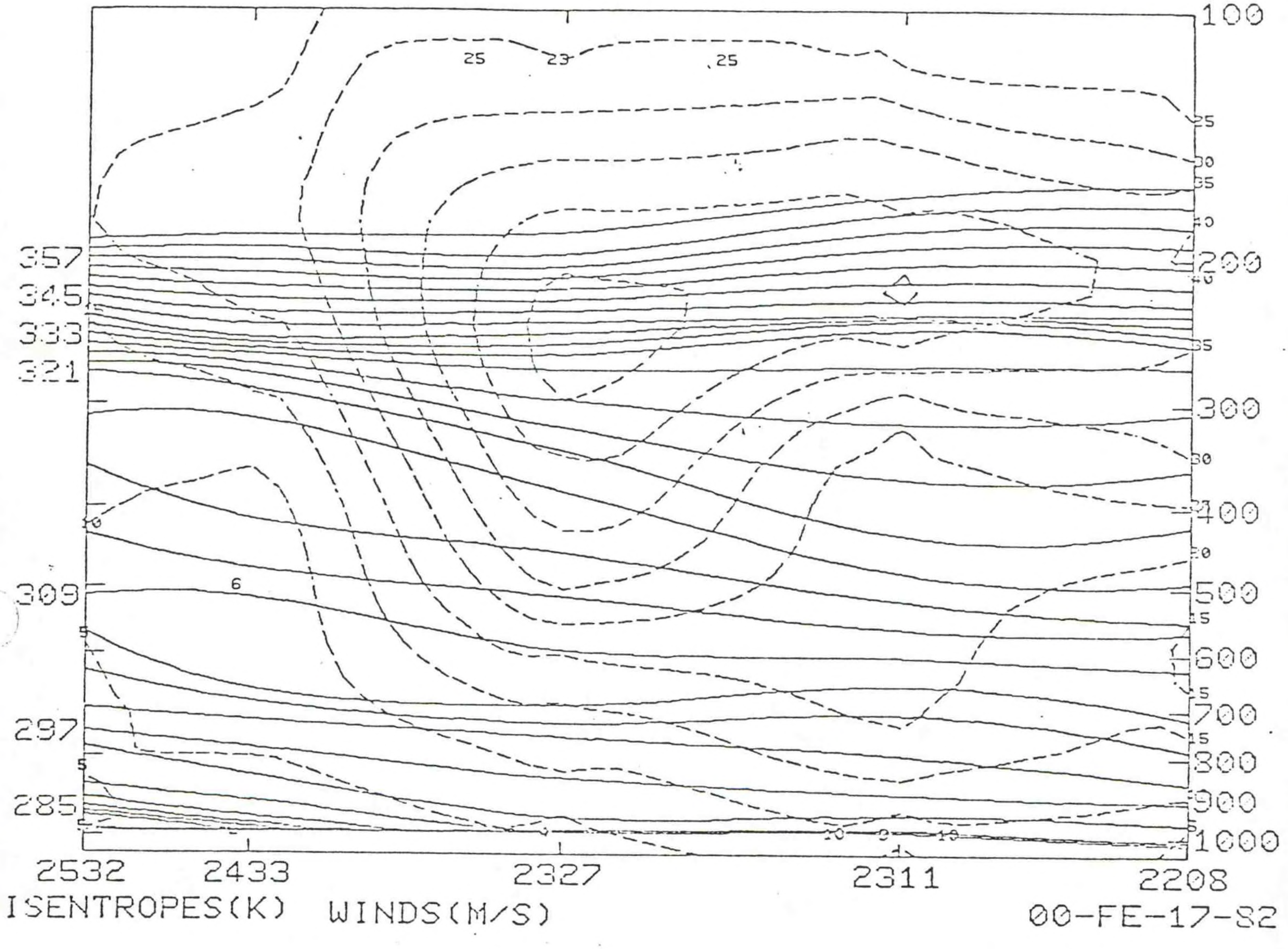


Figure 3. Isentropes (solid contours) and wind speeds (dashed contours) for the cross section indicated in Fig. 2. Data are for 0000 GMT February 17, 1982. This is graphics product NMCGPHTM3 (dashed) overlaid on NMCGPHTM2 (solid).

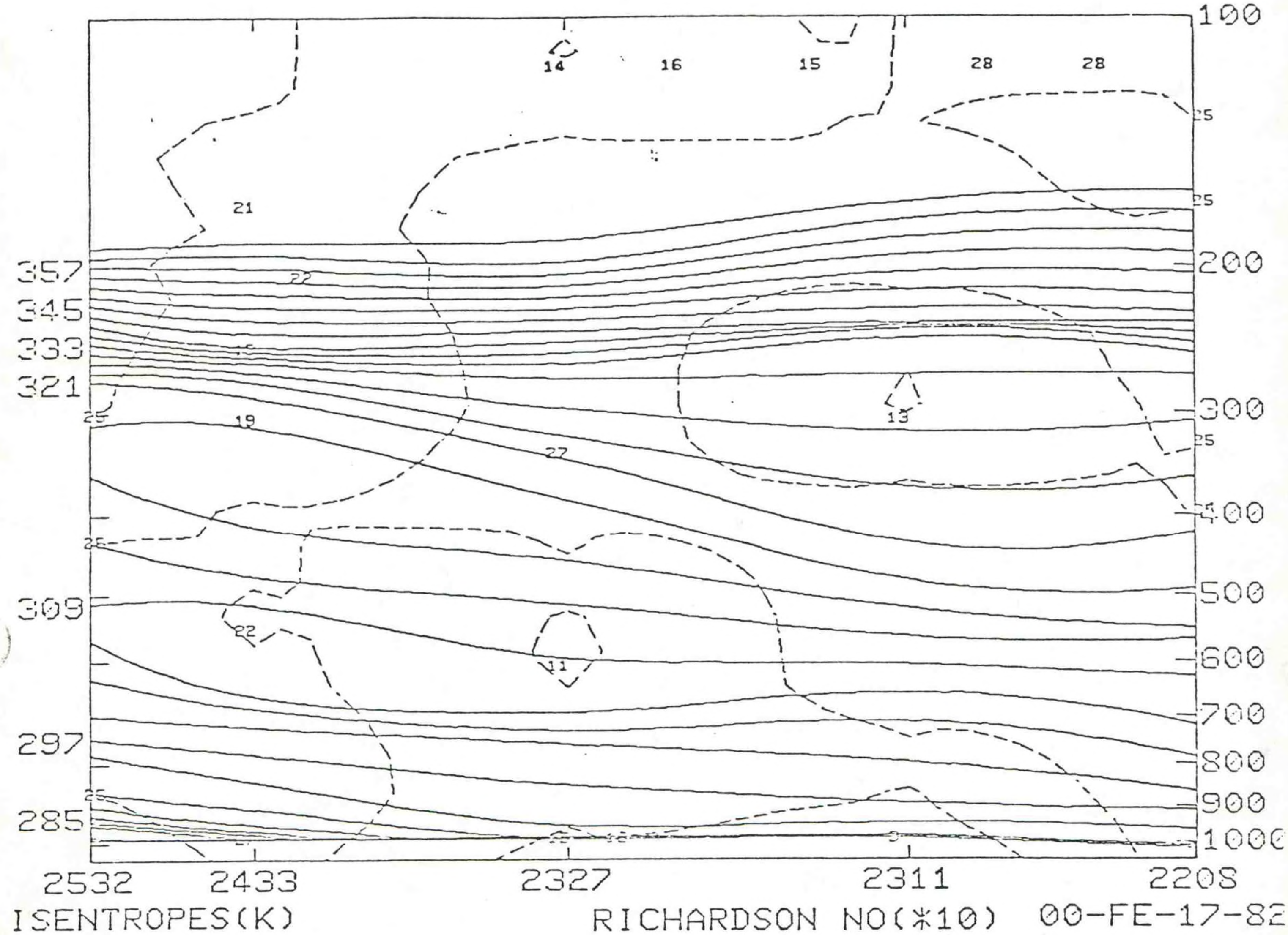


Figure 4. Isentropes (solid contours) and contours of Richardson number (dashed) for the cross section indicated in Fig. 2. Richardson numbers have been multiplied by 10. Data are for 0000 GMT February 17, 1982. This is graphics product NMCGPHTM4 (dashed) overlaid on NMCGPHTM2 (solid).

MAIN PROGRAM

WSANAL

SUBROUTINES

```
RDCOEF
CRSSET
SMOOTH              ┌COLPT
CNTR3 ─────────────>│MAXMN1 ───────────>ASCII
                    └LABEL ────────────>ASCII
```

LIBRARIES

	ROUTINE		
UTIL.LB	FCOM	GCHN	WRS
	COMCM	ERROR	WRB
	UNPAC	RDS	KLOSE
	OPENN		
BG.LB	FSTOR	FORKP	FORKE
GRS.LB	GINIT	ALFA	UTF
	RVEC	GFONT	

LOAD LINE

RLDR WSANAL RDCOEF CRSSET SMOOTH CNTR3 COLPT MAXMN1 LABEL ASCII WSANAL.LM/L GRS.LB BG.LB UTIL.LB FORT.LB

Figure 5. Software structure and load line for program WSANAL.

MAIN PROGRAM

RICHNO

SUBROUTINES

RDCOEF

LIBRARIES

		ROUTINE	
UTIL.LB	GCHN	RDS	ERROR
	KLOSE	OPENN	DELET
	CREAT	WRS	
BG.LB	FORKP		

LOAD LINE

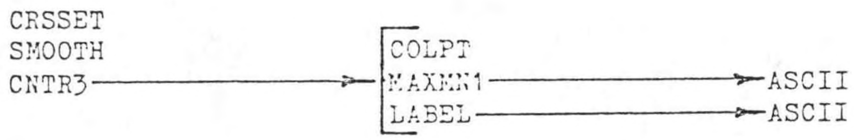
RLDR RICHNO RDCOEF RICHNO.LM/L BG.LB UTIL.LB FORT.LB

Figure 6. Software structure and load line for program RICHNO.

MAIN PROGRAM

RIANAL

SUBROUTINES



LIBRARIES

		ROUTINE	
UTIL.LB	FCOM	GCHN	WRS
	COMCM	ERROR	WRB
	UNPAC	RDS	KLOSE
	OPENN		
BG.LB	FSTOR	FORKP	FORKE
GRS.LB	GINIT	ALFA	UTF
	RVEC	GFONT	

LOAD LINE

RLDR RIANAL CRSSET SMOOTH CNTR3 COLPT MAXMN1 LABEL ASCII
RIANAL.LM/L GRS.LB BG.LB UTIL.LB FORT.LB

Figure 7. Software structure and load line for program RIANAL.

CROSS SECTIONAL ANALYSIS OF WIND SPEED

PROGRAM DESCRIPTION and EXECUTION PROCEDURE

PROGRAM NAME: WSANAL

APPLICATION: Meteorological analysis at WSFO's and RFC's

PURPOSE: Produces isotachs for overlaying on an isentropic cross section that has been previously generated by applications program CRS. Creates a local use graphics product stored on both DPO and in the AFOS database.

DESCRIPTION:

Programmers: David B. Gilhousen, James E. Kemper, David J. Vercelli

Office: Techniques Development Laboratory, FTS: 427-7639

Type: Background application program

Issue date: July 15, 1982

Revision date: Not applicable

Revision No.: First issue

Core: 15K words

Running time: About 1 minute

Language: FORTRAN IV

Product: Local use AFOS

Disk space: Program (-.SV file) - 57 RDOS blocks
Input files - 25 RDOS blocks
Output files - 27 RDOS blocks on DPO and in the AFOS database.

REQUIRED PROGRAMS AND FILES

	NAME	COMMENTS
Programs:	WSANAL.SV	
Input:	COEF.DT CRSRD.DT	Produced by applications program CRS.SV, stored on DPOF.
Output:	NMCGPHTM3	TM3 can be specified by the user as a RUN argument.

LOAD LINE

RLDR WSANAL RDCOEF CRSSET SMOOTH CNTR3 COLPT MAXMN1 LABEL ASCII GRS.LB
BG.LB UTIL.LB FORT.LB

PROGRAM SETUP

NOTE: Macros: Setup is START.MC, and breakdown is FINISH.MC. See Appendix A, TDL CP 82-1.

1. Move WSANAL.SV to DPOF. Create links on DPO to WSANAL.SV on DPOF.

2. Run the upper air decoder, TTBBD (ISL Office Note 81-1). If TTBBD has already been run on the current set of upper air data, it does not have to be rerun.

3. Run the cross section program, CRS (ISL Office Note 81-2), which will create current COEF.DT and CRSRD.DT files on DPO. COEF needs about 18 RDOS blocks and CRSRD needs about 7 RDOS blocks of disk space.

PROGRAM EXECUTION:

From the ADM, enter: RUN:WSANAL TM3 N/I

TM3 specifies the output product identifier as part of NMCGPHTM3. If TM3 is omitted, the program assumes TM3 = T67. The I switch sets the isotach contour interval to N m/s. If N/I is omitted, N is assumed to be 5.

For a different set of stations to form another cross section, CRS must be rerun to generate the appropriate data. WSANAL is then rerun on the new data.

The message "JOB WSANAL COMPLETED--PRODUCT NMCGPHTM3 STORED" will appear at the initiating ADM when the job is successfully completed.

ERROR CONDITIONS

Error conditions other than those listed here denote problems that occur while accessing files, most likely caused by system/disk problems rather than program failures. Check RDOS error code and rerun program if appropriate.

ADM MESSAGES	MEANING
1- "JOB WSANAL ABORTED--ERROR CONDITION: CRSRD.DT MSG"	CRSRD.DT probably does not exist. Check DPOF to see if it's there. If it is, there is a system problem. If it isn't, run program CRS to a successful completion, then rerun WSANAL.
2- "JOB ABORTED--ERROR CONDITION: COEF.DT MSG"	COEF.DT probably does not exist. Check DPOF to see if it's there. If it is, there is a system problem. If it isn't, run program CRS to a successful completion, then rerun WSANAL.
3- "JOB WSANAL ABORTED--ERROR CONDITION: FSTOR PBLMS"	Error occurred while trying to store TM3 into the AFOS database. Check to see if a copy of NMCGPHTM3 is on DPO. If so, you can display TM3 from DPO. Otherwise, rerun WSANAL.

DASHER MESSAGES	
1- "SOMETHING WRONG WITH REPORTED SURFACE PRESSURE--NOT WITHIN GRID--SKIPPING TO NEXT REPORT"	Probable observation or coding error. Program fix is automatic--complete wind report eliminated from the wind speed analysis.

CROSS SECTIONAL ANALYSIS OF RICHARDSON NUMBER

PROGRAM DESCRIPTION and EXECUTION PROCEDURE

PROGRAM NAME: RICHNO

APPLICATION: Meteorological analysis at WSFO's and RFC's

PURPOSE: Produces Richardson number analysis for overlaying on an isentropic cross section that has been previously generated by applications program CRS. Creates a local use graphics product stored on DPO and also in the AFOS database.

DESCRIPTION:

Programmers: David B. Gilhousen
James E. Kemper
David J. Vercelli

Type: Background applications program

Revision date: Not applicable

Core: 14 K words

Language: FORTRAN IV

Office: Techniques Development Laboratory
FTS: 427-7639

Issue date: July 15, 1982

Revision No.: First issue

Running time: About 1 minute

Product: Local use AFOS graphical stored in NMCGPHTM4

Disk space:	Program (-.SV files)	- 63 RDOS blocks
	Input files	- 15 RDOS blocks
	Output files	- 18 RDOS blocks on DPO and in the AFOS database.

REQUIRED PROGRAMS AND FILES

	NAME	COMMENT
Programs:	RICHNO.SV RIANAL.SV	RICHNO chains to RIANAL.
Input:	COEF.DT CRSRD.DT	Produced by applications program CRS.SV.
Output:	NMCGPHTM4	TM4 can be specified by the user as a RUN argument.

LOAD LINE

```
RICHNO:  RLDR RICHNO RDCOEF RICHNO.LM/L BG.LB UTIL.LB FORT.LB
RIANAL:  RLDR RIANAL CRSSET SMOOTH CNTR3 COLPT MAXMN1 LABEL ASCII RIANAL.LM/L
              CRS.LB BG.LB UTIL.LB FORT.LB
```

PROGRAM SETUP

NOTE: Macros: Setup is START.MC, and breakdown is FINISH.MC. See Appendix A, TDL CP 82-1.

1. Move RICHNO.SV and RIANAL.SV to DPOF. Create links in DPO to RIANAL and RICHNO on DPOF.

2. Run the upper air decoder, TTBBD (ISL OFFICE NOTE 81-1). TTBBD has to be run only once for a particular cycle.

3. Run the cross section program, CRS (ISL OFFICE NOTE 81-2), which will create current COEF.DT and CRSRD.DT files on DPO. COEF needs about 18 RDOS blocks and CRSRD needs about 7 RDOS blocks of disk space.

PROGRAM EXECUTION

From the ADM, enter: RUN:RICHNO TM4

TM4 specifies the output product identifier as part of NMCGPHTM4. If TM4 is omitted, the program assumes TM4 = T68.

For a different set of stations to form another cross section, CRS must be rerun to generate the appropriate data. RICHNO is then rerun on the new data.

The message "JOB RICHNO COMPLETED--PRODUCT NMCGPHTM4 STORED" will appear at the initiating ADM when the job is successfully completed.

ERROR CONDITIONS

Error conditions other than those listed here, appearing at the Dasher, denote problems that occur while accessing files, most likely caused by system/disk problems rather than program failures. Check RDOS error code and rerun program if appropriate.

ADM MESSAGES	MEANING
1- "JOB ABORTED--ERROR CONDITION: COEF.DT MSG"	COEF.DT probably does not exist. Check DPOF to see if it's there. If it is, there is a system problem. If it isn't, run program CRS to a successful completion, then rerun RICHNO.
2- "JOB RICHNO ABORTED--ERROR CONDITION: CRSRD.DT MSG"	CRSRD.DT probably does not exist. Check DPOF to see if it's there. If it is, there is a system problem. If it isn't, run program CRS to a successful completion, then rerun RICHNO.
3- "JOB RICHNO ABORTED--ERROR CONDITION: FSTOR PBLMS"	Error occurred while trying to store TM4 into the AFOS database. If a copy of NMCGPHTM4 is on DPO, display from there. Otherwise, rerun RICHNO.

APPENDIX A

Setup and Breakdown Macros

Macros to setup and breakdown the cross section series of programs are supplied in the cross section program distribution. The set up macro, START.MC, performs the service of moving all the required files from the program floppy to DPOF and creating the necessary links on DPO. The breakdown macro, FINISH.MC, reverses the procedure by deleting the programs and data files, and performs the UNLINKING of items associated with the cross section programs. It also deletes all the graphics products with the identification NMCGPHT-.- from DPO.

The macros are invoked at the ADM by loading the cross section program floppy in DP3, entering INIT:DP3, followed by RUN:DP3:START. START sends a message to the ADM announcing its completion and also a suggestion to display a text file which contains the instructions for running all the programs: TTBBD, CRS, WSANAL, and RICHNO.

When the user has completed all the desired executions, enter RUN:FINISH. FINISH.MC has been placed on DPO by START, and will delete itself automatically.

The macros are:

START.MC

```
DIR DP3
MOVE/R DPO FINISH.MC
DIR TTBBD
MOVE/A/R DPOF TTBBD.SV TTBBD.OL TTBBSTAS.DB
DIR DP3:CRS
MOVE/A/R DPOF CRS.SV CRSEDIT.SV CRSETS.XX
        CRSINIT.SV TPL.SV UPRDIR.MS
DIR DP3:WSANAL
MOVE/A/R DPOF WSANAL.SV RIANAL.SV RICHNO.SV
DIR DPO
LINK TTBBSTAS.DB DPOF:TTBBSTAS.DB CRSETS.XX DPOF:CRSETS.XX
LINK TTBBD.SV DOPOF:TTBBD.SV TTBBD.OL DPOF:TTBBD.OL
LINK CRS.SV DPOF:CRS.SV TPL.SV DPOF:TPL.SV
LINK WSANAL.SV DPOF:WSANAL.SV RIANAL.SV DPOF:RIANAL.SV
LINK RICHNO.SV DPOF:RICHNO.SV UPRDIR.MS DPOF:UPRDIR.MS
LINK CRSRD.DT DPOF:CRSRD.DT COEF.DT DPOF:COEF.DT
DIR DP3
SENADM
RELEASE DP3
DIR DPO
```

FINISH.MC

```
DIR DPO
DELETE FINISH.MC
DIR DPOF
DELETE TTBBD.SV TTBBD.OL TTBBSTAS.DB
DELETE CRS.SV CRSEDIT.SV CRSETS.XX CRSINIT.SV TPL.SV UPRDIR.MS
DELETE WSANAL.SV RIANAL.SV RICHNO.SV
DELETE CRSRD.DT COEF.DT
DIR DPO
UNLINK TTBBD.SV TTBBD.OL CRS.SV TPL.SV
       WSANAL.SV RIANAL.SV RICHNO.SV UPRDIR.MS
       CRSETS.XX TTBBSTAS.DB
DELETE @FILNAM.TX@
DELETE FILNAM.TX RINOS
DELETE NMCGPHT-.-
```