1994

Implementation of PCGRIDDS and associated case studies

Isidora Mateu
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IMPLEMENTATION OF PCGRIDDS AND ASSOCIATED CASE STUDIES

A Thesis

Presented to

The Faculty of the Department of Meteorology

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Isidora Mateu

December 1994

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ABSTRACT

IMPLEMENTATION OF PCGRIDDS AND ASSOCIATED CASE STUDIES

by Isidora Mateu

The software package called PCGRIDDS is used to study the intensification of a cyclone on March 12-12 1993 over the United States (i.e. "The storm of the Century"), and to analyze the conditions previous to a severe weather outbreak over northeastern Oklahoma on 24 April 1993.

Cold advection under a short wave trough at 500 mb was responsible for the amplification of the wave and therefore for the intensification of the surface cyclone during the development of the "Storm of the Century." Meanwhile, the strong low level moisture advection allowed intensification to continue even after the surface cyclone was very deep.

In the second case study, even though the atmosphere was potentially unstable before the severe weather outbreak over Oklahoma, the trigger mechanism could not be found among the key parameters posted by Maddox and Doswell III to forecast severe weather. However, this study shows that the quasi-geostrophic forcing along with convection were the mechanisms that released the instability.

DEDICATION

This work is dedicated to my husband and sons

ACKNOWLEDGMENTS

First, I would like to thank my thesis advisor, Dr. Douglas M. Sinton and my committee member, Dr. Peter Lester for giving me the opportunity to combine synoptic, mesoscale and dynamic meteorology in this interesting project and, for guiding me through its obstacles. I also want to express my appreciation to my other committee member, Dr. Alison Bridger for her valuable comments on the manuscript. Additionally, I would like to express my sincere gratitude to Dr. Kenneth McKay, to Ms. Donna Hurth and to the rest of the faculty and staff members at the Meteorology Department: Dr. Goodman and Dr. Steffens for their unconditional patience and kindness. Although we have never met, I would like to thank Mr. Keith Meier from the National Weather Service for the help he has given me since the beginning of this project.

Special thanks go to my husband, Hugo and to my sons Ariel and Alejandro. I am also grateful to my parents, whose advice and encouragement have always been with me. I am grateful as well to the rest of my relatives who have collaborated to make this project possible.

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LIST OF SYMBOLS

The following is a list of the symbols used in the main body of the text.

f	Coriolis parameter ($\cong 2\Omega \sin\phi$)
f_0	constant reference latitude value of the Coriolis parameter
g	gravitational acceleration
p, P	pressure
P_θ	Ertel's potential vorticity
t	time
T	temperature
V_g	geostrophic wind vector
V_H	horizontal component of the wind vector
V_0	1000 mb wind
ζ_g	vertical component of the geostrophic relative vorticity
ξ_θ	relative vorticity on an isentropic surface

θ	potential temperature
ρ	density
σ	$\equiv -\alpha \frac{\partial \theta}{\partial p}$, static stability parameter in isobaric coordinates
ψ	stream function
ϕ	latitude
ω	vertical velocity ($\equiv dp/dt$) in isobaric coordinates
Γ	$\equiv -dT/dz$, lapse rate of temperature
Γ_d	dry adiabatic lapse rate
Φ	geopotential
$\overline{(\quad)}$	average value
$[\ ]_0$	quantity measured on an isentropic surface

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Chapter 1

INTRODUCTION

In the last few years, Man computer Interactive Data Access System (McIDAS) has revolutionized the teaching of synoptic meteorology at San Jose State University (SJSU) by bringing analyses, forecasts and satellite images to the students in real time. However, quasigeostrophic analyses cannot be performed using McIDAS.

For instructive purposes, one of the most valuable analyses to forecast the weather is the large scale forcing of vertical motion. The omega field and its associated ageostrophic circulation can be visualized by computing the Qvector divergence field. With the development of the Personal Computers (PCs) some attempts have been made to make this possible.

Mr. Stanley L. Barnes from the National Oceanic and Atmospheric Administration's (NOAA) Environmental Research Laboratories at Boulder, Colorado developed a menu driven software package (Omega Diagnostics) that is capable of displaying the fields of: 1000/500 mb thickness, geostrophic winds, thermal advection, Qvectors, divergence of Qvectors

among other analyses at different levels by using rawinsonde data. This software has been used in the last years at San Jose State University to study severe weather over the United States in the synoptic meteorology laboratory, as well as in the training course that SJSU offers for the National Weather Service (NWS) personnel every other year. Nevertheless, this package uses only real-time radiosonde data. Therefore, this package cannot be used for forecasts or for regions upstream of the west coast where radiosonde data are sparse.

Recently, the National Weather Service (NWS) has developed a software package called PCGRIDDS (Personal Computer GRidded Interactive Display and Diagnostic System) which runs on Personal Computers (PCs). It displays meteorological fields of gridded model (Nested Grid Model-NGM and Enhanced Topography Model-ETA) output on Personal Computers as they become available from NWS; i.e., in real time. This software is well suited for SJSU because of its ability to run on a PC in real time and also because of its meteorological comprehensiveness.

PCGRIDDS performs analyses on isobaric (Meier, 1993) and isentropic surfaces (Baumgardt, 1993 and Pike, 1993), and also produces cross- and time sections (Conger, 1993).

The primary data fields that can be displayed on isobaric surfaces, isentropic surfaces and cross sections are shown on Tables 1, 2 and 3 at the end of this chapter.

1.1 PCGRIDDS capabilities

Unlike Omega Diagnostic, PCGRIDDS uses gridded output data from the ETA and NGM models. Therefore, analyses and forecasts for both models can be displayed over an area that extends, farther than Omega Diagnostic, into the Pacific Ocean. This fact lets the students compare the output from different models and to prepare more accurate forecasts for the western coast of the United States.

As it has been mentioned before, PCGRIDDS can display basic fields over isentropic surfaces. Since the isentropic surfaces act like "material surfaces" for the motion of air over the synoptic scale, this constitutes an invaluable tool to track the three dimensional motion of the air parcels.

1.2 PCGRIDDS improvements

Although PCGRIDDS is a very useful tool, some adjustments need to be made in order to make it more suitable for teaching meteorology. The development of new diagnostic tools, the automatization of the data download and the adaptation of the menu inside PGRIDDS to facilitate synoptic laboratory activities are some of them.

1.3 Objectives of this thesis

- i) Develop access to the gridded model output data of the National Weather Service's models in real time.
- ii) Use this data with PCGRIDDS to develop a computer based learning module that will integrate comprehensive meteorological analysis into the synoptic curriculum.

The following Chapter will describe in detail the changes made to PCGRIDDS. Chapter 3 will describe the case studies, performed with PCGRIDDS, of the severe weather conditions that affected the eastern coast of USA on March 12 and 13 1993 and, northeast Oklahoma on April 24 1993. Chapter 4 will summarize what has been done and will present some possible improvements that might be achieved by expanding the use of PCGRIDDS in the future.

A user's manual for PCGRIDDS and a step through tutorial to its application are in Appendices A and B, respectively.

Table 1: Basic fields on isobaric surfaces

Height Coordinate	Level	Field	Units
Pressure	Mean Sea Level and Standard isobaric surfaces	Temperature	°C, °F, °K
		Dew Point Temperature	°C, °F, °K
		Potential Temperature	°K
		Equivalent Potential Temperature	°K
		Mixing ratio	g/kg, kg/kg
		Relative Humidity	%
		Specific Humidity	g/kg, kg/kg
		Saturation deficit	kg/m ³
		Saturation mixing ratio	g/kg, kg/kg
		Vertical Velocity	microbar/s
		Total precipitation in six hours	in, mm
		Convective precipitation	in
		Four layer Lifted Index	°C
		Precipitable water	in, mm
		1000/500 mb Thickness	m
		1000/500 mb Thermal wind	m/s

Table 1 (cont.)

Height coordinate	Level	Field	Units
Pressure	Mean sea level and standard isobaric surfaces	Observed wind vector	m/s, kt, mph, kph
		Geostrophic wind vector	m/s, kt, mph, kph
		Ageostrophic wind vector	m/s, kt, mph, kph
		Contour values of direction of wind	degrees
		Convective Available Potential Energy (CAPE)	$\text{m}^2 \text{s}^{-2}$

Table 2: Basic fields on isentropic surfaces

Coordinate	Level	Field	HeightUnits
Isentropes	Isentropic surfaces selected previously	Pressure	mb
		Temperature	$^{\circ}\text{C}$, $^{\circ}\text{F}$, $^{\circ}\text{K}$
		Total wind	m/s, kt, mph, kph
		Mixing ratio	g/kg, kg/kg

Table 3: Basic analyses on cross sections

Coordinate	Horizontal Field Units	Height	
Pressure	Latitude/Longitude	Temperature °C, °F, °K	
	or	Potential °K Temperature	
	Time	Total, geostrophic and ageostrophic wind	m/s, kt, mph, kph
		Relative wind to the cross section (*)	m/s, kt, mph, kph
		Component of the wind normal to the cross section	m/s, kt, mph, kph
		Component of the wind tangent to the cross section	m/s, kt, mph, kph
		Vertical circulation(**)	m/s, kt, mph, kph
		Isentropic Potential Vorticity	K mb ⁻¹ s ⁻¹

(*) In a north-south cross section a westerly wind would appear directed from the bottom to the top of the screen.

(**) This may be computed using geostrophic wind and vertical velocity or ageostrophic wind and vertical velocity i.e. a true secondary circulation.

Chapter 2

CHANGES TO PCGRIDDS

2.1 Changes in PCGRIDDS

The 12/93 PCGRIDDS version has been modified in order to make the software more helpful for the Meteorology students at SJSU. New commands have been created and included in the PCGRIDDS menu, and a batch file that prints the graphs on a dot matrix printer has been prepared.

2.1.1 *New PCGRIDDS macro files*

To detect areas of rising and sinking air in the troposphere, the 500 mb absolute vorticity along with the 1000/500 mb thickness field, instead of the 600/400 mb thickness field, have been used for simplicity and real time availability in the SJSU meteorology classes. According to Trenberth's (1978) omega equation (Eq. 2.1), the vertical velocity is proportional to the vorticity advection by the thermal wind. This combines the vertical change of Positive Vorticity Advection (PVA) and the Laplacian of thickness advection terms in the omega equation (Eq. 2.2).

$$\sigma \nabla^2 \omega + f_0^2 \frac{\partial^2 \omega}{\partial p^2} \approx f_0 \left[2J \left(\frac{\partial \psi}{\partial p}, \nabla^2 \psi + f \right) \right] \quad (2.1)$$

$$\left(\nabla^2 + \frac{f_0^2}{\sigma} \frac{\partial^2}{\partial p^2} \right) \omega = \frac{f_0}{\sigma} \frac{\partial}{\partial p} \left[\mathbf{v}_g \cdot \nabla \left(\frac{1}{f_0} \nabla^2 \Phi + f \right) \right] + \frac{1}{\sigma} \nabla^2 \left[\mathbf{v}_g \cdot \nabla \left(-\frac{\partial \Phi}{\partial p} \right) \right] \quad (2.2)$$

where:

$$\nabla \text{ two-dimensional } \nabla \text{ operator} \left[= \frac{\partial}{\partial x} \mathbf{i} + \frac{\partial}{\partial y} \mathbf{j} \right]$$

$$\nabla^2 \text{ Laplacian} \left[= \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} \right]$$

$$J(\alpha, \beta) \text{ Jacobian} \left[= \frac{\partial \alpha}{\partial x} \frac{\partial \beta}{\partial y} - \frac{\partial \beta}{\partial x} \frac{\partial \alpha}{\partial y} \right]$$

Therefore, a new command has been included in the PCGRIDDS menu that displays the fields of absolute vorticity at 700 mb, 500 mb and 300 mb superimposed on the 850/500 mb, 700/300 mb and 400/200 mb thickness fields. These graphs are presented in a loop for the forecast times: 00, 24 and 48 hours. Note that the layers considered to compute the thickness fields include the level considered to compute the absolute vorticity. In this way, it is possible to integrate visually the Quasi geostrophic forcing of omega at different levels in a more realistic way.

In the past, the meteorology students at SJSU only had access to the output of the RAFS (Regional Area Forecast) and LFM (Limited-area Fine-Mesh) models from the NWS. With PCGRIDDS it is now possible to get the ETA (Enhanced Topography Amplitude) and the RAFS models output data in real time. A significant difference between the RAFS and ETA models is the vertical coordinate system used by each model. The RAFS' vertical coordinate uses terrain following sigma surfaces while the ETA uses a vertical coordinate system in which vertical levels are nearly horizontal everywhere in the domain. A disadvantage of using sigma surfaces is that the horizontal pressure gradients cannot be calculated accurately over areas with steeply sloping terrain. Therefore, although the ETA model is still experimental, it is able to better represent horizontal pressure gradients, associated wind fields, and subsequently the vertical motion fields in regions of greatly varying terrain. Besides, the RAFS boguses moisture values to grid points on pressure surfaces which are actually below terrain level while the ETA model does not. In order to gain experience on the use of the ETA model, several commands have been developed that show the mean sea level pressure and 1000/500 mb thickness heights, the fields of 700 mb heights and relative humidity and, the 500 mb heights and absolute vorticity for the ETA and the RAFS models at 00, 24

and 48 hours arranged in a loop. With the new commands developed it is also possible to see the difference in 500 mb heights and in the 24 hour precipitation fields obtained with both models at various times.

In order to facilitate the Met.171 briefing presentations, the BRIEF command was prepared. By running this command the students can save all the maps they will need, before the presentation. These graphs can be restored on the screen from the command line of PCGRIDDS in a few seconds as they are needed through the briefing (See Appendix A).

Although several instability indices were already included in the menu, the Sweat (Severe Weather Threat Index) was not. This index is computed from five terms which contribute to severe weather potential: low-level moisture (850 mb dew point), instability ($\text{Total Totals} = 850 \text{ mb temperature} + 850 \text{ mb dew point} - 2[500 \text{ mb temperature}]$), low-level jet (850 mb wind speed), upper-level jet (500 mb wind speed), and warm advection (veering between 850 and 500 mb). Since this index is valuable when making forecasts east of the Rockies, a command that displays the Sweat Index, at a time previously selected, has been added to the menu.

2.1.2 Printing with PCGRIDDS

The version of PCGRIDDS received at SJSU allows printing of the analysis, already obtained with a PCGRIDDS command, on a laser printer. Since there is not such a printer connected to the PC that runs PCGRIDDS in the DH614 room at SJSU, a short program was developed that prints PCGRIDDS graphs from screen onto a dot matrix printer.

Chapter 3

CASE STUDIES

In this chapter, the case studies for the "Storm of the Century" that affected the eastern United States on March 12-14 1993 and, the severe weather outbreak that spread tornadoes over northeastern Oklahoma on April 24 1993 are presented with the help of PCGRIDDS.

The synoptic discussions for both cases are based on the NWS DIFAX charts of surface, hemispheric 500 mb and, radar charts received at SJSU, as well as on the satellite pictures obtained from the McIDAS historical archives and the PCGRIDDS output data.

3.1 Case Study: 12-13 March 1993

The development theory of Sutcliffe (1947) and Petterssen (1956) will be used as a framework for this case study. This theory is based on the quasi-geostrophic Omega

(2.2) and vorticity equations (3.1) (For simplicity, the diabatic heating term in the thermodynamic energy equation has been ignored even though it may be important in some cases).

If ω is considered to be a sinusoidal curve in the horizontal and in the vertical, it is possible to see from (2.2) that positive (negative) differential vorticity advection increasing with height is associated with rising (sinking) motions. Meanwhile, the warm (cold) advection, represented by the thickness advection in this equation, is connected with rising (sinking) air.

The quasi-geostrophic vorticity equation is:

$$\frac{\partial \zeta_g}{\partial t} = -V_g \cdot \nabla (\zeta_g + f) - f_0 \nabla_p \cdot V_H \quad (3.1)$$

The vorticity tendency owing to vorticity advection can be expressed as the first term on the right of (3.1). It is governed by the advection of relative and planetary vorticity for short ($L_x < 3000$ km) and long ($L_x > 10,000$ km) waves respectively. Since positive maxima in relative

vorticity are associated with cyclonic disturbances such as short wave troughs, regions of positive vorticity advection can therefore be used to forecast synoptic-scale weather.

Typically, when a cyclone develops, the upper level geopotential height contours undergo a deformation that is related to cyclogenesis. These changes, evident in the increasing amplitude of the upper-level short wave, represent an increase of the vorticity advection, which helps the development of the cyclone at the surface. This process is known as "self-development" after Sutcliffe and Forsdyke (1950).

The "self-development" process can be seen as the progressive deformation of the upper current in the vicinity of a surface cyclone. These changes in the upper-level structure may be explained in terms of changes in the thermal structure of the troposphere.

The local temperature change at a given level may be written as:

$$\frac{\partial \bar{T}}{\partial t} \approx -V_0 \cdot \nabla \bar{T} + \overline{\omega(\Gamma_d - \Gamma)} \quad (3.2)$$

where V_0 is the 1000 mb wind, Γ_d and Γ are the dry adiabatic and actual lapse rate and, the overbar represents the average value between the 1000 mb surface and an isobaric surface in the upper troposphere.

When a cyclone is already present at the surface, the horizontal thermal advection [first term on the right hand side of Eq.(3.2)], induces a deformation of the isotherms and therefore of the thickness and upper-air height fields. As the amplitude of the upper wave increases, so will the vorticity and its gradient along the stream. This implies that the divergence will also increase in the upper troposphere thus deepening the surface cyclone. The low level convergence will become stronger, yielding rising motion over the surface cyclone. This process of distortion of the upper level contours stops at some point due to the effect of the static stability [second term on the right hand side of Eq.(3.2)] that produces local cooling (warming) in regions of ascent (descent).

Thus, the influence of horizontal advection is balanced by the influence of the vertical motion and the static stability. When the cyclone is in such a stage that the

condensation process is taking place over an extended area, the damping effect of the static stability becomes smaller because $(\Gamma_d - \Gamma)$ is much smaller for moist ascent than for dry ascent. Therefore, the cyclone may undergo a stronger intensification if the air is saturated.

To detect areas of rising and sinking air, the quasi-geostrophic omega approximation (2.2) will be considered in isobaric coordinates and the vertical velocity will be computed in isentropic coordinates (3.3). The vertical motion (ω) in isentropic coordinates can be expressed as:

$$\omega = \underbrace{\left[\frac{\partial p}{\partial t} \right]_0}_A + \underbrace{V \cdot \nabla_\theta P}_B + \underbrace{\frac{\partial p}{\partial \theta} \frac{d\theta}{dt}}_C \quad (3.3)$$

where term A is the local change in pressure on an isentropic surface, term B is the advection of pressure along an isentropic surface and, term C is the diabatic heating component. Term C can be neglected except when strong latent heat release is taking place (i.e. deep convection) or near the ground. The potential temperature is not conserved when latent heating occurs and therefore

the parcels tend to rise through the isentropic surfaces. Wilson (1985) noted that terms A and C are usually opposite in sign and that the term B typically dominates, especially in regions of strong advection. From term B, rising motion ($\omega < 0$) can be inferred where the wind is directed toward lower pressure on a given isentropic surface and, subsidence ($\omega > 0$) where the wind is directed toward higher pressures. Therefore this term can be evaluated using PCGRIDDS.

The omega equation (2.2) can also be written as:

$$\sigma \nabla^2 \omega + \frac{\partial^2 \omega}{\partial p^2} = -2 \nabla \cdot \mathbf{Q} \quad (3.4)$$

where
$$\mathbf{Q} = -\frac{R}{p} \left(\frac{\partial T}{\partial y} \right) \left(\frac{\partial v_g}{\partial x} \mathbf{i} + \frac{\partial v_g}{\partial y} \mathbf{j} \right) \quad (3.5)$$

The Qvector can be diagnosed from observations of geopotential height and temperature. It is aligned with the ageostrophic wind below its level while being opposed to the ageostrophic wind above its level. Thus, its divergence accounts for the adiabatic forcing of vertical motion due to geostrophic motion. Therefore, it is possible to visualize the omega field and its associated ageostrophic circulation by computing the Qvector divergence field.

3.1.1 Synoptic discussion

In early March 1993, a long wave trough was located close to the eastern coast of the United States while a series of short wave troughs in the upper troposphere were crossing the central portion of the United States. One of these short wave troughs was located just west of an extra tropical cyclone over the Gulf of Mexico by 1200 UTC 12 March 1993 (Fig. 1). Consequently, the low level cyclone developed and moved rapidly, spreading rain and severe weather from southern Texas up the eastern coast of the United States.

By 12 March 1993, the long wave pattern was characterized by four long waves over the Northern Hemisphere. The trough axis of one of them was anchored at 70°W while the upstream ridge axis was approximately at 125°W.

Figure 1 shows the geopotential and absolute vorticity fields at 500 mb every 12 hours for 1200 UTC 12 March 1993 through 1200 UTC 13 March 1993.

Fig.1a. Geopotential heights (solid) in decameters and absolute vorticity (dashed) in 10^{-5} s^{-1} for 500 mb at 1200 UTC 12 March 1993.

Fig.1b. Same as Fig.1a but at 0000 UTC 13 March 1993.

Fig.1c. Same as Fig. 1a but at 1200 UTC 13 March 1993.

Figure 2 shows the sea level pressure contoured every four millibars, and 1000 mb moisture convergence for the same period.

At 1200 UTC 12 March, an upper level trough was located along the 102 °W meridian at 500 mb while a positive absolute vorticity center was over southwestern Arkansas (see Fig. 1a). At this time, a strong ridge was prevailing at the surface over the northern half of the United States while a low pressure system associated with a front was located over southern Texas (see Figure 2a). At 500 mb, cold advection into the trough (see Figure 3a) over western Texas, Oklahoma, and Kansas coupled with warm advection over the Gulf of Mexico northeast of the surface low produced the amplification of this short wave. At the same time, the low level circulation associated with this low pressure system transported large amounts of water vapor from the Gulf of Mexico producing moisture convergence at 1000 mb over southern and western Texas (see Fig. 2a). Since there was

Fig.2a. Mean Sea Level pressure (solid) in mb and moisture flux convergence (dashed) at 1200 UTC 12 March 1993.

Fig.2b. Same as Fig.2a but at 0000 UTC 13 March 1993.

Fig.2c. Same as Fig.2a but at 1200 UTC 13 March 1993.

Fig.3a. Mean Sea Level pressure (solid) in mb and 1000-500 mb thickness (dashed) in decameters at 1200 UTC 12 March 1993.

Fig.3b. Same as Fig.3a but at 0000 UTC 13 March 1993.

Fig.3c. Same as Fig.3a but at 1200 UTC 13 March 1993.

strong positive vorticity advection (PVA), implying rising motion, over that area in the middle troposphere (see Fig. 1a) all this moisture was forced to rise and condense. Due to the combination of the cold advection upstream of the surface cyclone and the rising of warm moist air downstream of the surface cyclone, the amplification of the trough was strong. This amplification of the short wave is correlated with an increase in the upper level vorticity gradient and therefore, with an increase of divergence aloft (Figure 4a). This divergence is in turn responsible for an 8 mb central pressure drop and a stronger low level convergence (Figure 5a) over the cyclone. The center values of pressure dropped 8 mb during the first six hours after 1200 UTC 12 March 1993 and 12 mb in the next six hours (see Figures 2a and 2b).

Figure 6 shows 300 mb heights every 100 m and isotachs contoured every 20 kt for 1200 UTC 12 March 1993 through 1200 UTC 13 March 1993.

Fig.4a. Geopotential heights (solid) in hectometers and divergence (dashed) in 10^{-5} s^{-1} for the 250 mb surface at 1200 UTC 12 March 1993.

Fig. 4b. Same as Fig.4a but at 0000 UTC 13 March 1993.

Fig.4c. Same as Fig.4a but at 1200 UTC 13 March 1993.

Fig.5c. Same as Fig.5a but at 1200 UTC 13 March 1993.

Figure 6a indicates the presence of several jet streaks one of which is located along 40°N east of 95°W at 1200 UTC 12 March 1993.

Figures 7a and 7b show term B of Eq.(3.3) over the 308K and 316K isentropic surfaces for 1200 UTC 12 March 1993. These surfaces were selected because they did not intersect the ground near the focus area (i.e. the cyclone). Omega distributions can be inferred from these figures if the terms A and C of Eq.(3.3) are neglected.

From Figure 7a, two major areas with rising air (i.e. term $B < 0$) can be detected over the 308K surface: one above the surface cyclone (see Fig.2) and another one over the Alabama-Tennessee border. Meanwhile, it is possible to see an area with strong rising motion over Louisiana at 316K.

Figures 8a and 8b show pressure, mixing ratio and total wind over the 308K and 316K isentropic surfaces for 1200 UTC 12 March 1993. Since parcels conserve their mixing ratio when moving along an isentropic surface (except when there is condensation or evaporation), these figures depict the three dimensional moisture advection (i.e. the isentropic surfaces are usually sloped surfaces).

Fig.6a. Geopotential heights (solid) in hectometers and isotachs (dashed) in knots for the 300 mb surface at 1200 UTC 12 March 1993.

Fig.6b. Same as Fig.6a but at 0000 UTC 13 March 1993.

Fig.6c. Same as Fig.6a but at 1200 UTC 13 March 1993.

Fig.7a. Term B of omega equation (Eq. 3.3) for the 308 K surface at 1200 UTC 12 March 1993.

Fig.7b. Same as Fig.7a but for the 316 K surface.

Fig.8a. Pressure in tens of mb (solid), mixing ratio in g Kg^{-1} (dashed) and wind ms^{-1} for the 308 K surface at 1200 UTC 12 March 1993.

Fig.8b. Same as Fig.8a but for the 316 K surface.

From these figures, the strongest moisture advection can be seen just down stream of the surface cyclone and over western Florida along both surfaces.

Figure 9 shows the Qvectors and the Qvector divergence field. Since convergence of Qvectors implies horizontal convergence (Eq. (3.4)) in the column below, the cyclonic vorticity will tend to increase below a region of convergent Qvectors supporting the intensification of the cyclone (see final term in Eq. 3.1). By 1200 UTC 12 March, there were three centers of convergence of Qvectors over the south-central United States. The strongest one was located over eastern Mexico, while the other two were over southern Texas and southeastern Colorado.

Figure 10 shows a vertical cross section along the line from A to B on Fig. 6a for 1200 UTC 12 March 1993. It displays divergence of the wind in solid lines every 10^{-5} s^{-1} and ageostrophic circulations in barbs. The rising branch of an ageostrophic circulation developed at $23^{\circ}\text{N } 98^{\circ}\text{W}$ consistent with a maximum of divergence in the upper levels associated with a short wave trough over northern Mexico (see Fig. 4a and 6a).

Fig.9a. Qvectors (arrows) and divergence of Qvectors (solid) for 500 mb at 1200 UTC 12 March 1993.

Fig.9b. Same as Fig.9a but at 0000 UTC 13 March 1993.

Fig. 9c. Same as Fig. 9a but at 1200 UTC 13 March 1993.

Fig. 10. Cross section for 1200 UTC 12 March 1993. The solid lines are divergence in 10^{-5} s^{-1} and the barbs are the ageostrophic circulation. Values at the bottom indicate latitude and longitude (positive if North and West) and the values in the left margin are pressure in mb.

The low level moisture advection along with the mid-tropospheric cold advection contributed to develop areas with high potential for severe weather, as measured by the Sweat index. Commonly accepted threshold values with the Sweat index are 300 for severe thunderstorms and 400 for tornadic storms. By 1200 UTC 12 March 1993, the Sweat index reached values of 400 east southeast of Texas and over 200 over west Florida (see Fig. 11a). The radar depiction showed at this time a "hook" echo, usually associated with the possibility of tornadoes, to the northwest of the surface cyclone center.

As the cold frontal system moved to the east, the cyclone and its associated moisture advection also moved eastward (see Figures 2b and 12) while the short wave trough at 500 mb became more organized. The positive vorticity center that was over Colorado at 1200 UTC 12 March moved to southern Oklahoma by 0000 UTC 13 March (Fig. 1a), while the positive center over eastern Oklahoma moved to southern Mississippi (Fig. 1b) where it merged with the positive center that had been over North Eastern Mexico at 1200 UTC 12 March 1993.

Fig. 11a. Sweat index divided by ten at 1200 UTC 12 March 1993.

Fig. 11b. Sweat index divided by ten at 0000 UTC 13 March 1993.

Fig. 11c. Sweat index divided by ten at 1200 UTC 13 March 1993.

Fig. 12a. Infrared satellite image for 2300 UTC 12 March 1993.
(Image obtained from McIDAS archived data)

Fig. 12b. Water vapor satellite image for 2100 UTC 12 March 1993.
(Image obtained from McIDAS archived data)

Figures 13a and 13b show the same fields as Figures 7a and 7b while Figures 14a and 14b are similar to Figures 8a and 8b but, for 0000 UTC 13 March 1993.

At this time, the area of rising motion involved all the states east of 90° W. The advection of moisture is particularly noticeable over western Florida at the 308K surface by this time (see Figure 14a). The cyclone and the area of strong moisture convergence at 1000 mb moved to southern Mississippi (Fig. 2b) by 0000 UTC 13 March 1993. The potential for severe weather was high over western Florida by this time, with Sweat indices above 300 and radar indicated echoes of Digital Vertically Integrated Precipitation (DVIP) levels 3 (heavy precipitation) to 4 (very heavy precipitation) with tops at 17,000 feet. This storm spread tornadoes over Florida on the late afternoon of March 12 1993. The cyclone was still intensifying by this time as can be seen from the Qvectors field (see Fig. 9b). The three centers of Qvector convergence that were over the south-central United States at 1200 UTC 12 March (see Fig.9a) coalesced and became more intense by 0000 UTC 13 March 1993 (see Fig. 9b).

Fig. 13a. Term B of omega equation (Eq. 3.3) for the 308 K surface at 0000 UTC 13 March 1993. Negative values are solid lines.

Fig. 13b. Same as Fig. 13a but for the 316 K surface.

Fig. 14a. Pressure in tens of mb (solid), mixing ratio in g Kg^{-1} (dashed) and wind in ms^{-1} for the 308 K surface at 0000 UTC 13 March 1993.

Fig. 14b. Same as Fig. 14a but for the 316 K surface.

The jet streak that was around 40°N 95°W at 1200 UTC 12 March 1993 became less zonally oriented and was on a line from northeastern Texas to southern Maine by 0000 UTC 13 March 1993 (see Fig. 6b). Since the wind speed in a jet streak is greater than the speed with which the jet streak moves, areas where parcels decelerate (exit region of the jet streak) and where parcels accelerate (entrance region) can be identified. The atmosphere, in order to reestablish geostrophic balance, develops ageostrophic circulations near the jet streaks. This circulation yields divergence (convergence) over the right (left) side of the entrance region (see Fig. 15).

The rising branch of the ageostrophic circulation (see Fig. 16a) at 28°N 89°W (right quadrant of the entrance region of this jet streak, i.e. see point B on Figure 6b) supported the further development of the surface cyclone.

Figure 16b shows a relative maximum of isentropic potential vorticity (IPV) close to and to the northwest of the center of the cyclone for the same cross section as Fig. 16a.

Fig. 15. (a) Schematic of transverse ageostrophic wind components and patterns of divergence (DIV) and convergence (CON) associated with the entrance and exit regions of a straight jet streak (based on Bjerknes 1951). (b) Vertical cross sections illustrate vertical motions and direct and indirect circulations in the entrance region (line A-A') and exit region (line B-B') of a jet streak. Cross sections include two representative isentropes (dotted), upper-level jet (J) location, upper-level divergence and horizontal ageostrophic wind components within the plane of each cross section. (c) Schematic of maximum and minimum relative vorticity centers, and associated PVA and NVA patterns, associated with a straight jet streak. Schematic is from Kocin and Ucellini (1990).

Fig. 16b. Cross section for 0000 UTC 13 March 1993. The solid lines are Isentropic Potential Vorticity (IPV) in Potential Vorticity Units (PVU) ($10^{-6} \text{ K mb}^{-1} \text{ s}^{-1}$).

The value of the maximum on Fig.16b mentioned above is close to the values that can be seen near the stratosphere with an associated tropopause fold extending below 500 mb at 35°N indicating that this air was descending from upper levels. The isentropic potential vorticity can be expressed as

$$P_\theta = -g(\xi_\theta + f) \frac{\partial \theta}{\partial P} \quad (3.6)$$

As the air descends in the troposphere, the air parcel is stretched vertically as it horizontally converges along isentropes and the static stability $(-\partial \theta / \partial P)$ decreases. Consequently the absolute vorticity increases as long as the IPV values are conserved (no diabatic heating or friction). Therefore, from Fig. 16b, it can be inferred that the injection of stratospheric air in the middle troposphere into the cyclone area was one of the major contributors to the strong development of this system.

The cyclone was on the border between North and South Carolina and its central pressure was around 976 mb by 1200

UTC 13 March (see Fig.2c). Heavy snow showers were falling west of the Appalachians and over the northeastern states as very cold air was over the area (see Fig. 3c), while rain showers were covering the area to the east of the Appalachians. The surface cyclone was still undergoing development as more positive vorticity was advected towards it in the middle troposphere (see Fig. 1c). By then, the areas with strong rising motion were restricted to the northeastern portion of the United States while the strength of the vertical velocity increased, compared with the previous figures (see Fig. 17, 7 and 13). Moisture levels increased rapidly over this area too. The short wave trough at 500 mb became well organized (see Fig.1c) and started to become in phase with the system at the surface (see Fig.3c).

3.2 Case Study: 24 April 1993

This case study will use the thirteen key parameters for severe weather forecasts prepared by Maddox and Doswell III (1982:see Table 4). This table is a simplified version of the summary of parameters that Miller (1972) considered important in his severe storm forecasting manual.

Fig. 17a. Term B of omega equation (Eq. 3.3) for the 308 K surface at 1200 UTC 13 March 1993. Negative values are solid lines.

Fig. 17b. Same as Fig. 17a but for the 316 K surface.

Table 4: Summary of Key Parameters indicating likelihood of
severe weather from Maddox and Doswell III (1982)

RANK	PARAMETER	WEAK (W)	MODERATE (M)	STRONG (S)
1	500mb vorticity advection	Neutral or NVA	PVA Contours cross vorticity pattern<30°	PVA Contours cross vorticity pattern>30°
2	Stability- Totals Index	TI≤50	55≤TI<50	TI>55
3	500 mb wind speed	WS≤35 kt	35<WS≤50 kt	WS>50 kt
4	300-200 mb wind speed (upper level maximum)	WS ≤55 kt	55<WS≤85 kt	WS>85 kt
5	850 mb wind speed	WS≤20 kt	20<WS≤35 kt	WS>35 kt

Table 4 (cont.)

RANK	PARAMETER	WEAK (W)	MODERATE (M)	STRONG (S)
6	850 mb dew point	$T_d \leq 8^\circ\text{C}$	$8 < T_d \leq 12^\circ\text{C}$	$T_d > 12^\circ\text{C}$
7	850 mb temperature ridge	East of moist axis	Over moist axis	West of moist axis
8	700 mb 12-h temperature change lines	Winds cross lines $\leq 20^\circ$	Winds cross lines $> 20^\circ$ and $\leq 40^\circ$	Winds cross lines $> 40^\circ$
9	700 mb dry intrusion	Not available or weak 700 mb winds	Winds from dry to moist intrude at angle of $< 40^\circ$ and are ≥ 15 kt	Winds intrude at an angle of $> 40^\circ$ and are ≥ 25 kt
10	12-h surface pressure fall	< 1 mb	1 to 5 mb	> 5 mb

Table 4 (cont.)

RANK	PARAMETER	WEAK (W)	MODERATE (M)	STRONG (S)
11	500 mb 12-h height change	<30 m	≥30m and ≤60m	>60 m
12	Surface pressure over threat area	≥1010 mb	<1010 mb and ≥1005 mb	<1005 mb
13	Surface dew point	Td≤55°F	55°F<Td<65°F	Td≥65°F

These key parameters, based upon the synoptic setting (especially in the spring), indicate the likelihood of widespread outbreaks of severe thunderstorms and tornadoes. However, severe storms often occur within relatively weak large-scale settings.

3.2.1 Synoptic discussion

On April 24, 1993 a series of severe thunderstorms brought tornadoes to northeastern Oklahoma, central Michigan and south-western Minnesota. An F4 tornado (in Fujita's scale) hit Tulsa (Oklahoma) at 5:50 CST killing seven people, injuring 100 people and producing property damage of 100 million dollars. An F3 tornado occurred over Catoosa (Oklahoma) at 5:57 CST injuring thirty people and producing property damage of 10 million dollars (Information obtained from the National Severe Storms Forecast Center of Kansas).

By 0000 UTC 24 April 1993, the 500 mb chart showed two long wave troughs positioned at 70° W and 155° W. A series of short waves were present in between these two long wave troughs by then. There was one short wave trough over western Oklahoma (see Fig. 18) that was associated with a stationary front over the area. By 1200 UTC this front turned into a weak cold front while a weak warm front was over northeastern Oklahoma as can be seen in the thickness field on Fig. 19. Tulsa and Catoosa were located between these two fronts. By this time of the day, a dry line extended from 29° N 102° W to 35° N 98° W (see Fig. 20).

Fig. 18. Geopotential heights (solid) in decameters and absolute vorticity (dashed) in 10^{-5} s^{-1} for 500 mb at 0000 UTC 24 April 1993.

Fig. 19. Mean sea level pressure (solid) in mb and 1000/500 mb thickness (dashed) in decameters at 1200 UTC 24 April 1993.

Fig. 20. Mean sea level pressure (solid) in mb and dew point temperature (dashed) in °C for the 982 mb sigma surface at 1200 UTC 24 April 1993.

Figures 21 to 31 show the key parameters of Table 4 and Table 5 shows an evaluation of the strength of the parameters from Table 4 for 1200 UTC 24 April 1993 and 0000 UTC 25 April 1993.

Table 5: Summary of Key parameters for 24/25 April 1993

PARAMETER	12 UTC	STRENGTH	00 UTC	STRENGTH
1	PVA (Fig.21)	W-M	PVA (Fig.47)	M-S
2	55 (Fig.22)	S	≥ 50 (Fig.48)	M
3	35 (Fig.23)	W	> 50 kt (Fig.49)	S
4	55 (Fig.23)	W	> 60 kt (Fig.49)	M-S
5	35-40 kt (Fig.24)	M	> 20 kt (Fig.50)	M
6	2-6°C (Fig.25)	W	$8^{\circ}\text{C} < T_d < 12^{\circ}\text{C}$ (Fig.51)	M
7	West (Fig.25)	S	West (Fig.51)	S
8	Available (Fig.26)	S	$< 20^{\circ}$ (Fig.52)	W
9	Available (Fig.27)	S	Available (Fig.53)	S
10	Available (Fig.28)	W	Available (Fig.54)	W-M
11	< 30 m (Fig.29)	W	< 30 m (Fig.55)	W
12	< 1005 mb (Fig.30)	S	< 1005 mb (Fig.56)	S
13	62-65 °F (Fig.31)	M	55-58 °F (Fig.57)	M

Fig.21. Height contours in decameters (solid) and absolute vorticity in 10^{-5} s^{-1} for the 500 mb surface at 1200 UTC 24 April 1993.

Fig. 22. Total totals index at 1200 UTC 24 April 1993.

Fig.23. Isotachs in tens of knot for the 500 mb surface (solid) and for the 200 mb surface (dashed) at 1200 UTC 24 April 1993.

Fig. 24. Isotachs in tens of knot for the 850 mb surface at 1200 UTC 24 April 1993.

Fig. 25. Temperature (solid) and dew point temperature (dashed) in degrees Centigrade for the 850 mb surface at 1200 UTC 24 April 1993.

Fig. 26. Winds in knots and 12 hour temperature changes in degrees Centigrade for the 700 mb surface at 1200 UTC 24 April 1993.

Fig. 27. Dew point temperature in degrees Centigrade and winds in knots for the 700 mb surface at 1200 UTC 24 April 1993.

Fig. 28. 12 hour surface pressure fall in mb at 1200 UTC 24 April 1993.

Fig. 29. 12 hour height change in decameters for the 500 mb surface at 1200 UTC 24 April 1993.

Fig.30. Mean sea level pressure in mb at 1200 UTC 24 April 1993.

Fig.31. Dew point temperature in degrees Fahrenheit for the 1000 mb surface at 1200 UTC 24 April 1993.

From all these figures, it is possible to see that the potential for severe weather existed at 1200 UTC even though it was not clear by then whether or not it would actually occur since the synoptic indicators were not very strong.

Less than 50% of the key parameters were strong, while 30% of them were weak. The synoptic settings, according to Table 4, were weak to moderate as can be seen from weak to moderate positive vorticity advection at 500 mb (see Fig. 21), no jets over the area (see Fig. 23) and weak surface pressure and 500 mb height falls (see Figures 28 and 29).

Most severe weather results from self-perpetuating convective systems, which require a certain minimum value of vertical wind shear to sustain the relative low level inflow into these systems. Operational experience suggests that in most situations the greater the vertical shear, the higher the potential for severe thunderstorms. Maddox and Doswell III (1982) pointed out that a large directional contribution to shear is almost always present in the northwesterly flow outbreaks occurring in the central USA. In this specific case, although the wind speeds at 850, 500 and 200 mb at 1200 UTC did not indicate severe potential, the wind shear

was strong between the first and fifth sigma level (see Fig. 32) over western Oklahoma/northeastern Texas by 1200 UTC.

Figure 33 shows a cross section using output data from the ETA model approximately perpendicular to the fronts along the dotted line on Fig. 19. It displays the equivalent potential temperature contoured every four degrees Kelvin, and omega in microbars per second. From this figure it can be inferred that there was potentially unstable air $\left(\frac{\partial \theta_e}{\partial z} < 0\right)$ and rising motion around 36° N 96° W up to 700 mb, i.e. this was happening in the region where tornadoes would later occur.

In order to detect which areas were more likely to liberate the potential for severe weather, the Qvector divergence, the Qvectors at 850 mb, 700 mb and 500 mb and the Sweat indices at 1200 UTC 24 April 1993 are overlaid on Figure 34. At 850 mb and at 500 mb, there was one major area of rising air over western Oklahoma, coincident with the cold front at the surface, and another area that seemed to have weaker rising motion over northeastern Oklahoma. The last area was superimposed on Sweat indices above 300.

Fig. 32. Winds in ms^{-1} for the 982 mb (solid) and 784 mb (dashed) sigma levels at 1200 UTC 24 April 1993.

Fig.33. Cross section at 1200 UTC 24 April 1993. Equivalent potential temperature in degrees Kelvin (solid) and omega in microbars per second (dashed). Values at the bottom indicate latitude and longitude (positive if North and West) and the values in the left margin are pressure in mb.

Fig. 34a. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors (dashed) for 850 mb at 1200 UTC 24 April 1993.

Fig. 34b. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors for 700 mb at 1200 UTC 24 April 1993.

Fig. 34c. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors for 500 mb at 1200 UTC 24 April 1993.

The threshold value used by the Air Force for the Sweat index is usually around 300 for severe thunderstorms, and 400 for tornadic storms. Since the Sweat index is only an indication of potential for severe weather, this figure shows that the quasi-geostrophic forcing might be the trigger mechanism for the outbreak of the severe storms.

All the analyses already presented have been carried out at 1200 UTC. This means that no contribution of convection has been included so far. Figure 35 shows the sequence of radar images from 1700 UTC through 1900 UTC 24 April 1993. By 1900 UTC stronger echoes were developing over northwestern Oklahoma.

Figures 36 to 46 show the thirteen key parameters for forecasting severe weather (after Miller, 1972) for the 12 hour forecast time, i.e., valid at 0000 UTC 25 April 1993. The potential for severe weather by this time was greater since now 10 out of 13 parameters were moderate to strong. Figures 47 to 57 show the key parameters for 0000 UTC 25 April 1993 (approximately the time when the tornadoes occurred).

Fig. 35a. Manually digitized radar chart at 1700 UTC 24 April 1993.
(Chart obtained from McIDAS archived data)

Fig. 35b. Manually digitized radar chart at 1800 UTC 24 April 1993.
(Chart obtained from McIDAS archived data)

Fig. 35c. Manually digitized radar chart at 1900 UTC 24 April 1993.
(Chart obtained from McIDAS archived data)

Fig.36. Height contours in decameters (solid) and absolute vorticity in 10^{-5} s^{-1} for the 500 mb surface forecast for 0000 UTC 25 April 1993.

Fig. 37. Total totals index forecast for 0000 UTC 25 April 1993.

Fig.38. Isotachs in tens of knot for the 500 mb surface (solid) and for the 200 mb surface (dashed) forecast for 0000 UTC 25 April 1993.

Fig. 39. Isotachs in tens of knot for the 850 mb surface forecast for 0000 UTC 25 April 1993.

Fig.40. Temperature (solid) and dew point temperature (dashed) in degrees Centigrade for 850 mb forecast for 0000 UTC 25 April 1993.

Fig. 41. Winds in knots and 12 hour temperature changes in degrees Centigrade for the 700 mb surface forecast for 0000 UTC 25 April 1993.

Fig. 42. Dew point temperature in degrees Centigrade and winds in knots for the 700 mb surface forecast for 0000 UTC 25 April 1993.

Fig. 43. 12 hour surface pressure fall in mb forecast for 0000 UTC 25 April 1993.

Fig. 44. 12 hour height change in decameters for the 500 mb surface forecast for 0000 UTC 25 April 1993.

Fig.45. Mean sea level pressure in mb forecast for 0000 UTC 25 April 1993.

Fig.46. Dew point temperature in degrees Fahrenheit for the 1000 mb surface forecast for 0000 UTC 25 April 1993.

At this time 11 of the 13 parameters were between moderate and strong (see Table 5).

Figures 58 and 59 are similar to Fig. 34 but forecast at 0000 UTC 25 April 1993 and the analysis for 0000 UTC 25 April 1993 respectively. From the comparison of these two figures it can be seen that the Sweat indices were overestimated by the forecast, although the area of maximum values was approximately well positioned. Meanwhile, the vertical motion was well estimated at the lower levels but was overestimated at 500 mb.

Fig.47. Height contours in decameters (solid) and absolute vorticity in 10^{-5} s^{-1} for the 500 mb surface at 0000 UTC 25 April 1993.

Fig. 48. Total totals index at 0000 UTC 25 April 1993.

Fig.49. Isotachs in tens of knot for the 500 mb surface (solid) and for the 200 mb surface (dashed) at 0000 UTC 25 April 1993.

Fig. 50. Isotachs in tens of knot for the 850 mb surface at 0000 UTC 25 April 1993.

Fig. 51. Temperature (solid) and dew point temperature (dashed) in degrees Centigrade for the 850 mb surface at 0000 UTC 25 April 1993.

Fig. 52. Winds in knots and 12 hour temperature changes in degrees Centigrade for the 700 mb surface at 0000 UTC 25 April 1993.

Fig. 53. Dew point temperature in degrees Centigrade and winds in knots for the 700 mb surface at 0000 UTC 25 April 1993.

Fig. 54. 12 hour surface pressure fall in mb at 0000 UTC 25 April 1993.

Fig. 55. 12 hour height change in decameters for the 500 mb surface at 0000 UTC 25 April 1993.

Fig.56. Mean sea level pressure in mb at 0000 UTC 25 April 1993.

Fig.57. Dew point temperature in degrees Fahrenheit for the 1000 mb surface at 0000 UTC 25 April 1993.

Fig. 58a. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors (dashed) for the 850 mb surface forecast at 0000 UTC 25 April 1993 (analysis at 1200 UTC 24 April 1993).

Fig. 58b. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors (dashed) for the 700 mb surface forecast at 0000 UTC 25 April 1993 (analysis at 1200 UTC 24 April 1993).

Fig. 58c. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors (dashed) for the 500 mb surface forecast at 0000 UTC 25 April 1993 (analysis at 1200 UTC 24 April 1993).

Fig. 59a. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors (dashed) for the 850 mb surface at 0000 UTC 25 April 1993.

Fig. 59b. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors (dashed) for the 700 mb surface at 0000 UTC 25 April 1993.

Fig. 59c. Sweat index divided by ten (solid), Qvectors (arrows) and divergence of Qvectors (dashed) for the 500 mb surface at 0000 UTC 25 April 1993.

Chapter 4

SUMMARY AND CONCLUSIONS

The main goal of this thesis was to introduce a new tool to enable the students at the Meteorology Department of San Jose State University to perform comprehensive meteorological analyses in real and forecast time. The software named PCGRIDDS was chosen because of its capability to run on a PC, because the data needed to run PCGRIDDS could be downloaded through the network (download of data is free), and because it is a very powerful tool that provides, among many other things, isentropic analyses, Qvector analyses and Convective Available Potential Energy (CAPE) analyses, etc.

The National Weather Service Office in Salt Lake City, Utah, provided PCGRIDDS to the Meteorology Department of San Jose State University and have been giving the support needed to run PCGRIDDS in real time at SJSU since the Fall semester 1993.

This software has the capability to display analyses and forecasts up to 48 hours in six hour intervals over the United States. The output gridded data files from the ETA and NGM models are downloaded at the Meteorology Department. Since the PCGRIDDS data files fit in a single 1.2 megabytes diskette, the students can work on the same assignment at different PCs simultaneously. The data files can also been transfered using the network but, it takes more time. The fact that new command files can be developed and attached to the menu by the users makes this software a very useful teaching tool in synoptic laboratories. Some of the new macro files developed during the course of this work allow the students to compute the Sweat Index and to save and restore analyses needed for briefings in the Met. 171 course for both the current time and for forecast times.

Two case studies were performed using PCGRIDDS, and a computer based learning module was developed based on them. The Sutcliffe-Petterssen theory was used to explain the "Storm of the Century" on 12-13 March 1993. This was a case of classic cyclone development. As stated earlier, PVA and cold advection in the upper levels along, with moisture and

warm advection in the lower levels, were responsible for the extreme and rapid intensification of the surface cyclone.

The severe weather outbreak over Oklahoma on 24-25 April 1993 was analyzed under the scope of the thirteen key parameter table prepared by Maddox and Doswell III (1982) to forecast severe weather. Additionally the quasigeostrophic forcing through the convergence of the Qvectors (associated with rising motion) and the computation of the Sweat index were considered. McIDAS archive data were used to get satellite and radar pictures for both case studies. Therefore, with the combination of PCGRIDDS and McIDAS, the students can see not just the analyses at different levels, but also the satellite pictures that were associated with these special meteorological conditions.

Due to the fact that PCGRIDDS is relatively new software, it is very difficult either to find documentation about it or to have access to a complete users manual or source code. This also made it impossible to develop a nested menu that could be accessed without dropping to DOS. Among the things that would be useful to have in the future are: the Aviation (AVN) model output data and the

possibility to perform analyses of the Montgomery stream function on isentropic surfaces.

Appendix A

PCGRIDDS MANUAL

INSTALLING PCGRIDDS

- . Load the diskette containing the software into the appropriate disk drive A (or B).
- . From the C:\> prompt, type A (or B):\INSTALL
This line will create the \PCGRD directory, \MACRO sub directory and download all files necessary for PCGRIDDS. All the gridded data and any new commands should be kept within C:\PCGRD. For PCs running under DOS, insert the following changes into the CONFIG.SYS file from which the computer boots. Typically, this is located in C:.

DEVICE=C:\DOS\ANSI.SYS

- . For PCs running under OS/2 make the following changes to the settings and values listed here:

Settings

DOS_DEVICE

Values

C:\OS2\MDOS\ANSI.SYS

- . Reboot the machine after performing these changes.

INTRODUCTION TO PCGRIDDS

How does PCGRIDDS work?

PCGRIDDS allows the user to run commands from a command line or command files from the command line or from the menu.

A PCGRIDDS command line is a string of variables and display options such as color and contour interval. The commands in the line are processed from RIGHT to LEFT. This concept must be remembered in order to avoid complications in using PCGRIDDS e.g.: HGHT CI60 CLR1 700 is a command line that displays the 700 mb geopotential height with a contour interval of 60 meters in the first color of the palette.

A PCGRIDDS command file is composed of a series of commands that can be run at once by entering the filename followed by a period at the command line e.g.: 70HT. entered at the command line will run the 70HT.CMD file. This file must be in the directory \PCGRD.

DATA RETRIEVAL

Before starting a PCGRIDDS session, the raw model data have to be obtained from the data source. The data files are currently downloaded from the NWS Salt Lake City (Utah) office through the network at San Jose State University. To retrieve the data follow steps 1 through 5.

1. Call up PCGRIDDS on the network (Begin an FTP session).
2. At the USER prompt enter **SANJOSE** as is, i.e. one word in capital letters.
3. At the PASSWORD prompt enter **Artichokes** as is.
4. Enter the following instruction to download the different files:

```
get filename1 C:\pcgrd\filename2
```

where *filename1* and *filename2* must follow the relationship:

<i>filename1</i>	<i>filename2</i>
wd20.PCGRIDDS.t00z.etax(eta6)	00z.etx(et6)
wd20.PCGRIDDS.t00z.rafs(raf6)	00z.rfs(rf6)
wd20.PCGRIDDS.t12z.etax(eta6)	12z.etx(et6)
wd20.PCGRIDDS.t12z.rafs(raf6)	12z.rfs(rf6)

The extension *rafs* (*etax*) identify the data files valid for the forecast hours from 00 to 48 hours in 12 hour

intervals. The extension raf6 (eta6) identify the data valid for the forecast hours 06 to 42 hours on 12 hour intervals. RAF and ETA refer to the NGM and ETA models respectively.

5. When the files are transferred, enter quit to logoff the remote session and exit from the network (FTP).

STARTING A PCGRIDDS SESSION FROM WINDOWS

- . Double click the PCGRIDDS folder from windows.

- . You have to merge the files with extensions RAF6 (ETA6) and RAFS (ETAX) you have already downloaded and convert the output file from this merge into PCGRIDDS' readable therefore you can use the data. Double click the appropriate "merge/convert" icon to perform these tasks.

If you want to work with forecast periods of 12 hours, you will only have to convert the file you have downloaded. Double click the appropriate "convert a single file" icon on the screen.

- . Double click the RUN PCGRIDDS icon and PCGRIDDS will prompt you for one of the following: 1) A filename, 2) DOS, 3) EXIT or 4) HELP.

Filenames typically follow the format:

MMDDYYHH.RFS(ETX), for the NGM (ETA) model. The month is

denoted by a two-letter abbreviation and the recommended values are:

JA:JAnuary	FE:FEbruary	MR:MARch	AP:APril
MY:MaY	JN:JuNe	JL:JuLy	AU:AUGust
SE:SEptember	OC:OCtober	NO:NOvember	DE:DEcember

The day is expressed by two digits justified to the right, i.e. the ninth day of the month will be encoded as 09 while the 23rd will be 23.

The year is represented by the last two digits of the actual year, i.e. the years 1816 and 1916 are coded as 16.

The time is expressed by two digits right justified, i.e. the hour 0 UTC is expressed as 00 while 12 UTC is encoded as 12.

Note that date and time are expressed in UTC (Universal Time Coordinate also called Greenwich Meridian Time or Zulu time), e.g.: the file containing output data from the RAF model for July 9 1916 at 0 UTC is named JL091600.RFS(RF6).

DOS provides temporary access to DOS. This command is very useful to locate the filename that the user wants to access (i.e.: entering `dir *.rfs` after a drop to DOS will list all the files with extension RFS contained in the directory \PCGRD) or to perform any DOS command/s before returning to PCGRIDDS.

This option also provides the opportunity to use the alternative menu (See below).

EXIT (or X), STOP (or S), or END (or E) stops the program.

HELP provides general HELP and elementary Tutorials.

Once you have entered the filename you want to work with, you can perform any of the following tasks:

- i) Run PCGRIDDS commands from this screen (command line screen)
- ii) Access the menu by entering MENU (or M). At this point, a list of available command files will appear on screen. To select any of them enter the corresponding number and follow the on screen directions.
- iii) Access an alternative menu by entering DOS in this screen and CMD once you are in the DOS shell. From this menu you can select the type of analysis you want by hitting the appropriate function key (this is a nested menu devised by Don Baker and currently used by the Western Region Forecast Offices). To run the CMD program the PC must have the following:

- . 505,000 bytes of conventional base memory before running PCGRIDDS.
- . A color graphics card and a color monitor.

After your analysis is completed by running CMD, you

will be back onto the command line of PCGRIDDS. To see the analysis performed you will have to enter 0000. at this point (do not forget to type the period behind the four zeroes).

- iv) End the PCGRIDDS session by entering eXit, Stop, or End.

SWITCHING DOMAINS DURING A PCGRIDDS SESSION

During a PCGRIDDS session you can switch among three different screens according to the kind of task you want to perform. These screens are: command line, menu, and DOS.

To access the command line screen enter EXIT (or X) at the menu screen.

To access the menu screen, enter MENU (or M) in the command line.

To temporarily drop to DOS, enter DOS in the command line.

COMMANDS

This section of the manual contains the PCGRIDDS commands. The different commands let the user search for files already opened or commands already executed; select time, area and characteristics of the graphics; display

primary gridded fields such as temperature, moisture or different type of winds. Commands invoke functions that may be applied to scalar/vector fields; display analyses on isentropic surfaces, and allow the user to work on cross sections (in space or time).

1. Gridded Data File Manipulation Commands

Some useful commands to use on the command line at any time during a PCGRIDDS session are:

- 1) **DOS** (or **DIR**): Returns to DOS to allow DIRectories of available grid files
- 2) **LIST** (or **L**): Lists contents of the currently active data file. i.e. this will show the user the parameters for each level in the gridded data. An example of a LIST screen is shown below.

3) **FIL#**: Changes the active gridded data file to the #th file opened. In this command # can be any number 1-9 or letter A-K i.e. it is possible to open up to 20 files in one session of PCGRIDDS. e.g. **FIL1** changes the active data file to the first file opened, **FILA** changes the active data file to the tenth file opened.

4) **FILS** (or **LFIL**): Lists the files already opened and the currently active file.

An example of screen that you could get with this command is shown below.

5) **OPEN**: Opens another grid file (A total of 20 can be opened).

e.g. **OPEN MR129312.ETX** opens the output data file for **March 12 1993** at **12 UTC** from the **ETA**

model.

6) **SFIL**: Interactively resets the active grid file.

e.g. **SFIL** prompts the user to reset active file.

FIL2 resets the active file to the second file opened.

2. Command manipulations

LCMD (or **CMDS**): Lists the previous 21 commands lines. An

example of a **LCMD** screen is shown below.

prepare a copy of a screen

LST#: Lists the # previous command given where # is any number from 1 to 9 or any letter from A to L i.e. this command displays any of the 21 previous commands.

e.g. **LST9** displays the ninth previous command while

LSTA list the tenth and **LSTL** lists the 21st.

RPT#: Repeats the #th previous command (A total of 21 commands can be repeated). Here # can be any number 1-9 or any letter A-L.

e.g. **RPT7** repeats the 7th previous command and

RPTL repeats the 21st previous command.

3. Time Specifications

ANAL (or **F-1**): Sets Forecast Hour to use analysis grid

F##: Sets Forecast Hour to use ## hour forecast grids.

e.g.: **F00** Sets forecast hour to use 00 hour forecast grids.

F06 Sets forecast hour to use 06 hour forecast grids.

F12 Sets forecast hour to use 12 hour forecast grids.

F18 Sets forecast hour to use 18 hour forecast grids.

F24 Sets forecast hour to use 24 hour forecast grids.

F30 Sets forecast hour to use 30 hour forecast grids.

F36 Sets Forecast Hour to use 36 hour forecast grids.

F42 Sets Forecast Hour to use 40 hour forecast grids.

F48 Sets Forecast Hour to use 48 hour forecast grids.

FHOR (or **SFHR**): Requests input of desired Forecast HOuR.

e.g.: **HGHT F12** or **HGHT SFHR 12** plots the height field for the 12 hour forecast.

F00 (or **INIT**): Sets forecast hour to use initialized grids.

GES6 (or **F-6**): Sets forecast hour to use analysis 6 h guess grids (not applicable to Western Region

PCGRIDDS datasets).

GUES (or **F-3**): Sets forecast hour to use analysis guess grids.

SFHR (or **FHOR**): Changes default forecast time.

4. Time interval manipulations

Time manipulation of the gridded data may be done by inserting keywords to the left or to the right of the desired variable. The following are the commands that can be used to perform time manipulations.

FHRS (or **SFHS**): Requests input of a pair of two-digit forecast hours. The time default pair to compute the difference between the values of any gridded data can be changed in this way i.e. even though the default time values to compute differences in time are 00 and 24, they may be changed to 24 and 36 by typing **FHRS 24 36** to the right of the desired difference.

e.g. the command line : **HGHT TDIF FHRS 24 36**, or

TMDP HGHT FHRS 24 36

calculates and displays the difference in the height fields between the 36 and 24 hour forecast i.e. height at 36 hour minus height at 24 hour.

FHR1: Gets data from first time of FHRS time pair

(beginning of the time period) for commands to left.

FHR2: Gets data from second time of FHRS time pair (ending of the time period) for commands to left.

e.g. **SFHR 24 36**

SDIF HGHT FHR2 HGHT FHR1

changes the default beginning and ending times to 24 and 36 forecast hour and then calculates and displays the difference in the height fields between the 24 and 36 hour forecasts.

SFHS (or FHRS): Changes the default forecast time pair.

TAVE: Calculates Time AVEerage of variables at its left using times FHR1 and FHR2.i.e. $[(\text{Field at time 2}) + (\text{Field at time 1})]/2$

e.g. **HGHT TAVE FHRS 24 12** computes the average geopotential height field between the 12 hour and the 24 hour forecast times.

TDIF: Calculates Time DIfference of variables at left between FHR1 and FHR2. i.e. $(\text{Field at time FHR2}) - (\text{Field at time FHR1})$.

e.g.: **PRES TDIF FHRS 24 00** computes the difference of pressure between the 24 hour forecast time and the actual time.

T MDF: Same as TDIF, except command precedes variable

e.g.: **PRES TDIF FHRS 24 00** and

TMDF HGHT FHRS 00 24

calculates and displays the difference in the height fields between the initial conditions and the 24 h forecast.

TTND: Calculates Time TeNDency of variables or computed functions at its left between FHR1 and FHR2. i.e. TDIF/time.

e.g. **PRES TTND FHRS 12 00** computes the pressure tendency for the next 12 hours.

TTOT: Calculates Time TOTal (or sum) of variables at its left in the command line using times FHR1 and FHR2. i.e. (Field at time FHR1) + (Field at time FHR2).
e.g.: **TPCP TTOT FHRS 12 24** computes the total precipitation accumulated for the period 00 to 24 forecast hour (see explanation of **TPCP** in section 10.1) . The command **SSUM TPCP F12 TPCP F24** produces the same output.

5. Level specification

(or **###**): Three or four digit integer that sets level to numerical value **####**.

e.g.: **HGHT 1000** displays the geopotential height of 1000 mb.

250 sets level to 250 mb.

B###: Sets level to "Boundary" layer centered at ### mb above ground.

I###: Sets level to ### Kelvin degrees isentropic surface.
e.g.: **I308** sets level to the 308°K isentropic surface.

LV+#: Changes LeVel to next # higher level defined for cross/time sections. i.e. if the current data level were 700 mb, this would reset the level to 500 mb.

LV-#: Changes LeVel to next # lower level defined for cross/time sections. i.e. if the current data level were 700 mb, this would reset the level to 850 mb.

S###: Sets level to Sigma level centered at ### mb.
e.g. **SDVR MIXR WIND S982** displays the moisture divergence at the bottom sigma level of the NGM.

S784: Sets level to fifth Sigma level of NGM.

S844: Sets level to fourth Sigma level of NGM.

S896: Sets level to third Sigma level of NGM.

S943: Sets level to second Sigma level of NGM.

S982: Sets level to bottom Sigma level of NGM.

SLVL: Specifies LeVeL for data selection. It must be followed by a four (or three) character specification of the level.
e.g.: **PRES SLVL MSL** first sets the level to the Mean Sea Level and then displays the pressure at this level

(remember that commands are executed from right to left).

6. Layer manipulation of the gridded data

Layer manipulations of primary gridded data variables can be done by inserting keywords to the right or to the left of the desired variable.

LAVE: Calculates Layer AVEverage of variables specified to its left in command line. i.e. [(Field at level 1) + (Field at level 2)]/2.

e.g.: **WSPK LAVE SLYR 1000 500** calculates the average total wind in knots for the 1000/500 mb layer.

LSUM (or LADD): Calculates the Layer SUM of variables specified to left in the command line.i.e. (Field at level 1) + (Field at level 2).

e.g.: **DWPT LSUM SLYR 850 700** computes the sum of the dew point temperatures (in degrees Centigrade) at 850 mb and 700 mb.

LDIF: Calculates Layer DIFference of variables specified to its left in the command line.

e.g.: **HGHT LDIF SLYR 1000 500** computes 1000/500 mb thickness.

LVL1 (or **LYR1**): Gets data from bottom of Layer for variables to its left.

LVL2 (or **LYR2**): Gets data from top of Layer for variables to its left.

e.g.: **SDIF HGHT LVL2 HGHT LVL1** computes
1000/500 mb thickness field.

LEVL: Overrides LVL1 and LVL2 and gets data from original level.

e.g.: **SDIF HGHT LVL2 HGHT LVL1**

TEMP LEVL/

displays the difference in height between level 2 and 1 and overlays the temperature of level 2
(Note that commands are processed from right to left, so the last level used in the first line was 2 and that is why LEVL resets the level to the last used in the previous computation or display.)

LYSM: Calculates LaYer SuM of functions to its right. Same as LTOT and LSUM, except command precedes functions or variables.

LYAV: Calculates LaYer AVerage of functions to its right. Same as LAVE, except command precedes variable.

LYDF: Calculates LaYer DiFference of functions to its right. Same as LDIF, except command precedes variable.
e.g.: **LYDF HGHT SLYR 1000 500** computes thickness.

7. Graphics Commands

&(or /): Overlays output on previous graphics.

e.g.: **HGHT 500**

TEMP/

or **TEMP/HGHT 500** or **TEMP&HGHT** displays

temperature and height fields at 500 mb. Note that there is no space before or after the ampersand or slash.

AREA: Optionally followed by center Latitude/Longitude and latitudinal distance between top and bottom of the desired area expressed in degrees all separated by spaces specifies the map area to display the subsequent commands. NOTE: Northern and Western hemisphere values are considered positive.

e.g.: **AREA 36 97 05** displays the area centered at 36°N 97°W and the distance between top and bottom of the area is 5 degrees. This area displays the gridded data over Oklahoma. Currently, the area map will not be seen until you ask for a specific data field.

BSMP (or **BASM**): Defines a new file containing base map geography information.

CLR#: Overrides the default color and uses the #th color in palette. # can be any number 1-9 or any letter A-G to

display solid lines.

can be any letter H-W to display dashed lines.

can be Y or Z to display dotted lines.

Examples follow:

CLR1: Overrides the default and use color 1 in
palette (Solid).

CLR2: Overrides the default and use color 2 in
palette (Solid).

CLR9: Overrides default and use color 9 in palette
(Solid).

CLRA: Overrides default and use color 10 in palette
(Solid).

CLRG: Overrides default and use color 16 in palette
(Solid).

CLRH: Overrides default and use color 1 in palette
(Dashed).

CLRI: Overrides default and use color 2 in palette
(Dashed).

CLRW: Overrides default and use color 16 in palette
(Dashed).

CLRX: Overrides default and use color 14 in palette
(Dotted).

CLRY: Overrides default and use color 15 in palette
(Dotted).

CLRZ: Overrides default and use color 16 in palette

(Dotted).

e.g. **HGHT 500 CLR2** displays the height field at 500 mb in the second color of the palette that appears at the bottom of your screen.

CROS: Re-activates CROSs-sectional display. i.e. you may choose CROS display if you want to produce a vertical cross section (space or time).

This command is used along with the **XSCT** or **TSCT** commands.

EMAP: Erases the screen and plots the map.

ENDS: Stops Saving graphics commands (See **SAVE** command).

LATT(or **LAT** or **LATI**): Displays latitude lines every five degrees on the map.

LONG(or **LON**): Displays longitude lines every five degrees on the map.

MAP: Draws map background on top of data already displayed.

MFTR: Provides a map factor at each grid point.

NCLB: Draws contours without labels for current request only.

e.g.: **TEMP 700 NCLB** displays temperatures at 700 mb without labeling the isotherms.

NLBL: Prevents plot label (top of screen) from being overwritten.

e.g.: **TEMP 700 NLBL**

TXI2 Temperatures at 700 mb

displays the 700 mb temperatures and the text
"Temperatures at 700 mb" in line 2 without
displaying the statistical data that PCGRIDDS
usually writes at the top of the screen.

OLAY: Overlays output on previous graphics (Same as & or /
between commands)

e.g.: **TEMP OLAY HGHT** or

TEMP

HGHT OLAY

displays the height field and overlays the
temperature field at the given level.

PLAN: Re-activates PLAN view display. i.e. the data is
displayed on a map after this command has been
executed.

e.g.: after displaying a cross section

TEMP/PLAN displays isotherms on a map while

TEMP displays the isotherms over the cross
section previously defined.

PRSC: Converts screen colors for printing using the PRINT
SCREEN key (See Section Generating hard copies).

RCLR: Restores color flag of last plot for overlaying on
restored graphics.

REST: Followed by a four character filename (NAME) RESTores
graphics SAVED in NAME (See command SAVE).

; preceded by a four character filename (NAME)

RESTores graphics SAVED in NAME too.

RSCR: Restores SCReen graphics saved by SSCR (Takes space).

SAVE: Followed by a four character filename (NAME) SAVES graphics commands to NAME.SVG.

e.g. **SAVE MOIS**

DWPT 850

ENDS

ERAS

REST 850 or ;850

saves the dew point temperature at 850 mb in a file named MOIS.SVG, then erases the screen and after this restores the 850.SVG file on screen. .

SCLR: Saves color flag of last plot for overlaying on restored graphics.

SSCR: Saves single SCReen of graphics for later display (Takes space).

TIME: Re-activates TIME-sectional display.

8. Contour Specification

The contour interval is calculated based on the variability of the field. This does not necessarily coincide with the most logical contour interval or scale of the particular quantity being computed. Thus, a choice of

contour interval is allowed, and in many cases encouraged, by typing **CINT** to the left of a field requested for display.

Any contour interval may also be requested by including any of the following commands (except **CINT**) to the left or right of the desired field.

The contour interval specification also acts as the standard for plotting wind arrows, where the length of the arrow is determined relative to the distance between grid points on the display. Normally, the arrow representing the largest wind in the display will be the length of the distance between two adjacent grid points. Adjustments in the length can be made by using the **CI--** commands discussed below where the interval specifies the speed to be plotted as a one grid interval arrow.

CINT: Displays maximum and minimum of field displayed and prompts the user for a contour interval.

e.g.:**CINT HGHT** displays extreme values for the height field and prompts for contour interval.

CISV: Maintains the contour interval of the variable at its left for future plots.

e.g.:**DWPT&TEMP CISV CIN5 700** displays the temperature and dew point at 700 mb, and overlays them with a 5 degree contour interval.

CINX: Returns to the mode in which the command selects

contour interval for each plot.

e.g.: **WSPK CINC/DWPT/TEMP CISV CI10 300** displays the temperature and dew point at 300 mb, and overlays them with a 10 degree contour interval, and then resets to the automatic contour determination and overlays the wind speed contours in knots.

CIN#: Sets Contour Interval to # units.

e.g.: **CIN1**: Sets Contour INterval to 1 unit.

CIN2: Sets Contour INterval to 2 units.

CI#0: Sets Contour INterval to # of tens of units.

e.g.: **CI10**: Sets Contour Interval to 10 units.

WIND CI10 displays the total wind with arrows (default) that are one grid spacing unit long when they show winds of 10 m s^{-1} .

CI20: Sets Contour INterval to 20 units.

C#00: Sets Contour INterval to # hundreds of units.

e.g.: **C100**: Sets Contour INterval to 100 units.

C200: Sets Contour INterval to 200 units.

C#+#: Sets Contour Interval to $\# \times 10^{\#}$ units .

e.g.: **C1+3**: Sets Contour INterval to $1 \times 10^{+3} = 1000$ units.

C2+3: Sets Contour INterval to $2 \times 10^{+3} = 2000$ units.

CI.#: Sets Contour Interval to .# units.

e.g.: **CI.1** or **C1-1** sets contour interval to 10^{-1} or 0.1 units.

C#+#: Sets Contour Interval to $\#*10^{**}-\#$ units.

e.g.: **C5-3**: Sets Contour Interval to .005 units.

C2-3 Sets Contour Interval to $2*10^{-3} = .002$ units.

MIXR C2-3 850 displays the mixing ratio at 850 mb in kg/kg every 10^{-3} units, i.e. mixing ratio expressed in g/kg.

CNSM (or **KSMO**): Followed by an integer, changes the SMoothing on CoNtours (Default=1).

CNUM: Followed by an integer, changes maximum NUMBER of Contours to display.

GRTN: Followed by a four digit value, displays contours greater than the value.

e.g.: **TEMP GRTN 00.0** displays temperatures greater than zero degree Centigrade.

LSTN: Followed by a four digit value, displays contours less than the value.

e.g.: **HGHT LSTN 5600 500** displays the 500 mb heights less than 5600 meters.

GT##: Displays contours greater than the value ##.

e.g.: **DWPT GT10** displays the dew point temperatures greater than 10 degrees Centigrade.

LT##: Displays contours less than the value ##.

e.g. TEMP LT00 displays temperatures below the
freezing point (temperature = 0°C)

9. Output specifications

AROW: Sets display mode to plot winds as ARrOWs (Default).

BARB: Sets display mode to plot winds as BARBs.

DASH: Sets display mode to plot dashed lines for the
variable at its left for the present plot only.
e.g. HGHT&TEMP DASH displays isotherms with dash
lines and height contours with solid lines (Default
value).

DPOS: Dashes the POSitive contours in a data field.

DNEG: Dashes the NEGative contours in a data field.
e.g.: TEMP DNEG displays negative temperatures with
dash lines.

DATA: Sets display mode to plot DATA values At grid points
i.e. no contours are displayed.
e.g.: HGHT DATA displays the height values at each
grid point.

DATT: Sets display mode to plot DATA values on Top of
(above) grid points (no contours).

DATB: Sets display mode to plot DATA values Below grid
points (no contours).

DATO: Sets display mode to plot DATA values Over grid

points (Above DATT).

DATU: Sets display mode to plot DATA values Under grid points (Below DATB).

STON: Provides statistics about gridded data below plt level.

e.g.: **STON**

HGHT CI60 500

displays the 500 mb height field contoured every 60 meters displaying the maximum, minimum, average and standard deviations (statistical) values of height.

STOF: Prevents statistics about gridded data from being plotted.

e.g.: **HGHT/STON**

TEMP/STOF

displays the height field with statistical values and then displays the temperature field without statistical values.

10. Displaying gridded data

Once a file has been opened, data may be displayed by typing a set of requests on the command line. The command line is read from right to left as it was mentioned earlier and several fields may be overlaid by using the ampersand

(**&**), the slash (/) or the **OLAY** command (See these commands under the Graphics commands section).

In order to display the gridded data, the user can display primary gridded data such as temperature or height, wind fields, or can choose from a variety of diagnostic functions that may be applied to scalar or vector fields.

10.1 Primary gridded data fields

CAPE: Convective Available Potential Energy.

CINH: Convective INHbition area - negative area to be overcome by lifting.

CPCI: 12 hour convective PreCiPitation fields, automatically sets level(in).

CPCP: 12 hour convective PreCiPitation fields, automatically sets level(units handled similarly to TPCP).

DWPT: DeW Point Temperature (C).

FFFF: Coriolis parameter at each grid point.

HGHT: Geopotential HEIGHT (meters).

e.g.:**HGHT 850** displays the geopotential height of 850mb.

IMAS: Inverse static stability within a layer.

LIFT: 4 Layer LIFTed Index (currently only valid with NGM

LNDX: Lifted index between LVL1 and LVL2.

MIXR: MIXing Ratio (kg/kg).

MMSL: Mean Sea Level pressure, using MAPS reduction. (Not applicable to Western Region PCGRIDDS datasets).

NMSL: Mean Sea Level pressure (mb), using NMC reduction (Not applicable to Western Region PCGRIDDS datasets).

PDEF: Pressure lift needed for saturation at LCL.

PLCL: Pressure of the LCL from level data.

PMSL: Mean Sea Level Pressure (mb) field without resetting.
e.g.: **PMSL CIN4** displays the pressure at mean sea level every four millibars.

PRES: Pressure (mb).
e.g.: **PRES I308** displays the pressure in millibars of the 308K isentropic surface.

PWAI: Precipitable WATER fields, automatically sets level(in).

PWAT: Precipitable WATER fields, automatically sets level(mm).

RELH: Relative Humidity (%).

SDEF: Saturation DEFicit (kg/m^3).

SMIX: Saturation MIXing ratio (kg/kg).

SPFH: SPeciFic Humidity (kg/kg).

STAB: Static stability within a layer.

TEMP: TEMPerature (C).
e.g.: **TEMP CI10 200** displays the temperature at 200 mb every 10 degrees Centigrade.

THCK: 1000-500 mb THiCKness field (m).
THTA: Potential Temperature - THeTA (K).
THTE: Equivalent Potential Temperature - THeTa/E (K).
THWN: 1000-500 mb THERmal WiNd (m s^{-1})
TLCL: Temperature at the LCL from level data.
TMPF: TeMPerature (F).
TMPK: TeMPerature (K).
TPCI: 12 hour total Precipitation fields, automatically
           sets level(in).
TPCP: 12 hour total PreCiPitation fields, automatically
           sets level (default plots in mm, but data is in cm,
           thus $0.4 \times \text{TPCP} = \text{precipitation in inches}$).
TTHE: Temperature of a parcel lifted from LVL1 to LVL2.
VVEL: Vertical VELOCITY (Omega) i.e. negative values are
           ascent(microbars s^{-1}).

10.2 Winds

Vector representations are displayed automatically for vector quantities when two grids are queued for plotting. The user may choose vectors (**AROW**) or barbs (**BARB**) by typing the appropriate choice to the right of the desired field. For example, **AGEO BARB** displays the ageostrophic wind using barbs.

Note: **AROW** and **BARB** remain active for other vector fields until changed.

AGEO: AGEOSTrophic wind vector (m s^{-1}).

BKNT: Wind Barbs (kts).

BKPH: Wind Barbs (kph).

BMPH: Wind Barbs (mph).

BWND (or **WNDB**): WiND Barbs (m s^{-1}).

DDDD: Followed by a vector (V), displays values of direction of V.

DDFF: Followed by a vector (V), displays packed value of Vector Direction and speed.

DRCT: Followed by a vector (V), contours values of DiReCTion of V.

GEOS: GEOSTrophic wind vector (m s^{-1}).

KMPH: Converts a scalar from m s^{-1} to kph.
e.g.: **KMPH WSPD**.

KNOT: Converts a scalar from m s^{-1} to knots.
e.g.: **KNOT WSPD**.

MLPH: Converts a scalar from m s^{-1} to mph.
e.g.: **MLPH WSPD**.

SPED: Followed by a wind vector (V), calculates the magnitude of V (m s^{-1}).

SPKM: Followed by a wind vector (V), calculates the magnitude of V (kph).

SPKT: Followed by a wind vector (V), calculates magnitude of V(knots).

SPML: Followed by a wind vector (V), calculates magnitude of V (mph).

THWN (or TWND): Generates 1000-500 mb THERmal WiNd.

VKNT: Converts vector (V) from m s^{-1} to knots.

VKPH: Converts vector (V) from m s^{-1} to kph.

VMPH: Converts vector (V) from m s^{-1} to mph.

WDDD: Displays value of total Wind Direction (degrees).

WDDF: Displays packed value of total Wind Direction and speed (m s^{-1}).

WDRC: Contours value of total Wind DiReCtion (degrees).

WGEO: Geostrophic wind from a scalar field i.e. HGHT (height).

WIND: Total WIND vector (m s^{-1}).

WKNT: Total Wind vector (KNoTs).

WKPH: Total Wind vector (KPH).

WMPH: Total Wind vector (MPH).

WNDA: Displays total WiND vector as an Arrow (m s^{-1}).

WSPD: Total Wind SPeeD (m s^{-1}).

WSPK: Total Wind SPeed (Knots).

Examples follow:

SPKT WIND converts the magnitude of the wind field from m

s-1 to knots.

WGEO HGHT 500 computes the geostrophic wind at 500 mb from the height field.

SPED WIND or **WSPD** displays the speed of the total wind in ms^{-1} .

10.3 Diagnostic Functions

PCGRIDDS can calculate and combine a variety of quantities derived from the grid point data. The diagnostics are expressed using a function name followed by an ordered set of arguments, optionally enclosed in parentheses or brackets and separated by commas.

The diagnostic functions are categorized as those using scalar and/or vector quantities. The mathematical expressions that follow represent the operations of each diagnostic function where S and V represent a specified scalar and a vector, respectively, and CNST represents a four digit constant.

For functions involving constants, the constant to be used (CNST) must follow the format **FUNCTION CONSTANT SCALAR**. For example, **SMLC 9.81 WVRT** multiplies the absolute vorticity by 9.81.

General Diagnostic functions

- DALY:** Converts diagnostic command results from s^{-1} to d^{-1} .
- HRLY:** Converts diagnostic command results from s^{-1} to h^{-1} .
- RGTN:** Followed by a 4 digit value (C), replaces values Greater Than with value (C).
- RLTN:** Followed by a 4 digit value (C), replaces values Less Than with value (C).
- SAVG:** Saves grid just generated into a grid file (i.e. **SAVG DIVG/DVRG** saves the calculated divergence field into a grid named DIVG within the data set). This command is not available on version 12/93.
- SMOO:** Applies a light SMOOther to the active gridded data.
- SMT#:** Applies a binomial SMooTher to the active grid data # times.
- SMT5:** Applies a binomial SMooTher 5 times to the active grid data.
- SMT9:** Applies a binomial SMooTher 9 times to the active grid data.
- SMTH:** Applies a binomial SMooTher to the active grid data.
- ZNEG:** Sets all negative values to zero.
- ZPOS:** Sets all positive values to zero.

Functions using Scalars

ABSV: Followed by a Scalar (S), calculates ABSolute Value of S (absv (S)).

BOX#: Plots a box at each gridpoint that meet a threshold value of the parameter indicated to its left, # can be any number from 1 to 9 where # is 1 for smallest box and 9 for largest box.

e.g.: **PMSL BOX1 LSTN 1000** displays a small box at gridpoints whose mean sea level pressure is below 1000 mb.

COSN: Followed by a Scalar (S), calculates the COSiNe of S (cos(S)).

e.g.: **COSN WDRC** computes the cosine of the total wind direction.

DSDX: Followed by a Scalar(S), calculates the x-component of the gradient of S (DS/DX).

DSDY: Followed by a Scalar(S), calculates the y-component of the gradient of S (DS/DY).

GRAD: Followed by a Scalar(S), computes the GRADient of S (∇S).

INV1: Followed by a Scalar (S), computes the INVerse of S with a maximum of 1(1.0/S).

INVS: Followed by a Scalar (S), computes the INVerSe of S (1.0/S).

MGRD: Followed by a Scalar (S), computes the Magnitude of the GRaDient of S.

NGRD: Followed by a Scalar (S), computes the Negative GRaDient of S.

SADC: Followed by a 4 digit value (C) and a Scalar (S), sums C to S ($C + S$).

SAVR: Followed by 2 Scalars (S1 and S2), calculates the scalar grids average $((S1+S2)/2)$.

SCPY: Followed by a scalar (S), makes a copy of S into next "stack" location.

e.g.: **SSUM SCPY HGHT** this command places HGHT on the first location of the storage stack then, makes a copy of the scalar on the second location of the storage stack and finally add the contents of the first and second stacks.

SDIF: Followed by 2 Scalars (S1 and S2), calculates the scalar grid difference $(S1-S2)$.

SDVC: Followed by a 4 digit value (C) and a scalar (S), divides Scalar by specified constant (S/C) .

SDVD: Followed by 2 scalars (S1 and S2), divides the scalar fields $(S1/S2)$.

SINE: Followed by a scalar (S), calculates the SINE of S ($\sin S$)

e.g.: **SINE WDRC** computes the sine of the total wind direction.

SMAX: Followed by two scalars (S1 and S2), plots a field containing the maximum values, at each grid point, between S1 and S2 ($\max(S1, S2)$).

SMIN: Followed by two scalars (S1 and S2), plots a field containing the minimum values, at each grid point, between S1 and S2 ($\min(S1, S2)$).

SMLC: Followed by a 4 digit value (C) and a scalar (S), multiplies a scalar by specified constant ($C*S$).

SMLT: Followed by 2 scalars (S1 and S2), multiplies two scalar fields ($S1*S2$).

SNeg: Followed by a scalar (S), computes the NEGative of a scalar grid ($-1.0*S$).

SQRT: Followed by a scalar (S), returns the square root of the absolute value of specified scalar $SQRT(S)$.

SSBC: Followed by a 4 digit value and a scalar(S), computes the difference of the scalar and the specified constant ($S-C$).

SSUM: Followed by 2 Scalars (S1 and S2), calculates the sum of the scalar grids ($S1+S2$).

SSWP: Followed by 2 Scalars Swaps the "stack" locations of them.

e.g. **SDIF SSWP DSDX HGHT DSDY HGHT**

First DSDY HGHT is calculated and placed on the first position of the storage stack. DSDX HGHT is then calculated and placed on the first position of the

storage stack, moving the field DSDY HGHT to the second position of the storage stack. Then the stack locations of these two scalars are swapped and finally DSDX is subtracted from DSDY.

STND: Followed by 2 Scalars, calculates a scalar grid time tendency $(S(\text{time } 2) - S(\text{time } 1)) / (\text{time } 2 - \text{time } 1)$ (s^{-1} rates).

TNGT: Followed by a scalar (S), calculates the TaNGent of S ($\tan S$)
e.g.: **TNGT WDRC** computes the tangent of the total wind direction.

Functions using Vectors

ADVT: Followed by a scalar(S) and a vector (V), calculates advection of S by V.

ASHD: Shearing deformation of the ageostrophic wind.

ASTD: Stretching deformation of the ageostrophic wind.

AVRT: Absolutre vorticity of the ageostrophic wind.

CRSP: Followed by 2 vectors (V1 and V2), calculates the CRoSS Product of V1 and V2 ($V1 \times V2$).

DOTP: Followed by 2 vectors (V1 and V2), calculates the DOT Product of V1 and V2 ($V1 \cdot V2$).

DVRG: Followed by a vector (V), calculates divergence of V ($\nabla \cdot V$).

FLUX: Followed by a scalar (S) and a vector (V), produces the flux vector of S and V.

GSHD: Shearing deformation of the geostrophic wind.

GSTD: Stretching deformation of the geostrophic wind.

GVRT: Absolute vorticity of the geostrophic wind.

MAGN: Followed by a vector (V), calculates MAGNitude of V.

PADV: Pressure advection by total wind (for use on isentropic surface).

NOTE: This is advection, or **ADVT PRES WIND**, and thus, to infer omega it must be multiplied by -1.

QADV: Mixing ratio advection by total wind.

RVRT: Followed by a vector (V), calculates the relative vorticity of V.

SDVR: Followed by scalar (S) and a vector (V), calculates flux divergence.

SHDF: Followed by a vector (V), calculates the SHearing DeFormation of V.

STDF: Followed by a vector (V), calculates the STretching DeFormation of V.

TADV: Temperature advection by total wind.

VADC: Followed by a 4 digit value (C) and a vector (V), sums C to V (C+V).

VAVR: Followed by 2 vectors (V1 and V2), calculates the vector average $((V1+V2)/2)$.

VCPY: Followed by a vector (V), makes a copy of V into next

"stack" location.

- VDIF:** Followed by 2 vectors (V1 and V2), calculates the vector difference $(V1-V2)$.
- VDVC:** Followed by a 4 digit value (C) and a vector (V), divides V by C (V/C) .
- VDVD:** Followed by 2 Vectors (V1 and V2), divides two vectors by components $(V1/V2)$
- VMLC:** Followed by a 4 digit value (C) and a vector (V), multiplies V by C $(C*V)$.
- VMLT:** Followed by 2 Vectors (V1 and V2), multiplies two vectors by components $(V1*V2)$.
- VNEG:** Followed by a vector (V), computes the NEGative of V $(-1.0*V)$.
- VORT:** Followed by a vector (V), calculates absolute vorticity of V.
- VSBC:** Followed by a 4 digit value (C) and a vector(V), computes the difference of V and C $(V-C)$.
- VSM#:** Applies a binomial SMOother # times to the active Vector field.
- VSMT:** Applies a binomial SMOother to the active Vector field.
- VSUM:** Followed by 2 vectors (V1 and V2), calculates the vector sum $(V1+V2)$.
- VSWP:** Swaps "stack" locations of the last two vectors.
- VTND:** Followed by one vector(V), calculates the vector

time tendency $((V(\text{time2}) - V(\text{time1})) / (\text{time2} - \text{time1}))$.

WDVR: Divergence of the total wind.

WSHD: Shearing deformation of the total wind.

WSTD: Stretching deformation of the total wind.

WVRT: Computes the absolute vorticity of the total wind.

XCMP: Followed by a vector (V), returns grid relative x-component of V.

YCMP: Followed by a vector (V), returns grid relative y-component of V.

11. Analysis on isentropic surfaces

Isentropic surfaces may be generated from the standard level data, becoming part of the data set. It should be noted that isentropic surfaces must be created for each unique forecast period used. For example, if isentropic surfaces were desired from the 00h through the 48 h forecast, the isentropic surfaces must be created at each time period 00-48 h. It is generally advisable to generate isentropic surfaces every 5°K, rather than every 1°K, primarily for space considerations. While any interval is acceptable, each user should generate only enough levels to be useful.

To display a field on an isentropic surface, the level and layers must be set appropriately, i.e. **SLVL I300** for the

300K isentropic surface. The I preceding the numeric isentropic level identifies it as an isentropic level versus a pressure level.

The commands to create isentropic surfaces are:

ALL: Preceded by the MTHT command, creates the desired isentropic surfaces for all times.

e.g.: MTHT 290 330 5 ALL creates the isentropic surfaces, every 5K, between 290K and 330K at all time periods, 00-48 h.

MTHT: Followed by the lower and upper isentropic surfaces and, the desired increment between isentropic levels (each eparated by spaces), generates the desired surfaces for the time previously selected.

e.g.: MTHT 290 330 5 creates isentropic surfaces, every 5K, between 290K and 330K at the time selected (FHOURL).

MTLV: Followed by a four letter filename (NAME), redefines levels for isentropic derivation. The file NAME.MTL contains one line of information:

Nlllv01 lv02 lv03 lv04 lv05 lv06 lv07 lv08 lv09
lv10 lv11 lv12 lv13 lv14 lv15 lv16 lv17 lv18 lv19 NB
where NL is the number of levels to be used from
bottom to top and lv01, lv02,..., etc. are the four
character names of the levels, where the first

NB levels can be boundary or sigma levels.

e.g.:13S982S896S784 1000 850 700 500 400 300 250 200
150 100 3

Specifies that a total of 13 levels should be used in generating isentropic data (surface data is always used also), with the first three levels being sigma levels (if available) and next the 10 mandatory levels between 1000 mb and 100 mb.

Once the isentropic surfaces have been created, most of the primary gridded data mentioned in section 8 can be obtained by following the same procedures to display fields on isobaric surfaces.

Cross sections

Cross-section displays in space can be established by typing **XSCT** followed by the left display latitude and longitude and the right display latitude and longitude, each separated by spaces. If the latitude and longitude information is not included, a prompt will appear. Latitude/longitude are considered positive (negative) when they are North/West (South/East).

Once a cross-section has been defined, the base map will be redrawn with the cross section path shown as a dotted line. The cross-section specification can be removed by entering `XSCT 0 0 0 0 .`

The cross-section displays in time can be established by typing `TSCT` followed by the latitude and longitude values separated by spaces.

Once the cross section has been established, the display mode must be changed before performing an analysis. Display modes can be switched from plan view to cross section by typing `CROS` or `TIME` for cross sections in space or time respectively. To change the display mode from cross section (in time or space) to plan view (e.g. to perform isobaric analyses) type `PLAN`.

Commands for cross-section

General commands

CROS: Changes the display mode from plan view to cross-section view. This command needs to be used after `XSCT` and before any field can be displayed on the cross-section.

DIST (or **XDST**): Distance from the left most point of the cross-section. This command allows the plotting of

angular momentum surfaces (M-lines) which may be used to diagnose areas of possible conditional symmetric instability (CSI).

e.g.: **SSUM NORM GEOS SMLT FFFF DIST** plots M-lines within a cross-section. When creating the cross section, be sure it is normal to the thermal wind at the point of interest.

PLAN: Changes the display mode from cross-section to plan view. Use this command to get an analysis on isobaric or isentropic surfaces after a cross-section in time or space has been done.

THRS: Followed by a four letter filename (NAME), reads the file NAME.HRS to define the hours for the time sections. Where the file NAME.HRS contains one line of information:

```
NTtm01 tm02 tm03 tm04 tm05 tm06 tm07 tm08 tm09 tm10
tm11 tm12 tm13 tm14 tm15 tm16 tm17 tm18 tm19 DT
```

where NT is the number of forecast times that can be displayed, tm01, tm02,..., etc. are the right justified four characters forecast times and DT is the incremental step to be used between output times.

e.g.: 17 48 45 42 39 36 33 30 27 24 21 18
15 12 9 6 3 0 4

specifies that the 17 3-hourly time steps between 00 and 48 hours could be displayed, but that only every 4th hour will be shown, with 48 hours at the left side of the display. The value of DT can be changed with the command **TINC**.

TIME: Changes the display mode from **PLAN** or **CROS** to time section.

TINC: Followed by an integer, changes time increments for time sections.

TSCT: Followed by latitude/longitude values (positive if North/West) initiates the time cross section.

XLVL: Followed by a four character filename (NAME), reads the file NAME.LVL to define the cross section levels. The file NAME.LVL contains one line of information:
Nllv01 lv02 lv03 lv04 lv05 lv06 lv07 lv08 lv09 lv10
lv11 lv12 lv13 lv14 lv15 lv16 lv17 lv18 lv19
where NL is the number of levels to be displayed and lv01, lv02,..., etc. are the four character names of the levels.

e.g., 101000 850 700 500 400 300 250 200 150 100
specifies that the 10 mandatory levels between 1000 and 100 mb will be displayed.

XSCT: Followed by the left and right latitude and longitude values (positive when North/West), displays the path

of the cross-section on the map and initiates the cross-section display.

e.g.: **XSCT 50 112 30 112** displays a dotted line between 50°N 112°W and 30°N 112°W on the map.

Graphics commands

The color and interval of the contours can be managed in the same way they are handled within isobaric analyses.

However, there are some special commands, only valid within cross-sections, that display lines to locate the different places and levels along the cross-section.

HOUR: Plots hour lines on time sections.

TLBL.: Macro that plots pressure and time lines on time-sections. Since this is a macro, instead of a command, you have to type the period after TLBL to run the command file TLBL from the command line of PCGRIDDS.

XLBB: Followed by a scalar (S), plots labels of scalar (S) along the bottom row of cross/time sections.

e.g.: **XLBB LATT** plots latitude on bottom margin.

XLBL: Followed by a scalar(S), plots labels of scalar(S) along the left most column of cross/time sections.

e.g.: **XLBL PRES** plots pressure levels on left margin.

XLBL.:Macro that plots pressure, latitude and longitude lines on cross sections. Since this is a macro you must type the period after XLBL to run this macro from the command line of PCGRIDDS.

XLNT: Plots longitude locations along a cross section.

XLTN: Plots latitude locations along a cross section.

Displaying data fields within a cross section

The primary gridded data fields (see Section 8) can be displayed on a cross-section after a cross section has been defined (**XSCT** or **TSCT**) and the display mode has been changed to cross section (**CROS** or **TIME**). NOTE: only one field can be displayed at a time, i.e. if you want to display more than one field in a cross section you will have to ask for each field at a time including the slash(/) or ampersand(&) at the end of the command line where you display the field that you want to overlay.

e.g.:**XSCT 40 112 35 80**

CROS

TEMP CIN5 CLR3

THTA CIN5 CLR1/

Initiates a cross section along the line 40 N 112 W-35 N 80 W, changes the display mode to cross-section, displays the temperature field contoured every five degrees

Centigrade in color three of the palette along the cross section and overlays the potential temperature field contoured every five degrees Kelvin in color one of the palette.

However, the following commands will display a messy screen.

```
XSCT 40 112 35 80
```

```
CROS
```

```
TEMP CIN5 CLR3/THTA CIN5 CLR1
```

The following commands will display the isentropic potential vorticity contoured every 0.5 PVU ($\text{K mb}^{-1} \text{ s}^{-1}$) along the cross section created with the XSCT command:

```
XSCT 40 112 35 80
```

```
CROS
```

```
SNEG SMLT WVRT LVL0 SDVD SDIF THTA LV+1 THTA LV-1 SDIF PRES  
LV+1 C5-6
```

Displaying winds in a cross-section

Viewing winds within a cross-section must be done with some care due to the various methods used to plot them in cross-sectional form. Winds along a cross-section may be modified to display them relative to the cross-section or to display the tangent/normal component of the wind respect the cross-section, etc..

The following commands display different winds along cross-sections:

- ACRC:** Displays vertical/tangential circulations of the ageostrophic wind.
- AGEX:** Displays the ageostrophic wind relative to the cross section.
- GCRC:** Displays vertical/tangential circulations of the geostrophic wind.
- GEOX:** Plots the geostrophic wind relative to the cross section.
- NORM:** Followed by a vector (V), contours component of V normal to the cross-section.
- TANG:** Followed by a vector (V), contours component of V tangential to the cross-section.
- VTNG:** Followed by a vector (V), plots the component of V tangential to the cross-section.
- VCRC:** Followed by a vector (V), plots the tangent component of V (VTNG) and the vertical velocity.
- VCR2:** Followed by a vector (V), plots the tangent component of V (VTNG) and the vertical velocity (VVEL) scaled by 2.
- VCR5:** Followed by a vector (V), plots the tangent component of V (VTNG) and the vertical velocity (VVEL) scaled by 5.

VNRM: Followed by a vector, plots component of V normal to the cross-section.

WCRC: Displays vertical/tangential circulations of the total wind.

WNDX: Plots the total wind relative to the cross section.

XREL: Followed by a vector (V), plots the component of V relative to the cross-section. For example: in a north-south cross-section a westerly wind would appear directed from the bottom to the top of the screen, while a northerly wind would appear directed from left to right on the screen.

The following set of commands will produce the displayed cross-section along a line 43N 105W-25N 85W .

XSCT 43 105 25 85

CROS

LATT CLRf   clrf is a color choice for this field

THTA CIN4/

ACRC BARB/

or,   **XSCT 43 105 25 85**

CROS

THTA CLRF

ACRC BARB/

XLBL.

Creating macros

Command files (or macros) are sequences of command lines that can be executed at once giving the user a shorthand method for running command sequences that are frequently used. These macros may be written using the DOS line editor (EDLIN) or by creating a DOS file using any word processor. These macros have to be named using a four letter name followed by the ".CMD" extension. To run a command file, you have to type the filename followed by a period at the beginning of the command line. The requested command lines will be displayed in sequence, with a prompt for an <ENTER> or carriage return <CR> between displays when needed.

The following macro requires an <ENTER> between commands:

```
VORT WIND C2-5/HGHT CI60 500 F00
```

```
VORT WIND C2-5/HGHT CI60 F12
```

```
VORT WIND C2-5/HGHT CI60 F24
```

```
VORT WIND C2-5/HGHT CI60 F36
```

```
VORT WIND C2-5/HGHT CI60 F48
```

This macro displays the 500 mb heights and absolute vorticity of the total wind from 00 to 48 hours forecast asking for an <ENTER> after each command is executed.

Useful commands within macros

CONT: Followed by a command, saves the calculated field for the next command without displaying the field. This command is very useful to use long commands.

e.g.: **CONT DWPT 850**

SDIF TEMP 850

Saves the dew point temperature field and then, computes the dew point depression, i.e. $T - T_d$.

CONT UGRD

VGRD

This macro saves the x component of the total wind and then, combines this with the y component to display the total wind.

ENDL: Stops a sequence of commands that was initiated with a **LOOP** command.

KEPS (or **LSTS** or **LAST**): retrieves the last scalar used or computed.

Note: this command is not necessary if **CONT** was used at the beginning of the previous command.

e.g.: **DWPT 850**

SDIF TEMP 850 KEPS

These commands display the dew point depression at 850 mb. See the example presented in **CONT**.

KEPV (or **LSTV**): retrieves the last vector used or computed.

e.g.: **GRAD TEMP**

DOTP WIND KEPV

This macro displays the gradient of temperature and then the dot product between the total wind and the gradient of temperature, i.e. the temperature advection with changed sign.

LOOP: Initiates a loop of commands without asking for carriage return <CR>.

e.g.: **WIND&TEMP CIN5&HGHT 850 CI60 F00**

LOOP

WIND&TEMP CIN5&HGHT CI60 F12

WIND&TEMP CIN5&HGHT CI60 F24 5SEC

WIND&TEMP CIN5&HGHT CI60 F36 5SEC

WIND&TEMP CIN5&HGHT CI60 F48 5SEC

ENDL

This sequence of commands displays the initial 850 mb heights, temperatures and winds, then waits for a carriage return. It then displays a loop of the 12, 24, 36 and 48 hours forecasts of those fields, pausing five seconds between displays.

#SEC: Pauses the execution of a loop for # seconds where # can be any number 1-9 (See example for **LOOP**).

STON: Provides statistics about gridded data below plot level.

e.g.: **STON**

HGHT CI60 500

displays the 500 mb height field contoured every 60 meters displaying the maximum, minimum, average and standard deviations (statistical) values of height.

STOF: Prevents statistics about gridded data from being plotted.

e.g.: **HGHT/STON**

TEMP/STOF

displays the height field with statistical values and then displays the temperature field without statistical values.

TXT#: Followed by a sequence of characters, displays these characters on the #th line of the screen.

e.g.: **TXT3 500mb height**, displays the text "500 mb height" on line 3 of the screen.

Generating hardcopies of plots

Hardcopies of the plots generated using PCGRIDDS may be obtained if an HP Laser Printer or a dot matrix printer is available from the PC.

Laser Printer

1. Save the graph with the SAVE command (See Section 7).

e.g.: **SAVG LIND**

LIFT

ENDS

These commands save the Lifted index in a graph named

- LIND.SVG 2. Exit PCGRIDDS and type HPOUT.
3. Type the name of the .SVG file to print, e.g.:LIND.
  4. Choose a Zoom Factor from 1 to 5, being 5 the largest plot.
  5. Type QUIT to terminate the program (sometimes you should have to press C while holding the CTRL key because this command does not work).
  6. Type PRINT *filename*.HPP, where *filename* matches the name of the .SVG file used.

Dot matrix printer

1. Save the graph with the SAVE command (See Section 7)

e.g.:SAVG LIND

LIFT

ENDS

These commands save the Lifted index in a graph named LIND.SVG.

2. Restore the graph on screen.

e.g.: REST LIND

3. Type PRSC on the command line (See Section 7)

Note: If you do not execute this command, the graph will be printed a little bigger but, the lines will not be very neat even when just two sets of lines were in the graph.

4. Hit the PRINT SCREEN key.

NOTE: The facility to print on a dot matrix printer is not included in PCGRIDDS. Therefore, if you are not running PCGRIDDS in room DH 614 at SJSU you will have to include the following steps after step 1 of the above list:

1 i. Enter DOS at the command line.

1 ii. Enter GRAPHICS in the DOS shell. This will run the GRAPHICS.COM command file (it is usually in the \DOS subdirectory of your PC).

Appendix B

TUTORIAL

In this chapter, the case studies presented in Chapter 3 will be used to present an educational module where the different fields will be obtained using PCGRIDDS commands. The PCGRIDDS commands will be written in bold capital letters in this tutorial.

The synoptic discussions for both cases are based on the NWS DIFAX charts of surface, hemispheric 500 mb and, radar charts received at SJSU as well as on the satellite pictures obtained from the McIDAS historical archives and the PCGRIDDS output data.

B.1 Case Study: 12-13 March 1993

The development theory of Sutcliffe (1947) and Petterssen (1956) will be used as a framework for this case study. This theory is based on the quasi-geostrophic Omega (2.2) and vorticity equations (3.1) (For simplicity, the diabatic heating term in the thermodynamic energy equation has been ignored even though it may be important in some cases).

If ω is considered to be a sinusoidal curve in the horizontal and in the vertical, it is possible to see from (2.2) that positive (negative) differential vorticity

advection increasing with height is associated with rising (sinking) motions. Meanwhile, the warm (cold) advection, represented by the thickness advection in this equation, is connected with rising (sinking) air.

The quasi-geostrophic vorticity equation is:

$$\frac{\partial \zeta_g}{\partial t} = -V_g \cdot \nabla (\zeta_g + f) - f_0 \nabla_p \cdot V_H \quad (3.1)$$

The vorticity tendency owing to vorticity advection can be expressed as the first term on the right of (3.1). It is governed by the advection of relative and planetary vorticity for short ($L_x < 3000$ km) and long ($L_x > 10,000$ km) waves respectively. Since positive maxima in relative vorticity are associated with cyclonic disturbances such as short wave troughs, regions of positive vorticity advection can therefore be used to forecast synoptic-scale weather.

Typically, when a cyclone develops, the upper level geopotential height contours undergo a deformation that is related to cyclogenesis. These changes, evident in the increasing amplitude of the upper-level short wave, represent an increase of the vorticity advection, which helps the development of the cyclone at the surface. This process is known as "self-development" after Sutcliffe and Forsdyke (1950).

The "self-development" process can be seen as the progressive deformation of the upper current in the vicinity

of a surface cyclone. These changes in the upper-level structure may be explained in terms of changes in the thermal structure of the troposphere.

The local temperature change at a given level may be written as:

$$\frac{\partial \bar{T}}{\partial t} \approx -V_0 \cdot \nabla \bar{T} + \overline{\omega(\Gamma_d - \Gamma)} \quad (3.2)$$

where V_0 is the 1000 mb wind, Γ_d and Γ are the dry adiabatic and actual lapse rate and, the over bar represents the average value between the 1000 mb surface and an isobaric surface in the upper troposphere.

When a cyclone is already present at the surface, the horizontal thermal advection [first term on the right hand side of Eq.(3.2)], induces a deformation of the isotherms and therefore of the thickness and upper-air height fields. As the amplitude of the upper wave increases, so will the vorticity along the stream. This implies that the divergence will also increase in the upper troposphere thus deepening the surface cyclone. The low level convergence will become stronger, yielding to rising motion over the surface cyclone. This process of distortion of the upper level contours stops at some point due to the effect of the static stability [second term on the right hand side of Eq.(3.2)] that produces local cooling (warming) in regions of ascent (descent).

Thus, the influence of horizontal advection is balanced by the influence of the vertical motion and the static stability. When the cyclone is in such a stage that the condensation process is taking place over an extended area, the damping effect of the static stability becomes smaller because $(\Gamma_d - \Gamma)$ is much smaller for moist ascent than for dry ascent. Therefore, the cyclone may undergo a stronger intensification if the air is saturated.

To detect areas of rising and sinking air, the quasi-geostrophic omega approximation (2.1) will be considered in isobaric (2.1) and in isentropic coordinates (3.3). The vertical motion (ω) in isentropic coordinates can be expressed as:

$$= \underbrace{\left[\frac{\partial p}{\partial t} \right]_\theta}_A + \underbrace{V \cdot \nabla_\theta P}_B + \underbrace{\frac{\partial p}{\partial \theta} \frac{d\theta}{dt}}_C \quad (3.3)$$

where term A is the local change in pressure on an isentropic surface, term B is the advection of pressure along an isentropic surface and, term C is the diabatic heating component. Term C can be neglected except when strong latent heat release is taking place (i.e. deep convection) or near the ground. The potential temperature is not conserved when latent heating occurs and therefore,

the parcels tend to rise through the isentropic surfaces. Wilson (1985) noted that terms A and C are usually opposite in sign and that the term B typically dominates, especially in regions of strong advection. From term B, rising motion ($\omega < 0$) can be inferred where the wind is directed toward lower pressure on a given isentropic surface and, subsidence ($\omega > 0$) where the wind is directed toward higher pressures. Therefore, this term can be evaluated using PCGRIDDS but not using Omega Diagnostic.

The omega equation (2.2) can also be written as:

$$\sigma \nabla^2 \omega + \frac{\partial^2 \omega}{\partial p^2} = -2 \nabla \cdot \mathbf{Q} \quad (3.4)$$

where
$$\mathbf{Q} = -\frac{R}{p} \left(\frac{\partial T}{\partial y} \right) \left(\frac{\partial v_g}{\partial x} \mathbf{i} + \frac{\partial v_g}{\partial y} \mathbf{j} \right) \quad (3.5)$$

The Qvector can be diagnosed from observations of geopotential height and temperature. It is aligned with the ageostrophic wind below its level while being opposed to the ageostrophic wind above its level. Thus, its divergence accounts for the adiabatic forcing of vertical motion due to geostrophic motion. Therefore, it is possible to visualize

the omega field and its associated ageostrophic circulation by computing the Qvector divergence field.

B.1.1 Synoptic discussion

In early March 1993, a long wave trough was located close to the eastern coast of the United States while a series of short wave troughs in the upper troposphere were crossing the central portion of the United States. One of these short wave troughs was located just west of an extra tropical cyclone over the Gulf of Mexico by 1200 UTC 12 March 1993 (Fig. 1). Consequently, the low level cyclone developed and moved rapidly, spreading rain and severe weather from southern Texas up the eastern coast of the United States.

By 12 March 1993, the long wave pattern was characterized by four long waves over the Northern Hemisphere. The trough axis of one of them was anchored at 70°W while the upstream ridge axis was approximately at 125°W.

Figure 1 shows the geopotential and absolute vorticity fields at 500 mb every 12 hours for 1200 UTC 12 March 1993 through 1200 UTC 13 March 1993. To get Figure 1a you have to open the output data file from the ETA model for 1200 UTC 12 March 1993. Then you need to type at the PCGRIDDS command line, the instructions that will let you see the absolute vorticity with dash white lines and the height field,

contoured every 60 meters, with white solid lines at 500 mb superimposed [**WVRT C2-5 DASH CLR3/HGHT CI60 CLR3 500 F00**]. The PCGRIDDS commands needed to display the figures will be typed with bold capital letters in this tutorial but, you can use either capital or small letters when you are actually typing the commands. To get Figures 1b and 1c you have to open the output data files from the ETA model for 0000UTC [**OPEN MR139300.ETX**] and 1200 UTC [**OPEN MR139312.ETX**] 13 March 1993 respectively before typing the command [**WVRT C2-5 DASH CLR3/HGHT CI60 CLR3 500 F00**].

Figure 2 shows the sea level pressure contoured every four millibars, and 1000 mb moisture convergence for the same period. Even though the sea level pressure is a basic field [**PMSL CIN4 CLR3**], the moisture convergence is obtained computing the flux divergence of the mixing ratio by the total wind and multiplying this scalar by -1 to get positive/negative values for areas with convergence/divergence [**SNEG SDVR MIXR WIND DASH CLR3 1000**].

By now you have opened three files. Type **FILS** to see the names of the files and which one is active. From this point on check which file is active before typing the command. If the active file is not the one you want to work with, type **FIL#** at the command line where # is the ordinal number assigned to the files by the order they have been open. You can see the number that you have to type in the place of # when you list the files with the **FILS** command. Therefore, to get figure 2b change the active file to the

one opened in second place by typing **FIL2** in the command line before you enter the command to get the analysis.

To get Figure 2 you have to type at the command line:
PMSL CIN4 CLR3&SNEG SDVR MIXR WIND DASH CLR3 1000.

At 1200 UTC 12 March, an upper level trough was located along the 102°W meridian at 500 mb while a positive absolute vorticity center was over southwestern Arkansas (see Fig. 1a). At this time, a strong ridge was prevailing at the surface over the northern half of the United States while a low pressure system associated with a front was located over southern Texas (see Figure 2a). At 500 mb, cold advection into the trough (see Figure 3a) over western Texas produced the amplification of this short wave. Figure 3 is obtained with the following command: **PMSL CIN4 CLR3&THCK CI60 DASH CLR3**. At the same time, the low level circulation associated with this low pressure system transported large amounts of water vapor from the Gulf of Mexico producing moisture convergence at 1000 mb over southern and western Texas (see Fig. 2a). Since there was strong positive vorticity advection (PVA), implying rising motion, over that area in the middle troposphere (see Fig. 1a) all this moisture was forced to rise and condense. Due to the combination of the cold advection upstream of the surface cyclone and the rising of warm moist air downstream of the surface cyclone, the amplification of the trough was strong. This amplification of the short wave is correlated with an increase in the upper level vorticity gradient and

therefore, with an increase of divergence aloft (Figure 4a) [WDVR C2-5 DASH CLR3/HGHT CI60 CLR3 250]. This divergence is in turn responsible for an 8 mb central pressure drop and a stronger low level convergence (Figure 5a) [WDVR C2-5 DASH CLR3/HGHT CI40 CLR3 1000] over the cyclone. The center values of pressure dropped 8 mb during the first six hours after 1200 UTC 12 March 1993 and 12 mb in the next six hours (see Figures 2a and 2b).

Figure 6 shows 300 mb heights every 100 m and isotachs contoured every 20 kt for 1200 UTC 12 March 1993 through 1200 UTC 13 March 1993 [WSPK CI20 DASH CLR3/HGHT C100 CLR3 300]. Figure 6a indicates the presence of several jet streaks one of which is located along 40°N east of 95°W at 1200 UTC 12 March 1993.

Figure 7a [MTHT 308 316 8 FIL1] and 7b show term B of Eq.(3.3) over the 308K [DOTP WIND,GRAD[PRES]] I308 CLR3] and 316K [DOTP WIND,GRAD[PRES]] I316 CLR3] isentropic surfaces for 1200 UTC 12 March 1993. These surfaces were selected because they did not intersect the ground near the focus area (i.e. the cyclone). Omega distributions can be inferred from these figures if the terms A and C of Eq.(3.3) are neglected.

From Figure 7a, two major areas with rising air can be detected over the 308K surface: one above the surface cyclone (see Figure 2) and another one over the Alabama-Tennessee border. Meanwhile, it is possible to detect an area with strong ascending motion over Louisiana at 316K.

Figures 8a and 8b show pressure, mixing ratio and total wind over the 308K [PRES CI50 CLR3/MIXR C1-3 DASH CLR6/WIND BARB I308 FIL1] and 316K [PRES CI50 CLR3/MIXR C1-3 DASH CLR6/WIND BARB I316] isentropic surfaces for 1200 UTC 12 March 1993. Since parcels conserve their mixing ratio when moving along an isentropic surface (except when there is condensation or evaporation), these figures depict the three dimensional moisture advection (i.e. the isentropic surfaces are usually sloped surfaces). From these figures, the strongest moisture advection can be seen just down stream of the surface cyclone and over western Florida along both surfaces.

Figure 9 shows the Qvectors and the Qvector divergence field [QVEC. this is not a command but a command file, therefore, you have to type a period after the name in order to run this macro. Be sure you have the right file as active. Since convergence of Qvectors implies horizontal convergence (Eq. (3.4)) in the column below, the cyclonic vorticity will tend to increase below a region of convergent Qvectors supporting the intensification of the cyclone (see final term in eq. 3.1). By 1200 UTC 12 March, there were three centers of convergence of Qvectors over the south-central United States. The strongest one was located over eastern Mexico, while the other two were over southern Texas and southeastern Colorado.

Figure 10 shows a vertical cross section along the line from A to B on Fig. 6a for 1200 UTC 12 March 1993. It

displays divergence of the wind in solid lines every 10^{-5} s^{-1} and ageostrophic circulations in barbs. To get this cross section you have to type the following commands:

XSCT 31 110 24 95 this initiates the cross-section
CROS changes the view mode to cross-section
DVRG WIND C2-5 CLR3 displays divergence of the total wind
every $2 \times 10^{-5} \text{ s}^{-1}$ in color white
ACRC BARB CLR3/ overlays the ageostrophic circulation in
color white
XLBL. displays pressure, latitude and
longitude lines on the cross-section

The rising branch of an ageostrophic circulation developed at 23°N 98°W consistent with a maximum of divergence in the upper levels associated with a short wave trough over northern Mexico (see Fig. 4a and 6a).

The low level moisture advection along with the mid-tropospheric cold advection contributed to develop areas with high potential for severe weather, as measured by the Sweat index. Commonly accepted threshold values with the Sweat index are 300 for severe thunderstorms and 400 for tornadic storms. By 1200 UTC 12 March 1993, the Sweat index reached values of 400 east-southeast of Texas and over 200 over west Florida (see Fig. 11a) [SWET.]. The radar depiction showed a "hook" echo, usually associated with the possibility of tornadoes, to the northwest of the surface cyclone center.

As the cold frontal system moved to the east, the cyclone and its associated moisture advection also moved eastward (see Figures 2b and 12) while the short wave trough at 500 mb became more organized. The positive vorticity center that was over Colorado at 1200 UTC 12 March moved to southern Oklahoma by 0000 UTC 13 March (Fig. 1a), while the positive center over eastern Oklahoma moved to southern Mississippi (Fig. 1b).

Figures 13a and 13b show the same fields as Figures 7a [DOTP WIND GRAD PRES DPOS I308] and 7b [DOTP WIND GRAD PRES DPOS I316] but, for 0000 UTC 13 March 1993. Be sure that this data file is active. Figures 14a and 14b are similar to Figures 8a [PRES CI50 CLR3/MIXR C1-3 DASH CLR3/WIND BARB CLR3 I308] and 8b [PRES CI50 CLR3/MIXR C1-3 DASH CLR3/WIND BARB CLR3 I316] but, for 0000 UTC 13 March 1993. At this time, the area of rising motion was involving all the states east of 90° W. The advection of moisture is particularly noticeable over western Florida at the 308K surface by this time (see Figure 14a). The cyclone and the area of strong moisture convergence at 1000 mb moved to southern Mississippi (Fig. 2b) by 0000 UTC 13 March 1993. The potential for severe weather was high over western Florida by this time, with Sweat indices above 300 and radar indicated echoes of Digital Vertically Integrated Precipitation (DVIP) levels 3 (heavy precipitation) to 4 (very heavy precipitation) with tops at 17,000 feet. (See radar depiction) This storm spread tornadoes over Florida on

the late afternoon of March 12 1993. The cyclone was still intensifying by this time as can be seen from the Qvectors field (see Fig. 9b). This figure is obtained by performing the following commands:

FIL2 to activate the file that has been opened in second place.

QVEC. to compute and display Qvectors and Qvector divergence.

The three centers of Qvector convergence that were over the south-central United States at 1200 UTC 12 March (see Fig.9a) coalesced and became more intense by 0000 UTC 13 March 1993 (see Fig. 9b).

The jet streak that was around 40 °N and 95 °W at 1200 UTC 12 March 1993 became less zonally oriented and was on a line from northeastern Texas to southern Maine by 0000 UTC 13 March 1993 (see Fig. 6b). Since the wind speed in a jet streak is greater than the speed with which the jet streak moves, areas where parcels decelerate (exit region of the jet streak) and where parcels accelerate (entrance region) can be identified. The atmosphere, in order to reestablish the geostrophic balance, develops ageostrophic circulations near the jet streaks. This circulation yields divergence (convergence) over the left (right) side of the exit region (see Fig. 15). The rising branch of the ageostrophic circulation (see Fig. 16a) at 28°N 89°W (right quadrant of the entrance region of this jet streak, i.e.see point B on

Figure 6b) supported the further development of the surface cyclone. Type the following commands to get figure 16a:

XSCT 43 97 27 88

CROS

ACRC BARB CLR3

XLBL.

Figure 16b shows a relative maximum of isentropic potential vorticity (IPV) close to and to the northwest of the center of the cyclone for the same cross section as Fig. 16a. The value of this maximum is close to the values that can be seen near the stratosphere with an associated tropopause fold extending below 500 mb at 35°N indicating that this air was descending from upper levels. The isentropic potential vorticity can be expressed as

$$P_{\theta} = -g(\zeta_{\theta} + f) \frac{\partial \theta}{\partial P} \quad (3.6)$$

As the air descends in the troposphere, the air parcel is stretched and the static stability $(-\partial \theta / \partial P)$ decreases. Consequently the absolute vorticity increases as long as the IPV values are conserved (no diabatic heating or friction). Therefore, from Fig. 16b, it can be inferred that the injection of stratospheric air in the middle troposphere

into the cyclone area in the middle troposphere was one of the major contributors to the strong development of this system.

The following commands will display Fig.16b on screen:

XSCT 43 97 27 88

CROS

SNEG SMLT WVRT LVL0 SDVD SDIF THTA LV+1 THTA LV-1 SDIF PRES

LV+1 PRES LV-1 C5-6   this command plots IPV every

$5 \times 10^{-6} \text{ K mb}^{-1} \text{ s}^{-1}$.

XLBL.

The cyclone was on the border between North and South Carolina and its central pressure was around 976 mb by 1200 UTC 13 March (see Fig. 2c). Heavy snow showers were falling west of the Appalachians and over the northeastern states as very cold air was over the area (see Fig. 3c) while rain showers were covering the area to the east of the Appalachians. The surface cyclone was still undergoing development as more positive vorticity was advected towards it in the middle troposphere (see Fig. 1c). By then, the areas with strong rising motion were restricted to the northeastern portion of the United States while the strength of the vertical velocity increased, compared with the previous figures (see Fig. 17, 7 and 13). Moisture levels increased rapidly over this area too. The short wave trough at 500 mb became well organized (see Figure 1c) and started

to become in phase with the system at the surface (see Figure 3c).

B.2 Case Study: 24 April 1993

This case study will use the thirteen key parameters for severe weather forecasts prepared by Maddox and Doswell III (1982: see Table 4). This table is a simplified version of the summary of parameters that Miller (1972) considered important in his severe storm forecasting manual.

Table 4: Summary of Key Parameters indicating likelihood of severe weather from Maddox and Doswell III (1982)

RANK	PARAMETER	WEAK (W)	MODERATE (M)	STRONG (S)
1	500mb vorticity advection	Neutral or NVA	PVA Contours cross vorticity pattern<30°	PVA Contours cross vorticity pattern>30°
2	Stability- Totals Index	TI≤50	55≤TI<50	TI>55
3	500 mb wind speed	WS≤35 kt	35<WS≤50 kt	WS>50 kt

Table 4 (cont.)

RANK	PARAMETER	WEAK (W)	MODERATE (M)	STRONG (S)
4	300-200 mb wind speed (upper level maximum)	WS $\leq$ 55 kt	55 < WS $\leq$ 85 kt	WS > 85 kt
5	850 mb wind speed	WS $\leq$ 20 kt	20 < WS $\leq$ 35 kt	WS > 35 kt
6	850 mb dewpoint	T _d $\leq$ 8°C	8 < T _d $\leq$ 12°C	T _d > 12°C
7	850 mb temperature ridge location	East of moist axis	Over moist axis	West of moist axis
8	700 mb 12-h temperature change lines	Winds cross lines $\leq$ 20°	Winds cross lines > 20° and $\leq$ 40°	Winds cross lines > 40°
9	700 mb dry intrusion	Not available or weak 700 mb winds	Winds from dry to moist intrude at angle of < 40° and are $\geq$ 15 kt	Winds intrude at an angle of > 40° and are $\geq$ 25 kt

Table 4 (cont.)

RANK	PARAMETER	WEAK (W)	MODERATE (M)	STRONG (S)
10	12-h surface pressure fall	<1 mb	1 to 5 mb	>5 mb
11	500 mb 12-h height change	<30 m	≥30m and ≤60m	>60 m
12	Surface pressure over threat area	≥1010 mb	<1010 mb and ≥1005 mb	<1005 mb
13	Surface dewpoint	Td≤55°F	55°F<Td<65°F	Td≥65°F

These key parameters, based upon the synoptic setting (especially in the spring), indicate likelihood of widespread outbreaks of severe thunderstorms and tornadoes. However, severe storms often occur within relatively weak large-scale settings.

B.2.1 Synoptic discussion

On April 24, 1993 a series of severe thunderstorms brought tornadoes to northeastern Oklahoma, central Michigan and South-western Minnesota. An F4 tornado (in Fujita's scale) hit Tulsa, Oklahoma at 5:50 CST killing seven people, injuring 100 people and producing property damage of 100 million dollars. An F3 tornado occurred over Catoosa, Oklahoma at 5:57 CST injuring thirty people and producing property damage of 10 million dollars (Information obtained from the National Severe Storms Forecast Center of Kansas).

By 0000 UTC 24 April 1993, the 500 mb chart showed two long wave troughs positioned at 70° W and 155° W. A series of short waves were present in between these two long wave troughs by then. There was one short wave trough over western Oklahoma that was associated with a stationary front over the area. To get Fig. 18 you have to type the following commands:

OPEN AP249300.RFS   Opens the output data file from the
NGM model for 0000 UTC 24 April 1993.

HGHT CI60 CLR3/WVRT C2-5 DASH CLR3 500 F00   Displays the
500 mb height contours (solid) and
absolute vorticity (dashed) in white.

By 1200 UTC this front turned into a weak cold front while a weak warm front was over northeastern Oklahoma as can be seen in the thickness field on Fig.19. Tulsa and Catoosa were located between these two fronts. By this time of the day, a dry line extended from 29° N 102° W to 35° N 98° W (see Fig. 20).

Figures 21 to 31 show the key parameters of Table 4 and Table 5 shows an evaluation of the strength of the parameters from Table 4 for 1200 UTC 24 April 1993 and 0000 UTC 25 April 1993. Figures 21 through 31 can be obtained by running the macro KEYP and restoring the graphics that shows the 13 parameters. The following commands produces these figures:

PLAN	restores the plan view.
OPEN AP239412.RFS	opens the data file for 1200 UTC 23 April 1993.
CCUS.	changes the display area to central U.S.
KEYP.	computes and saves the key parameters charts.
REST 0001	restores the chart for key parameter 1.
REST 0002	restores the chart for key parameter 2.
REST 03-4	restores the chart for key parameters

3 and 4.

REST 0005	restores the chart for key parameter 5.
REST 06-7	restores the chart for key parameter 6 and 7.
REST 0008	restores the chart for key parameter 8.
REST 0009	restores the chart for key parameter 9.
REST 0010	restores the chart for key parameter 10.
REST 0011	restores the chart for key parameter 11.
REST 0012	restores the chart for key parameter 12.
REST 0013	restores the chart for key parameter 13.
REST COMP	restores the composite chart (not shown) .

Table 5: Summary of Key parameters for 24/25 April 1993

PARAMETER	12 UTC	STRENGTH	00 UTC	STRENGTH
1	PVA (Fig.21)	W-M	PVA (Fig.47)	M-S
2	55 (Fig.22)	S	≥ 50 (Fig.48)	M
3	35 (Fig.23)	W	>50 kt (Fig.49)	S
4	55 (Fig.23)	W	>60 kt (Fig.49)	M-S
5	35-40 kt (Fig.24)	M	>20 kt (Fig.50)	M
6	$2-6^{\circ}\text{C}$ (Fig.25)	W	$8^{\circ}\text{C} < T_d < 12^{\circ}\text{C}$ (Fig.51)	M
7	West (Fig.25)	S	West (Fig.51)	S
8	Available (Fig.26)	S	$<20^{\circ}$ (Fig.52)	W
9	Available (Fig.27)	S	Available (Fig.53)	S

Table 5 (cont.)

PARAMETER	12 UTC	STRENGTH	00 UTC	STRENGTH
10	Available (Fig.28)	W	Available (Fig.54)	W-M
11	<30m (Fig.29)	W	<30 m (Fig.55)	W
12	<1005 mb (Fig.30)	S	<1005 mb (Fig.56)	S
13	62-65 °F (Fig.31)	M	55-58 °F (Fig.57)	M

From all these figures, it is possible to see that the potential for severe weather existed at 1200 UTC even though it was not clear by then whether or not it would actually occur since the synoptic indicators were not very strong.

Less than 50% of the key parameters were strong, while 30% of them were weak. The synoptic settings, according to the Table 4, were weak to moderate as can be seen from weak to moderate positive vorticity advection at 500 mb (see Fig.

21), no jets over the area (see Fig. 23) and weak pressure and 500 mb height falls (see Figures 28 and 29).

Most severe weather results from self-perpetuating convective systems, and a certain minimum value of vertical wind shear is necessary to sustain the relative low level inflow into these systems. Operational experience suggests that in most situations the greater the vertical shear the higher the potential for severe thunderstorms. Maddox and Doswell III (1982) pointed out that a large directional contribution to shear is almost always present in the northwesterly flow outbreaks occurring in central USA. In this specific case, even though the wind speeds at 850, 500 and 200 mb at 1200 UTC did not indicate severe potential, the wind shear was strong between the first and third sigma level (see Fig. 32) over western Oklahoma/northeastern Texas in this case by 1200 UTC [WIND BARB CLR3 S982/WIND BARB CLR2 S896 plots the wind at the first sigma level in white and at the third sigma level in red]

Figure 33 shows a cross section using output data from the ETA model approximately perpendicular to the fronts along the dotted line on Fig. 19). It displays the

equivalent potential temperature contoured every four degrees Kelvin, and omega in microbars per second. The commands you have to type to get this figure follows:

OPEN AP249312.ETX	Opens the data file from the ETA model for 1200 UTC 24 April 1993
F00	Sets time to initial time
XSCT 40 102 30 89	This initiates the cross-section
CROS	Changes the view mode to cross-section
THTE CIN4 CLR3	Displays equivalent potential temperature every 4 K in white
VVEL DASH CLR3/	Displays omega in dash white
XLBL.	Labels the axis

From this figure it can be inferred that there was potentially unstable air $\frac{\partial \theta_e}{\partial z} < 0$ and rising motion around 36 °N 96 °W up to 700 mb, i.e. this was happening in the region where tornadoes would later occur.

In order to detect which areas were more likely to liberate the potential of severe weather, the Qvector divergence, the Qvectors at 850 mb, 700 mb and 500 mb and

the Sweat indices at 1200 UTC 24 April 1993 are overlaid on Figure 34. To get figures 34a, 34b and 34c type the following commands after check that the active file is

AP249312.RFS:

SLVL level   Sets the level where level should be replaced by 850, 700 or 500 to get the three figures.

SWEQ.   Runs the macro that displays Sweat indices and Qvectors for level already set.

At 850 mb and at 500 mb, there was one major area of rising air over western Oklahoma, coincident with the cold front at the surface, and another area that seemed to have weaker rising motion over northeastern Oklahoma. The last area was superimposed on Sweat indices above 300. The threshold value used by the Air Force for the Sweat index is usually around 300 for severe thunderstorms, and 400 for tornadic storms. Since the Sweat index is only an indication of potential for severe weather, this figure shows that the quasi-geostrophic forcing might be the trigger mechanism for the outbreak of the severe storms.

All the analyses already presented have been carried out at 1200 UTC. This means that no contribution of convection has been included so far. Figure 35 shows the sequence of radar images from 1700 UTC through 1900 UTC 24 April 1993. By 1900 UTC stronger echoes were developing over northwestern Oklahoma.

Figures 36 to 46 show the thirteen key parameters for forecasting severe weather (after Miller, 1972) for the 12 hour forecast time, i.e., valid at 0000 UTC 25 April. To obtain these charts it is necessary to change the time before running the KEYP macro. Therefore, you have to enter the commands in the following order:

```
SFHR 12      selects the forecast hour 12
KEYP.        runs the macro KEYP
REST #####  restores the key parameter ##### (see
              explanation for figures 21 through 31).
```

The potential for severe weather by this time was greater since now 10 out of 13 parameters were moderate to strong. Figures 47 to 57 show the key parameters for 0000 UTC 25 April 1993 (approximately the time when the tornadoes occurred). The commands to obtain these figures follow:

```
OPEN AP259300.RFS
```


SFHR 00

SWEQ.

REST ####

At this time 11 of the 13 parameters were between moderate and strong (see Table 5).

Figures 58 and 59 are similar to Fig. 34 but forecast at 0000 UTC 25 April 1993 and analysis for 0000 UTC 25 April 1993. Use the commands used for figure 34 after change time (SFHR) and/or file (FIL#). From the comparison of these two figures it can be seen that the Sweat indices were overestimated by the forecast, although the area of maximum values was approximately well positioned. Meanwhile, the vertical motion was well estimated at the lower levels but was overestimated at 500 mb.

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