Tropical Storms

TROPICAL CYCLONE AND RELATED METEOROLOGICAL DATA SETS AVAILABLE AT CSU AND THEIR UTILIZATION

BY

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OTHER PROJECT PERSONNEL

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ABSTRACT

This report has been prepared to familiarize the international meteorological community with the comprehensive collection of tropical cyclone and other meteorological data which are available on our research project. We provide a rationale for the research philosophy behind the assembling of these data sets over the last decade, describe the data and indicate how other researchers may use them for their own research purposes. In particular, we summarize the rawindsonde compositing philosophy and the other research techniques employed on our project. We describe our data processing procedures, the various formulations we have used for different research purposes, the coordinate systems employed and the data availability by region. Our research accomplishments, types of compositing runs, and a list of publications are also presented.

These data sets and their software support represent a considerable manpower and financial investment. An investment that is now able (we believe) to provide a high return in the form of new knowledge on tropical cyclones and other weather systems. We are currently exploring a number of exciting avenues. The possibilities are quite broad and we encourage other research workers to help exploit this resource.

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1. NEED FOR MORE OBSERVATIONAL ANALYSIS OF TROPICAL CYCLONES

Tropical cyclones have been a subject of meteorological concern for many centuries. Yet, because of the severe data limitations which exist over the tropical oceans, the broad-scale structure and physical processes of these storms are only now being documented. This report lists the observational information on tropical cyclones that has been compiled at Colorado State University for the purpose of documenting the various aspects of the tropical cyclone and its environmental flow patterns. This report discusses the research potential available from the expanded data handling capacities of modern computers that are able to process vast amounts of rawinsonde data from many storms at many time periods. This enables us to document and analyze the persistent features of tropical cyclones and increases our knowledge of the basic structure of these storms together with their large structural and behavioral variability. Despite recent knowledge gains, there is still much more that needs to be learned about the physical processes of the tropical cyclone. It is now possible to obtain new observational facts which can increase our understanding of these storm systems. Progress requires that one piece together observational information and physical inferences derived from a variety of different storm behavior characteristics.

Justification. Growing population densities along tropical coastlines are increasing the damage potential of tropical cyclones. At the same time the general population explosion in tropical countries has made the economic impact to agriculture of tropical cyclone rainfall crucial. Agricultural activity in India, China and the southeast US and other locations is influenced by the seasonal variability of tropical cyclones. Maritime interests are often affected by these cyclones. It is important that man gains more knowledge about tropical cyclones so that he is better able to understand and predict their behavioral characteristics. From a global modelling and forecasting point-of-view it is necessary that the broad-scale influences of tropical cyclones be properly incorporated into these models.

The main reason for our ignorance of these storms is that they are grossly undermeasured. Since tropical storms occur where rawinsonde station density is thin, it is quite difficult to quantitatively sample an individual tropical storm at an individual time period. Typically, there are only 1-5 rawinsonde reports (or less) within 10 degrees of the center of a tropical storm at a particular time. Quantitative analysis requires that one resort to some form of rawinsonde compositing procedure.

There has been a large expenditure of resources over the last 20-30 years to establish a network of rawinsonde stations throughout the tropics. The data collected have been almost exclusively utilized for real time tropical analyses, they then sit in US and foreign archives and are only rarely utilized for tropical weather research. When one considers the large costs of collecting the rawinsonde data over and around the tropical ocean basins in the last 20-30 years (probably between 100-200 million dollars) one questions the cost effectiveness of not utilizing these data sources for research on tropical weather systems. Studies utilizing already collected and stored rawinsonde data are much less expensive than the original cost of taking such observations or devising new programs for additional data collection such as GATE, BOMEX, LIE, etc.

<u>Computer Technology Advances and Increased Research Potential</u>. We have been fortunate in the last 10-15 years with the advances made by the semi-conductor electronics industry. This has led to the advent of new and innovative methods to store and retrieve meteorological data on magnetic tape and disks. Without this technology development the research methodology here discussed could not be undertaken. One must realize that the development of this computer technology may prove as beneficial or even more beneficial for meteorological research than the already accepted and established use of the numerical computer for primitive equation and other numerical modelling. We are optimistic about what may be accomplished in observational research advancement and forecasting improvement through the use of this growing computer technology.

It is quite important that studies be made with these already collected and stored rawinsonde data sets, especially when one considers the gradual but steady deterioration of the number of tropical rawinsonde stations which is occurring due to the general belief that the new weather satellites can supply most of the needed oceanic observations at lower cost. Unfortunately, satellite measurements at this time are not able to provide the necessary information needed for in-depth quantitative understanding of tropical weather systems.

There is no question that the weather satellite has had a profound influence on tropical cyclone forecasting and research. The satellite has taught us:

1) how different the cloud patterns of the hurricane and weaker tropical systems can be from one storm system to another,

2) how storm cloud amounts are not well related to storm intensity

3) how cyclone centers can form in regions away from the primary deep convection area, and

4) how large the diurnal range of hurricanes and weaker cyclone system cloudiness can be.

Despite its unique usefulness as a locator and tracker of hurricanes, the satellite observational information has to this date been level restricted. This makes it very difficult or impossible to perform the types of quantitative analysis of the mass, energy, momentum fields, etc. which are necessary for a basic physical understanding of these systems. It is hoped that this level restriction on the satellite information may be gradually reduced as the new satellite vertical sounder systems become more useful in coming years and as we learn more about the hurricane (from rawinsonde compositing) so that we can better interpret these new satellite sounder systems.

Our CSU tropical meteorology research group has been advocating the utilization of rawinsonde composite studies of hurricanes and weaker tropical systems for over a decade. We believe that a great deal has already been learned about the hurricane and weaker tropical cloud clusters from our rawinsonde composite studies. A summary of a good portion of our composite studies to date is contained in a recently issued World Meteorological Organization (WMO) report titled 'Recent Advances in Tropical Cyclone Research from Rawinsonde Composite Analysis', 407 pp. Yet, only a fraction of the potential of this methodological approach has so far been exploited. As we expand our data sets and make more studies we are confident that much new quantitative information on the tropical cyclone can be obtained which will be of both theoretical and operational value.

Besides the desired understanding of the physical processes of tropical storms, there is also the larger and probably more important practical needs of the tropical cyclone forecaster. It is important to distinguish from weather maps which physical parameters best differentiate between developing and non-developing tropical disturbances, which parameters are associated with weather system intensity change, and which factors are most related to the alteration of cyclone motion, etc. Although ambiguity may persist about the scientific interpretation of the relevant physical processes of the tropical cyclone it is important that a general consensus be reached on the surrounding empirical parameter differences which cause cyclone behavioral differences.

When firmer relationships are established between tropical cyclone behavior and surrounding environment conditions through the types of rawinsonde composite analyses being advocated, then justification can likely be made for special aircraft flights, dropsondes, special satellite measurements, etc. to supply the necessary individual case information so that better individual storm forecasts can be made. This is the ultimate purpose of our research philosophy.

2. RAWINSONDE COMPOSITING PHILOSOPHY AND METHODOLOGY

2.1 Overview

The best method of analyzing an atmospheric phenomenon from observations is to perform detailed, quantitative case studies of a large sample of similar systems and then statistically compare the cases. This provides information on both the mean characteristics and the variability of individual systems. However, in practice there are a number of problems to this approach for the study of tropical storms and other oceanic phenomena , the most serious of which is the inevitable scarcity of data available for individual case situations. An ideal case study requires quality data in four dimensions with an appropriate spatial density as well as adequate time resolution. The resolution that is required depends upon the nature of the phenomena to be studied. Ideally, for tropical cyclones and other tropical weather systems of meso to synoptic scale, one would want sufficient data to resolve significant organized convective elements. This would require sampling resolutions on the order of 1-10 km spacing and a few minutes in time. Since the relevant domains extend to thousands of kilometers, merely handling such data would be impractical even if they were available (and, of course, they are not).

One method of improving spatial data resolution is the compositing of data from weather systems showing similar behavioral characteristics. The hypothesis is that by combining data from many systems one can:

a) Improve the effective spatial resolution of the data,

b) Focus on the features common to all systems while averaging out unimportant idiosyncrasies, and

c) Average out sampling noise resulting from measurement errors and subgrid scale influences.

But there are difficulties with compositing as well:

1) variable features of individual systems are lost,

2) time resolution is seriously degraded, and

3) each system exists in a somewhat different mean state from the others. This introduces the possibility of surrounding region biases.

The objectives of compositing are to maximize benefits a-c while minimizing difficulties 1-3.

Even though rawinsonde compositing will not answer all relevant questions in individual storm cases it will, if used properly, greatly improve our general and basic knowledge of weather systems. Compositing is particularly valuable at showing physical differences between systems with different behavioral characteristics. For instance, one can determine quantitative parameter differences between intensifying and weakening storm systems, between right turning vs. straight moving storms, etc., by subtracting the composite data for one type of system from the composite data for the other type of system. In these cases all systematic data biases will likely be in both systems and will be eliminated through the subtraction process. What remains are the true physical differences between systems.

We really have no other choice at this juncture of tropical meteorological development than to try to fully exploit the information available with this compositing methodology. Alternate suggestions for quantitative research advancement will be appreciated!

Rawinsonde compositing has been performed on our CSU research project with both cylindrical and rectangular grids, which extend horizontally to 1500-2000 km for the cylindrical grid and 10000 km for the rectangular grid and vertically from sea level to 50 mb, about hundreds of tropical cloud clusters and tropical storm systems in three different ocean basins. The weather system circulation center for the lowest level is located at each time period and positioned at the grid center. Whenever a rawinsonde report at a given period for a given storm is available within the confines of the grid being used the sounding is positioned relative to the storm center and then averaged with other soundings which fall within the same grid space. Since the relative position of the storm center and the balloon change due to their respective motions during the balloon's ascent, the position of each is recalculated at every pressure level.

2.2 Cylindrical Grid

The basic compositing grid used for studying the tropical cyclone is a 15^{o} latitude radius cylindrical grid extending from sea level to 50 mb. The cylindrical grid consists of eight octants of 45^{o} azimuthal extent and eight radial bands extending from 0-1^{o}, 1-3^{o}, 3-5^{o}, 5-7^{o}, 7-9^{o}, 9-11^{o}, 11-13^{o}, 13-15^{o} as shown in Fig. 2.1. Octant 1 points to the north or to the direction that the storm is moving. The specific pressure levels being composited vary with the data region and are delineated in Chapter 3. For finer detail, wind and budget parameters are also averaged for 2-4^{o} and 4-6^{o}, and thermodynamic parameters for 1^{o} increments from 0-7^{o} to give the radial belts described in the output displays discussed in Chapter 5.

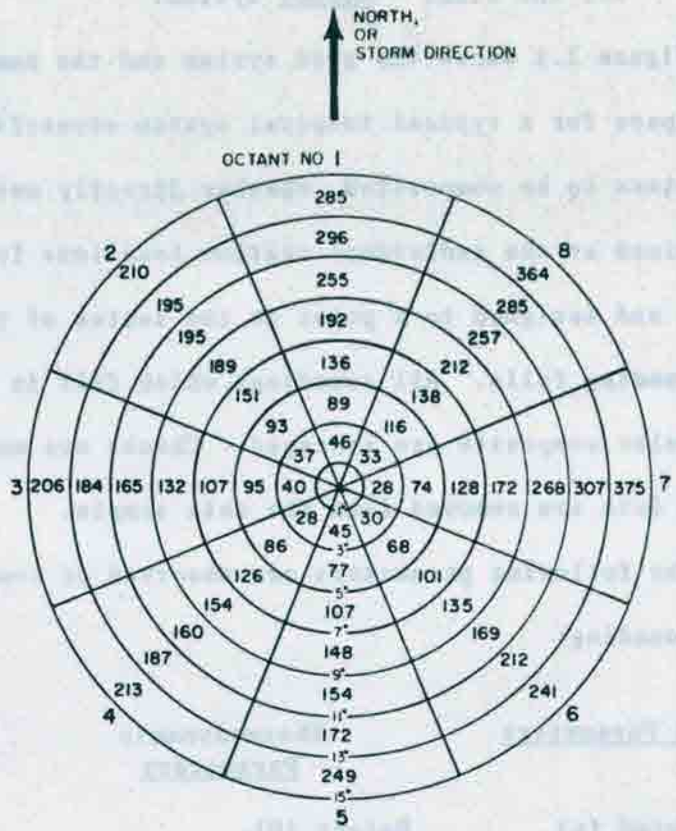

Fig. 2.1. Compositing grid (15° latitude radius) with the number of rawinsonde reports in each octant and each 2° radial band for a typical stratification. Azimuthal octant numbers are outside the circle, 3 to the left, 7 to the right, etc. Arrow points north in NAT and MOT coordinate systems and in the direction of the storm in the ROT and MOTROT systems.

Four coordinate systems are in use. Each offers a different viewing perspective of the storm system. The systems are:

1) With respect to the (instantaneously fixed) cyclone center given by the best track position in a N-S or geographical coordinate system with Octant 1 pointing due North - Natural or <u>NAT</u> system.

2) With respect to the cyclone center in a geographical coordinate system with cyclone motion subtracted out of all the winds (portrayal of data relative to the moving cyclone center in geographical coordinates) - Motion or <u>MOT</u> system.

3) With respect to the (instantaneously fixed) cyclone center with Octant 1 oriented in the direction to which the storm is moving - rotated or <u>ROT</u> system.

4) With respect to the cyclone center and the direction to which the storm is moving with the cyclone motion subtracted out of all the winds - MOTROT system.

Figure 2.1 shows the grid system and the number of soundings per grid space for a typical tropical system stratification. All the parameters to be composited, whether directly measured or computed are determined at the individual station locations for 16 to 21 pressure levels and assigned to a point at the center of the grid box in which the sounding falls. All soundings which fall in that grid space for the particular composite are averaged. Checks are made so that obviously biased data are removed from the data sample.

The following parameters are observed or computed at each level for each sounding:

Wind Parameters	Thermodynamic Parameters	Thermodynamic Parameters (cont'd)
Zonal wind (u)	Height (H)	Relative humidity (RH)
Meridional wind (v)	Temperature (T)	Specific humidity (q)
Radial wind (V_r)	Virtual temperature (T_v)	Dry static energy (s)
Tangential wind (V_θ)	Potential temperature (θ)	Moist static energy (h)
Total wind speed (V)	Saturated moist static energy (h*)	Equivalent potential temperature (θ_E)

The above parameters are composited at each grid space at each level. The composite wind values are then used to compute the derived quantities of divergence, vorticity and other wind related parameters for each grid space. Similar derived quantities are computed from the basic thermodynamic variables.

Budget Calculations. The best technique for estimating the values of horizontal transports of various parameters for use in budget studies is to compute the radial flux of that quantity for each sounding at each level. The radial winds (V_r) are initially composited and mass balanced from the surface to 100 mb by adding a small constant correction factor (ΔV_r) to each individual radial wind in a given radial band. The mass balance correction is applied to the computed V_r for each observation and the product of the corrected V_r and the quantity (e.g., Q) being analyzed is computed at each level. These products are then composited as before, giving a mean transport value for each octant at each level, $\overline{V_r Q}$, where the bar denotes time and space averaging of the $V_r Q$ products. By subtracting the product of the mean $\overline{V_r}$ and the mean $\overline{Q}$ one can achieve a good estimate of horizontal eddy transport, thus

$$\overline{V'_r Q'} \approx \overline{V_r Q} - \overline{V}_r \overline{Q} \tag{2.1}$$

The types of radial fluxes so far computed are:

$V_r h$ (moist static energy)

$V_r s$ (dry static energy)

$V_r q$ (specific humidity)

$V_r V_\theta r$ (relative angular momentum)

$V_r (fr^2/2)$ (earth momentum)

$V_r V^2$ (kinetic energy)

Vertical Resolution. Vertical motion and budget analyses require sufficient vertical resolution to permit accurate integration of kinematic divergences. Based on experience with numerous composites of tropical convective systems it is desirable to have 25-50 mb vertical resolutions from the surface to 900 mb, 50 mb resolution between 300-100 mb and 100 mb resolution at intermediate levels. Some data above 100 mb should also be included. When this vertical resolution is accomplished with reasonable data density, then the tropospheric vertically integrated divergence closely approximates zero and the vertically integrated mass balance corrections are quite small.

Horizontal Resolution. This should be fine enough to allow computation of gradients (r,θ) on the scales of interest but the grid spaces must be large enough to encompass sufficient observations for meaningful averages. For cylindrical composites eight azimuthal octants and 100-200 km radial resolution has proven satisfactory.

Minimum Sample Size. The number of required soundings depends upon the nature of the analysis. Mean large scale wind patterns can be estimated from a relatively small number of soundings since the signal to noise ratio is high. Analysis of thermodynamic fields requires much more data since gradients often are smaller than intersounding errors and true convective (subgrid) scale variability. However, the most critical parameter in the composite cyclone is the radial wind (V_r). In general, the closer the observed vertical profiles of mean radial wind come to achieving mass balance (defined as zero mass flux between the surface and 100 mb), the better the data may be considered. Thus, we use the smallness of these mass balance corrections as a major indicator of the validity of the sample size. These corrections are typically very small (0.1-0.3 m/s), indicating that the instrumental errors and subgrid scale fluctuations are evenly distributed about the mean and cancel out in a reasonably large sample.

Additional Features. One important feature of the cylindrical grid is the ability to eliminate the pressure gradient acceleration at individual radii when one integrates the momentum equation completely around the circle. This is a great aid in isolation of specific wind acceleration influences which is not possible using a rectangular coordinate system.

As discussed earlier rawinsonde composite analysis is an especially powerful tool for distinguishing physical differences between two data sets such as those shown in Fig. 2.2. It is also possible to composite different periods of the life cycle of storms to study the systematic time changes which occur. The potential number of rawinsonde subsets is limited only by the minimum number of data points needed to provide meaningful composites.

Stratifications. Due to the extremely large quantity of rawinsonde data we have assembled, it is possible to form a variety of composites which are stratified according to system behavior characteristics. By compositing storms with different characteristics, it is possible to systematically examine the subtle quantitative structural and dynamic differences which are associated with each behavioral system class.

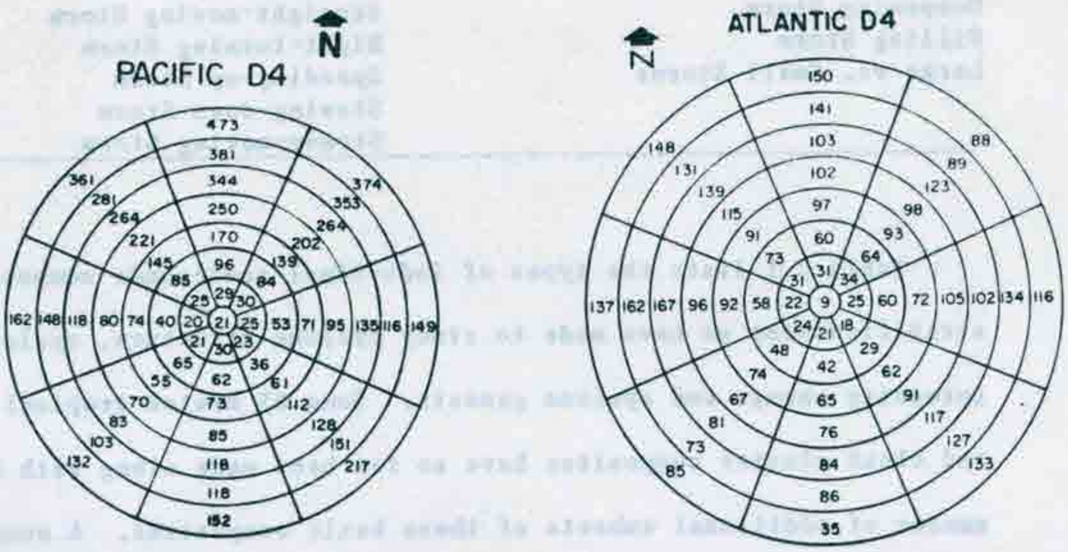

Fig. 2.2. Typical illustration of one of our west Pacific typhoon data sets (left diagram - figures represent number of rawinsonde reports per 2° radial interval per azimuthal octant). The data on the left can be compared with a similar Atlantic hurricane data set (right diagram).

Some of the stratification criteria which have been employed thus far are:

Size	Character of Satellite Picture
Central Sea Level Pressure	Longitude
Maximum Winds	Latitude
Intensity Change	Time of Day
Movement Characteristics	Season

An example of the types of cyclone stratifications for tropical cyclone motion studies which we have already studied are:

For Northwest Pacific Tropical Cyclones	For West Atlantic Tropical Cyclones
LAT. > 20^o	Hurricane (V_{max} > 33 m/s)
LAT. < 20^o	Tropical storm (V_{max} 17-33 m/s)
Slow (< 3 m/s)	Deepening storm (V_{max} < 17 m/s)
Moderate (3-7 m/s)	Intensifying storm (V_{max} > 17 m/s)
Fast (> 7 m/s)	Region I storm (South and East)
Westerly Direction (250-310^o)	Region II storm (North and West)
Northwesterly Direction (310-350^o)	Slow (< 4 m/s)
Northeasterly Direction (350-060^o)	Fast (> 4 m/s)
Intensity 1 (980-1000 mb)	Northward Direction (316-045^o)
Intensity 2 (950-980 mb)	Westward Direction (225-315^o)
Intensity 3 (< 950 mb)	Left-turning Storm
Deepening Storm	Straight-moving Storm
Filling Storm	Right-turning Storm
Large vs. Small Storms	Speeding-up Storm
	Slowing-down Storm
	Steady-moving Storm

Table 2.1 lists the types of individual rawinsonde composite stratifications we have made to study cyclone structure, cyclone intensity change and cyclone genesis. Some 25 master tropical cyclone and cloud cluster composites have so far been made along with a large number of additional subsets of these basic composites. A complete listing (as of 1981) is given in Chapter 8.

Data Coverage. These composites make use of many years of rawinsonde data to provide high density coverage around all cyclones occurring in a particular region. Many thousands of soundings from hundreds of rawinsonde stations located in the west Atlantic,

TABLE 2.1

An example of various rawinsonde composite stratifications related to tropical cyclone structure, intensity change and genesis.

Basic Data Sets For Cyclone Structure	For Tropical Cyclone Intensity Change Studies	For Tropical Cyclone Genesis Studies
Pacific Non-developing		
N1 Cloud Cluster	PN1 Cloud Cluster PN3(F) Type B	Zehr (Stage 00) All Type B
Pacific Developing		
D1 Early pre-typhoon cloud cluster	PD1a Early pre-typhoon cloud cluster	Erickson Developing
D2 Pre-typhoon cloud cluster	PD1a Early pre-typhoon cloud cluster	Zehr (Stage2)
D3 Intensifying cyclone	PD3 Intensifying cyclone	Zehr (Stage 4)
D4 Typhoon	PD4 Typhoon PD5 Supertyphoon PD4(D) WP Deepening PD4(F) WP Filling PD3(D) WP Type A	Pacific $P_c \leq 980$ mb Pacific $P_c \leq 950$ mb All Type A Early
	RD-24 Rapidly Deepening -24 RD-0 Rapidly Deepening -0 RD+24 Rapidly Deepening +24	
Atlantic Non-developing		
N1 Cloud Cluster	AN1a Cloud Cluster	Dvorak Systems
N2 Wave Trough cluster	AN1b Wave Trough cluster	Neil Frank II Systems
N3 Non-developing Depression	AN2 Non-developing Depression	Non-developing Depression
Atlantic Developing		
D1 Prehurricane Cloud Cluster	AD1 Prehurricane Cloud Cluster	Early Developing
D2 Prehurricane Depression	AD2 Prehurricane Depression	Developing Depression (steady complete)
D3 Intensifying Cyclone	AD3 Intensifying Cyclone	Intensifying Complete
D4 Hurricane	AD4 Hurricane AD4(D) WI Deepening	Intensifying complete

northwestern Pacific and the south Pacific-Australian region have been utilized (as discussed in Chapter 3). We also intend to build a tropical cyclone rawinsonde data deck in the North Indian Ocean.

Table 2.2 lists the typical number of rawinsonde reports which are available by 2° radial intervals for some of our basic stratifications. Large numbers of rawinsonde data are available within 15° radius of the typhoon (7756 soundings) and the hurricane (4721 soundings) composites and in all southwest Pacific wind composites. We expect a significant improvement in observation density in the near future when our current rawinsonde data network expansion is completed and as we gradually update our data sets year by year.

Sampling Biases and Stratifications. Despite its unique potential there are a number of biases which may creep into a rawinsonde composite analysis and the researcher has to be wary. Some of these biases can be avoided by special data handling. But in certain data-sparse situations it often is necessary to accept a certain amount of bias in the data in order to obtain a data sample of sufficient size. Among the problems:

1) If the systems are not properly stratified into groups, one ends up mixing dissimilar systems or at best similar systems with different larger scale circulations. Whenever possible systems should be grouped by similar location, time of year, intensity, intensity tendency and direction of movement, etc.

2) Data networks tend to be asymmetrical, particularly where large data-void areas exist. If variations in the larger scale mean circulation are not corrected for these data asymmetries, then the analyzed fields can be distorted.

3) If only a few widely spaced stations are used, it is possible to get into a situation where, for example, all of the data to the west of a system come from different stations than the data to the east. If the mean flow at the stations differs significantly, the composite can create a circulation even if none exists.

By careful handling of these rawinsonde data sources most of the

TABLE 2.2

Number of rawinsonde observations included within various radial belts from the center of each composited tropical cyclone stratification.

	Radius (° Latitude)							
	1-3	3-5	5-7	7-9	9-11	11-13	13-15	Total <15
West Pacific								
N1 Cloud Cluster	143	224	282	315	341	336	320	1961
D1 Early pre-typhoon cloud cluster	22	45	72	60	66	63	56	384
D2 Pretyphoon cloud cluster	151	281	352	388	369	428	420	2389
D3 Intensifying cyclone(10 yrs)	135	272	357	389	451	525	531	2660
D4 Typhoon (10 yrs)	203	521	1121	787	1454	1651	2019	7756
West Atlantic								
N1 Cloud cluster	170	393	548	525	503	541	475	3155
N2 Wave trough cluster	197	364	477	468	394	420	440	2760
N3 Non-developing depression	46	75	137	174	158	170	138	898
D1 Prehurricane cloud cluster	49	84	94	119	126	123	119	714
D2 Prehurricane depression	113	179	267	365	392	451	401	2168
D3 Intensifying cyclone(14 yrs)	111	227	299	409	431	488	482	2447
D4 Hurricane (14 yrs)	206	434	646	741	889	942	863	4721
South Pacific-Australia Region (Approximate Number of Wind Soundings Contained in Each Radial Belt)								
D1 Prehurricane cloud cluster	250	1000	1500	2100	2600	3100	4000	14565
D2 Prehurricane depression	300	1150	1700	2300	2900	3400	4400	16170
D3 Intensifying cyclone(21 yrs)	300	1150	1700	2300	2900	3400	4400	16170
D4 Hurricane	300	1150	1700	2300	2900	3400	4400	16170

major bias influences can be corrected. We have recently developed special 'bias correction' techniques which in most cases account for the largest part of these inherent compositing deficiencies.

2.3 Basic Cylindrical Compositing Programs

There are four basic programs involved with our cylindrical composites. They are related to: 1) wind data, 2) temperature and moisture data, 3) budget (mass, moisture, momentum, energy, etc.) calculations and 4) storm motion relationships. Typically, the wind and thermal programs are run for a stratification to give the complete storm structure for an initial structure analysis. The special budget and/or motion programs are then run for a more in-depth analysis of the basic physical processes occurring within the cyclone. All results from the composite runs are stored on magnetic tape or disk for current or later use. Each composite has a standard output, a plan view output, and a cross-section output. Chapter 5 gives a listing of the parameters that are calculated in each of these programs together with a description of these various output formats.

2.4 Rectangular Compositing Grid

We have recently started using a rectangular compositing grid similar to the one originally used by Williams and Gray (1973) for compositing rawinsonde data around tropical cloud clusters. Data falling within each rectangular grid box is averaged. Parameters similar to those composited on the cylindrical grid have been composited for combined northern and southern hemisphere regions in the western Pacific and for various other synoptic and planetary-scale composites surrounding tropical weather systems within the ITCZ. Figure 2.3 shows a basic grid and Fig. 2.4 shows a typical distribution of rawinsonde

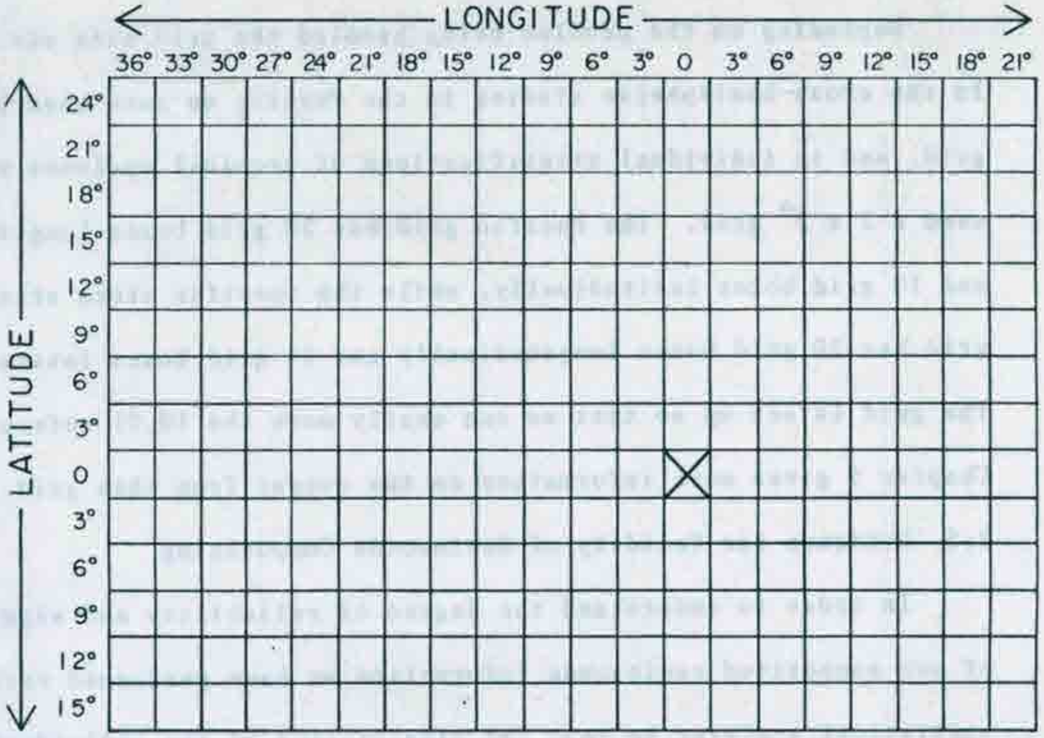

Fig. 2.3. Example of the typical rectangular grid which is employed about a reference grid box (X).

NO CASES

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	29	34	34	45	40	39	32	36	38	29	26	18	17	8	8	6	2	3	0	0
21	43	47	44	44	55	49	47	30	28	26	20	22	18	13	5	3	1	1	2	1
18	52	52	57	53	43	39	43	38	29	19	14	13	3	6	6	5	3	4	1	0
15	54	55	53	46	38	41	37	30	28	19	15	9	9	5	4	2	2	1	0	0
12	29	40	43	43	36	30	22	26	14	16	11	8	4	1	1	0	0	0	0	0
9	36	31	27	33	28	30	24	20	16	16	15	6	7	5	1	0	0	0	0	0
6	21	27	36	30	33	28	27	20	16	13	16	18	12	8	5	4	0	0	0	0
3	15	15	17	17	30	26	35	30	22	24	17	18	12	9	9	7	5	4	2	0
0	10	12	15	15	16	17	17	13	15	14	14	10	[12] A	13	9	9	2	3	1	0
3	8	9	7	6	11	10	17	12	15	15	10	10	3	2	3	3	4	3	0	1
6	4	7	7	9	7	6	5	8	4	5	5	8	4	7	4	4	0	2	2	1
9	3	3	3	4	7	10	5	2	3	3	2	2	2	1	0	0	0	0	0	0
12	0	2	1	2	2	1	2	4	1	1	1	0	0	0	1	0	0	0	0	0
15	1	2	1	1	0	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0

Fig. 2.4. Example of the typical rawinsonde case counts within a composite rectangular grid (as in Fig. 2.3) where the area of major interest is to the northwest of the central reference grid point (A).

data within each grid box.

Depending on the problem being handled the grid size can be varied. In the cross-hemispheric studies in the Pacific we have used a 5 x 5^{o} grid, and in individual stratifications of tropical cyclones we have used a 3 x 3^{o} grid. The Pacific grid has 20 grid boxes longitudinally and 10 grid boxes latitudinally, while the specific storm stratification grid has 20 grid boxes longitudinally and 14 grid boxes latitudinally. The grid is set up so that we can easily move the (0,0) reference box. Chapter 5 gives more information on the output from this grid.

2.5 Evidence for Validity of Rawinsonde Compositing

In order to understand the degree of reliability and significance of our composited rawinsonde information we have performed various statistical analyses to test the significance of the individual parameter differences between different composited data sets. A discussion of the statistical tests made so far has been reported on by Gray (1981) in a recent report issued by the World Meteorological Organization titled 'Recent Advances in Tropical Cyclone Research from Rawinsonde Composite Analysis' pp. 43-58. These statistical tests have been made with the assistance of Professors Paul W. Mielke and Kenneth J. Berry of the CSU Statistics Department. The recent published papers by Mielke et al. (1976, 1981) describe the Multi-Response Permutation Procedures (or MRPP) which have been developed by these statisticians and which are being applied to the testing of our rawinsonde composites.

The more we work with our rawinsonde data sets the more confident we become of the authenticity of the composite averages for distinguishing parameter differences between storm systems of different behavioral characteristics. Repeatability of results from independent data sets consistently occurs in parameters which are required or expected to be similar. For instance, the integrated tropospheric mass divergence is almost zero when the data sample is sufficiently large. Nonrepresentative data and sounding errors average themselves out in the large data sample and are believed to be random. Levels of inflow and outflow are quite consistent. Momentum, energy, and water budgets can be consistently and reasonably made.

As an example of some of the expected data composite consistencies we have compared independent data sets which are expected to yield similar results. For example, 14 years of hurricane composited 'even-day' vs. 'odd-day' parameters should indicate very similar values. Figures 2.5 to 2.10 show that cross sections of tangential and radial wind components and temperature are almost identical. Similarly, a comparison of the 'even-day' vs. 'odd-day' plan view 150 mb outflow patterns of radial and tangential wind are almost identical as shown in Figs. 2.11 to 2.14. Plan views of other parameters at other levels indicate similar features.

Such similarity of even-day vs. odd-day hurricane results from independent data sets should lend confidence to the rawinsonde compositing philosophy which has been espoused by our research group for the last decade. Many other tests and consistency cross-checks testify to the basic accuracy of these rawinsonde data sets.

References

Gray, W. M., 1981: Recent advances in tropical cyclone research from rawinsonde composite analysis. WMO Programme on Research in Tropical Meteorology Report, WMO, Geneva, Switzerland, 407 pp.

Mielke, P. W., K. J. Berry and E. S. Johnson, 1976: Multi-response permutation procedures for a priori classification. Commun. Statist.-Theor. Meth., A5, 1409-1424.

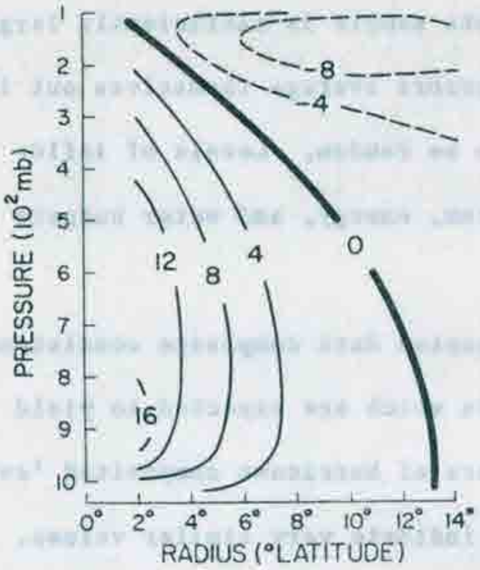

Fig. 2.5. Cross-section of rawinsonde composite of 1961-1974 hurricane (<30°N) tangential winds (in m/s) on even days.

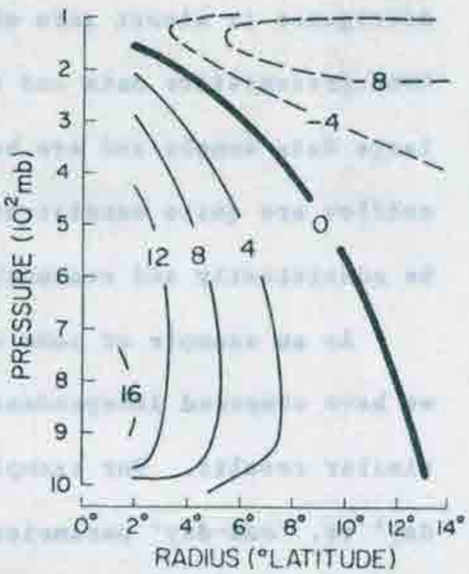

Fig. 2.6. Same as Fig. 2.5 but for odd days.

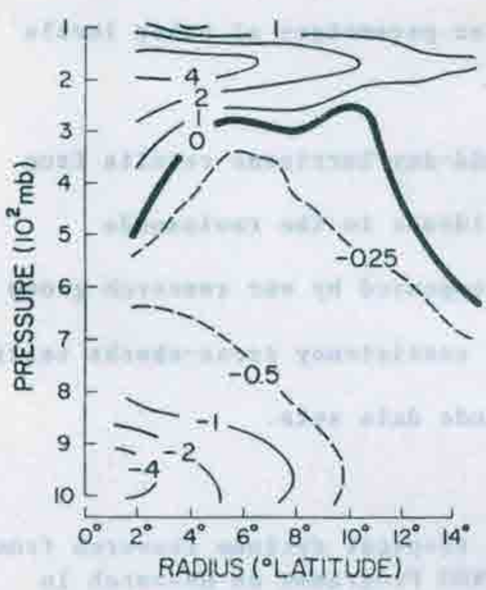

Fig. 2.7. Cross-section of rawinsonde composite of all 1961-1974 hurricane (< 30°N) radial winds (in m/s) on even days.

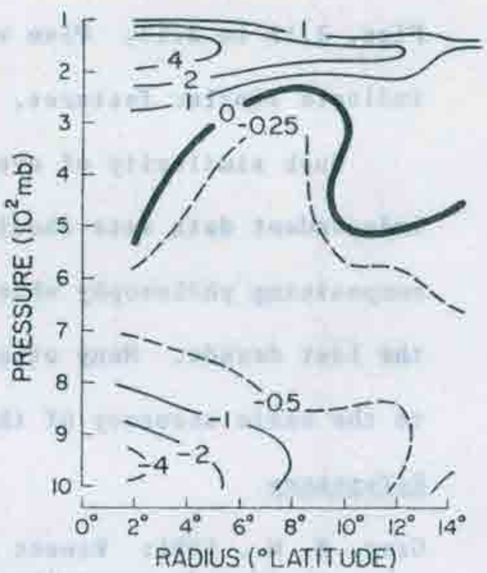

Fig. 2.8. Same as Fig. 2.7 but for odd days.

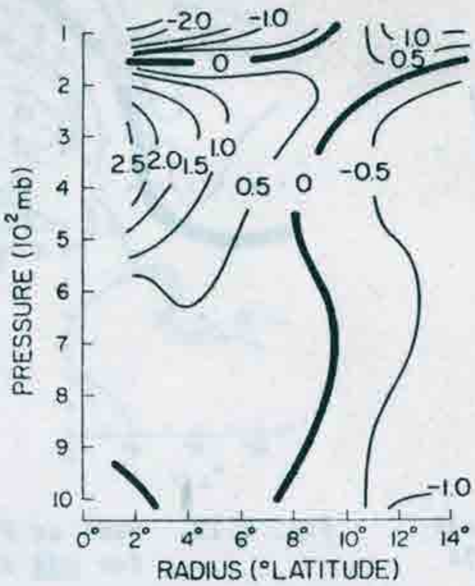

Fig. 2.9. Cross-section of rawinsonde composite of 1961-1974 hurricane (<30^{o}N Lat.) of temperature deviation (in ^{o}C) on <u>even</u> days.

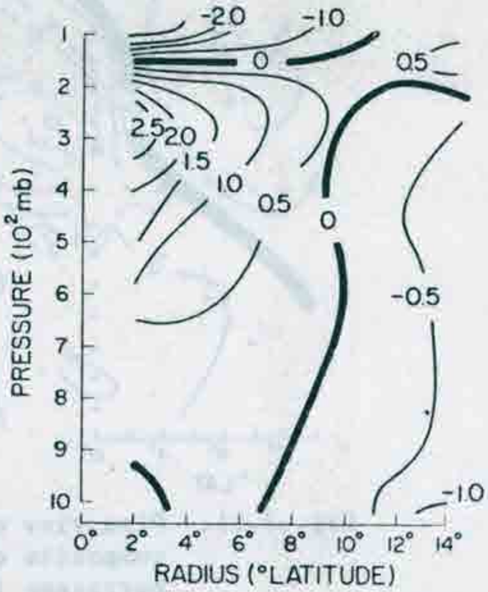

Fig. 2.10. Same as for Fig. 2.9 but for <u>odd</u> days.

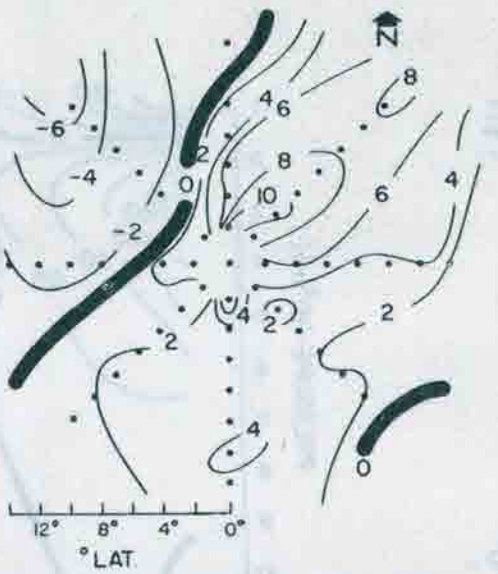

Fig. 2.11. Plan view of rawinsonde composite of 1961-1974 hurricane (<30°Lat.) 150 mb level radial wind (in m/s) on <u>even</u> days.

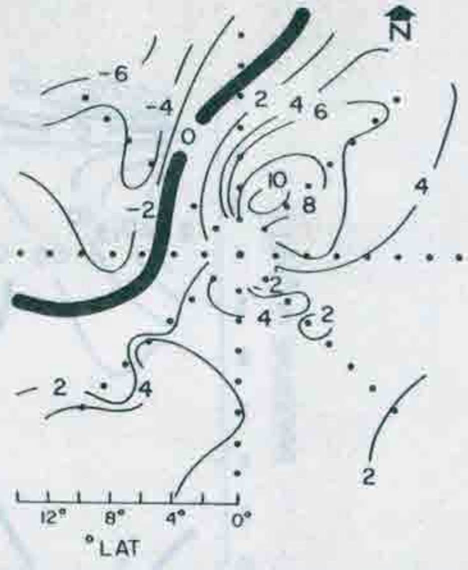

Fig. 2.12. Same as Fig. 2.11 but for <u>odd</u> days

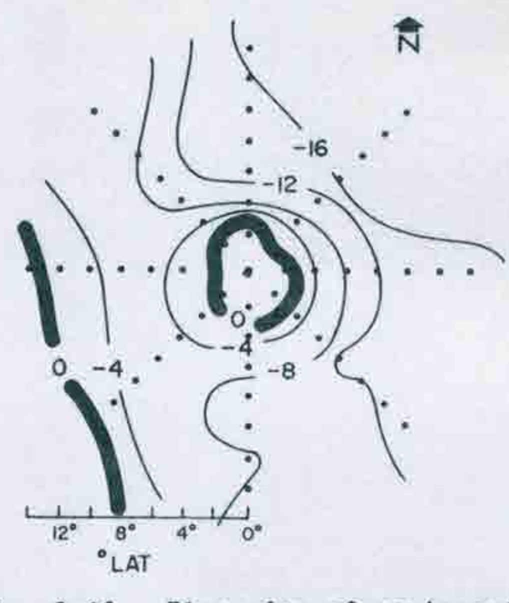

Fig. 2.13. Plan view of rawinsonde composite of 1961-1974 hurricane (< 30°Lat.) 150 mb level tangential wind (in m/s) on <u>even</u> days.

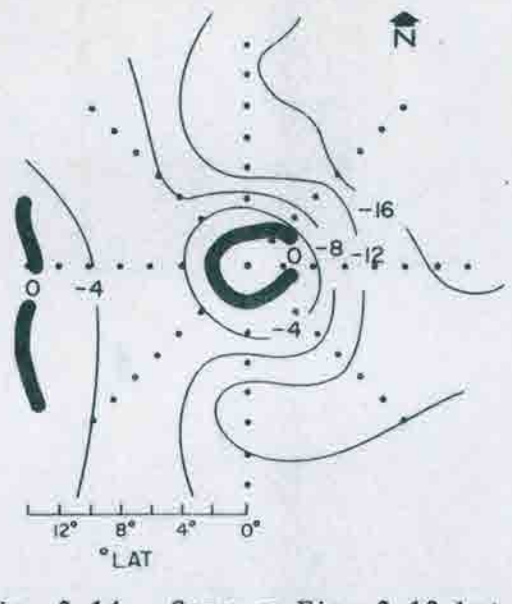

Fig. 2.14. Same as Fig. 2.13 but for <u>odd</u> days.

Mielke, P. W., K. J. Berry and G. W. Brier, 1981: Application of Multi-response permutation procedures for examining seasonal changes in monthly mean sea level pressure patterns. Mon. Wea. Rev., Vol. 109, 1, 120-126.

3. RAWINSONDE DATA AVAILABILITY BY REGION

3.1 West Indies Region (1957-1977)

3.1.1 Introduction

The West Indies data set is one of our most widely used data sets. There are 103 stations contained in this data region as shown in Fig. 3.1, for a period from January 1, 1957 to December 31, 1977. The region has been divided into five latitude and longitude sub-regions as denoted by [1], [2], [2A], [3] and [4] in Fig. 3.1. A detailed listing of station numbers and locations is presented in Table 3.1. The 21 years of data were acquired entirely from the time series RAOB data located at the U. S. National Center for Atmospheric Research (NCAR). The set contains some one million upper air radiosonde flights taken twice daily near 00Z and 12Z. The data have been converted to the Northern Hemisphere Data Tabulation (NHDT) 645 upper air format which contain data for 26 pressure levels: surface, 1000, 950, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 250, 200, 175, 150, 125, 100, 80, 70, 60 and 50 millibars. The soundings include height/pressure, temperature, relative humidity, and wind direction and speed. The cyclone positions associated with this data set were obtained from the best track positions from the National Hurricane Center in Miami, Florida.

3.1.2 Process for Building the Data Set

The process for building the West Indies data set is shown in Fig. 3.2. The soundings for the stations listed in Table 3.1 are taken from the archived volumes of data at NCAR and placed on magnetic tape. The magnetic tapes are then returned to CSU where the data are converted to the NHDT 645 format. After the conversion the data are sorted by date,

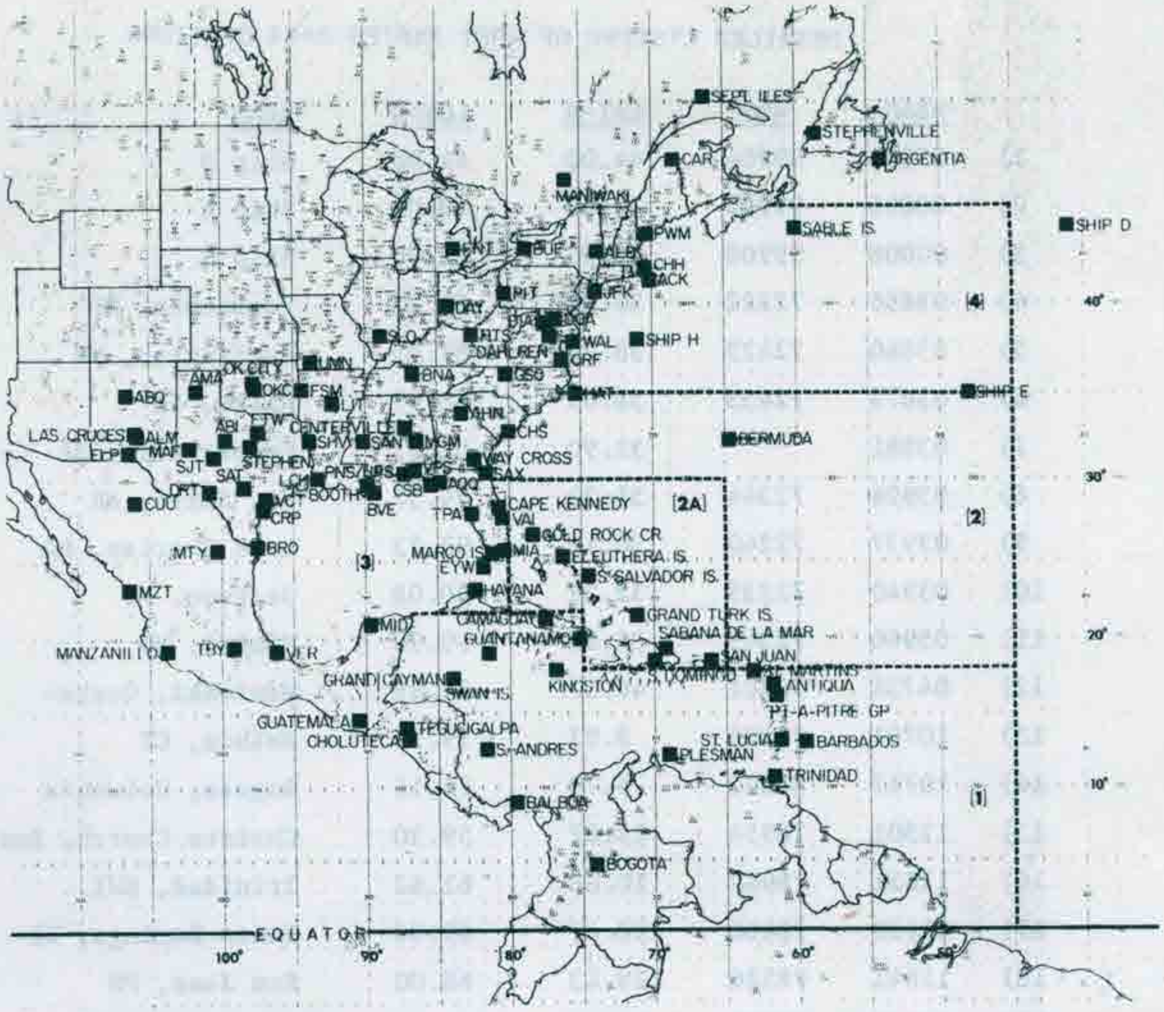

Fig. 3.1. Map showing the locations of the 103 stations contained in the West Indies data set for the years 1957-1977. The region has been divided into 5 sub-regions denoted by the dashed lines.

hour, and station to give us a chronologically ordered data set. Finally, the information is broken up into one month files and placed on magnetic tape for archiving. The final data set is contained on twenty-one 9 track 1600 BPI tapes, with one year of data per tape. The data are categorized by month and year to allow easier access if work is to be done on only a portion of the information.

TABLE 3.1

DETAILED LISTING OF WEST INDIES DATA STATIONS

	WBAN	WMO	LAT-N	LON-W	NAME
1)	00004	99904	44.00	41.00	Ship D
2)	00005	99905	35.00	48.00	Ship E
3)	00008	99908	38.00	71.00	Ship H
4)	03855	72222	30.35	87.32	Pensacola, FL
5)	03860	72425	38.37	82.55	Huntington, WV
6)	03879	72433	38.65	88.97	Salem, IL
7)	03881		32.90	87.25	Centerville, AL
8)	03926	72344	35.33	94.37	Ft. Smith, AR
9)	03937	72240	30.12	93.22	Lake Charles, LA
10)	03940	72235	32.32	90.08	Jackson, MS
11)	03946	72349	36.88	93.90	Monett, MO
12)	04734	72722	46.37	75.98	Maniwaki, Quebec
13)	10701	78806	8.97	79.55	Balboa, CZ
14)	10717	80222	4.70	74.15	Bogota, Columbia
15)	11501	78954	13.07	59.50	Christs Church, Barbados
16)	11621	78967	10.68	61.62	Trinidad, BWI
17)	11629	78486	18.47	69.88	Santo Domingo, DR
18)	11641	78526	18.43	66.00	San Juan, PR
19)	11642	78897	16.27	61.52	PT-A-PITRE GP
20)	11643	78988	12.20	68.97	Willemstad Curaco/Plesman Apt.
21)	11644	78949	13.75	60.98	St. Lucia Island LC
22)	11645	78866	18.05	63.12	St. Martin Ant
23)	11646	78467	19.05	69.38	Sabana de la Mar, DR
24)	11647	78861	17.13	61.78	St. Johns Antiqua
25)	11706	78367	19.90	75.15	Guantanamo Bay, CU
26)	11715	78397	17.93	76.78	Kingston, Jamaica BWI
27)	11807	78501	17.40	83.93	Swan Island, WI
28)	11813	78384	19.30	81.37	Grand Cayman, BWI
29)	11814	80001	12.58	81.70	San Andres Is., Columbia
30)	11816		13.30	87.18	Choluteca, Honduras
31)	11817		14.03	87.23	Tegucigalpa, Honduras
32)	11901	78640	14.53	90.57	Guatemala City, Guatemala
33)	11903	76679	19.20	99.10	Tacubaya/Mexico City, Mexico
34)	11904	76692	19.15	96.12	Vera Cruz/Hacienda, Mexico

TABLE 3.1 (cont'd)

DETAILED LISTING OF WEST INDIES DATA STATIONS

	WBAN	WMO	LAT-N	LON-W	NAME
35)	12711	78355	21.42	77.87	Camaguay, Cuba
36)	12712	78063	26.62	78.37	Gold Rock Creek, Bahamas
37)	12713	78076	25.27	76.30	Eleuthera Island
38)	12714	78118	21.43	71.13	Grand Turk Island
39)	12716	78089	24.07	74.52	San Salvador Island
40)	12832	72220	29.73	84.98	Apalachicola, FL
41)	12839	72202	25.80	80.27	Miami, FL
42)	12842	72211	27.97	82.53	Tampa, FL
43)	12850	72201	24.85	81.78	Key West, FL
44)	12863	72232	28.98	89.37	Burrwood, LA
45)	12864	78325	23.15	82.33	Havana/Casa Blanca Cuba
46)	12868	74794	28.48	80.57	Cape Kennedy, FL
47)	12878	76644	20.95	89.68	Merida, Mexico
48)	12879	72224	29.68	85.35	Cape San Blas, FL
49)	12880		25.90	81.72	Marco Island, FL/Site D-7
50)	12881		27.95	80.57	Valkaria, FL/Apt FAA
51)	12884	72232	29.33	89.40	Boothville, LA
52)	12912	72255	28.85	96.92	Victoria, TX
53)	12919	72250	25.90	97.43	Brownsville, TX
54)	12921	72253	29.53	98.47	San Antonio, TX
55)	12926	72251	27.70	97.27	Corpus Christi, TX
56)	13601	78016	32.27	64.68	St. George Bermuda
57)	13723	72317	36.08	79.95	Greensboro, NC
58)	13737	72308	36.90	76.20	Norfolk, VA
59)	13760		38.33	77.03	Dahlren, VA
60)	13840	72429	39.87	84.12	Dayton, OH
61)	13858	72221	30.48	86.52	Valparaiso, FL
62)	13861	72213	31.25	82.40	Way Cross, GA
63)	13873	72311	33.95	83.32	Athens, GA
64)	13880	72208	32.90	80.03	Charleston, SC
65)	13889	72206	30.50	81.70	Jacksonville, FL
66)	13895	72226	32.30	86.40	Montgomery, AL
67)	13897	72327	36.12	86.68	Nashville, TN

TABLE 3.1 (cont'd)

DETAILED LISTING OF WEST INDIES DATA STATIONS

	WBAN	WMO	LAT-N	LON-W	NAME
68)	13901		32.22	98.18	Stephenville, TX
69)	13911	72259	32.77	97.42	Ft. Worth, TX
70)	13919	72345	35.42	97.38	Oklahoma City, OK
71)	13957	72248	32.47	93.82	Shreveport, LA
72)	13962	72266	32.43	99.68	Abilene, TX
73)	13963	72340	34.73	92.23	Little Rock, AR
74)	13967	72353	35.40	97.60	Oklahoma City, OK
75)	14503	72815	48.53	58.55	Stephenville NFLD
76)	14508	72807	47.30	54.00	Argentia NFLD
77)	14607	72712	46.87	68.02	Caribou ME
78)	14642	72600	43.93	60.02	Sable Island, NS
79)	14684	74494	41.67	69.97	Chatham, MA
80)	14756	72506	41.25	70.07	Nantucket, MA
81)	14733	72528	42.93	78.73	Buffalo, NY
82)	14735	72518	42.75	73.80	Albany, NY
83)	14764	72606	43.65	70.32	Portland, ME
84)	14826	72637	42.97	83.73	Flint, MI
85)	15613	72811	50.22	66.27	Sept Iles, Quebec
86)	21001		19.07	104.33	Manzanillo, Mexico
87)	22001	72261	29.37	100.78	Del Rio, TX
88)	22007	76225	28.70	106.07	Chihuahua, Mexico
89)	22009	76458	23.18	106.42	Mazatlan, Mexico
90)	22012	76393	25.87	100.25	Monterrey, Mexico
91)	23002	72269	32.85	106.10	Alamogordo, NM
92)	23017		31.40	100.40	San Angelo, TX
93)	23023	72265	31.93	102.20	Midland, TX
94)	23039	72269	32.37	106.48	Las Cruces/White Sands, NM
95)	23044	72270	31.80	106.40	El Paso, TX
96)	23047	72363	35.23	101.70	Amarillo, TX
97)	23050	72365	35.05	106.62	Albuquerque, NM
98)	93722	72405	38.83	76.95	Washington, DC
99)	93729	72304	35.27	75.55	Cape Hatteras, NC
100)	93734	72403	38.98	77.47	Sterling, VA

TABLE 3.1 (cont'd)

DETAILED LISTING OF WEST INDIES DATA STATIONS

	WBAN	WMO	LAT-N	LON-W	NAME
101)	93739	72402	37.85	75.48	Wallops Island, VA
102)	94789	74486	40.65	73.78	New York, NY
103)	94823	72520	40.50	80.22	Pittsburgh, PA

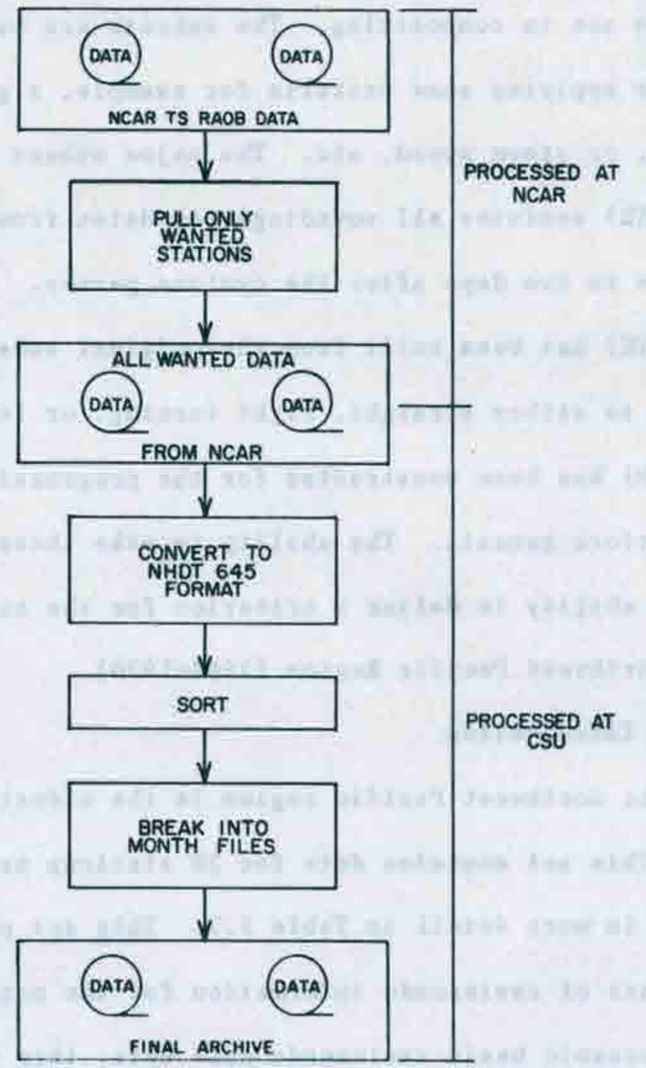

Fig. 3.2. Diagram showing the procedure for building the West Indies data set.

3.1.3 Using the Data

The availability of soundings for every day during the 21 years allows us a great deal of flexibility in making calculations and provides several benefits. Long term climatological means for a particular station or group of stations can be calculated. Composite means for time periods when there is no storm activity can be computed giving us a representative null storm environment.

When working with composites it is quite costly and cumbersome to work with all of the data. For this reason we select subsets of the data to use in compositing. The subsets are built from the original data by applying some criteria for example, a group of dates, storm motion, or storm speed, etc. The major subset called West Indies Master (WIMASTR) contains all soundings for dates from two days before cyclone genesis to two days after the cyclone passes. An additional subset (RECURVE) has been built from the original subset for periods when storm motion is either straight, right turning, or left turning. A set called (PREGEN) has been constructed for the pregenesis period three to ten days before genesis. The ability to make these subsets is only limited by the ability to define a criterion for the subset.

3.2 Northwest Pacific Region (1961-1970)

3.2.1 Introduction

The northwest Pacific region is the oldest rawinsonde data set at CSU. This set contains data for 28 stations as shown in Fig. 3.3 and listed in more detail in Table 3.2. This set presently contains only ten years of rawinsonde information for the period 1961 to 1970. Of our three oceanic basin rawinsonde data sets, this one contains the fewest number of soundings because unlike the other basins it only has data for

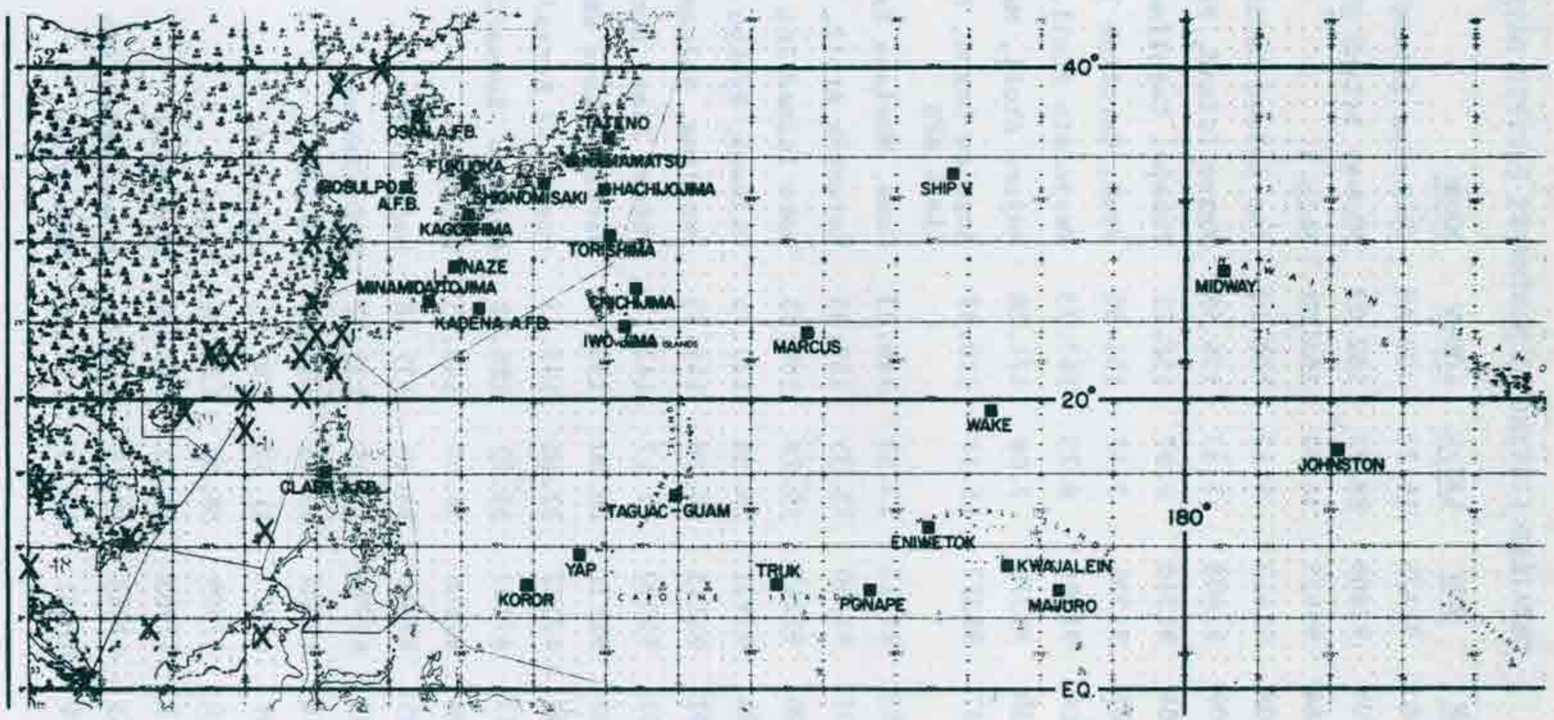

Fig. 3.3. Map showing the locations of the 28 stations contained in the northwest Pacific data set for the period 1961-1970 (solid boxes). Within the next year we hope to have these stations for a 21-year period, 1957-1977. The X's show the new upper-air stations we plan to incorporate into our upper-air network within the next 1-2 years. Each of these latter stations will be for a 10-20 year period or as much as can be obtained. See Figs. 3.13 and 3.15.

TABLE 3.2

DETAILED LISTING OF NORTHWEST PACIFIC DATA STATIONS

	WBAN	WMO	LAT-N	LON-W	NAME
1)	21603	91275	16.73	190.48	Johnston Island WB
2)	22701	91066	28.22	182.63	Midway Island NS
3)	23464	99925	34.00	164.00	Ship V
4)	40308	91413	9.52	138.13	Yap Island Caroline Island WB
5)	40309	91408	7.33	134.48	Koror Island, Palau Islands WB
6)	40504	91348	6.97	158.22	Ponape, Caroline Islands WBO
7)	40505	91334	7.47	151.85	Truk, Caroline Islands WBO
8)	40604	91366	8.73	167.73	Kwajelein Atoll, Marshall Is. WBAP
9)	40710	91376	7.08	171.38	Majuro Atoll, Marshall Islands
10)	41207	98327	15.17	120.57	Angeles Luzon, Philippine Islands/ Clark AFB
11)	41415	91217	13.55	144.83	Guam, Mariana Islands/TAGUAC
12)	41601	91250	11.35	162.35	Eniwetok Atoll, Marshall Islands
13)	41606	91245	19.28	166.65	Wake Island Int Apt WBO
14)	42204	47931	26.35	127.75	Okinawa, Ryukyu Island/Kadena AFB
15)	42401	91115	24.78	141.33	Iwo Jima, Volcano Islands AB
16)	42402	91030	32.17	142.17	Chichi Jima, Bonin Islands NF
17)	42502	91131	24.30	153.97	Marcus Island WB
18)	43242	47122	37.10	127.03	Osan - NI Korea/Osan AFB K-55
19)	43263	47187	33.20	126.22	Mosulpo Korea/Cheju Do R.O.K. K-39
20)	88004	47646	36.05	140.13	Tateno
21)	88005	47646	33.10	139.78	Hachijojima
22)	88007	47778	33.45	135.77	Shionomisaki
23)	88008	47807	33.58	130.37	Fukuoka
24)	88009	47827	31.57	130.55	Kagoshima
25)	88010	47909	28.38	129.50	Naze
26)	88011	47963	30.42	140.25	Torishima
27)	88013	47945	25.83	131.23	Minamidaitojima
28)	88014	47681	34.73	137.67	Hamamatsu

storm periods, giving much smaller set of approximately 18,000 soundings. The data for this region came from three sources: rawinsonde data taken from Daily Northern Hemisphere Data Tabulation (NHDT) tapes at the National Climatic Center in Asheville, North Carolina, the National Center for Atmospheric Research (NCAR), in Boulder, Colorado and from Japanese Aerological Data Books. The Japanese data were taken from the Japan Meteorological Agency (JMA) published books available at the NOAA Meteorological Library in Washington, DC and punched onto cards and magnetic tape by the U.S. Navy Environmental Prediction Research Facility (NEPRF) at facilities in Asheville, North Carolina and Monterey, California at a cost of approximately $100,000. We very much appreciate the help of NEPRF in punching the Japanese rawinsonde observations. Data are available twice daily at 00Z and 12Z and are in the NHDT 645 upper air format which contains information for 26 pressure levels: surface, 1000, 950, 900, 850, 800, 750, 700, 650, 600, 550, 500, 450, 400, 350, 300, 250, 200, 175, 150, 125, 100, 80, 70, 60 and 50 millibars. The cyclone positions associated with this data set were obtained from the Best Tracks in the Annual Report of the Joint Typhoon Warning Center at Guam and from NEPRF.

3.2.2 Process for Building the Northwest Pacific Data Set

The process for building the northwest Pacific data set is shown in Fig. 3.4. The soundings for storm dates were extracted from the NHDT tapes and from the NCAR tapes which are converted to the NHDT 645 format. The Japanese data were punched in NHDT 645 format by NEPRF for storm days when a particular station was within 15° latitude of a storm center. The data from all three sources were then combined and sorted

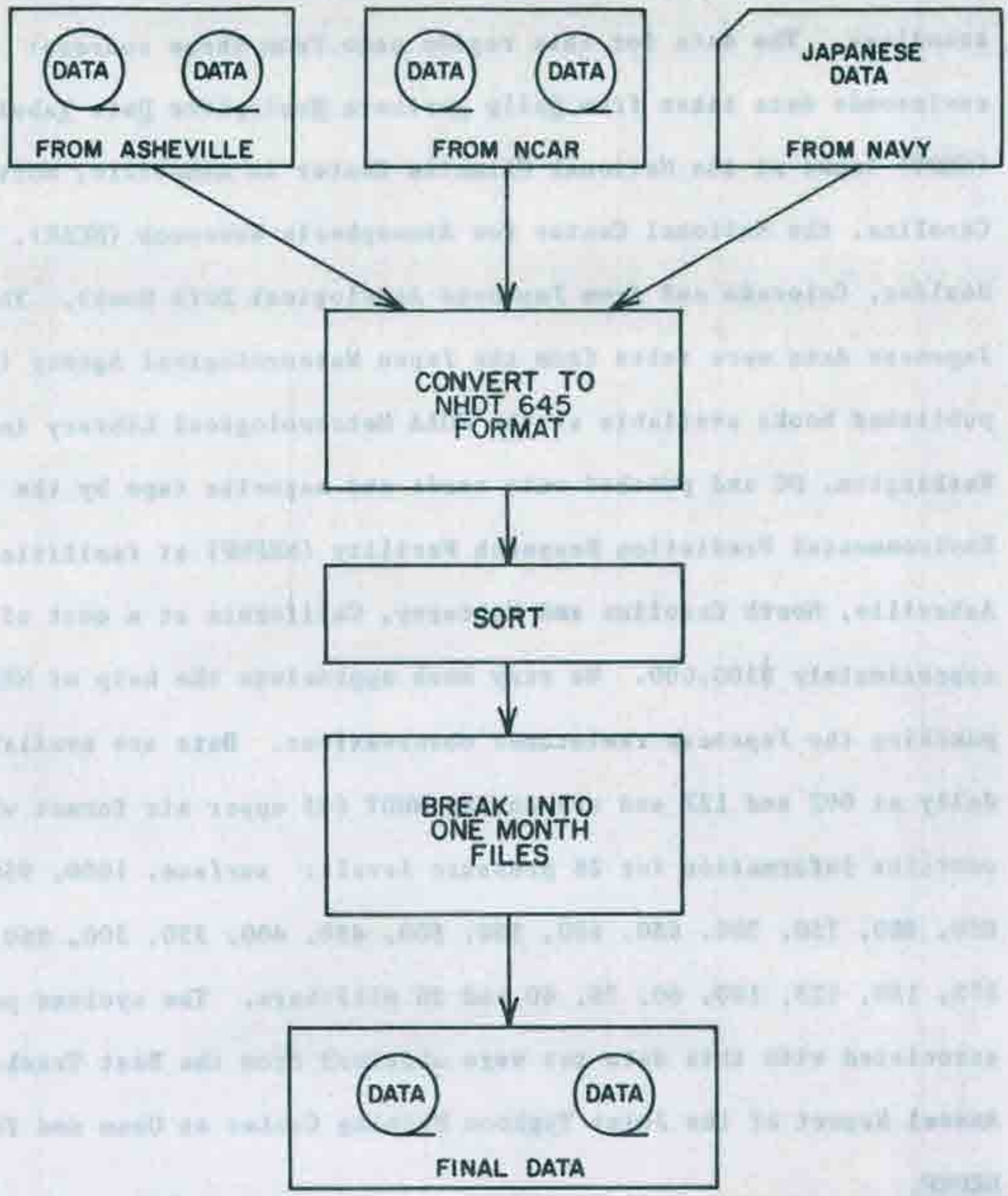

Fig. 3.4. Diagram showing the overall procedure used in building the northwest Pacific data set.

by date, hour, and station to give a chronologically ordered data set which was then broken into one month files and placed on magnetic tape for archiving. The final data set is archived on two 7 track 800 BPI tapes.

3.3 Southwest Pacific/Australian Region (1958-1979)

3.3.1 Introduction

The southwest Pacific/Australian data region is the newest addition to our global data sets at CSU. It is comprised of three separate data sets; a 'wind-only set' a 'temperature-only set' and a 'thermal set' (which is a combination of wind and temperature information). All sets were built from data supplied by the Australian Bureau of Meteorology, the New Zealand Meteorological Service, the Malaysian Meteorological Service, and the U.S. National Center for Atmospheric Research. Most of the data used in building these sets came from archive sources. However, we were able to supplement the archived data with 'real time' data supplied by the Australian Bureau of Meteorology. The real time data were obtained by routinely saving all observations coming across the WMO Global Telecommunications System (GTS) since 1972. We have been able to incorporate some 90% of these data with the archive data, thus increasing the data density of each set, especially in the later years.

3.3.2 Southwest Pacific 'Wind-only Set'

The 'wind-only set' contains data for the 155 stations shown in Fig. 3.5. A detailed listing of these stations is given in Table 3.3. Although the data goes as far back as the 1940's for some stations, we have built the set for a 22 year period starting in 1958 (a period which Holland, 1981 determined to be the optimum for tropical cyclone research). This 22 year data set contains some 3 million wind flights, which were generally taken four times daily near 05Z, 11Z, 17Z and 23Z. Contained within each wind flight are wind speeds (in meters/sec) and wind directions for 18 pressure levels: surface, 950, 900, 850, 750, 700, 600, 500, 400, 300, 250, 200, 150, 100, 80, 70, 60 and 50

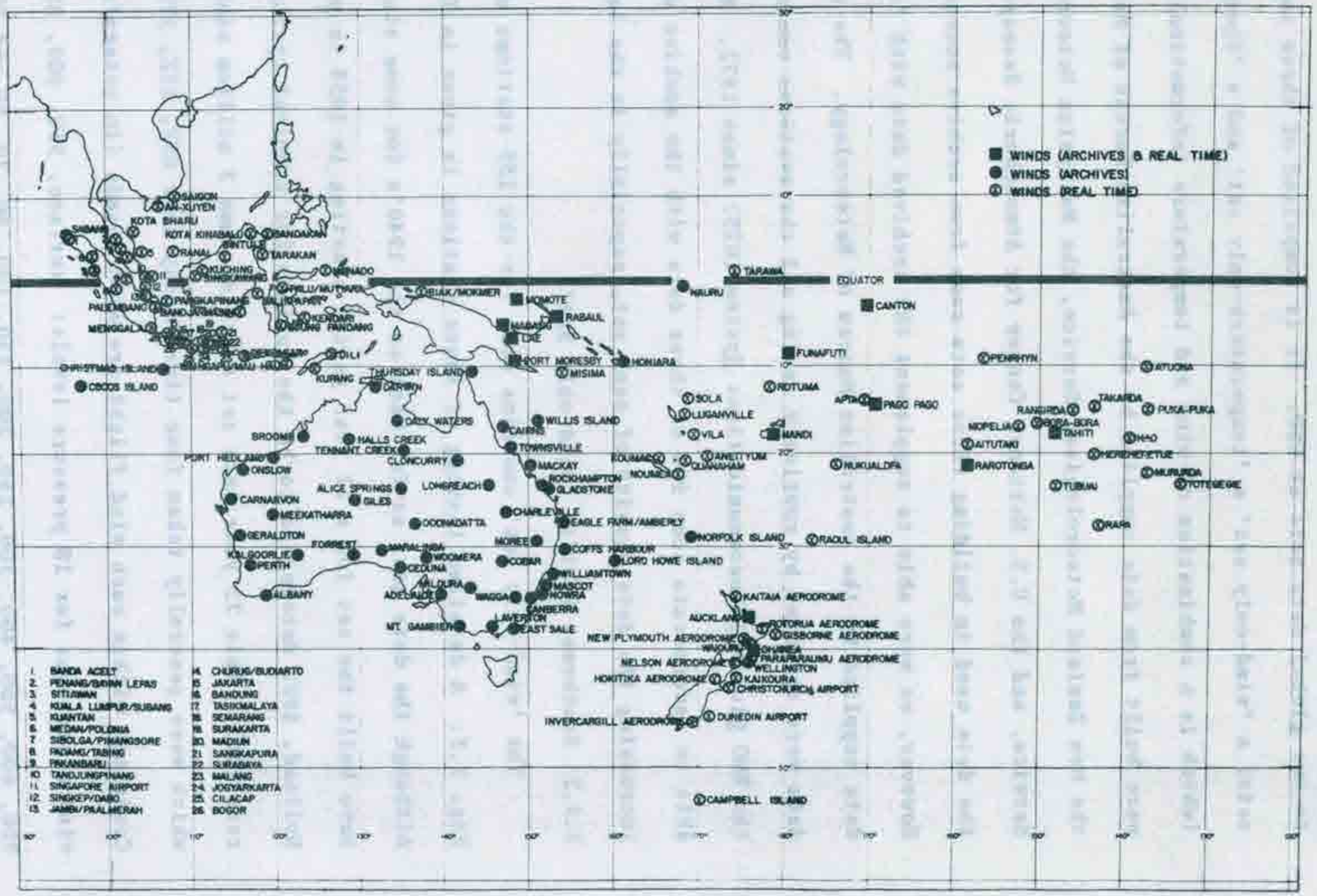

Fig. 3.5. Map showing locations of the 155 stations contained in the southwest Pacific/Australian 'wind-only' data set for the period 1958–1979.

TABLE 3.3

DETAILED LISTING OF SOUTHWEST PACIFIC/AUSTRALIAN WIND DATA STATIONS

	STATION NUMBER	STATION NAME	PERIOD OF RECORD	LAT	LONG	ELV
1.	48601	PENANG/BAYAN LEPAS	7810 - 7911	-5.3	100.27	4
2.	48615	KOTA BHARU	7810 - 7912	-6.1	102.28	9
3.	48620	SITIAWAN	7810 - 7912	-4.2	100.70	8
4.	48647	KUALA LUMPUR/SUBANG	7810 - 7911	-3.1	101.55	17
5.	48657	KUANTAN	7810 - 7911	-3.7	103.20	21
6.	48694	SINGAPORE AIRPORT	7403 - 7911	-1.3	103.90	10
7.	48900	SAIGON	7810 - 7909	-10.8	106.67	10
8.	48914	AN-XUYEN (CAMAU)	7812 - 7911	-9.1	105.17	3
9.	91517	HONIARA	4912 - 7906	9.4	159.97	58
10.	91530	NAURU	5102 - 6405	.5	166.92	37
11.	91551	SOLA (VANUA LAVA)	7201 - 7809	13.8	167.60	42
12.	91554	LUGANVILLE	7201 - 7909	15.5	167.13	146
13.	91558	VILA (EFATE)	7201 - 7912	17.7	168.32	20
14.	91568	ANEITYUM	7201 - 7912	20.2	169.78	8
15.	91577	KOUMAC	7201 - 7912	20.5	164.28	18
16.	91582	QUANAHAM	7201 - 7912	20.7	167.23	29
17.	91592	NOUMEA	7201 - 7912	22.2	166.45	75
18.	91610	TARAWA	7201 - 7912	-1.3	172.92	4
19.	91643	FUNAFUTI	6010 - 7912	8.5	179.22	2
20.	91650	ROTUMA	7201 - 7912	12.5	177.05	26
21.	91680	NANDI	5601 - 7912	17.7	177.45	18
22.	91700	CANTON	4801 - 7412	2.7	188.28	4
23.	91762	APIA	7201 - 7912	13.8	188.22	2
24.	91765	PAGO PAGO	6604 - 7912	14.3	189.28	3
25.	91788	NUKUALOFA	7204 - 7911	21.1	184.82	3
26.	91800	PENRHYN	7204 - 7912	9.0	201.93	2
27.	91830	AITUTAKI	7204 - 7912	18.8	200.23	6
28.	91843	RAROTONGA	5810 - 7912	21.2	200.20	4
29.	91925	ATUONA	7204 - 7912	9.8	220.98	52

TABLE 3.3 (cont'd)

DETAILED LISTING OF SOUTHWEST PACIFIC/AUSTRALIAN WIND DATA STATIONS

	STATION NUMBER	STATION NAME	PERIOD OF RECORD	LAT	LONG	ELV
30.	91928	PUKA - PUKA	7204 - 7912	14.8	221.18	3
31.	91930	BORA - BORA	7410 - 7912	16.4	208.25	3
32.	91931	MOPELIA	7204 - 7912	16.7	206.05	3
33.	91938	TAHITI	5707 - 7912	17.5	210.38	2
34.	91941	RANGIROA	7801 - 7912	14.9	212.37	2
35.	91943	TAKAROA	7204 - 7912	14.4	214.97	2
36.	91944	HAO	7204 - 7912	18.0	219.07	3
37.	91945	HEREHERETUE	7204 - 7410	19.8	215.00	3
38.	91948	TOTEGEGIE	7204 - 7910	23.1	225.05	127
39.	91952	MURUROA	7410 - 7412	21.8	221.18	3
40.	91954	TUBUAI	7204 - 7912	23.3	210.52	3
41.	91958	RAPA	7301 - 7912	27.6	215.67	7
42.	93011	KAITAIA AERODROME	7201 - 7912	35.0	173.28	80
43.	93119	AUCKLAND	5601 - 7912	37.0	174.80	6
44.	93246	ROTORUA AERODROME	7201 - 7912	38.1	176.32	288
45.	93291	GISBORNE AERODROME	7201 - 7912	38.6	177.98	8
46.	93308	NEW PLYMOUTH AERODROME	7201 - 7912	39.0	174.18	48
47.	93337	WAIOURU	7201 - 7603	39.4	175.60	823
48.	93401	OHAKEA	5601 - 7912	40.2	175.38	52
49.	93417	PARAPARAUMU AERODROME	7201 - 7912	40.9	174.98	12
50.	93434	WELLINGTON	7201 - 7912	41.2	174.77	119
51.	93545	NELSON AERODROME	7201 - 7912	41.3	173.22	7
52.	93614	HOKITIKA AERODROME	7201 - 7912	42.7	170.98	40
53.	93677	KAIKOURA	7201 - 7912	42.4	173.70	101
54.	93780	CHRISTCHURCH AIRPORT	7201 - 7912	43.4	172.55	34
55.	93844	INVERCARGILL AERODROME	7201 - 7912	46.4	168.53	0
56.	93890	DUNEDIN AIRPORT	7201 - 7912	45.9	170.20	2
57.	93944	CAMPBELL ISLAND	7201 - 7912	52.5	169.15	19
58.	93997	RAOUL ISLAND	7201 - 7912	29.3	182.08	49
59.	94014	MADANG	5010 - 7912	5.2	145.80	12
60.	94027	LAE	4701 - 7912	6.7	147.00	9

TABLE 3.3 (cont'd)

DETAILED LISTING OF SOUTHWEST PACIFIC/AUSTRALIAN WIND DATA STATIONS

	STATION NUMBER	STATION NAME	PERIOD OF RECORD	LAT	LONG	ELV
61.	94035	PORT MORESBY	4601 - 7912	9.4	147.22	47
62.	94044	MOMOTE	5007 - 7811	2.0	147.33	5
63.	94085	RABAUL	5001 - 7912	4.2	152.18	8
64.	94087	MISIMA (LOAGA)	7509 - 7807	10.7	152.83	8
65.	94120	DARWIN	5001 - 7906	12.4	130.87	29
66.	94175	THURSDAY ISLAND	5009 - 7906	10.5	142.22	61
67.	94203	BROOME	5001 - 7906	17.9	122.22	9
68.	94212	HALLS CREEK	5001 - 7906	18.2	127.67	406
69.	94234	DALY WATERS	5001 - 7002	16.2	133.38	214
70.	94238	TENNANT CREEK	6908 - 7906	19.6	134.18	376
71.	94287	CAIRNS	4707 - 7906	16.5	145.73	7
72.	94294	TOWNSVILLE	4601 - 7906	19.2	146.77	4
73.	94299	WILLIS ISLAND	5106 - 7906	16.3	149.98	8
74.	94300	CARNARVON	5001 - 7906	24.8	113.65	4
75.	94305	ONSLOW	5001 - 7502	21.6	115.07	4
76.	94312	PORT HEDLAND	5001 - 7906	20.3	118.62	11
77.	94326	ALICE SPRINGS	5001 - 7906	23.8	133.88	548
78.	94335	CLONCURRY	5001 - 7505	20.6	140.50	191
79.	94346	LONGREACH	6703 - 7906	23.4	144.25	193
80.	94367	MACKAY	5909 - 7906	21.1	149.17	4
81.	94374	ROCKHAMPTON	4301 - 7906	23.3	150.48	14
82.	94380	GLADSTONE	5711 - 7906	23.8	151.27	76
83.	94403	GERALDTON	5001 - 7906	28.8	114.70	34
84.	94430	MEEKATHARRA	5104 - 7906	26.6	118.48	518
85.	94461	GILES	5609 - 7906	25.0	128.30	599
86.	94476	OODNADATTA	4801 - 7906	27.5	135.48	113
87.	94510	CHARLEVILLE	4204 - 7906	26.4	146.28	304
88.	94527	MOREE	6404 - 7906	29.4	149.85	212
89.	94578	EAGLE FARM / AMBERLY	5001 - 7906	27.6	152.72	26
90.	94610	PERTH	5001 - 7906	31.9	115.97	18
91.	94637	KALGOORLIE	5001 - 7906	30.7	121.45	361

TABLE 3.3 (cont'd)

DETAILED LISTING OF SOUTHWEST PACIFIC/AUSTRALIAN WIND DATA STATIONS

	STATION NUMBER	STATION NAME	PERIOD OF RECORD	LAT	LONG	ELV
92.	94646	FORREST	5001 - 7906	30.8	128.10	157
93.	94650	MARALINGA	5511 - 6504	30.2	131.50	150
94.	94653	CEDUNA	5001 - 7906	32.1	133.70	17
95.	94659	WOOMERA	5001 - 7906	31.1	136.80	166
96.	94672	ADELAIDE	5501 - 7906	34.9	138.53	11
97.	94693	MILDURA	5011 - 7906	34.2	142.08	50
98.	94711	COBAR	6205 - 7906	31.5	145.83	265
99.	94750	NOWRA	5001 - 7906	34.9	150.57	117
100.	94767	MASCOT	4601 - 7906	33.9	151.18	3
101.	94776	WILLIAMTOWN	5001 - 7906	32.8	151.83	9
102.	94791	COFFS HARBOUR	5109 - 7906	30.3	153.13	5
103.	94802	ALBANY	5001 - 7906	34.9	117.80	69
104.	94821	MT. GAMBIER	4502 - 7906	37.7	140.78	69
105.	94865	LAVERTON	5308 - 7906	37.8	144.75	14
106.	94907	EAST SALE	5001 - 7812	38.1	147.13	8
107.	94910	WAGGA	4603 - 7812	35.1	147.47	214
108.	94926	CANBERRA	4701 - 7812	35.3	149.18	577
109.	94995	LORD HOWE ISLAND	5001 - 7812	31.5	159.07	46
110.	94996	NORFOLK ISLAND	4806 - 7906	29.0	167.93	109
111.	96001	SABANG	7410 - 7809	-5.8	95.32	126
112.	96011	BANDA ACELT	7311 - 7911	-5.5	95.42	21
113.	96035	MEDAN/POLONIA	7312 - 7909	-3.5	98.68	25
114.	96073	SIBOLGA/PINANGSORE	7311 - 7905	-1.5	98.88	3
115.	96091	TANDJUNGPINANG	7504 - 7604	-.9	104.53	18
116.	96109	PAKANBARU	7312 - 7911	-.4	101.45	31
117.	96147	RANAI	7505 - 7905	-3.9	108.38	2
118.	96163	PADANG/TABING	7604 - 7909	.8	100.35	3
119.	96179	SINCKEP/DABO	7810 - 7911	.4	104.58	31
120.	96195	JAMBI/PAALMERAH	7305 - 7911	1.6	103.65	25
121.	96221	PALEMBANG	7604 - 7911	2.9	104.70	10
122.	96237	PANGKAPINANG	7604 - 7911	2.1	106.13	33

TABLE 3.3 (cont'd)

DETAILED LISTING OF SOUTHWEST PACIFIC/AUSTRALIAN WIND DATA STATIONS

	STATION NUMBER	STATION NAME	PERIOD OF RECORD	LAT	LONG	ELV
123.	96273	MENGGALA	7502 - 7911	5.4	105.18	19
124.	96413	KUCHING	7810 - 7911	-1.4	110.33	27
125.	96441	BINTULU	7810 - 7911	-3.2	113.03	5
126.	96471	KOTA KINABALU	7810 - 7911	-5.9	116.05	7
127.	96491	SANDAKAN	7810 - 7911	-5.9	118.07	14
128.	96509	TARAKAN	7810 - 7911	-3.3	117.57	6
129.	96533	SINGKAWANG II	7802 - 7809	-1.0	109.67	38
130.	96633	BALIKPAPAN	7605 - 7911	1.2	116.90	3
131.	96685	BANDJARMASIN	7604 - 7911	3.4	115.75	20
132.	96739	CHURUG/BUDIARTO	7510 - 7706	6.2	106.65	46
133.	96743	JAKARTA	7305 - 7911	6.1	106.85	5
134.	96755	BOGOR	7710 - 7911	6.5	106.90	171
135.	96781	BANDUNG	7605 - 7911	6.9	107.58	740
136.	96801	TASIKMALAYA	7706 - 7910	7.3	108.25	334
137.	96805	CILACAP	7604 - 7911	7.7	109.02	6
138.	96839	SEMARANG	7604 - 7909	6.9	110.38	3
139.	96845	SURAKARTA	7310 - 7911	7.8	110.92	104
140.	96853	JOGYARKARTA	7604 - 7911	7.7	110.43	107
141.	96881	MADIUN	7310 - 7911	7.6	111.52	110
142.	96925	SANGKAPURA (BAWEAN ISLAND)	7305 - 7911	5.8	112.63	3
143.	96933	SURABAYA	7305 - 7911	7.2	112.72	3
144.	96947	MALANG	7406 - 7910	7.9	112.70	526
145.	96995	CHRISTMAS ISLAND	5906 - 7812	10.4	105.67	17
146.	96996	COCOS ISLAND	5202 - 7906	12.1	96.83	8
147.	97014	MENADO	7311 - 7911	-1.5	124.92	80
148.	97072	PALU/MUTIARA	7503 - 7604	.6	119.73	6
149.	97146	KENDARI	7605 - 7911	4.1	122.43	50
150.	97180	JJUNG PANDANG	7305 - 7911	5.0	119.55	14
151.	97230	DENPASAR	7305 - 7911	8.7	115.17	1
152.	97340	WAINGAPU/MAU HAU	7604 - 7911	9.6	120.33	12
153.	97372	KUPANG	7406 - 7911	10.1	123.67	108
154.	97390	DILI	7305 - 7911	8.5	125.58	5
155.	97560	BIAK/MOKMER	7604 - 7911	1.1	136.12	11

millibars.

The overall process for building the 'wind-only' data set is shown in Fig. 3.6. Since these data came from several foreign sources and agencies the first step was to convert the tapes to an internal Control Data Corporation (CDC) format which we could work with easily. The next step consisted of deleting all levels not shown above and verifying that the units on all parameters are the same or changing them if required. This step was necessary because of inconsistencies between the different government agencies from which these data were received. With the addition of the real time 'wind-only' data (discussed later), the data were then sorted by date, hour, and station to give a chronologically ordered data set which was then categorized into one month files and placed on magnetic tape for archival. The final data set is contained on six 9 track 1600 BPI tapes.

3.3.3 Southwest Pacific 'Temperature-only' and 'Thermal Set'

The 'thermal set' contains data for those stations shown in Fig. 3.5 for which temperatures were available at 23Z (or ~ 07-12 LST). These stations are shown in Fig. 3.7 and presented in detail in Table 3.4. The data set covers the same 22 year period as the 'wind-only' data set but contains only 300,000 soundings since there are fewer stations and most flights were only taken once daily near 23Z. The 'temperature-only' flights contain height, temperature, and mixing ratio for 16 pressure levels: surface, 900, 850, 800, 700, 600, 500, 400, 300, 200, 150, 100, 80, 70, 60 and 50 millibars. There are 18 levels within each sounding in the 'thermal set' containing height, temperature, relative humidity, wind direction, and wind speed for the surface, 950, 900, 850, 750, 700, 600, 500, 400, 300, 250, 200, 150,

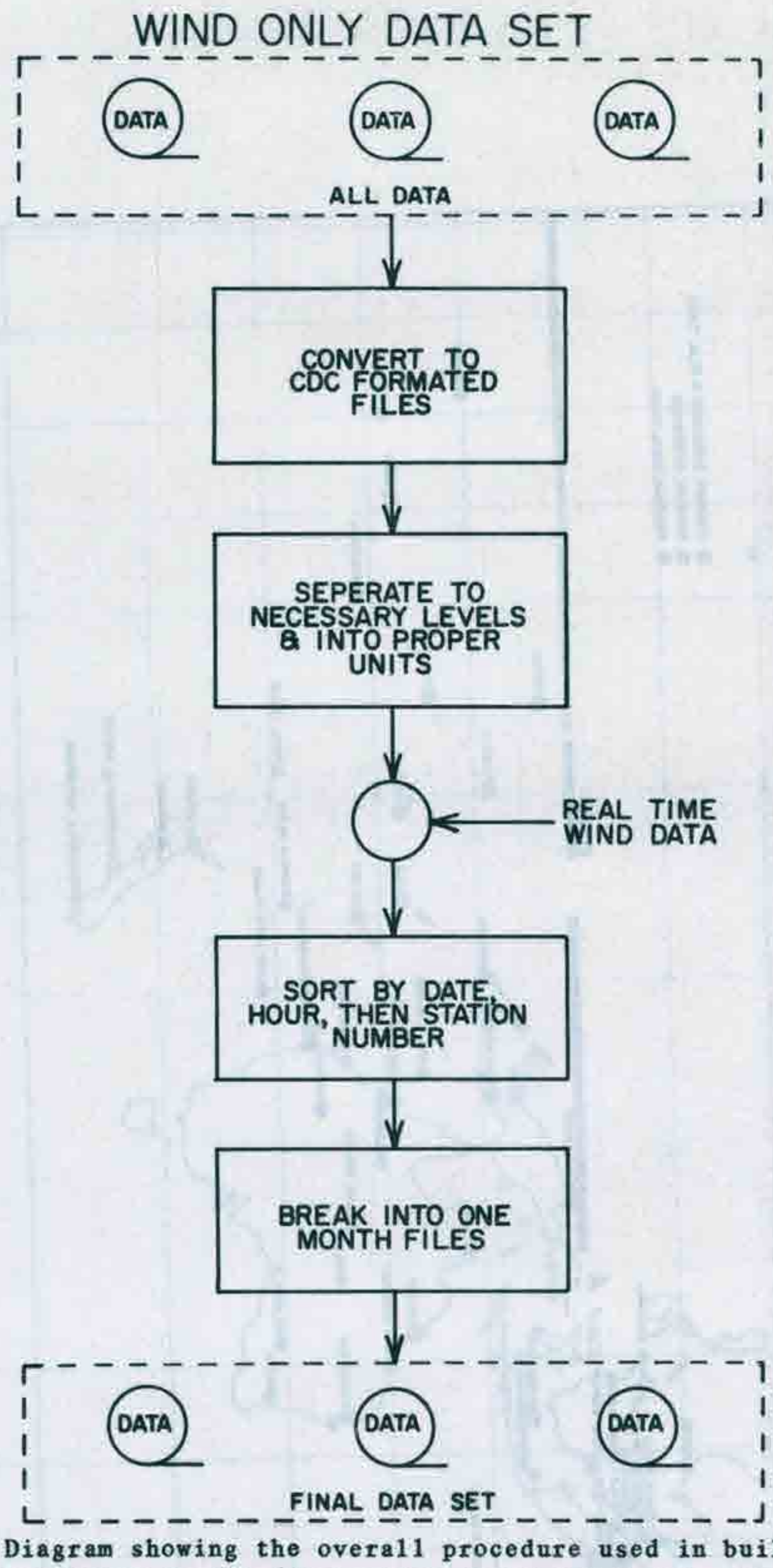

Fig. 3.6. Diagram showing the overall procedure used in building the southwest Pacific/Australian 'wind-only' data set.

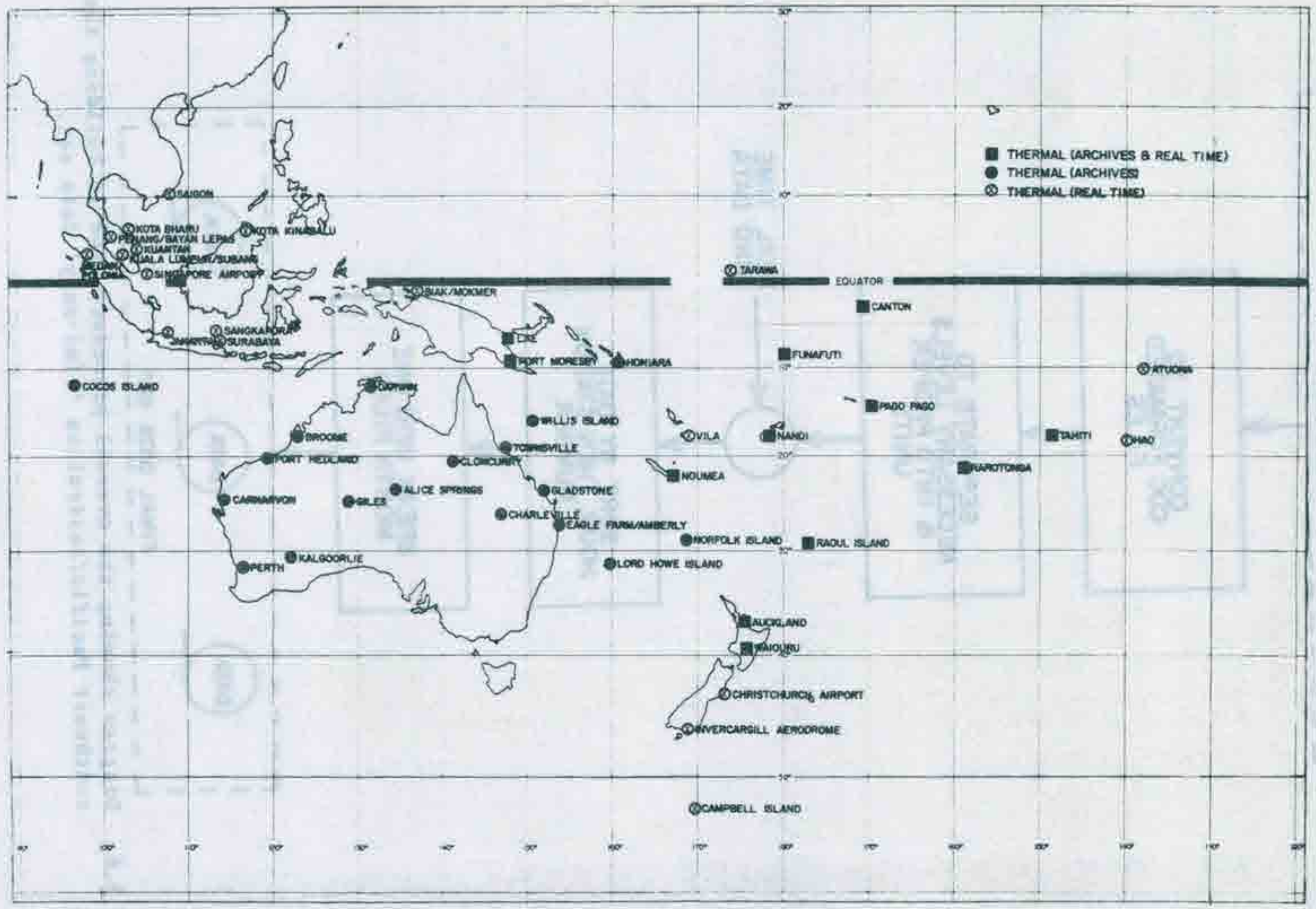

Fig. 3.7. Map showing locations of the 51 stations contained in the southwest Pacific/Australian 'temperature-only' and 'thermal-set' for the period 1958–1979.

TABLE 3.4

DETAILED LISTING OF SOUTHWEST PACIFIC/AUSTRALIAN TEMPERATURE AND THERMAL DATA STATIONS

	STATION NUMBER	STATION NAME	PERIOD OF RECORD	LAT	LONG	ELV
1.	48601	PENANG/BAYAN LEPAS	7310 - 7901	-5.3	100.27	4
2.	48615	KOTA BHARU	7403 - 7911	-6.1	102.28	9
3.	48647	KUALA LUMPUR/SUBANG	7403 - 7911	-3.1	101.55	17
4.	48657	KUATAN	7403 - 7912	-3.7	103.20	21
5.	48694	SINGAPORE AIRPORT	7310 - 7911	-1.3	103.90	10
6.	48900	SAIGON	7310 - 7911	-10.8	106.67	10
7.	91517	HONIARA	4912 - 7912	9.4	159.97	58
8.	91558	VILA	7606 - 7912	17.7	168.32	20
9.	91592	NOUMEA	6301 - 7912	22.2	166.45	75
10.	91610	TARAWA	7402 - 7912	-1.3	172.92	4
11.	91643	FUNAFUTI	7303 - 7912	8.5	179.22	2
12.	91680	NANDI	5601 - 7912	17.7	177.45	18
13.	91700	CANTON	4801 - 7412	2.7	188.28	4
14.	91765	PAGO PAGO	6604 - 7812	14.3	189.28	3
15.	91843	RAROTUNGA	7408 - 7912	21.2	200.20	4
16.	91925	ATOONA	7204 - 7912	9.8	220.98	52
17.	91938	TAHITI	5707 - 7912	17.5	210.38	2
18.	91944	HAO	7204 - 7912	18.0	219.07	3
19.	91948	RIKITEA	7204 - 7912	23.1	225.05	127
20.	91958	RAPA	7204 - 7912	27.6	215.67	7
21.	93119	AUCKLAND	5601 - 7912	37.0	174.80	6
22.	93337	WAIOURU	6607 - 7811	39.4	175.60	823
23.	93780	CHRISTCHURCH AIRPORT	7201 - 7912	43.4	172.55	34
24.	93844	INVERCARGILL AERODROME	7201 - 7912	46.4	168.33	0
25.	93944	CAMPBELL ISLAND	7310 - 7901	52.5	169.15	19
26.	93997	RAOUL ISLAND	5801 - 7912	29.3	182.08	49
27.	94027	LAE	4701 - 7504	6.7	147.00	9
28.	94035	PORT MORESBY	7505 - 7710	9.4	147.22	47
29.	94120	DARWIN	5001 - 7909	12.4	130.87	29
30.	94203	BROOME	6506 - 7909	17.9	122.22	9

TABLE 3.4 (cont'd)

DETAILED LISTING OF SOUTHWEST PACIFIC/AUSTRALIAN TEMPERATURE AND THERMAL DATA STATIONS

	STATION NUMBER	STATION NAME	PERIOD OF RECORD	LAT	LONG	ELV
31.	94207	TALGARNO	6003 - 6102	19.2	121.50	3
32.	94294	TOWNSVILLE	4601 - 7909	19.2	146.77	4
33.	94299	WILLIS ISLAND	6006 - 7906	16.3	149.98	8
34.	94300	CARNARVON	6107 - 7910	24.8	113.65	4
35.	94312	PORT HEDLAND	5001 - 7909	20.3	118.62	11
36.	94326	ALICE SPRINGS	5001 - 7910	23.8	133.88	548
37.	94335	CLONCURRY	5001 - 7505	20.6	140.50	191
38.	94380	GLADSTONE	7402 - 7909	23.8	151.27	76
39.	94461	GILES	5609 - 7910	25.0	128.30	599
40.	94510	CHARLEVILLE	4204 - 7910	26.4	146.28	304
41.	94578	AMBERLY / EAGLE FARM	5001 - 7910	27.6	152.72	26
42.	94610	GUILDFORD	5001 - 7909	31.9	115.97	18
43.	94637	KALGOORLIE	5001 - 7708	30.7	121.45	361
44.	94995	LORD HOWE ISLAND	5001 - 7910	31.5	159.07	46
45.	94996	NORFOLK ISLAND	4806 - 7910	29.0	167.93	109
46.	96035	MEDAN/POLONIA	7504 - 7910	-3.5	98.68	25
47.	96471	KOTA KINABALU	7311 - 7911	-5.9	116.05	7
48.	96743	JAKARTA	7306 - 7912	6.1	106.85	5
49.	96933	SURABAYA	7306 - 7911	7.2	112.72	3
50.	96996	COCOS ISLAND	5202 - 7912	12.1	96.83	8
51.	97560	BIAK/MOKMER	7605 - 7808	1.1	136.12	11

100, 80, 70, 60 and 50 millibars.

The overall process for building the 'temperature-only' and 'thermal set' is shown in Fig. 3.8. The process was the same as the 'wind only' set until the final step at which we merged the 'temperature-only' data and the 'wind-only' data. The criteria adopted was that all temperature flights were to be used in the 'thermal set'. Wind flights were added to these temperature flights or a missing code used if no wind flight existed. Because there were some slight differences in the levels between winds and temperatures, some temperatures were interpolated to match the wind levels. The final 'thermal set' is contained on three, nine track, 1600 BPI tapes. Thus, summarizing this by time periods we have:

05Z	11Z	17Z	23Z
wind	wind	wind	wind temperature thermal

3.3.4 Real Time Data

The 'real time' data were derived from the original observations coming from the Global Telecommunications System (GTS). This GTS data contains various wind and temperature messages and ship and aircraft observations. The process of creating the wind and temperature soundings from the real time data is shown in Fig. 3.9. All wind and temperature messages were extracted from the total data and separated. Each individual flight or sounding is made up of several small messages which create a problem in working with real time data because they are not all the same type. The wind data, for example, are made up of 3 messages, some of which have data for specific pressure levels while others contain data for specific heights. In order to get a sounding

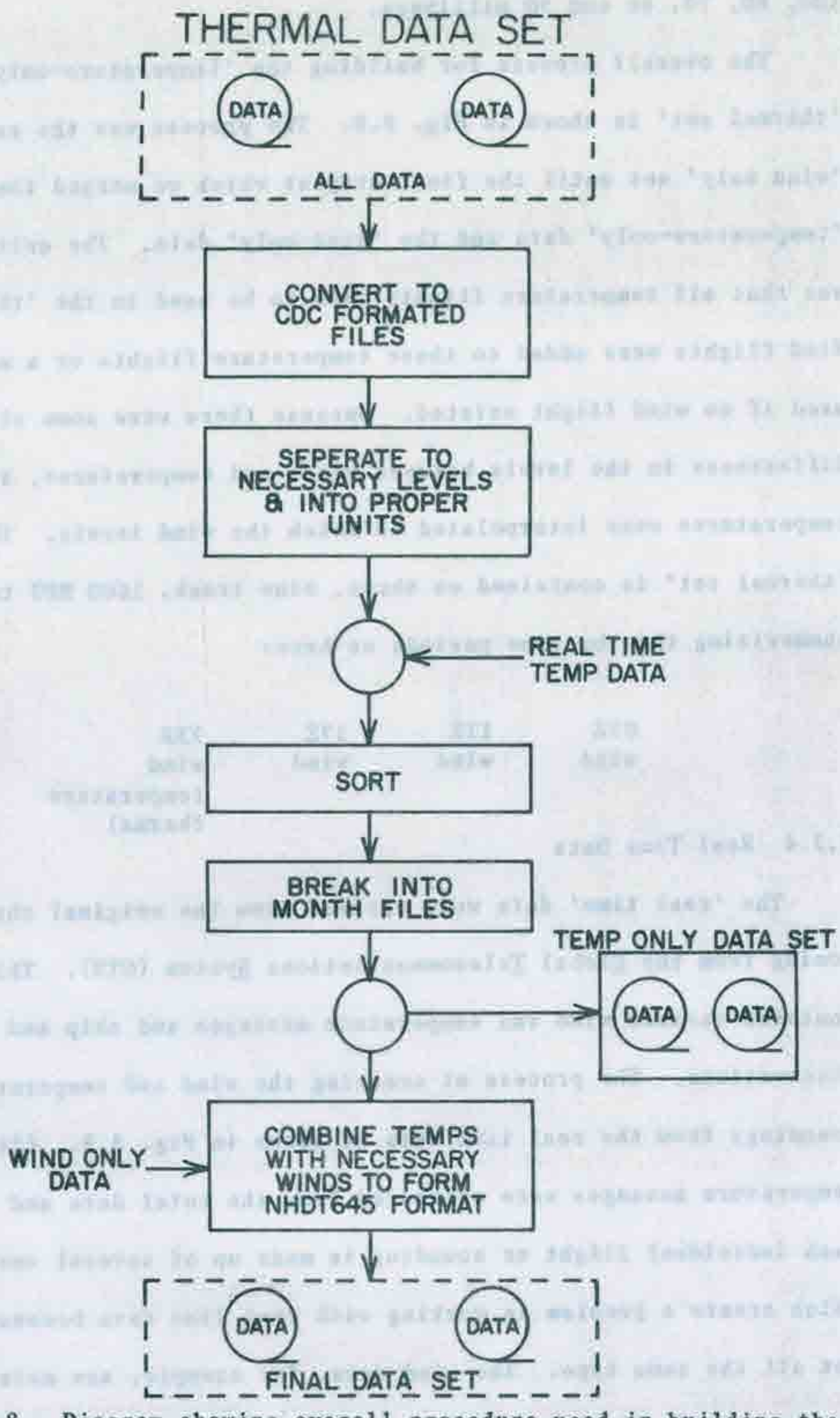

Fig. 3.8. Diagram showing overall procedure used in building the southwest Pacific/Australian temperature and thermal data set.

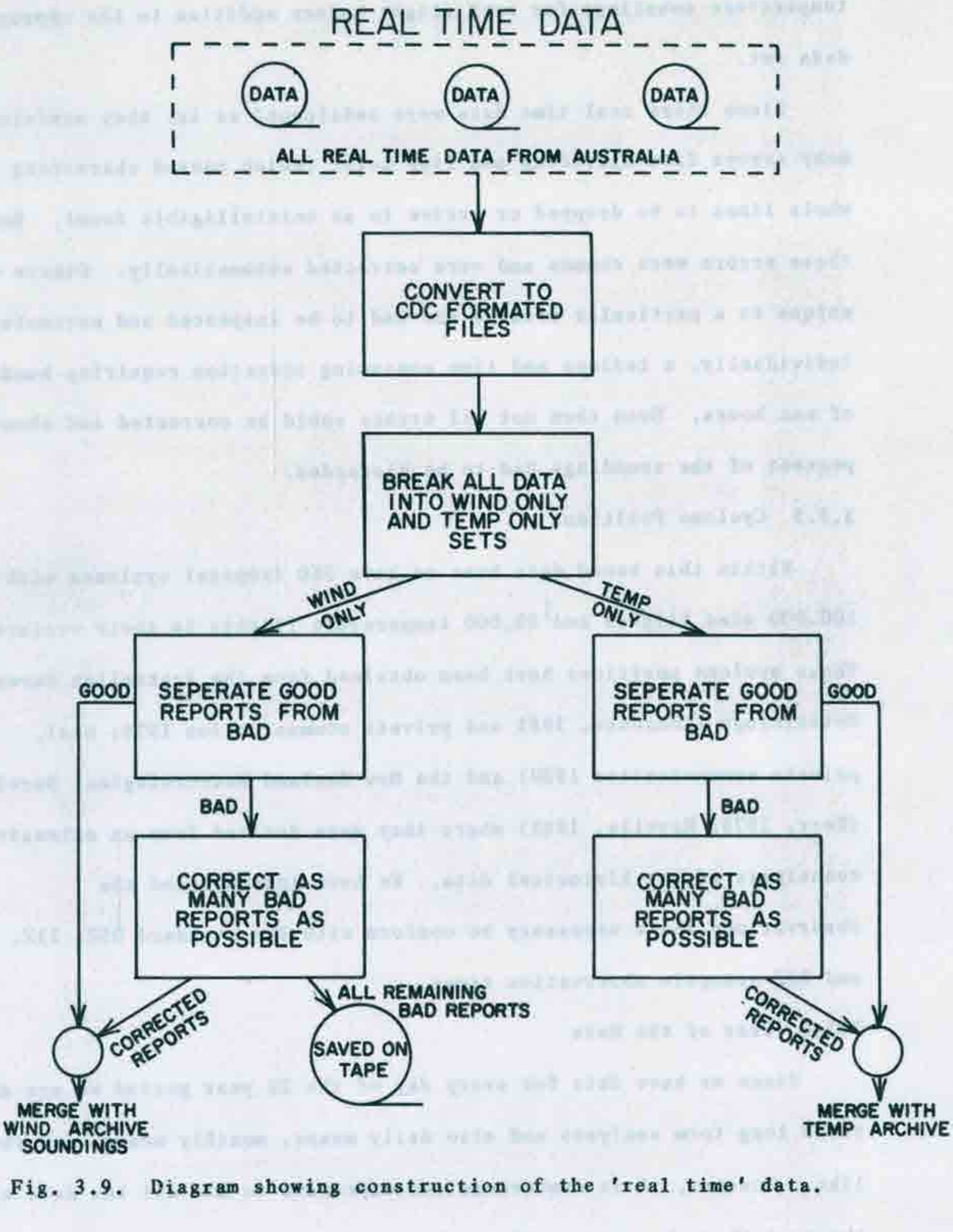

Fig. 3.9. Diagram showing construction of the 'real time' data.

that contains data for the whole atmosphere the messages had to be converted to a compatible format, then sorted to create complete wind or temperature soundings for each flight before addition to the appropriate data set.

Since these real time data were catalogued as is, they contained many errors from miscoding and line noise (which caused characters or whole lines to be dropped or arrive in an unintelligible form). Some of these errors were common and were corrected automatically. Others were unique to a particular message and had to be inspected and corrected individually, a tedious and time consuming operation requiring hundreds of man hours. Even then not all errors could be corrected and about 10 percent of the soundings had to be discarded.

3.3.5 Cyclone Positions

Within this broad data base we have 360 tropical cyclones with over 100,000 wind flights and 20,000 temperature flights in their vicinity. These cyclone positions have been obtained from the Australian Bureau of Meteorology (Lourensz, 1981 and private communication 1979; Neal, private communication 1980) and the New Zealand Meteorological Service (Kerr, 1976; Revelle, 1981) where they were derived from an extensive reanalysis of the historical data. We have interpolated the observations where necessary to conform with the standard 05Z, 11Z, 17Z and 23Z synoptic observation times.

3.3.6 Uses of the Data

Since we have data for every day of the 22 year period we are able to do long term analyses and also daily means, monthly means, and the like. However, it is cumbersome and expensive to use all the data at the same time, hence we employ only subsets of the data for our compositing work on specific research topics. Currently we have two such subsets. One set (SPMASTR) contains data for a period two days before cyclone genesis to two days after a cyclone has passed. The other subset contains data for use in performing cross-hemispheric studies of active and quiet tropical cyclone days.

3.4 Pacific Equatorial Region (1972-1977)

We have recently constructed a Pacific Equatorial data set to aid in cross-hemispheric studies of cyclone related phenomena. This data set consists of the 38 stations shown in Fig. 3.10 and listed in detail in Table 3.5. The set covers the period from 1972 to 1977, and contains approximately 135,000 soundings. The data set is a combination of data from time series RAOBS at NCAR and the southwest Pacific/Australian 'wind-only' data, and contains wind fields only for the 18 levels in the southwest Pacific/Australian region discussed in Section 3.3.2.

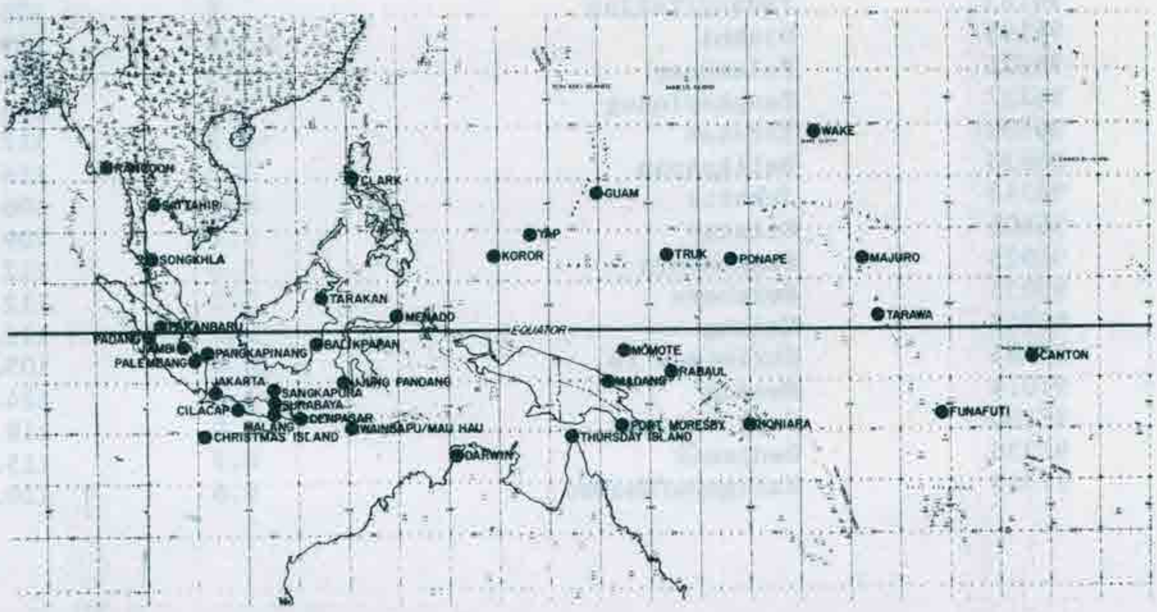

Fig. 3.10. Map showing the locations of the 38 stations in the Pacific Equatorial data set for the period 1972-1977. Only winds are available for the stations.

TABLE 3.5

DETAILED LISTING OF PACIFIC EQUATORIAL DATA STATIONS

Station Number	Station Name	Latitude	Longitude
48097	Rangoon	16.4	96.10
48477	Sattahip	12.4	100.59
48568	Songkhla	7.1	100.36
91217	Guam	13.3	144.50
91245	Wake	19.2	166.39
91327	Clark	15.1	120.34
91334	Truk	7.3	151.51
91348	Ponape	6.6	158.13
91376	Majuro	7.1	171.23
91408	Koror	7.2	134.29
91413	Yap	9.3	138.05
91517	Honiara	9.4	159.97
91610	Tarawa	-1.3	172.92
91643	Funafuti	8.5	179.22
91700	Canton	2.7	188.28
94014	Madang	5.2	145.80
94035	Port Moresby	9.4	147.22
94044	Momote	2.0	147.33
94085	Rabaul	4.2	152.18
94120	Darwin	12.4	130.87
94175	Thursday Is.	10.5	142.22
96109	Pakanbaru	-.4	101.45
96163	Padang/Tabing	.8	100.35
96195	Djambi	1.6	103.65
96221	Palembang	2.9	104.70
96237	Pangkapinang	2.1	106.13
96509	Tarakan	-3.3	117.57
96633	Balikpapan	1.2	116.90
96743	Jakarta	6.1	106.85
96805	Cilacap	7.7	109.02
96925	Sankkapura	5.8	112.63
96933	Surabaya	7.2	112.72
96747	Malang	7.9	112.70
96995	Christmas Is.	10.4	105.67
97014	Manado	-1.5	124.92
97180	Jung Pandang	5.0	119.55
97230	Denpasar	8.7	115.17
97340	Waingapu/MauHau	9.6	120.33

The process for building this data set is shown in Fig. 3.11. All the data have been chronologically sorted by date, hour, and station, broken into months and archived on tape.

3.5 Future Development of Regional Data Sets

3.5.1 West Indies/North American Region

Since we now have data from all available stations in the West Indies region future development of this region will consist of gathering the data for more recent years and adding it to our sample.

We are also planning to expand our U.S. Canadian network so that we can treat middle latitude cyclone systems, meso-systems, Meso-scale Convective Complexes (MCC's), frontal systems, etc. over the U.S. The rawinsonde data to the southeast of the solid line in Fig. 3.12 we already have available for all days for a 21 year period. The data to the northwest of this line have to be incorporated into our general network.

3.5.2 Northwest Pacific Region

This is currently our weakest data set and the one which we most want to improve. Future plans include getting a continuous daily period of soundings from 1957 through the present for as many stations as possible. We are currently in the process of acquiring 15-20 years of rawinsonde observations for the 11 Chinese coastal stations shown in Fig. 3.13 (courtesy of the Chinese government). We are also planning to receive data from the five Taiwan stations shown in Fig. 3.15. We will also receive a continuous 20 year period of rawinsonde data for Hong Kong. For later years we plan to integrate the Northern Hemisphere stations within the southeast Asia area which are available in the Australian 'real time' data into the sample. We also plan to purchase

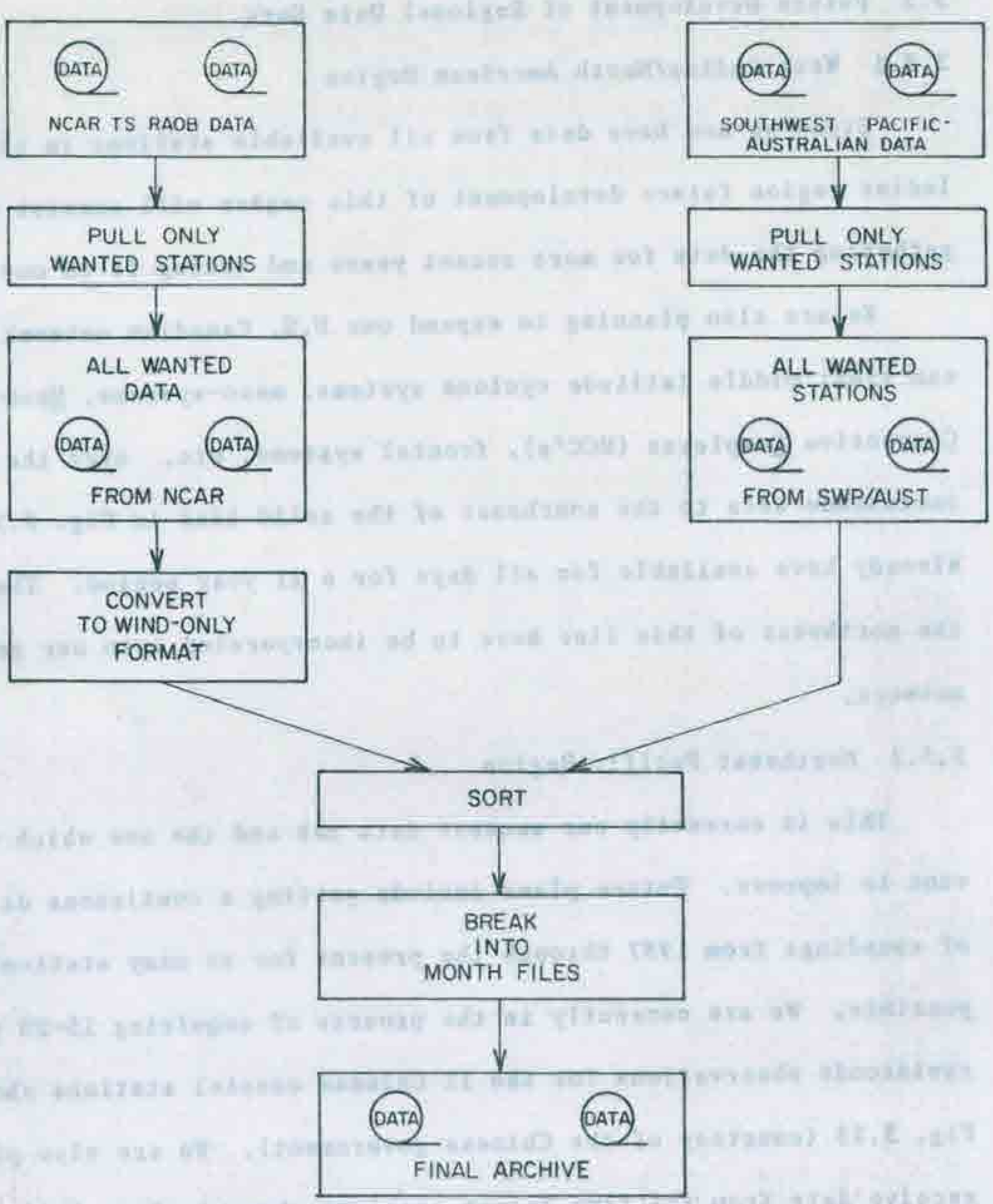

Fig. 3.11. Diagram showing the overall procedure used in building the Pacific Equatorial data set.

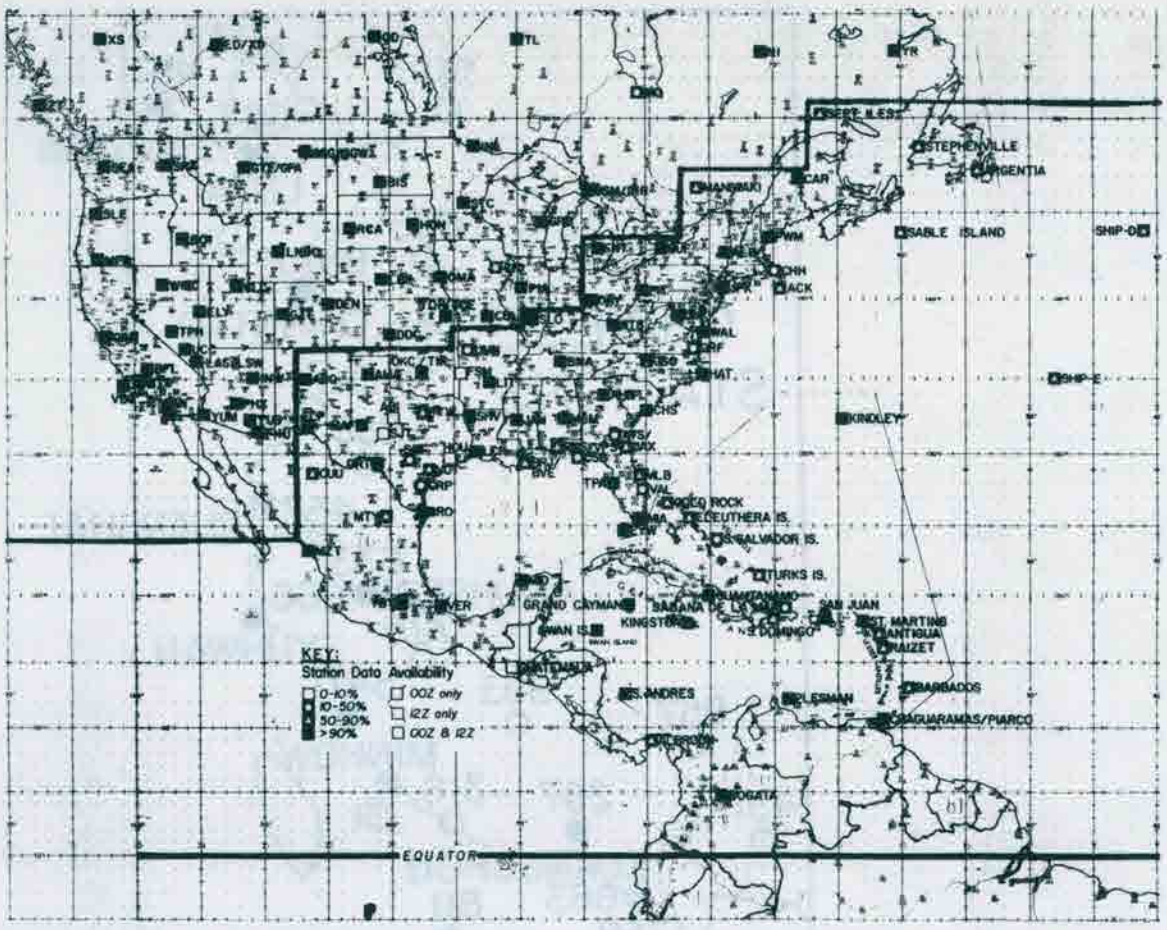

Fig. 3.12. Map showing locations of the US and Canadian stations above the solid line to be incorporated into our network.

special southeast China data from the Hong Kong Royal Observatory. The frequency of tropical cyclones off the South China coast and in the Taiwan area is the highest in the globe (see Fig. 3.14).

In cooperation with NEPRF we are having more of the Japanese soundings punched for 1957-1960 and 1971-1977. Due to the reluctance of the Japanese to place their upper air data onto magnetic tape it appears that we will never be able to obtain a daily record for these Japanese stations. It is just too expensive for our project to obtain and punch such a large number of data.

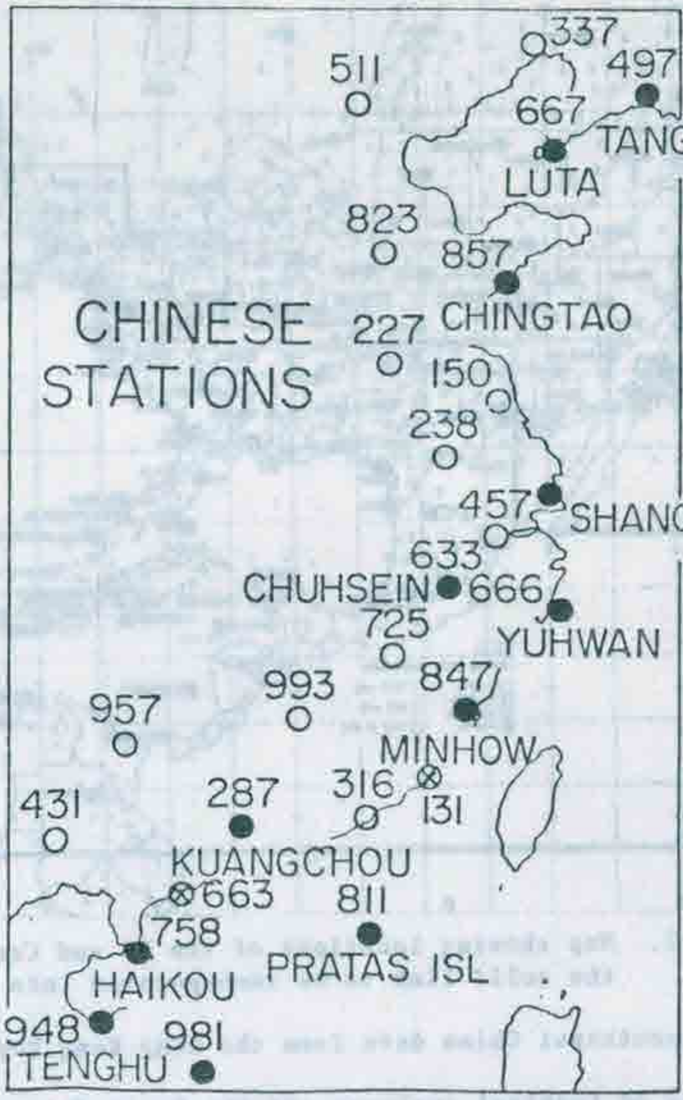

Fig. 3.13. Chinese rawinsonde stations (solid dots) which are being supplied to our CSU project as a special favor of the National Meteorological Center of China during 1982. 15-20 years of data around tropical cyclone days are being made available. The open circle stations will be made available at a later date.

It is anticipated that this newer Japanese rawinsonde data, the Chinese and Taiwan rawinsonde stations, and the other auxillary SE Asia data sets (see the stations marked with and X in Fig. 3.3) will be integrated into our archive by the end of 1982 or early 1983. This will give us 21 years of rawinsonde data instead of the 10 years which we

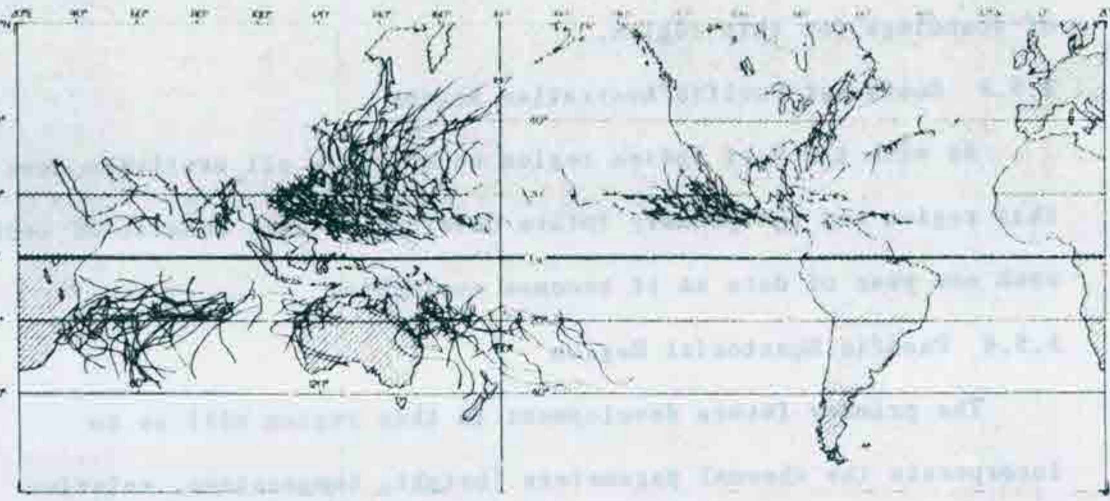

Fig. 3.14. The tracks of tropical cyclones for a 3-year period during the late 1970's.

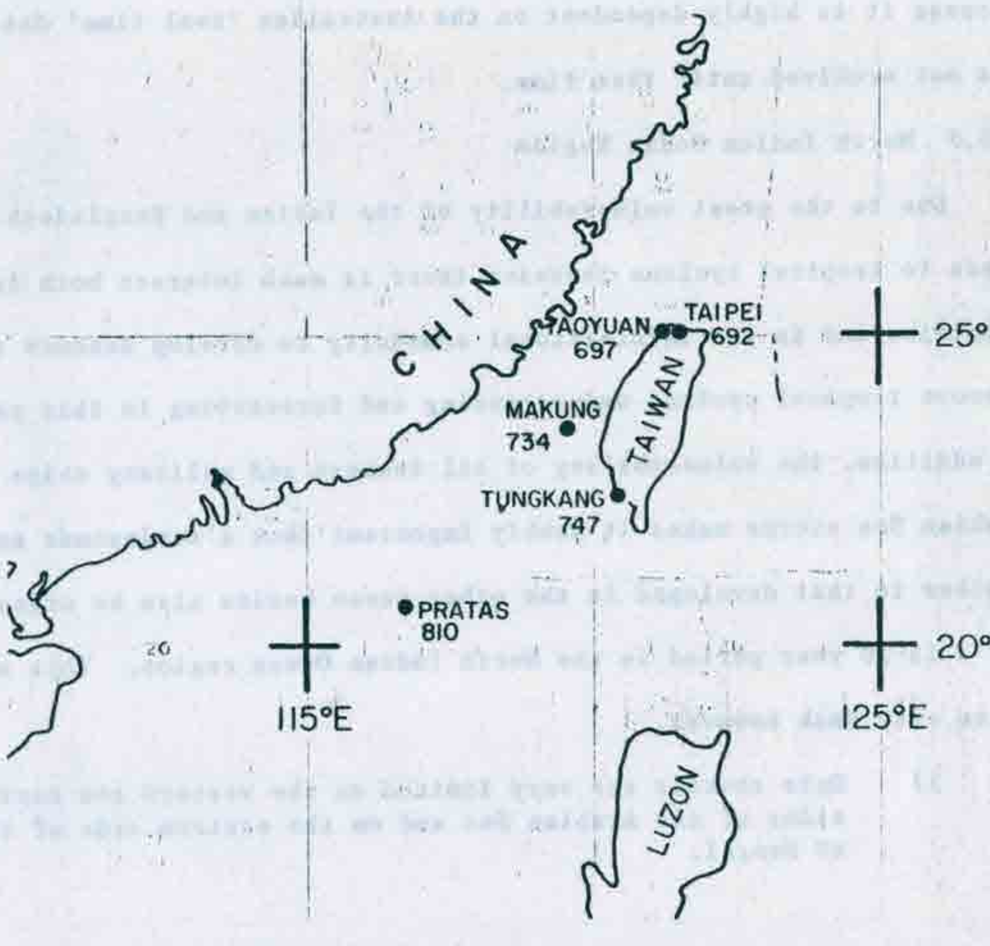

Fig. 3.15. Map of radiosonde stations from Taiwan that we will be receiving.

presently have and increase by approximately 5 times the current number of soundings for this region.

3.5.3 Southwest Pacific/Australian Region

As with the West Indies region we now have all available data for this region and the primary future development will consist of adding each new year of data as it becomes available.

3.5.4 Pacific Equatorial Region

The primary future development in this region will be to incorporate the thermal parameters (height, temperature, relative humidity) into this sample. We will also add the data for later years, but the sample will probably never be expanded to a period prior to 1972 because it is highly dependent on the Australian 'real time' data which was not archived until that time.

3.5.5 North Indian Ocean Region

Due to the great vulnerability of the Indian and Bangladesh coast lines to tropical cyclone invasion there is much interest both in these countries and in the international community to develop schemes to improve tropical cyclone understanding and forecasting in this region. In addition, the vulnerability of oil tankers and military ships to Arabian Sea storms makes it doubly important that a rawinsonde network similar to that developed in the other ocean basins also be organized for a 15-20 year period in the North Indian Ocean region. This will not be an easy task however.

1) Data sources are very limited on the western and northern sides of the Arabian Sea and on the eastern side of the Bay of Bengal.

2) India has been slow at putting its rawinsonde data onto magnetic tape. This is the pivotal country. Without data tape information from this country, a worthwhile rawinsonde composite for this region cannot be made.

3) For a complete data set, rawinsonde and pibal information from a number of other countries besides India must be obtained such as: Burma, Thailand, Malaysia, Indonesia, Pakistan, United Kingdom stations on the southeast Arabian peninsula, Somalia, Kenya, Tanzania, Seychelles, and Diego Garcia (see the map of this region's upper air stations given in Fig. 3.16). Obtaining upper air data from all of these countries will be a most difficult task.

Despite the above problems, it appears that it will be possible to build a reasonably adequate data network for this region in the next few years. The authors have recently learned that many years of Indian upper air data have been put onto magnetic tape and that much of this upper air data will soon become available at NCAR. It is planned that through the combined meteorological archive facilities at NCAR; the NOAA Meteorological Library, Washington, DC; National Climatic Center, Asheville, NC; British Meteorological Office, Bracknell; Australia Bureau of Meteorology, Melbourne; through writing directly to the foreign countries involved for their data, through the selective interception of this region's data off the GTS tapes, and/or through the laborious copying of upper-air and surface data off microfilmed copies of analyzed weather maps that sufficient North Indian Ocean data can be assembled for a 15-20 year period to make composite analysis feasible and worthwhile for this region.

A favorable circumstance with regard to the building of this data set is the fact that tropical cyclones are not frequent events in this region and data do not have to be gathered for all time periods (although this is highly desirable) but only at time periods a few days

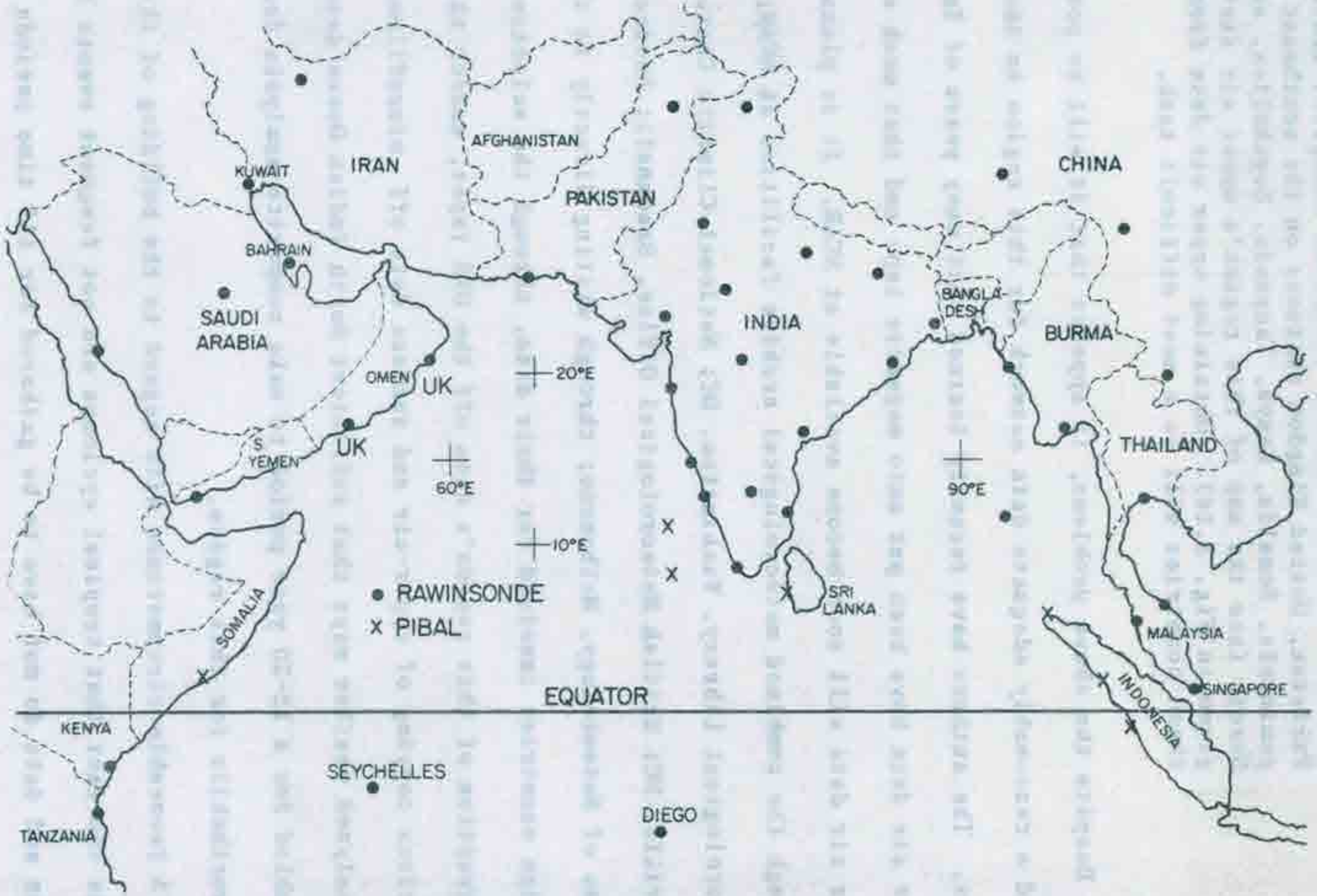

Fig. 3.16. North Indian Ocean upper-air data network and the many associated political units involved.

before, during, and after a storm event or a potential storm event has occurred. This makes the copying of needed data off of weather maps and the obtaining of necessary data from foreign countries, or the selective interception of this region's data off of the stored GTS data tapes (currently at NCAR) much less of a prohibitive task.

From a variety of points-of-view, it is important that some group take on the task of organizing such a North Indian Ocean tropical cyclone data network. It is hoped that resources become available to our group at CSU so that we might take on this task.

3.5.6 Southwest Indian Ocean Upper Air Storm Data Set

Our project is also in a position to develop a south Indian Ocean tropical cyclone data set from the stations in Fig. 3.17 if interest in the development of such a network were expressed by the WMO and if resources were available. This is the last of the global tropical cyclone ocean basins for which upper air data are available. The lack of upper air stations in the northeast Pacific precludes the building of a rawinsonde network in that area.

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McBride, J. L. and T. D. Keenan, 1982: Climatology of tropical cyclone genesis in the Australian region. To appear in J. Climat.

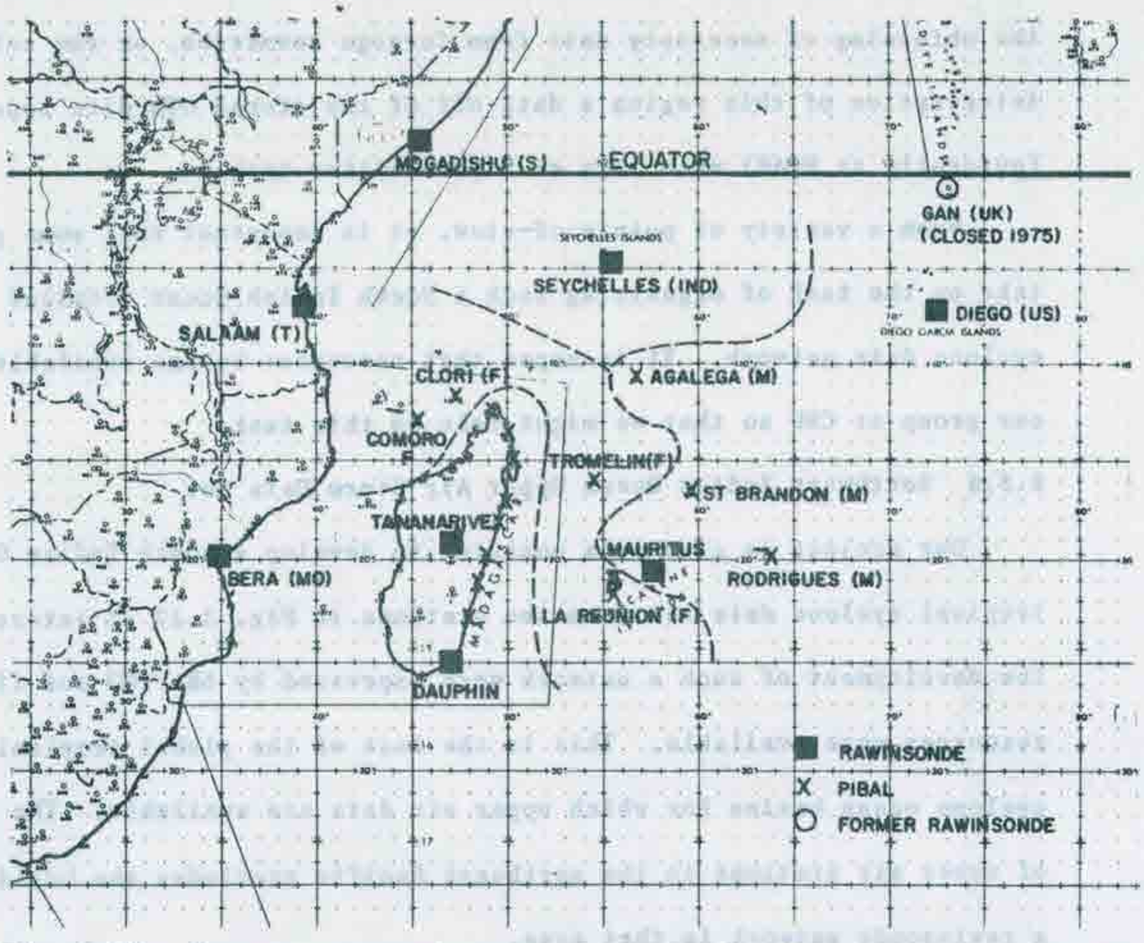

Fig. 3.17. Current upper-air network in the South Indian Ocean and the countries involved.

References (cont'd)

Neal, A. B. and G. J. Holland, 1978: The Australian Tropical Cyclone Forecasting Manual. Australian Bureau of Meteorology, Melbourne, 274 pp.

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4. COMPUTER ACCESS AND COMPUTER SYSTEMS USED

4.1 Introduction

All computer runs are initiated directly from the Colorado State University (CSU) Department of Atmospheric Science (ATMOS). The jobs are either submitted in a batch mode or run interactively. We have the ability to submit jobs in a batch mode to two mainframes on the central CSU campus or two mainframes at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, but interactive access is currently only available to the two mainframes on the CSU campus. A schematic of our computer systems and the access capabilities is shown in Fig. 4.1.

4.2 ATMOS Batch Entry System

The ATMOS batch entry system is based on a Digital Equipment Corporation PDP 11/34A mini-computer. This system is configured with 128K bytes of main memory, a 2K high speed cache memory (high speed random access), 2-5 megabyte disk drives, 2 synchronous line interfaces, 1-8 line asynchronous interface, 3-VT 100 CRT's, a 600 card per minute card reader, 1-300 line per minute printer, and 1-600 line per minute printer as shown in Figs. 4.2 and 4.3.

This system allows for simultaneous communications with both CSU main campus computers and both NCAR computers. Two of the VT-100's are used to initiate input/output from CSU and the other is used to initiate input/output with NCAR. At CSU access to the two mainframes is direct from the 11/34 to the particular mainframe through the CSU Modular Computer Corp. (MODCOMP) computer. At NCAR access to the two mainframes

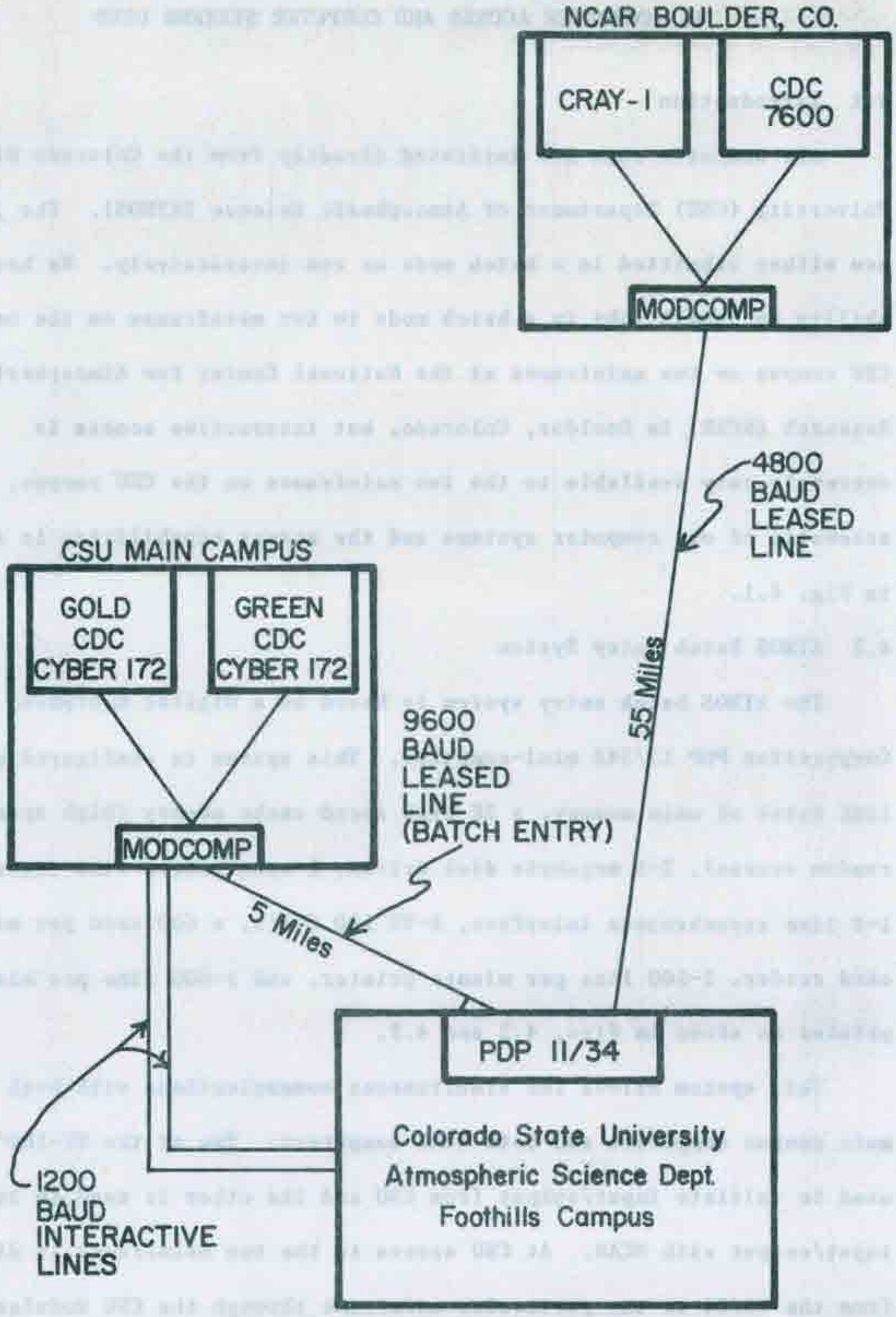

Fig. 4.1. Schematic showing available computer systems and access capabilities.

Fig. 4.2. Picture showing PDP 11/34, 3-VT 100 CRT's and 600 card per minute reader on ATMOS system.

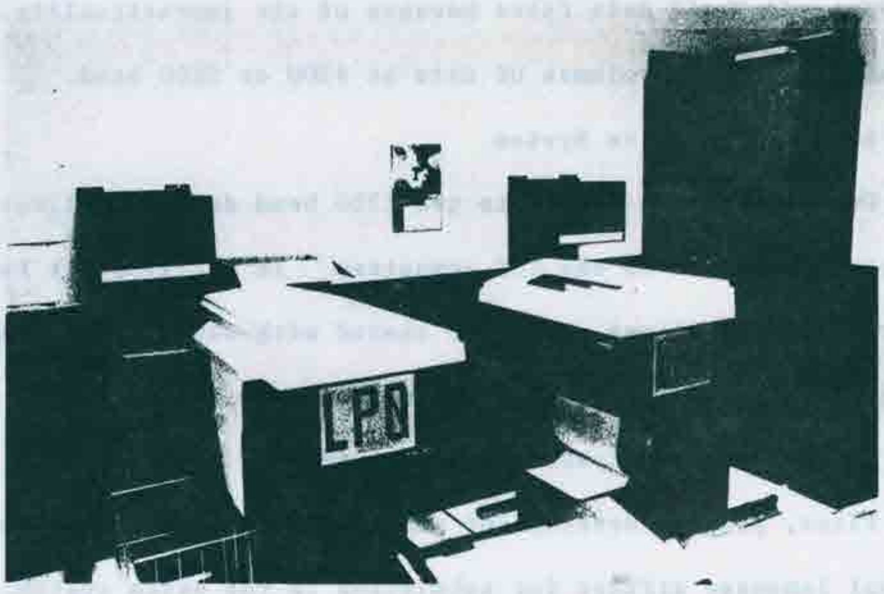

Fig. 4.3. Picture showing the 300 line per minute and 600 line per minute printers on the ATMOS PDP 11/34.

is through the NCAR MODCOMP. All input and output is routed to or from the MODCOMP to the necessary mainframe.

Input from cards or disk is performed by initiating a read operation from the proper VT100 on the 11/34. Output from the sites is 'spooled' to the disk on the 11/34 and then printed. This allows output to be received from all 3 sites simultaneously. The output from disk can then be printed on a first-in first-out basis or on priorities assigned internally.

The 11/34 is also used to transfer programs and small amounts of data between NCAR and CSU or vice versa. The output (program or data) from a site is stored on the 11/34 disk, edited with the proper control cards, and then sent on to the other site. This is only used for programs and small data files because of the impracticality of transmitting large volumes of data at 4800 or 9600 baud.

4.3 ATMOS Interactive System

Our project has access to two 1200 baud dedicated lines for interactive access to the CSU computers. In addition, we have access to several 300 baud lines which are shared with other users. Access to the CSU gold or green system is selected at login time by code.

The interactive system is used primarily for real-time editing of data files, program development and editing, and preparation of job control language strings for submission to the batch system. Few programs are executed interactively because there is a 50% surcharge over batch execution. Programs or job control strings can be submitted for batch processing with the output returned to the batch 11/34. Any output coming to the interactive terminal can also be routed to the 11/34 if a hard copy is needed.

4.4 CSU Computer Systems

The two CSU mainframes are identical CONTROL DATA CORPORATION (CDC) CYBER 172/720 computers with $131{,}072_{10}$ 60 bit words of central memory. The difference between the two systems is their basic function and the configuration of peripherals on the systems. The GOLD machine serves the needs of commercial accounts and sponsored research, and the GREEN machine serves administrative needs, classroom usage and unsponsored research.

The GOLD system is configured with 1-7 track tape drive, 3-9 track 1600 BPI tape drives, 5 quad density disc units (fixed pack 1.2 billion) characters/unit), and 2 dual density disc drives (removable pack 238 million characters/unit) which belong to ATMOS. The GREEN system is configured with 1-7 track tape drive, 2-9 track 1600 BPI tape drives, and 3 quad density disc drives. In addition, the systems share a card reader, a card punch, 1-1200 line per minute printer, 2-1000 line per minute printers, and 2-9 track 6250 BPI tape drives. Any output from ATMOS can be routed to the main site printer for special forms or large jobs that we do not want to print in-house.

4.4.1 Magnetic Tape and Disk Storage Usage

As we described earlier, CSU provides us with two kinds of storage for our data sets. First, we have magnetic tape drives which allow us to read or write 7 and 9 track tapes in 556 BPI to 6250 BPI. Secondly, we have two CDC 844/41 removeable disk drives which belong to ATMOS. Using these disk drives allows us to store ten or more tapes on a disk pack. We have very good reliability in retrieving the data which is not always true with magnetic tape. Also, by using these disks, access to the data is much faster thus decreasing the execution time of a program.

Once a data set has been completed, it is put onto disk pack and backed up on magnetic tape. Because these data sets are quite large, as shown in Table 4.1, it becomes very impractical to use all the data in a particular program. Therefore, given various criteria, usually in the form of dates, the larger data sets can be subdivided into much smaller versions which can easily be handled in the compositing programs. These smaller versions are also maintained on the removeable disk packs for reasons of reliability and speed of execution. Figure 4.4 shows some of the 1200 computer tapes belonging to our project.

TABLE 4.1

Data Set	Number of Tapes/ Type of Tapes	Number of Soundings
West Indies	21/9 track 1600 BPI	1.5 million
South Pacific/Australia	10/9 track 1600 BPI	2.0 million
Northwest Pacific	2/7 track 800 BPI	.018 million
GATE	4/7 track 800 BPI	.005 million

4.5 NCAR Computer Systems

NCAR has a CDC 7600 and a CRAY-1 which are used for certain segments of our research. The 7600 is used primarily for the acquisition of rawinsonde and hemispheric data, and the smoothing of some of our composited data fields. The CRAY-1 is used primarily for our numerical modelling efforts on tropical storms.

The 7600 is configured with $65K_{10}$ 60-bit words of small core memory, $512K_{10}$ 60-bit words of large core memory, 8 disk drives (2.5 billion bits/drive), 2-7 track tape drives, and 5-9 track tape drives. The CRAY-1 is configured with $1,048,576_{10}$ 64-bit words and 16 disk drives (2.4 billion bits/drive). NCAR also has an AMPEX TERABIT MEMORY SYSTEM/TMS-4) which is used for data storage. The TMS-4 has the capacity of approximately 150,000 computer tapes and provides very high speed random access to the data.

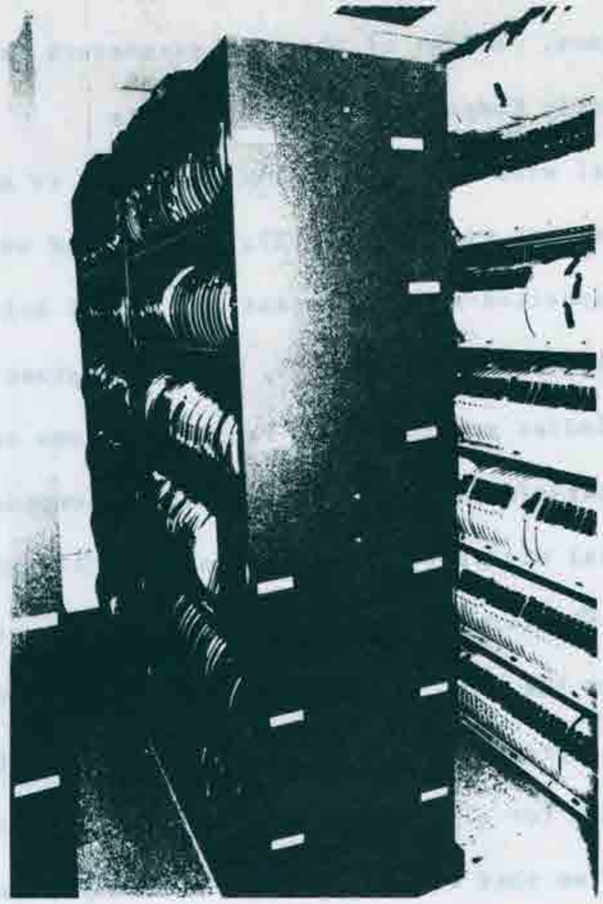

Fig. 4.4. Some of the 1200 data tapes belonging to our project.

5. STANDARD PARAMETERS CALCULATED AND OUTPUT FORMATS

5.1 Cylindrical Composites

5.1.1 Wind Parameters

The wind parameters are divided into two groups: those directly measured and composited and those parameters derived from the directly measured values. A list of the wind parameters is given in Table 5.1.

5.1.1a Directly Composited Wind Parameters

The zonal wind (u or U), meridional wind (v or V), radial wind (V_r or VR), tangential wind (V_θ or VT), radial wind with moisture ($V_r(q)$ or VRQC) are composited at each octant for radial belts of 0-1, 1-3, 3-5, 5-7, 7-9, 9-11, 11-13, 13-15, 2-4, and 4-6 degrees for each of 21 levels in the West Indies and northwest Pacific regions or 18 levels in the southwest Pacific/Australian region. The u-component, v-component, and moisture radial wind are calculated for the NAT and MOT systems as discussed in Chapter 2. The radial wind and tangential wind are calculated for the NAT, MOT, ROT and MOTROT systems. The radial wind with moisture parameter is the radial wind calculated only when there is also a moisture (or q value) in the sounding. This separate parameter is calculated so that we have a simultaneously mass-balanced wind profile when the radial moisture flux calculations are made.

The data for each individual level are output in the form shown in Fig. 5.1. The header information on the first line is the pressure level, average NAT latitude, average NAT longitude, average ROT latitude, average ROT longitude, average direction from which the storm moves and its speed, and average storm linear speed. The second line contains a label that identifies the stratification. For each parameter the octant means (octant 1 top of column, octant 8 bottom of column) are

TABLE 5.1

Wind Parameters

DIRECTLY CALCULATED PARAMETERS

NAT	MOT	ROT	MOTROT
Zonal Wind (u)	Zonal Wind (u_r)		
Meridional Wind (v)	Meridional Wind (v_r)		
Radial Wind when Moisture is Available ($V_r(q)$)	Radial Wind when Moisture is Available ($V_{rr}(q)$)		
Radial Wind (V_r)	Radial Wind (V_{rr})	Radial Wind (V_r)	Radial Wind (V_{rr})
Tangential Wind (V_θ)	Tangential Wind ($V_{\theta r}$)	Tangential Wind (V_θ)	Tangential Wind ($V_{\theta r}$)

SOME DERIVED QUANTITIES

NAT	MOT
Divergence (DIV)	Divergence (DIV)
Vertical Velocity (ω)	Vertical Velocity (ω)
Relative Vorticity (VOR)	Relative Vorticity (VOR)
Radial Flux of Angular Momentum ($R^2/2\ fV_R$)	Radial Flux of Angular Momentum ($R^2/2\ fV_R$)

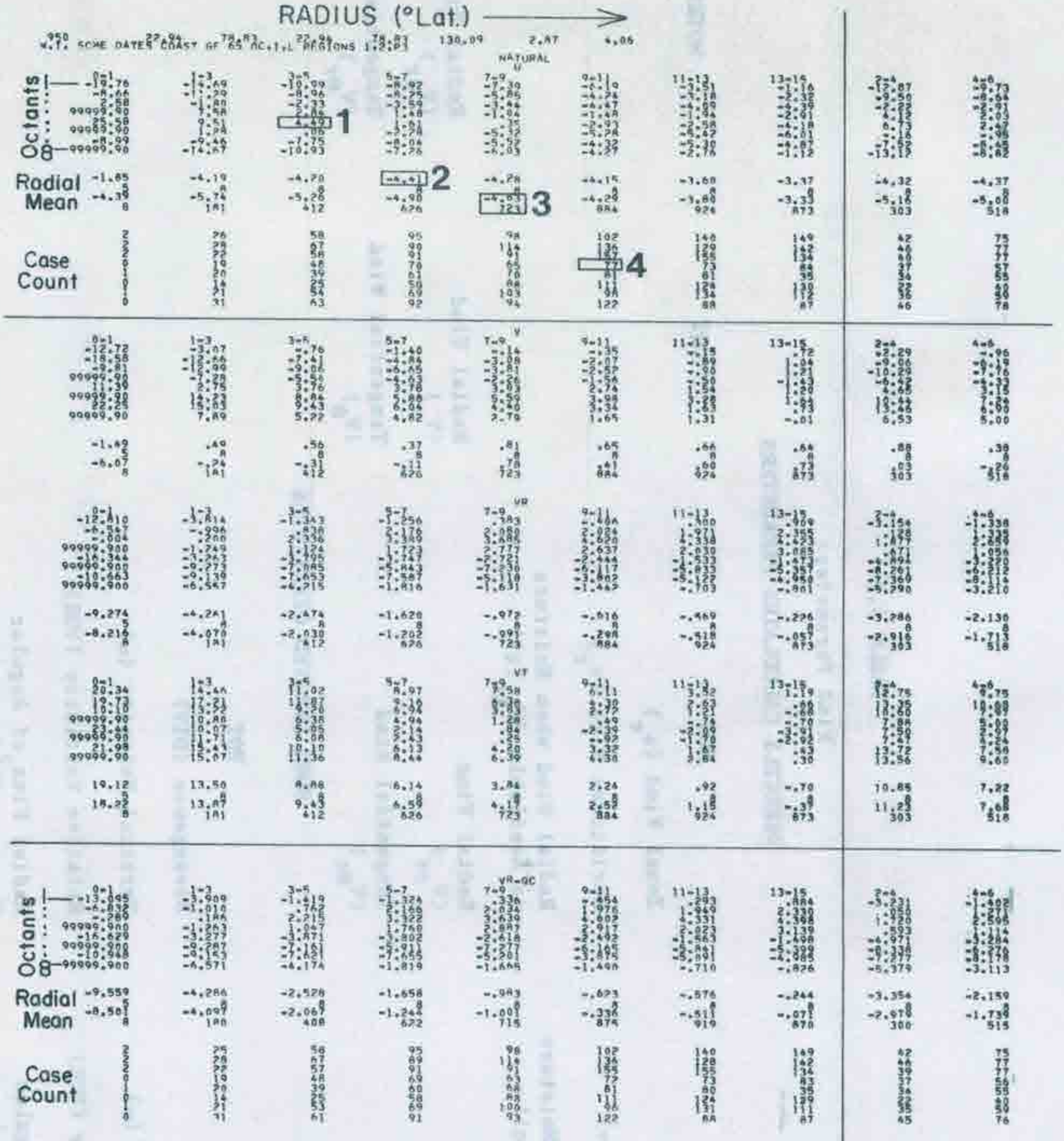

Fig. 5.1. Form of the standard wind output for a single level (950 mb) of a cylindrical composite. The NAT coordinate u component for octant 5 in the 3-5° radial belt denoted ☐1 is 4.49 m/s. The belt mean for 5-7° radius based on the 8 octant means denoted ☐2 is -4.41 m/s. The belt mean fo 7-9° radius based on the 723 individual soundings mean denoted ☐3 is -4.63 m/s. The number of soundings in octant 4 for 9-11° radius denoted ☐4 is 77.

displayed in each radial belt as well as a belt mean based on the average of all the octant means. In addition, a belt mean based on the average of all individual soundings in the radial belt is displayed. The case counts (number of soundings) are displayed for each octant and each belt. For example, in Fig. 5.1 the NAT coordinate zonal wind (U) in octant 5 in the 3-5^{o} radial belt denoted □ 1 is 4.49 m/s. The belt mean for 5-7^{o} radius based on the 8 octant means denoted □ 2 is -4.41 m/s. The belt mean for 7-9^{o} radius based on the 723 individual soundings mean denoted □ 3 is -4.63 m/s. The number of soundings in octant 4 for 9-11^{o} radius denoted □ 4 is 77.

All parameters are also displayed in a vertical summary by belt in the form shown in Fig. 5.2. The 950 mb 5-7^{o} radius value of -4.4 m/s denoted □ 1 is the same value denoted by □ 2 in Fig. 5.1. Parameters are also displayed for analysis by level in a cylindrical plan view as shown in Fig. 5.3. The octant 5 3-5^{o} radius value of 4.49 m/s is the same value denoted by □ 1 in Fig. 5.1. The 2-4 and 4-6 degree radial bands are not displayed in these plan views. The column of values in the lower left of the figure are the values for the 0-1 degree belt, and the column of values in the lower right are the belt average values. The value for the 5-7^{o} radial belt (belt average 4) of -4.41 m/s is the same as the value denoted □ 2 in Fig. 5.1.

The data are also displayed for each parameter in a vertical cross-section for the front (north), back (south), left (west) and right (east) side of the storm as shown in Figs. 5.4 and 5.5. For example, in Fig. 5.4 the 600 mb front tangential wind for 6^{o} (5-7) radius denoted □ 1 is 4.25 m/s. The 600 mb back tangential wind for 6^{o} (5-7) radius denoted □ 2 is .76 m/s. In Fig. 5.5 the 600 mb left tangential wind

Pressure (mb)	0-1	1-3	3-5	5-7	7-9	9-11	11-13	13-15	2-4	4-6
	RADIUS (°Lat.) →						NATURAL U			
50	-14.7	-9.8	-10.4	-10.2	-10.0	-9.6	-8.4	-8.7	-10.1	-10.2
70	-15.5	-8.2	-8.2	-7.7	-7.4	-6.9	-6.3	-6.0	-8.6	-7.6
80	-10.5	-7.3	-6.8	-6.2	-5.9	-5.5	-4.7	-4.3	-7.1	-6.5
100	-9.0	-3.3	-3.5	-3.4	-3.1	-2.8	-1.3	-1.3	-3.4	-3.4
125	-6.8	.2	.8	.5	.3	.2	1.0	.9	1.0	.7
150	-.7	1.0	2.6	3.4	2.8	2.7	3.0	2.9	2.1	3.4
175	-1.1	.3	2.5	4.2	3.7	4.3	4.3	4.2	1.6	3.8
200	-3.3	.3	2.2	4.1	3.7	4.1	4.4	4.6	1.5	3.5
250	-2.2	-.1	1.6	2.8	3.0	3.3	3.5	3.8	.9	2.5
300	-1.6	.1	.9	1.7	2.5	2.2	2.8	3.0	.4	1.5
350	-4.3	-.1	-.0	1.0	1.7	1.5	2.0	2.2	-.1	.5
400	-6.9	-.7	-.7	.2	.9	.7	1.3	1.3	-.8	-.2
500	-5.4	-1.3	-1.2	-1.0	-.3	-.3	.5	.2	-1.3	-1.2
600	-6.9	-2.4	-1.9	-1.6	-1.1	-1.3	-.4	-.6	-2.1	-2.0
700	-7.9	-3.6	-2.5	-2.3	-1.8	-2.0	-1.2	-1.3	-2.8	-2.5
800	-8.6	-4.4	-3.4	-2.9	-2.6	-2.6	-2.0	-2.1	-3.8	-3.3
850	-8.9	-4.9	-3.9	-3.6	-3.3	-3.1	-2.6	-2.5	-4.3	-3.9
900	-7.5	-5.0	-4.2	-4.1	-3.8	-3.8	-3.2	-3.0	-4.4	-4.3
950	-4.4	-4.2	-4.2	-4.4 1	-4.3	-4.1	-3.6	-3.4	-4.3	-4.4
1000	-3.1	-2.3	-2.8	-2.8	-3.1	-3.0	-2.7	-2.6	-2.8	-2.8
1013	-1.0	-1.9	-2.3	-2.0	-2.2	-2.1	-1.9	-2.1	-2.3	-2.1

Fig. 5.2. Vertical pressure summary by radial belt for NAT zonal or u component. The 950 mb 5-7° radius value of -4.4 m/s is denoted ☐1.

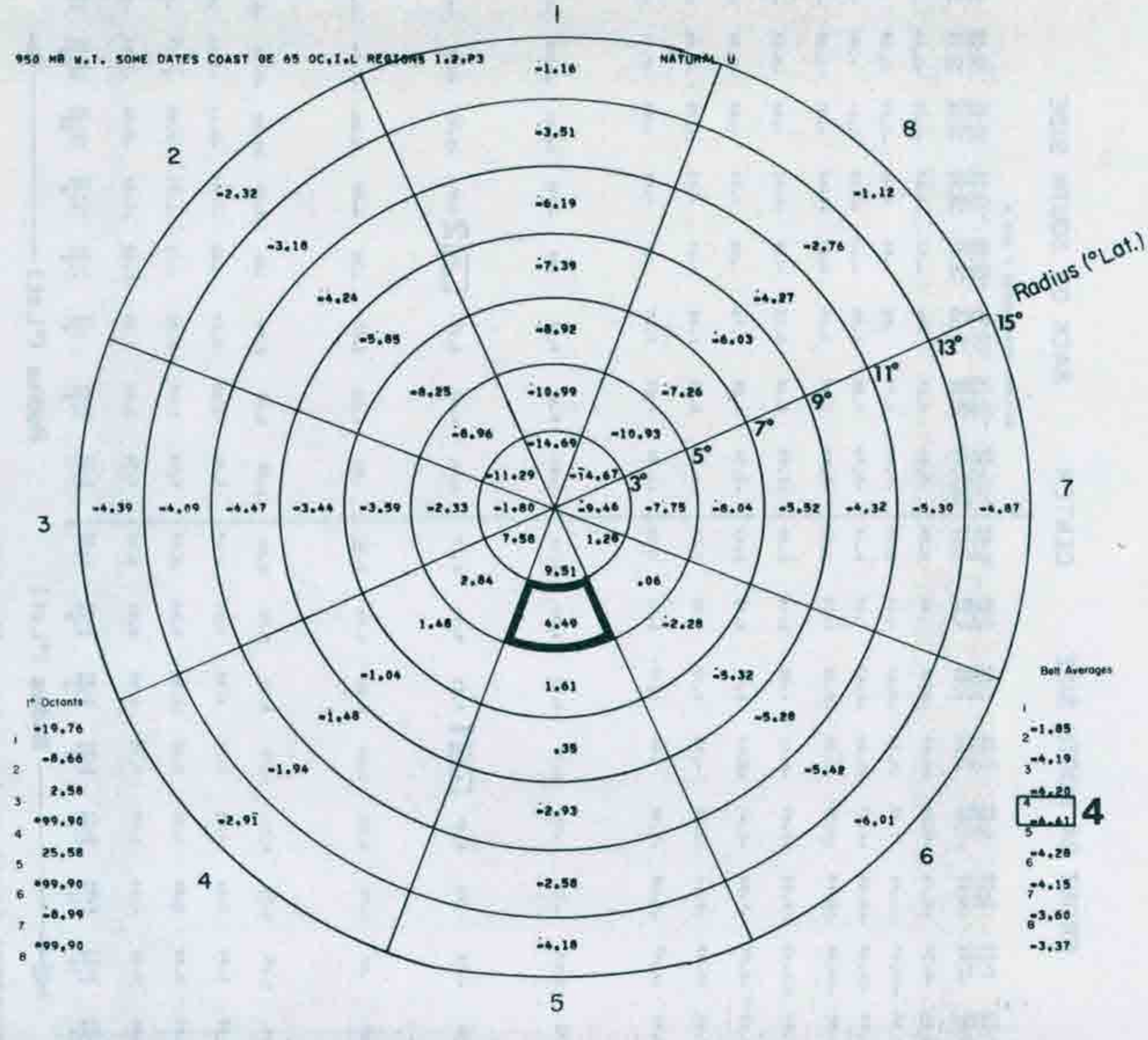

Fig. 5.3. Plan view of NAT u-component for a single level (950 mb) of a cylindrical composite. The octant 5 3-5^{o} radius value (outlined) is 4.49 m/s. The 5-7^{o} radial belt average (belt average 4 outlined in lower right) is -4.41 m/s.

Pressure (mb)	FRONT OR NORTH SIDE							CENTER		BACK OR SOUTH SIDE (NATURAL TANG PRESS F AND B)						
50	3.79	4.83	5.45	6.49	7.80	9.63	9.24	16.54	-11.79	-10.12	-10.90	-12.23	-11.01	-8.51	-7.86	-9.98
70	.48	1.49	2.48	3.68	4.99	6.98	6.31	8.72	-9.96	-6.43	-7.12	-8.40	-7.64	-6.62	-5.98	-7.62
80	-1.26	-.20	1.04	2.32	3.43	5.20	5.54	7.13	9999.90	-5.22	-4.72	-5.99	-5.91	-5.10	-4.52	-6.52
100	-5.91	-4.48	-3.91	-1.62	-.08	2.46	3.96	5.82	9999.90	-2.22	-.32	-3.15	-3.11	-2.86	-2.18	-2.04
125	-10.42	-9.18	-8.25	-5.90	-4.48	-2.22	.56	2.26	-5.81	2.08	.94	-.51	-1.47	-1.13	-1.59	-.30
150	-13.58	-12.67	-11.65	-7.85	-5.73	-3.54	-.16	2.80	-5.55	1.79	.82	-.50	-.92	-1.07	-1.37	-.39
175	-14.89	-14.08	-12.59	-8.17	-6.20	-2.53	.37	4.00	-5.72	1.56	1.98	-.43	-1.15	-1.14	-.97	-1.14
200	-14.81	-14.06	-12.28	-8.30	-5.38	-2.08	1.78	2.53	-2.68	1.99	1.49	-.67	-1.60	-.81	-1.38	-1.12
250	-12.90	-11.43	-10.53	-7.27	-4.11	-.50	2.16	4.34	-1.97	2.46	2.13	-.35	-1.41	-.46	-2.17	-1.43
300	-10.10	-8.27	-7.65	-5.48	-2.60	1.61	2.75	4.01	-3.74	3.28	1.70	.06	-.78	-.59	-2.38	-1.84
350	-7.66	-5.92	-5.14	-3.29	-.86	3.72	1.85	3.88	-4.11	3.53	1.45	.47	-.43	-.79	-2.49	-2.68
400	-5.84	-4.07	-3.19	-1.50	.84	4.71	3.11	1.53	-1.38	3.83	1.62	.29	-.48	-.97	-2.72	-3.76
500	-3.83	-1.99	-.78	.93	2.75	6.28	3.97	2.14	-.83	3.82	2.68	.68	-.46	-1.31	-2.68	-3.84
600	-1.84	-.73	.92	2.37	4.25 1	7.23	5.99	2.03	1.51	4.09	3.57	.76 2	-.44	-1.91	-3.27	-4.35
700	-.80	.02	1.79	3.33	5.42	8.25	6.52	3.39	.56	4.05	3.07	.33	-.87	-1.66	-3.18	-4.38
800	.01	1.25	2.71	4.25	6.79	8.92	7.70	3.88	1.32	3.66	2.94	.01	-1.38	-1.93	-3.15	-4.82
850	.89	1.96	3.61	4.92	7.39	9.96	8.63	4.07	2.91	3.88	2.47	-.40	-1.60	-2.40	-3.08	-5.11
900	1.55	3.02	3.99	5.31	7.98	10.38	9.50	3.87	4.24	3.55	1.97	-.74	-1.84	-2.59	-3.27	-5.83
950	2.06	3.61	4.20	5.57	7.38	8.95	8.84	2.88	4.76	2.91	1.18	-1.02	-1.87	-2.76	-3.51	-5.83
1000	2.26	2.73	2.99	3.71	4.86	5.39	5.39	1.58	3.33	2.08	.19	-.76	-1.18	-2.15	-2.62	-4.32
1013	1.46	1.78	1.93	2.52	3.80	3.94	4.28	1.75	2.57	1.78	.07	-.61	-.80	-1.55	-2.12	-3.99
Radius (°Lat.)	14	12	10	8	6	4	2	0		2	4	6	8	10	12	14

← Radius (°Lat.)   Radius (°Lat.) →

Fig. 5.4. Vertical pressure cross-section by radius of tangential wind (m/s) for front (octants 2,1,8) and back (octants 4,5,6) quadrants. For instance, the 600 mb front 6^{o} $(5-7^{o})$ radius value denoted □1 is 4.25 m/s. The 600 mb back 6^{o} $(5-7^{o})$ radius value denoted □2 is .76 m/s.

NATURAL TANG PRESS L AND R

Pressure (mb)	LEFT OR WEST SIDE				LEFT			CENTER		RIGHT		RIGHT OR EAST SIDE				
50	-.23	-.34	-.55	-.60	.79	.23	.65	9999.90	-.61	.83	-.36	-.81	-.81	-.06	-1.55	-.37
70	-.09	-.17	-.36	.31	.22	.69	1.30	-3.63	.39	.04	.06	-1.37	-1.30	-2.18	-1.97	-2.03
80	-.03	.28	.07	.56	.81	.86	2.01	-.39	-.98	-.37	-1.06	-1.67	-1.20	-2.13	-2.27	-2.95
100	.39	.93	.77	.76	2.35	.99	2.57	2.87	9999.90	-.44	-1.08	-2.74	-3.41	-4.09	-4.43	-4.69
125	.53	2.06	1.71	1.67	2.27	.60	1.16	.90	.08	-1.65	-2.16	-4.95	-7.04	-7.23	-7.61	-7.84
150	.22	2.78	2.49	2.07	1.85	.45	.23	-1.86	2.12	-.83	-2.96	-4.96	-7.84	-8.91	-9.59	-10.79
175	.04	2.48	2.19	1.67	1.89	.43	-.40	-.75	2.01	.09	-1.07	-5.39	-7.84	-8.53	-9.24	-11.37
200	.25	2.27	1.75	1.65	2.39	.25	-1.02	-1.55	3.46	.67	-1.17	-4.54	-6.96	-7.37	-8.98	-11.04
250	-.44	.93	1.43	1.14	1.44	-.37	-.57	-.45	1.81	2.14	.37	-2.36	-4.63	-4.80	-7.15	-8.11
300	-.36	.67	.95	1.26	2.61	.71	.10	.12	5.48	2.67	2.69	-.72	-2.39	-3.07	-4.10	-5.44
350	-.71	.83	.90	1.37	3.05	1.21	1.10	4.19	4.93	2.97	4.35	1.00	-.16	-1.95	-3.05	-3.89
400	-1.05	.35	1.23	1.61	3.18	1.86	2.20	4.50	2.24	4.05	5.39	2.29	.59	-.70	-1.88	-3.00
500	-.54	-.00	.84	1.53	2.46	2.05	2.61	4.09	-1.56	4.43	7.30	3.99	2.02	1.22	-.46	-1.73
600	-.38	-.27	.54	1.54 1	2.66	2.76	3.26	2.71	1.15	5.79	7.70	4.90	3.51 2	2.20	.56	-.66
700	-.62	-.41	.50	1.59	2.45	3.51	3.55	1.15	5.10	7.98	7.65	5.49	3.81	2.35	.24	-.09
800	-.71	-.36	.61	1.88	3.01	3.77	4.20	.65	6.29	8.44	7.74	5.33	3.67	2.20	.60	.55
850	-.85	-.46	.88	2.03	3.39	4.12	4.55	1.25	6.22	9.64	7.51	5.04	3.68	2.23	.98	.96
900	-.75	-.49	1.02	2.02	3.63	4.28	4.20	1.96	6.12	9.38	7.06	5.25	3.55	2.28	.91	1.05
950	-.51	.01	1.19	2.05	3.89	4.26	3.85	2.32	5.93	8.52	5.76	4.22	2.88	1.79	.63	1.00
1000	.14	.33	1.26	1.61	2.79	3.07	3.22	2.40	2.90	5.15	2.56	1.78	.91	.53	.05	.53
1013	.04	.26	.94	1.07	2.24	2.33	2.76	1.82	2.97	4.25	2.26	1.24	.73	.24	-.17	.44
	14	12	10	8	6	4	2	0		2	4	6	8	10	12	14

← Radius (°Lat.) | Radius (°Lat.) →

Fig. 5.5. Vertical pressure cross-section by radius of tangential wind (m/s) for left (octants 2,3,4) and right (octants 5,6,7) quadrants. For instance, the left 600 mb 8° (7-9°) radius value denoted [box] 1 is 1.54 m/s. The right 600 mb 8° (7-9°) radius value denoted by [box] 2 is 3.51 m/s.

for 8^{o} (7-9) radius denoted by ▭ 1 is 1.54 m/s. The 600 mb right tangential wind for 8^{o} (7-9) radius denoted by ▭ 2 is 3.51 m/s. The front values are made up of a weighted value of octants 1 (50%), 2 (25%), and 8 (25%). Similarly, the back is made up of values from octants 4, 5 and 6; the left from octants 2, 3 and 4; and the right from octants 6, 7 and 8. The orientation of the octants was explained in Chapter 2.

5.1.1b Derived Wind Parameters

Divergence (DIV), vertical velocity (ω or omega), relative vorticity (VOR), radial flux of earth momentum (Vrf or VRF), and other derived wind quantities are calculated from the octant means for various radial belts. Divergence and vertical velocity are calculated for radial belts of 0-2, 2-4, 4-6, 6-8, 8-10, 10-12, 12-14, 0-3, 0-4, 0-5, 3-5, 2-3, 3-4, 4-5, and 5-6 degrees and displayed in a vertical summary as shown in Fig. 5.6. Only divergence is depicted in Fig. 5.6 where the 500 mb $6\text{-}8^{o}$ radius value denoted by ▭ 1 is $-.94 \times 10^{-6}s^{-1}$. Relative vorticity is calculated at each octant for radii of 2, 3, 4, 5, 6, 8, 10 and 12 degrees and displayed as shown in Fig. 5.7 with a belt mean. For simplicity only values for the surface, 1000 mb, 70 mb and 50 mb were displayed. The 1000 mb octant 3, 3^{o} radius value denoted ▭ 1 is $13.24 \times 10^{-5} sec^{-1}$. The 1000 mb 5^{o} radius belt average denoted ▭ 2 is $3.00 \times 10^{-5} sec^{-1}$. Radial flux of earth momentum is calculated in two ways at 2, 3, 4, 5, 7, 9, 11 and 13 degrees radius. $\overline{V_r} * \overline{f_o}$ gives the mean flux of earth momentum, and $\overline{V_r * f_o}$ gives the total flux of earth momentum as displayed in Figs. 5.8 and 5.9. The values are displayed in

Pressure (mb)	RADIUS (°Lat.) → 0-2	2-4	4-6	6-8	8-10	10-12	12-14	MOTION DIV 0-3	RADIUS (°Lat.) → 0-4	0-5	3-5	2-3	3-4	4-5	5-6
50	5.77	-.69	-.60	1.99	-1.54	-.20	1.87	1.25	.92	.28	-.26	-2.37	.50	-.86	-.39
70	5.86	-1.31	1.14	.29	.26	-.02	1.59	1.47	.48	.90	.58	-2.04	-.79	1.65	.73
80	-1.56	-.30	1.88	1.57	-.25	.81	.25	-.83	-.61	-.38	-.13	-.24	-.34	.03	3.39
100	3.40	-2.24	2.78	1.08	1.07	-1.31	.71	-1.10	-.83	.66	1.64	-4.70	-.49	3.30	2.35
125	24.45	5.56	-.11	-.57	-.06	.41	.50	16.33	10.28	6.34	.71	9.83	2.51	-.68	.36
150	42.54	12.04	2.80	-1.67	-1.16	.16	-.98	28.95	19.66	13.48	4.77	18.08	7.72	2.49	3.06
175	42.60	14.80	4.10	-1.66	.18	.62	-3.06	30.30	21.75	15.83	7.69	20.47	10.75	5.32	3.09
200	36.87	11.62	3.40	-2.23	-.93	2.07	-4.49	25.37	17.94	12.77	5.68	16.18	8.37	3.58	3.25
250	20.03	2.50	-.50	-1.94	-.32	1.46	-1.47	11.93	6.89	4.35	.09	5.45	.40	-.16	-.78
300	7.76	-1.51	-1.66	.21	-.92	2.14	.25	3.87	.81	.59	-1.26	.75	-3.12	.20	-3.18
350	6.04	-3.83	-.18	-.09	.59	.62	.25	2.49	-1.36	-.86	-2.74	-.36	-6.31	.04	-.37
400	4.11	-2.15	-1.21	.09	.57	1.13	-.61	.60	-.59	-1.08	-2.02	-2.21	-2.11	-1.95	-.61
500	1.27	-2.20	.30	-.94 1	.63	.22	.16	-.18	-1.33	-.63	-.88	-1.35	-2.81	.62	.03
600	-6.35	-1.10	.83	.09	-.90	-.60	1.22	-3.70	-2.41	-.82	.80	-1.58	-.76	2.02	-.14
700	-4.44	-1.16	-.55	.44	-.25	-1.13	.02	-3.60	-1.98	-1.42	-.19	-2.93	.11	-.41	-.66
800	-7.25	-1.16	-.77	.66	.15	-1.64	.53	-6.17	-2.68	-1.87	.55	-5.31	1.81	-.44	-1.04
850	-12.13	-1.28	-1.54	1.20	-.20	-1.19	.92	-7.87	-4.00	-3.39	-.87	-4.46	.99	-2.31	-.90
900	-23.05	-1.01	-1.13	1.16	.26	-.50	.27	-11.71	-6.52	-5.21	-1.55	-2.64	.15	-2.87	.31
950	-37.95	-2.41	.25	1.19	1.22	-.69	1.21	-19.87	-11.29	-7.76	-.95	-5.41	-.27	-1.47	1.66
1000	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00	0000.00
1013	-30.77	-3.28	.29	2.03	.26	.34	1.02	-17.45	-10.15	-6.95	-1.05	-6.79	-.77	-1.26	1.56

Fig. 5.6. Vertical summary by radial belt of divergence in the MOT coordinate system in units of $10^{-6} s^{-1}$. The 500 mb 6-8° radius value denoted □1 is -.94.

RADIUS (°Lat.) →

Pressure (mb) 1013	2	3	4	5	6	8	10	12
·	17.79	5.63	4.29	1.32	.26	-.47	-1.94	-2.52
2	18.30	-.82	1.77	-2.92	-.69	-.56	-3.55	-4.67
·	27.40	12.04	1.02	.48	-.35	-1.33	-2.92	-4.28
4	*9999.00	6.52	6.35	8.36	2.94	-2.96	-1.63	-.73
·	2.73	6.29	9.63	6.40	2.03	-4.66	-3.00	-5.64
6	21.59	2.88	3.38	6.97	-.48	-5.68	-2.68	-3.99
·	-16.19	-1.11	-6.21	-5.17	-5.00	-3.38	-3.60	-2.14
8	*9999.00	10.27	6.83	-3.54	-4.19	-3.76	-2.74	-2.31
Mean	11.94	5.21	3.38	1.49	-.68	-2.85	-2.76	-3.29

1000	2	3	4	5	6	8	10	12
·	13.37	7.88	3.78	4.75	3.57	1.14	-1.89	-4.77
2	8.89	4.46	5.17	-.99	.54	-.60	-4.52	-6.35
·	18.70	13.24 [box 1]	4.67	4.42	1.42	-2.11	-2.71	-4.74
4	*9999.00	11.18	7.88	7.85	3.42	-2.62	-1.33	.24
·	*9999.00	5.02	8.80	6.86	1.64	-5.37	-3.43	-4.79
6	*9999.00	6.22	3.51	5.49	-1.02	-6.17	-3.45	-4.37
·	*9999.00	2.46	-6.31	-2.93	-3.66	-3.34	-4.48	-3.86
8	*9999.00	11.84	6.20	-1.47	-2.11	-3.20	-4.65	-4.41
	13.65	7.79	4.21	3.00 [box 2]	.48	-2.78	-3.31	-4.13

70	2	3	4	5	6	8	10	12
·	*9999.00	-7.28	-8.37	-14.89	-10.97	-2.99	-8.58	-11.63
2	*9999.00	-13.81	-8.86	-2.76	-4.92	-6.88	-2.59	-3.55
·	*9999.00	-9.31	-4.38	-2.74	-1.84	-.95	-2.47	-2.60
4	*9999.00	2.33	-2.81	-2.69	-4.75	-2.92	.61	-2.82
·	*9999.00	-25.35	.71	10.60	-1.33	-6.75	.21	3.09
6	20.61	-14.31	.85	-9.03	-7.80	-2.59	-1.84	-4.81
·	-3.47	2.03	5.73	1.03	-3.43	-6.25	-2.34	-2.91
8	*9999.00	-10.07	-10.74	-10.30	-7.81	-3.73	-4.66	-7.29
Mean	8.57	-9.47	-3.48	-3.85	-5.36	-4.13	-2.71	-4.07

50	2	3	4	5	6	8	10	12
·	*9999.00	-6.68	-9.07	-10.64	-7.34	-.83	-7.92	-10.02
2	*9999.00	-9.15	-12.33	-6.72	-3.70	-1.39	-1.52	-2.93
·	*9999.00	-2.76	-.82	4.35	1.82	-3.70	-1.47	.43
4	*9999.00	-.07	.73	1.89	-.26	-1.15	1.11	-1.31
·	*9999.00	-32.37	-12.33	12.28	2.79	-2.51	3.64	2.13
6	43.89	-6.26	-11.56	-6.59	-6.77	-5.69	-1.86	-3.56
·	*9999.00	7.19	.24	-3.57	-3.58	-3.70	-2.10	-1.68
8	*9999.00	2.12	-.82	-6.47	-6.85	-3.31	-3.30	-7.15
	43.89	-6.00	-5.74	-1.93	-2.99	-2.79	-1.68	-3.01

(Rows: Octants)

Fig. 5.7. MOT coordinate system relative vorticity by octant and belt. For simplicity only values for surface, 1000 mb, 70 mb and 50 mb are displayed. The 1000 mb octant 3, 3° radius value denoted [box] 1 is $13.24 \times 10^{-5}\ s^{-1}$. The 1000 mb 5° belt average denoted [box] 2 is $3.00 \times 10^{-5}\ s^{-1}$.

Pressure (mb)	RADIUS (°Lat.) → 2	3	4	5	7	9	11	13
50	8.09	3.94	5.17	2.46	9.47	11.92	-.32	13.65
70	8.22	4.64	2.71	7.89	12.17	15.17	16.74	29.72
80	-2.19	-2.61	-3.43	-3.33	16.65	23.90	27.62	36.27
100	4.77	-3.47	-4.67	5.73	19.71	31.68	29.78	24.55
125	34.30	51.52	57.64	55.45	55.44	51.32	53.45	60.75
150	59.67	91.33	110.21	117.97	125.09	107.80	99.98	92.51
175	59.75	95.60	121.91	138.58	146.24	136.32	140.90	119.63
200	51.71	80.04	100.54	111.75	117.07	97.96	105.24	84.35
250	28.10	37.64	38.60	38.08	27.46	14.42	22.35	22.20
300	10.89	12.19	4.54	5.15	-6.33	-10.28	-1.62	18.43
350	8.48	7.85	-7.64	-7.49	-9.44	-6.50	2.02	9.28
400	5.77	1.89	[-3.29] 1	-9.42	-11.60	-7.74	4.27	8.59
500	1.78	-.58	-7.46	-5.50	-9.50	-11.16	-5.12	-1.87
600	-8.91	-11.67	-13.54	-7.17	-7.45	-11.93	-22.32	-16.95
700	-6.23	-11.37	-11.10	-12.39	-13.33	-12.12	-21.67	-30.78
800	-10.17	-19.48	-15.02	-16.39	-17.95	-13.20	-23.59	-32.73
850	-17.02	-24.83	-22.40	-29.67	-28.64	-22.68	-32.24	-34.28
900	-32.33	-36.94	-36.55	-45.58	-40.26	-31.77	-33.22	-34.93
950	-53.22	-62.69	-63.31	-67.91	-57.59	-43.36	-39.35	-34.84
1000	99999.90	99999.90	99999.90	99999.90	99999.90	99999.90	99999.90	99999.90
1013	-43.16	-55.04	-56.90	-60.84	-47.22	-33.79	-29.28	-17.72
	.4 .00	.0 .00	-.5 -.00	.7 .00	-8.2 -.01	-3.8 -.00	.5 .00	-.1 -.00

Fig. 5.8. Vertical summary by pressure level of the radial flux of earth momentum in the MOT coordinate system in the form $\overline{V_r * f_o}$. Units are m/s (10^{-4} s^{-1}). The 400 mb 4° radius value denoted [ ] 1 is -3.29.

Pressure (mb)	RADIUS (°Lat.) → 2	3	4	5	7	9	11	13
50	6.83	.36	-1.44	-6.90	-6.11	-11.37	-31.73	-31.84
70	6.74	1.37	-3.78	-2.96	-5.32	-11.13	-21.49	-29.12
80	-3.65	-6.44	-10.03	-13.15	-2.99	-6.66	-16.48	-31.15
100	2.72	-8.04	-12.57	-5.37	-2.58	-4.67	-25.75	-56.35
125	33.27	47.78	51.62	48.65	36.30	12.74	-6.43	-27.63
150	59.74	90.38	109.10	118.88	117.85	82.53	56.10	21.19
175	60.17	96.26	124.59	144.46	146.76	124.60	115.18	66.64
200	51.92	80.88	104.85	120.00	120.75	90.69	81.35	35.96
250	28.07	38.10	41.78	42.66	26.50	2.32	-5.51	-20.80
300	10.05	11.21	4.28	4.19	-14.18	-30.09	-35.97	-29.20
350	7.21	5.52	-10.44	-11.54	-22.13	-31.99	-36.43	-40.58
400	4.74	-.52	-6.98 1	-14.08	-23.71	-32.17	-31.42	-39.97
500	.89	-2.75	-10.63	-10.12	-17.89	-27.32	-31.87	-41.34
600	-8.99	-11.61	-13.35	-7.42	-9.99	-20.81	-39.70	-44.50
700	-5.95	-10.50	-9.43	-10.12	-12.09	-17.68	-34.98	-54.81
800	-10.13	-18.35	-13.43	-14.57	-15.96	-16.54	-32.79	-54.86
850	-16.91	-23.89	-21.02	-28.05	-26.31	-24.80	-39.88	-52.75
900	-32.67	-36.73	-36.49	-45.79	-38.89	-32.56	-36.84	-46.90
950	-53.89	-63.91	-65.50	-70.98	-59.71	-47.50	-46.56	-49.18
1000	9999.90	9999.90	9999.90	9999.90	9999.90	9999.90	9999.90	9999.90
1013	-43.68	-56.64	-61.03	-66.70	-57.14	-52.32	-56.51	-55.63
	-350.3 -.39	-556.7 -.61	-514.9 -.57	-614.8 -.67	-3922.7 -4.30	-11836.4 -12.96	-21239.9 -23.24	-33805.7 -36.98

Fig. 5.9. Vertical summary by pressure level of earth momentum in the MOT coordinate system in the form $\overline{V_r * f_o}$. Units are m/s (10^{-4} s^{-1}). The 400 mb 4° radius value denoted ☐ 1 is -6.98.

units of [m/s($10^{-4}s^{-1}$)]. In Fig. 5.8 the 400 mb 4^{o} radius $\overline{V_r} * \overline{f_o}$ value denoted □ 1 is -3.29. In Fig. 5.9 the 400 mb 4^{o} radius $\overline{V_r * f_o}$ value denoted □ 1 is -6.98.

5.1.2 Thermodynamic Parameters

The thermodynamic parameters which are output are listed in Table 5.2. The height (z or HT), temperature (t or T), theta (θ or TH), saturated moist static energy (h^* or H-STAR), virtual temperature (Tv or TV), relative humidity (rh or RH), specific humidity (q or Q), dry static energy (s or S), and moist static energy (h or H) are composited at each octant for radial belts of 0-1, 1-3, 3-5, 5-7, 7-9, 9-11, 11-13, 13-15, 1-2, 0-2, 2-3, 3-4, 2-4, 4-5, 5-6, and 4-6 degrees for the same levels as the wind parameters. These parameters are composited in the NAT coordinate system only. The radial geopotential gradient (dgz/dr or DGZDR) is also calculated for radii of 2, 3, 4, 5, 7, 9, 11 and 13 degrees. A surface pressure is calculated for each belt using the 900 mb height and mean weighted virtual temperatures from 900 mb to the surface.

TABLE 5.2

Thermodynamic Parameters

NAT System only

Height (z)	Relative Humidity (rh)
Virtual Temperature (T_v)	Moist Static Energy (h)
Dry Static Energy (s)	Radial Geopotential Gradient(dgz/dr)
Saturated Moist Static Energy (h*)	Theta (θ)
Temperature (t)	Specific humidity (q)

The data for each individual level are output in the form shown in Figs. 5.10 and 5.11. The header information, octant means, belt means, and associated case counts are displayed in the same way as for the wind

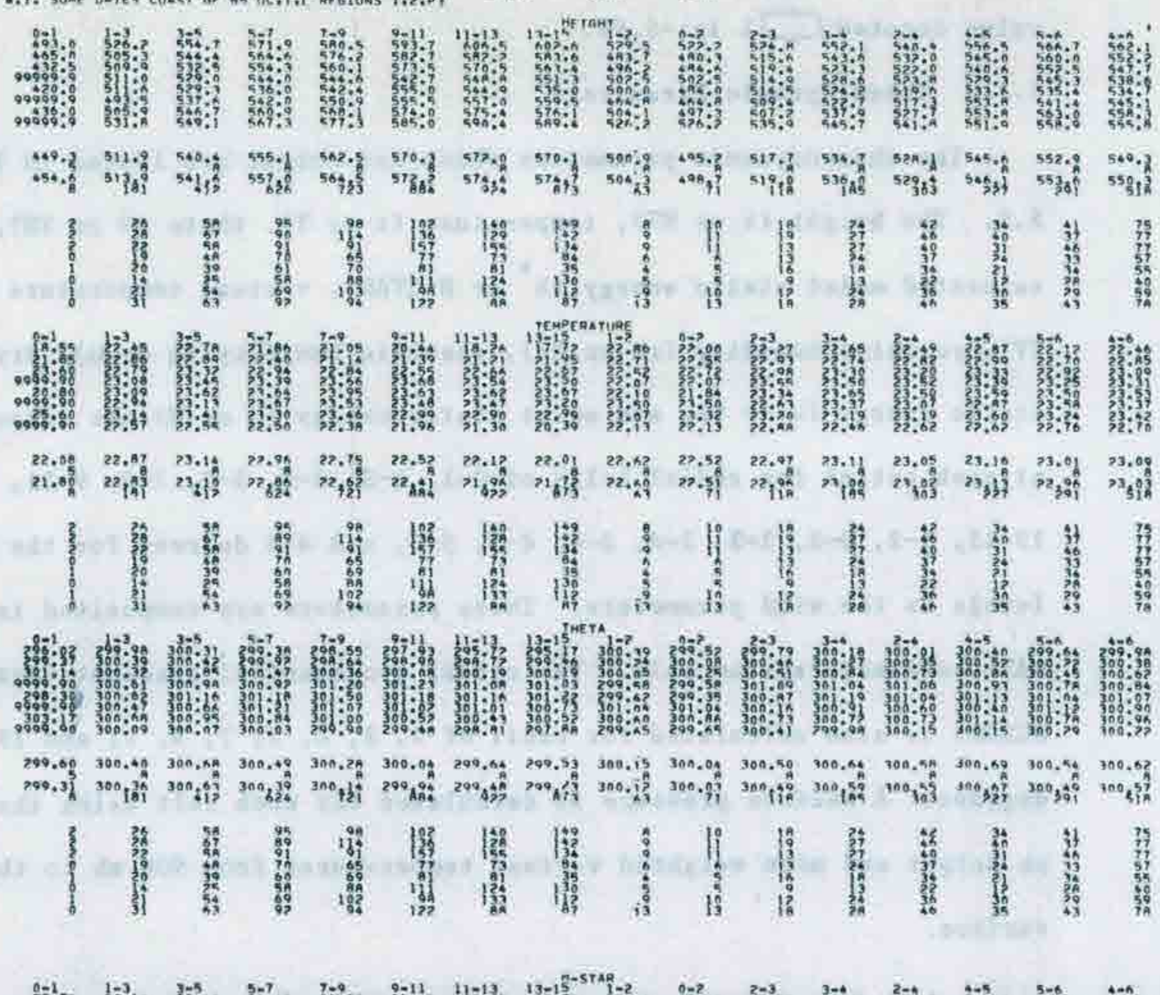

Fig. 5.10. Form of the standard thermal output for a single level (950 mb) for height (meters), temperature (^{o}C), theta (^{o}A), h* (cal/gm), and radial pressure gradient dgz/dr. The form of this output is similar to that of Fig. 5.1.

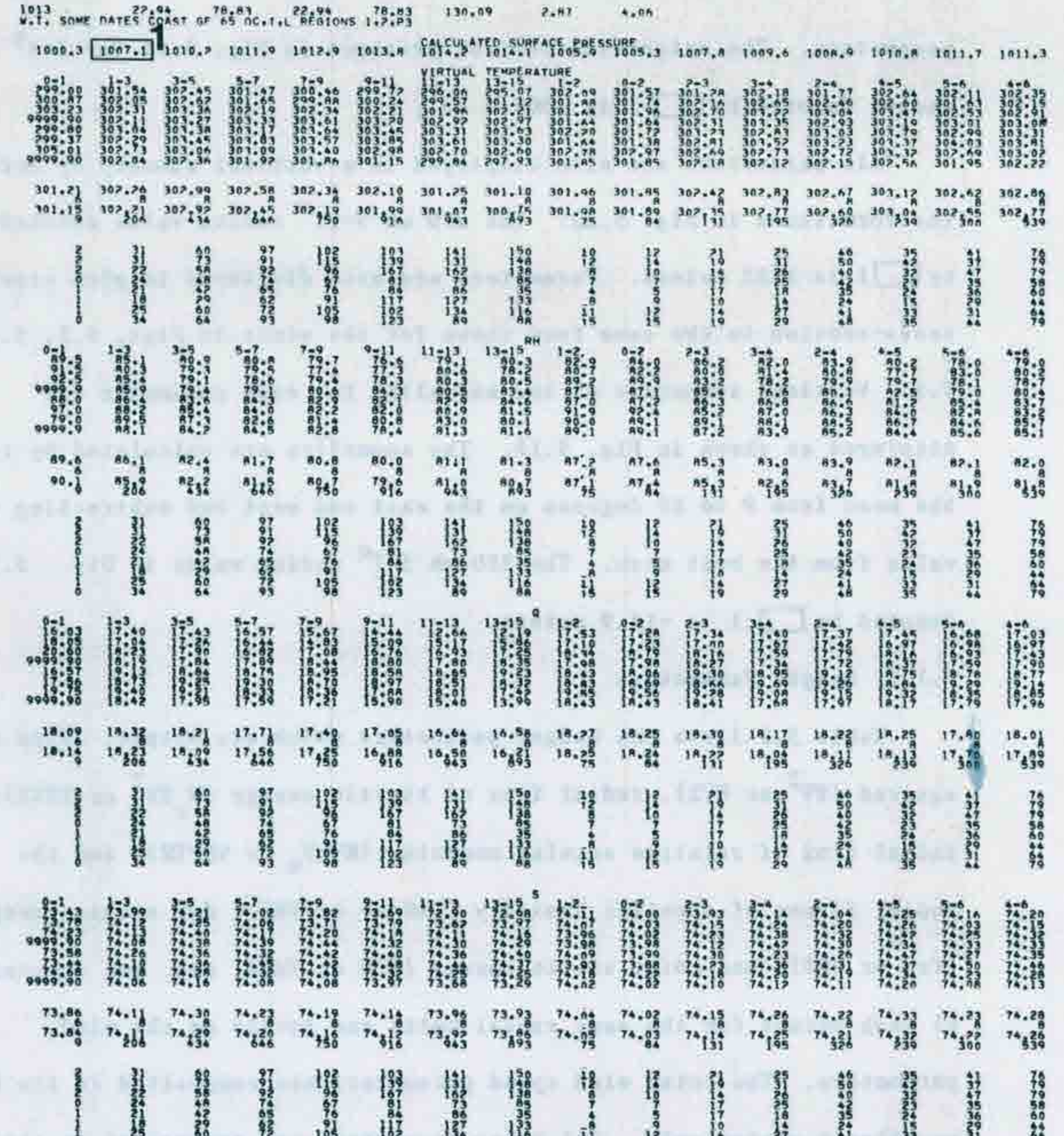

Fig. 5.11. Form of the standard thermal output for a single level (surface) for surface pressure (mb), virtual temperature (°A), relative humidity (%), mixing ratio (g/kg), dry static energy (s) (cal/gm), and moist static energy (h) (cal/gm). Calculated surface pressure denoted [box]1 for 1-3° radius is 1007.1 mb. The form of this output is similar to that of Fig. 5.1.

parameters. The calculated surface pressure in Fig. 5.11 for 1-3^{o} radius denoted by ☐ 1 is 1007.1 mb.

All parameters are also displayed in a vertical summary by belt in the form shown in Fig. 5.12. The 850 mb 9-11^{o} radius value denoted by ☐1 is 1532 meters. Parameters are also displayed in plan view and cross-section in the same form shown for the winds in Figs. 5.3, 5.4 and 5.5. Vertical summaries of the anomalies for each parameter are displayed as shown in Fig. 5.13. The anomalies are calculated by taking the mean from 9 to 15 degrees on the east and west and subtracting that value from the belt mean. The 850 mb 5-7^{o} radius value in Fig. 5.13 denoted by ☐ 1 is -15.9 meters.

5.1.3 Budget Parameters

Table 5.3 lists the budget parameters which are output. Wind speed squared (WV^2 or WV2), radial flux of kinetic energy ($V_r WV^2$ or VRV2), radial flux of relative angular momentum ($RVrV_\theta$ or VRVTR), and the radial fluxes of specific humidity (VrQ(m) or VRQ), dry static energy (VrS or VRS), and moist static energy (VrH or VRH), etc. are composited at each octant for the same radial belts and levels as the wind parameters. The total wind speed parameters are composited in the NAT coordinate system only. All other parameters are composited in the NAT and MOT coordinate systems.

Pressure (mb)	RADIUS (°Lat.) → 0-1	1-3	3-5	5-7	7-9	9-11	11-13	HEIGHT 13-15	RADIUS (°Lat.) → 1-2	0-2	2-3	3-4	2-4	4-5	5-6	4-6
50	20765.0	20736.4	20747.6	20761.0	20764.1	20768.2	20764.5	20762.7	20723.4	20734.8	20737.7	20741.8	20740.3	20752.9	20755.3	20754.4
70	18628.0	18676.6	18683.3	18691.6	18695.8	18697.0	18692.4	18688.0	18665.0	18666.6	18679.5	18679.6	18679.6	18687.4	18689.1	18688.2
80	17828.0	17879.4	17883.1	17889.7	17893.8	17893.0	17885.9	17881.4	17875.1	17875.7	17879.0	17882.6	17881.7	17883.8	17889.0	17887.0
100	16566.5	16578.2	16576.4	16580.9	16580.6	16574.7	16565.6	16559.2	16577.8	16576.1	16578.9	16575.6	16576.7	16577.0	16582.6	16580.4
125	15278.7	15287.0	15283.8	15285.4	15280.8	15269.3	15256.1	15249.0	15285.3	15282.5	15287.4	15282.5	15284.1	15285.2	15287.6	15286.8
150	14196.5	14207.2	14206.1	14203.6	14196.9	14183.7	14168.0	14160.0	14208.5	14206.4	14207.2	14204.0	14205.3	14208.2	14207.7	14208.2
175	13259.7	13261.2	13260.5	13259.0	13251.3	13238.3	13221.2	13214.2	13259.7	13258.6	13262.6	13258.8	13260.4	13262.1	13261.8	13262.3
200	12408.4	12413.0	12413.5	12412.5	12406.0	12394.1	12377.3	12372.1	12412.3	12410.0	12414.6	12412.8	12413.6	12414.2	12415.1	12415.1
250	10918.9	10930.1	10938.3	10938.5	10934.1	10925.4	10912.0	10907.3	10927.5	10925.6	10932.0	10936.7	10935.0	10940.0	10940.3	10940.3
300	9641.6	9659.2	9673.6	9675.9	9673.8	9669.4	9657.2	9653.7	9655.9	9653.6	9662.1	9671.7	9668.0	9675.3	9676.7	9676.3
350	8522.9	8544.3	8563.2	8567.7	8568.1	8566.0	8556.0	8553.1	8538.6	8535.2	8548.3	8560.1	8555.5	8566.1	8567.8	8567.1
400	7520.5	7549.8	7571.5	7578.3	7580.2	7579.9	7571.9	7569.3	7541.3	7536.7	7554.9	7567.6	7562.6	7575.1	7577.9	7576.7
500	5780.1	5830.4	5856.3	5866.6	5869.6	5872.6	5867.2	5865.0	5816.3	5811.1	5837.0	5850.9	5845.8	5861.0	5866.1	5863.8
600	4317.9	4375.6	4404.4	4416.1	4422.9	4425.4	4421.8	4420.1	4361.3	4355.1	4383.1	4398.7	4393.0	4409.3	4414.9	4412.4
700	3050.9	3113.5	3141.5	3154.8	3160.7	3165.5	3164.0	3162.4	3099.6	3093.0	3120.6	3135.4	3129.9	3146.9	3153.2	3150.2
800	1930.0	1994.2	2021.3	2035.0	2041.9	2047.6	2047.3	2045.9	1982.0	1975.1	2000.5	2014.8	2009.3	2027.1	2033.0	2030.2
850	1413.2	1477.5	1504.7	1518.6	1525.6	1532.0 1	1532.3	1531.0	1465.9	1458.6	1483.7	1498.5	1492.8	1510.2	1516.7	1513.6
900	922.1	984.6	1012.5	1026.5	1033.8	1040.7	1041.9	1040.5	973.4	968.0	990.5	1006.6	1000.4	1017.9	1024.5	1021.3
950	454.6	511.9	540.4	555.1	562.5	570.3	572.0	570.1	500.9	495.2	517.7	534.7	528.1	545.6	552.9	549.3
1000	50.5	66.5	89.9	104.3	112.5	120.4	123.2	122.4	59.9	58.8	69.1	83.9	78.2	95.2	101.8	98.5
1013	999.1	1005.6	1009.1	1010.8	1011.7	1012.5	1012.8	1012.8	1004.4	1003.8	1006.4	1008.4	1007.6	1009.7	1010.6	1010.2

Fig. 5.12. Vertical pressure summary by radial belt for height (meters). The 1013 mb values are non sea-level corrected surface pressures from the soundings. The 850 mb 9-11° radius value denoted ☐ 1 is 1532 meters.

HEIGHT ANAMOLIE (BELT MEAN-EW 9TO15)

	0-1	1-3	3-5	5-7	7-9	9-11	11-13	13-15	1-2	0-2	2-3	3-4	2-4	4-5	5-6	4-6
50	-8.9	-37.5	-26.2	-12.9	-9.7	-5.7	-9.3	-11.2	-50.4	-39.1	-36.1	-32.0	-33.6	-21.0	-18.6	-19.5
70	-75.6	-27.0	-20.3	-12.0	-7.7	-6.5	-11.1	-15.5	-38.6	-37.0	-24.1	-24.0	-23.9	-16.2	-14.4	-15.4
80	-71.2	-19.7	-16.1	-9.4	-5.3	-6.2	-13.2	-17.7	-24.0	-23.5	-20.1	-16.6	-17.4	-15.3	-10.2	-12.1
100	-13.7	-2.0	-3.8	.8	.4	-5.5	-14.5	-21.0	-2.4	-4.1	-1.3	-4.6	-3.5	-3.1	2.4	.3
125	4.7	13.1	9.9	11.4	6.9	-4.6	-17.8	-25.0	11.4	8.5	13.5	8.6	10.1	11.2	13.7	12.9
150	8.6	19.2	18.2	15.7	9.0	-4.2	-19.9	-28.0	20.6	18.5	19.3	16.1	17.3	20.2	19.8	20.2
175	16.8	18.3	17.6	16.0	8.4	-4.7	-21.7	-28.8	16.8	15.7	19.7	15.9	17.5	19.2	18.9	19.4
200	9.5	14.1	14.6	13.6	7.1	-4.8	-21.6	-26.8	13.4	11.1	15.7	13.9	14.7	15.3	16.2	16.2
250	-12.1	-.9	7.3	7.5	3.1	-5.5	-19.0	-23.7	-3.5	-5.4	1.1	5.7	4.0	9.0	9.3	9.3
300	-32.9	-15.2	-.8	1.5	-.7	-5.1	-17.3	-20.7	-18.6	-20.9	-12.4	-2.7	-6.4	.9	2.2	1.8
350	-48.0	-26.5	-7.7	-3.2	-2.8	-4.9	-14.9	-17.8	-32.3	-35.7	-22.6	-10.7	-15.4	-4.8	-3.1	-3.8
400	-63.8	-34.4	-12.8	-6.0	-4.1	-4.4	-12.4	-15.0	-43.0	-47.6	-29.4	-16.7	-21.7	-9.2	-6.4	-7.6
500	-96.2	-45.9	-20.0	-9.8	-6.7	-3.7	-9.1	-11.3	-60.0	-65.2	-39.3	-25.4	-30.5	-15.3	-10.2	-12.5
600	-110.8	-53.1	-24.3	-12.6	-5.8	-3.3	-6.9	-8.6	-67.4	-73.6	-45.6	-30.1	-35.7	-19.4	-13.8	-16.3
700	-117.9	-55.2	-27.3	-13.9	-8.1	-3.2	-4.8	-6.3	-69.2	-75.7	-48.1	-33.4	-38.9	-21.8	-15.6	-18.5
800	-120.4	-56.2	-29.1	-15.4	-8.5	-2.8	-3.0	-4.5	-68.3	-75.2	-49.9	-35.5	-41.0	-23.3	-17.3	-20.2
850	-121.2	-57.0	-29.8	-15.9 1	-8.8	-2.5	-2.1	-3.5	-68.6	-75.9	-50.8	-36.0	-41.7	-24.3	-17.7	-20.9
900	-120.6	-58.1	-30.2	-16.2	-9.0	-2.0	-.8	-2.3	-69.3	-74.7	-52.2	-36.1	-42.3	-24.8	-18.2	-21.5
950	-117.5	-60.2	-31.7	-17.0	-9.6	-1.9	-.2	-2.1	-71.3	-76.9	-54.4	-37.4	-44.1	-26.6	-19.2	-22.8
1000	-71.1	-55.1	-31.8	-17.4	-9.1	-1.3	1.5	.8	-61.8	-62.8	-52.5	-37.7	-43.5	-26.5	-19.8	-23.1
1013	-13.6	-7.1	-3.6	-1.9	-1.0	-.2	.1	.1	-8.3	-9.0	-6.3	-4.3	-5.1	-3.1	-2.1	-2.6

Fig. 5.13. Vertical pressure summary by radial belt of the height anomaly. Anomaly is calculated by taking the east and west 9 to 15 degrees mean and subtracting that value from the belt mean. The 850 mb 5-7^{0} radius value denoted by ☐ 1 is -15.9 meters. The from of this output is similar to Fig. 5.12.

TABLE 5.3

Some Budget Parameters

NAT	MOT
Total Wind Speed Squared (WV^2)	
Radial Flux of Kinetic Energy ($V_r WV^2$)	Radial Flux of Kinetic Energy ($V_{rr} WV^2$)
Radial Flux of Relative Angular Momentum ($RV_r V_\theta$)	Radial Flux of Relative Angular Momentum ($RV_{rr} V_{\theta r}$)
Radial Flux of Specific Humidity ($V_r Q(m)$)	Radial Flux of Specific Humidity ($V_{rr} Q(m)$)
Radial Flux of Dry Static Energy ($V_r S$)	Radial Flux of Dry Static Energy ($V_{rr} S$)
Radial Flux of Moist Static Energy ($V_r H$)	Radial Flux of Moist Static Energy ($V_{rr} H$)

The data for each individual level are output in the form shown in Fig. 5.14. The header information, the octant means, belt means, and associated case counts are displayed in the same way as for the wind parameters. All parameters are also displayed in a vertical summary by belt in the form shown in Fig. 5.15. The 850 mb 3-5^o radius wind velocity denoted by ☐ 1 is 11.7 m/s. The values at the bottom of the columns are the total pressure integration and pressure weighted average through the atmosphere. The total and average integration denoted by ☐ 2 are 7953.2 and 8.5 respectively.

5.2 Rectangular Composites

As previously stated in Chapter 2 there are two different rectangular grids being used. Since different parameters are being calculated for each grid, each grid will be described separately.

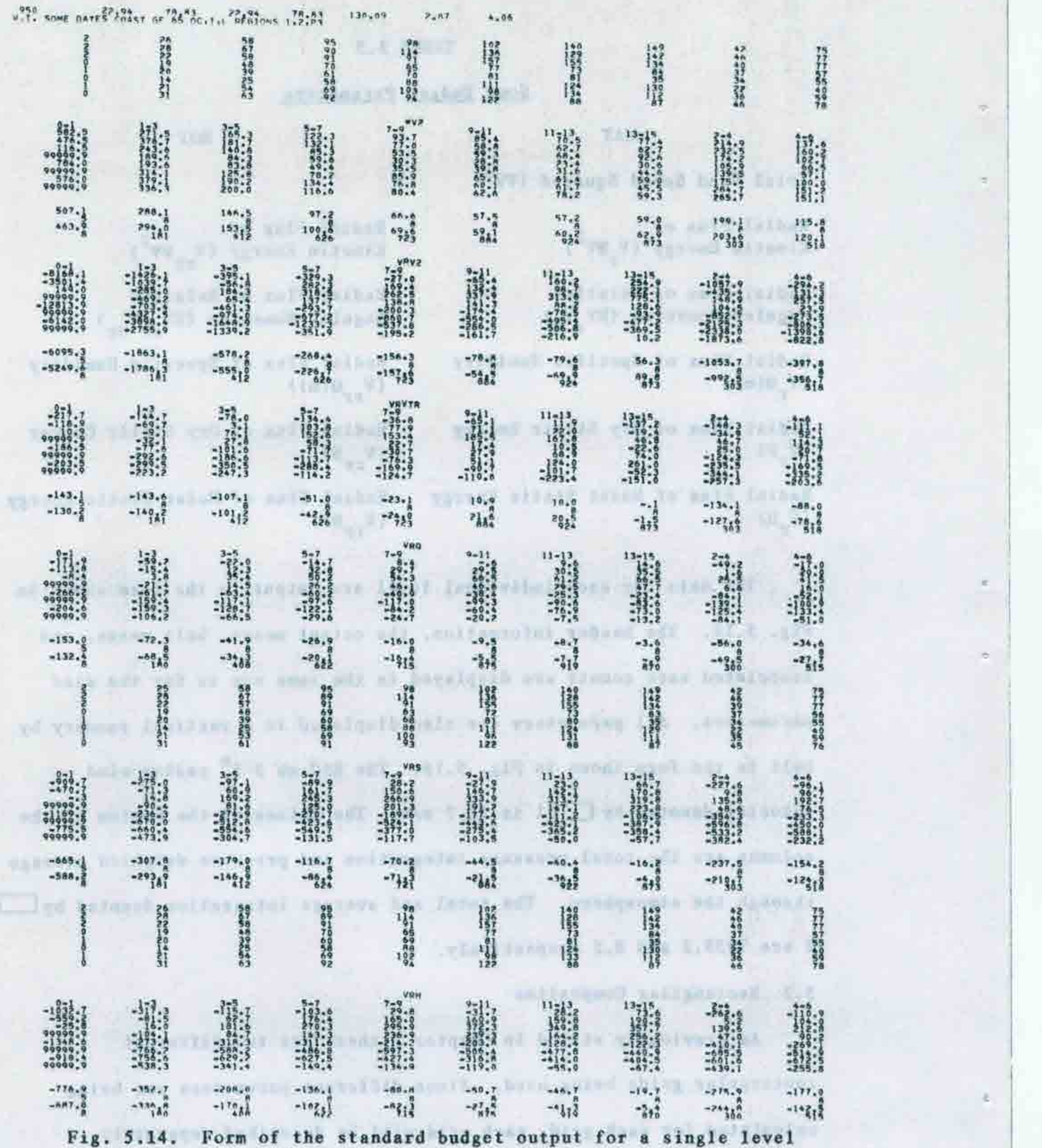

Fig. 5.14. Form of the standard budget output for a single level (950 mb) of a cylindrical composite. The form of this output is similar to that of Fig. 5.1.

RADIUS (°Lat.) →

NATURAL WV

Pressure (mb)	0-1	1-3	3-5	5-7	7-9	9-11	11-13	13-15	2-4	4-6
50	15.0	10.9	11.1	11.1	10.8	10.5	10.0	10.1	10.8	11.1
70	15.5	9.5	9.1	8.9	8.9	8.5	8.6	8.5	9.3	8.9
80	10.5	8.9	8.4	8.0	8.1	8.1	8.2	8.1	8.3	8.3
100	11.0	7.9	7.8	8.2	8.8	8.8	8.8	8.9	7.7	8.0
125	10.3	8.5	9.3	10.7	12.1	12.1	12.6	12.2	8.7	10.1
150	9.0	9.4	10.7	12.8	14.7	15.1	15.8	15.0	10.1	11.9
175	9.1	10.2	11.1	13.0	15.0	16.1	17.1	16.4	10.5	12.2
200	10.7	9.7	10.8	12.3	14.2	15.4	16.6	16.0	10.1	11.8
250	13.8	9.8	9.4	10.1	11.6	12.6	13.7	13.3	9.5	9.9
300	15.9	10.9	9.0	8.8	9.5	10.2	11.1	10.9	9.8	9.0
350	21.3	12.1	9.3	8.1	8.2	8.5	9.6	9.4	10.6	8.6
400	23.2	13.6	9.4	7.6	7.0	7.4	8.2	8.3	11.3	8.2
500	21.7	15.2	10.0	7.2	6.2	5.9	6.6	7.1	12.4	8.3
600	21.4	16.6	10.9	7.6	6.1	5.7	6.1	6.4	13.7	8.6
700	21.8	16.7	11.1	7.8	6.1	5.7	5.8	6.0	13.6	9.0
800	23.5	16.9	11.5	8.2	6.4	5.8	5.8	5.9	13.9	9.5
850	22.7	17.1	11.7 (1)	8.7	6.8	6.2	6.1	6.2	14.0	10.0
900	24.0	17.1	11.6	8.9	7.2	6.6	6.4	6.4	13.9	10.0
950	21.3	15.5	11.1	8.9	7.3	6.8	6.6	6.7	12.9	9.7
1000	10.5	8.8	7.2	6.1	5.3	5.0	4.8	4.9	8.0	6.7
1013	11.7	8.0	6.1	4.9	4.1	3.9	3.7	3.9	7.0	5.5
Total	17838.0	12973.2	9573.8	7953.2 (2)	7381.0	7365.4	7763.5	7799.3	11084.6	8564.5
Vert. Ave.	19.4	14.0	10.3	8.5 (2)	7.9	7.9	8.3	8.4	12.0	9.2

NATURAL WV2

Pressure (mb)	0-1	1-3	3-5	5-7	7-9	9-11	11-13	13-15	2-4	4-6
50	225.0	138.9	149.4	168.8	144.9	136.6	129.4	132.0	139.3	150.9
70	246.5	108.2	101.1	98.0	99.6	92.1	93.8	91.4	105.2	97.7
80	110.5	101.7	86.3	81.3	85.3	84.0	85.0	87.4	85.5	87.1
100	137.0	80.3	76.8	85.0	99.4	103.0	100.9	106.6	74.9	82.1
125	124.3	93.5	120.5	151.9	188.3	195.1	212.6	205.8	101.5	138.2
150	95.0	113.9	153.0	216.1	278.9	301.8	332.4	317.3	132.6	189.9
175	94.4	132.5	163.3	221.8	292.4	345.4	394.2	386.0	144.7	198.4
200	130.7	122.1	158.8	201.6	269.7	320.2	377.8	366.3	134.0	189.3
250	221.4	130.7	117.3	140.8	194.4	228.1	271.2	269.8	118.9	133.0
300	320.3	157.3	106.1	109.0	137.5	147.7	183.8	188.6	126.9	111.5
350	571.7	195.2	115.5	90.7	97.9	105.0	137.0	139.7	146.1	103.2
400	599.4	228.4	120.3	76.4	69.9	78.3	100.2	105.3	163.8	92.2
500	505.5	272.2	127.3	67.9	54.4	48.6	64.2	74.7	187.6	89.9
600	524.0	323.3	148.7	76.4	51.0	43.0	52.6	59.1	227.8	95.5
700	517.8	334.0	151.7	78.7	48.4	43.6	46.8	52.6	221.0	103.2
800	596.3	345.6	162.4	85.5	52.2	44.3	45.7	49.9	233.8	114.2
850	559.5	355.0	167.0	94.6	57.9	49.3	48.9	54.0	236.0	124.2
900	622.4	359.5	163.3	98.0	65.0	54.7	52.7	56.7	233.3	124.8
950	507.1	288.1	146.5	97.2	66.6	57.5	57.2	59.0	199.1	115.8
1000	114.2	90.9	63.8	46.5	35.8	32.1	30.3	32.6	76.4	55.2
1013	151.8	79.7	49.0	32.4	23.0	21.3	19.5	22.4	61.2	40.4
Total	411099.6	231795.2	127361.1	92752.4	88772.0	92106.8	106924.2	109812.5	167951.8	105247.2
Vert. Ave.	447.5	250.4	137.1	99.7	95.3	98.8	114.6	117.7	181.1	113.2

Fig. 5.15. Vertical pressure summary by radial belt for NAT wind velocity and NAT wind velocity squared. The values at the bottom of the columns are the total vertical integration surface to 100 mb and average through the atmosphere. The 850 mb 3-5° radius wind velocity denoted by □1 is 11.7 m/s. The total and average vertical pressure integration for the 5-7° radius value of wind denoted by □2 are 7953.2 m/s mb and 8.5 m/s respectively.

5.2.1 Pacific Rectangular Grid

The output parameters for this grid are listed in Table 5.4.

TABLE 5.4

Pacific Rectangular Grid Parameters

Directly Composited

Zonal Wind (u) Meridional Wind (v) Total Wind Speed Squared (WV^2)

Derived

Mean Wind Direction (DDD) Mean Wind Velocity (VV)
Divergence (DIV) Vorticity (VOR)
Vertical Velocity (ω)

5.2.1a Directly Composited Parameters

The zonal wind (u-component), meridional wind (v-component) and total wind speed squared (WV^2 or WV2) are composited for each grid box at each level and displayed as shown in Fig. 5.16. Also, included in this display are the case counts for each individual grid square. The grid squares denoted by ☐1, 2, 3, 4 are the center (0,0) of the grid and have values of -9.7 m/s, 12.3 m/s, 3328 m^2/s^2, and 19 respectively. This grid box contains all soundings which are within 2 1/2° latitude of the grid center.

5.2.1b Derived Parameters

Mean wind direction (DDD), mean wind velocity (VV), divergence (DIV), and vorticity (VOR) are calculated from the mean u and v components. Vertical velocity (ω or OMEGA) is kinematically calculated from the divergence values. The values are displayed as shown in Figs. 5.17 and 5.18. The center grid box (0,0) in Fig. 5.17 denoted by ☐1 has a direction of 142° and a velocity of 16 m/s. The center grid boxes

RELATIVE LONGITUDE (Deg.)

950 13.39 144.53 S.H. ACTIVE MINUS ONE SDEFF DOVE

U-COMPONENT

RELATIVE LATITUDE (Deg.)	50	45	40	35	30	25	20	15	10	5	0	5	10	15	20	25	30	35	40	45
20	999.9	999.9	999.9	999.9	999.9	999.9	4.0	-.6	999.9	999.9	999.9	999.9	-1.7	-.9	999.9	999.9	999.9	999.9	999.9	999.9
15	-1.0	999.9	-.4	999.9	3.0	-23.3	10.9	3.2	.3	.9	-1.0	-7.1	8.2	-3.9	-5.8	2.6	.8	-3.7	999.9	-1.3
10	-.2	-.2	3.7	2.0	1.8	-2.4	4.1	7.2	6.0	5.6	.5	2.4	1.3	1.8	-.2	1.7	1.1	1.7	.1	.4
5	2.4	-1.1	-1.2	3.4	.0	2.9	2.6	.9	2.7	2.6	3.8	5.2	2.4	.8	.4	1.6	1.1	.1	-1.8	-.6
0	3.8	-5.0	.8	-1.0	-.9	-1.5	-.5	1.0	-1.4	.1	-9.7 (1)	-3.5	-1.3	.6	-1.1	-1.5	-2.3	-3.2	.0	-1.8
5	.2	2.3	-1.4	-2.2	-2.6	-3.5	-2.7	-4.9	-.7	-3.1	-4.6	-6.2	-3.9	-.8	-2.3	-3.9	-3.3	-1.7	-2.0	-3.4
10	-1.9	-2.0	-.1	-4.0	-3.2	-3.5	-4.3	-4.9	-3.2	-3.6	-5.6	-3.2	-5.1	-3.3	-3.0	-3.9	-4.4	-1.4	-2.5	-4.3
15	-1.6	-3.0	-2.1	-2.8	-2.6	-4.1	-3.2	-3.4	-4.1	-3.3	-3.4	-2.8	-3.9	-3.6	-1.1	-3.3	-2.7	-1.0	-1.5	-3.3
20	-4.1	.4	-1.0	-1.5	-1.1	-1.8	-2.7	-2.0	-1.1	-2.6	-.5	-2.1	-2.0	-1.4	-1.0	-.8	.6	-1.3	-3.0	-5.5
25	4.1	-1.0	-1.3	.5	.6	-1.1	-2.6	-2.9	2.2	-1.3	-.0	-.2	.4	.7	1.4	2.8	-1.6	-3.2	.8	2.9

V-COMPONENT

RELATIVE LATITUDE (Deg.)	50	45	40	35	30	25	20	15	10	5	0	5	10	15	20	25	30	35	40	45
20	999.9	999.9	999.9	999.9	999.9	999.9	-1.2	-.7	999.9	999.9	999.9	999.9	-.4	-.3	999.9	999.9	999.9	999.9	999.9	999.9
15	-1.3	999.9	.7	999.9	-1.6	-17.7	-4.4	-3.5	-10.2	-1.7	-4.4	-.7	-.1	3.8	-1.6	-2.8	-1.1	-.4	999.9	3.5
10	.0	-.8	-1.4	-2.2	-.5	8.5	-.2	-.1	-1.7	-.4	-1.7	-2.8	-.9	-.3	-.2	.4	-.8	-.7	.9	-.9
5	.7	-.2	.6	-.8	.8	-.5	.7	.3	1.5	1.5	-2.3	-3.5	-2.9	-1.2	-.7	-1.6	-1.0	-.2	-.2	.2
0	.8	3.2	-1.4	.6	.6	1.1	.8	.2	1.7	2.4	12.3 (2)	-.3	-.5	-.7	-.4	-.6	-.5	-.5	-2.0	-.7
5	.1	-.5	1.0	-.4	.9	2.3	1.1	3.2	1.8	2.9	2.1	.8	.7	.5	-1.0	-.2	-.2	-.5	-.3	1.3
10	3.8	1.4	-.0	-1.0	-.0	2.3	.8	2.8	3.1	1.3	2.4	1.1	2.2	.2	.6	.7	2.1	-1.7	2.0	.6
15	3.3	2.6	-.4	-.6	-.3	.1	.9	.7	1.8	1.3	.1	-.2	.1	1.1	-.6	1.6	1.8	-.2	-.9	.2
20	1.1	1.0	2.0	-1.0	-1.9	-1.1	-1.4	.2	1.1	1.4	-.7	-.1	.5	1.9	.7	1.3	1.9	1.3	.8	1.0
25	.8	-.3	-1.2	-.1	-.3	1.3	-2.3	-1.9	-3.1	.9	-.3	-.3	2.8	2.9	.9	1.7	-2.0	-2.1	-4.3	-4.8

AVZ

RELATIVE LATITUDE (Deg.)	50	45	40	35	30	25	20	15	10	5	0	5	10	15	20	25	30	35	40	45
20	1000.	1000.	1000.	1000.	1000.	1000.	44.	65.	1000.	1000.	1000.	1000.	33.	1.	1000.	1000.	1000.	1000.	1000.	1000.
15	3.	1000.	3.	1000.	13.	3226.	514.	74.	451.	29.	76.	86.	85.	91.	76.	74.	25.	35.	1000.	21.
10	13.	13.	51.	43.	17.	1573.	59.	138.	114.	77.	22.	36.	33.	8.	25.	37.	14.	15.	43.	14.
5	21.	24.	47.	38.	12.	42.	49.	29.	46.	53.	39.	164.	55.	29.	26.	51.	41.	93.	39.	21.
0	45.	69.	55.	39.	33.	32.	33.	27.	43.	35.	3328. (3)	64.	64.	25.	51.	58.	34.	40.	53.	56.
5	40.	63.	47.	42.	62.	49.	44.	75.	41.	80.	77.	82.	74.	46.	30.	52.	35.	34.	34.	66.
10	89.	43.	32.	62.	60.	83.	78.	75.	82.	66.	80.	52.	81.	52.	63.	64.	71.	38.	53.	63.
15	60.	61.	61.	54.	57.	78.	59.	59.	79.	77.	68.	58.	70.	53.	49.	60.	64.	43.	71.	81.
20	101.	83.	60.	76.	78.	54.	86.	64.	64.	88.	69.	90.	89.	66.	56.	54.	81.	33.	87.	119.
25	46.	48.	16.	70.	85.	64.	51.	111.	111.	76.	54.	56.	55.	73.	78.	103.	100.	62.	123.	107.

Case Count

	50	45	40	35	30	25	20	15	10	5	0	5	10	15	20	25	30	35	40	45
20	0	0	0	0	0	0	6	6	0	0	0	0	2	1	0	0	0	0	0	0
15	3	0	3	0	2	4	12	4	9	9	10	4	2	4	6	8	8	4	5	2
10	5	9	10	18	15	11	26	14	20	12	12	12	14	7	10	25	34	10	23	14
5	8	18	27	50	41	49	30	28	37	30	14	34	37	30	44	42	23	47	18	17
0	24	15	31	39	23	32	53	33	46	42	19 (4)	44	39	34	58	65	26	34	22	26
5	29	62	45	79	55	45	56	45	53	71	57	69	80	66	70	59	56	41	36	12
10	48	56	53	73	84	63	75	64	80	135	65	82	111	64	82	95	51	42	37	24
15	43	66	34	65	104	84	96	113	80	118	116	86	153	79	64	118	62	51	61	35
20	35	57	44	71	102	106	119	141	75	119	97	108	90	114	132	106	137	45	46	16
25	21	27	6	66	81	51	62	41	60	51	47	76	50	95	65	51	44	18	45	16

Fig. 5.16. Standard form of the output for the Pacific rectangular grid at 950 mb for directly composited parameters. The values of the center grid box (0,0) denoted by □ 1, 2, 3, 4, are -9.7 m/s, 12.3 m/s, 3328 m^2/s^2, and 19 respectively. This grid box contains all soundings within 2 1/2° latitude of the storm center.

in Fig. 5.18 are denoted by □ 1, 2, 3 and have values of -7.2, -9.9 x $10^{-6} s^{-1}$ and -17.9 mb d^{-1} respectively.

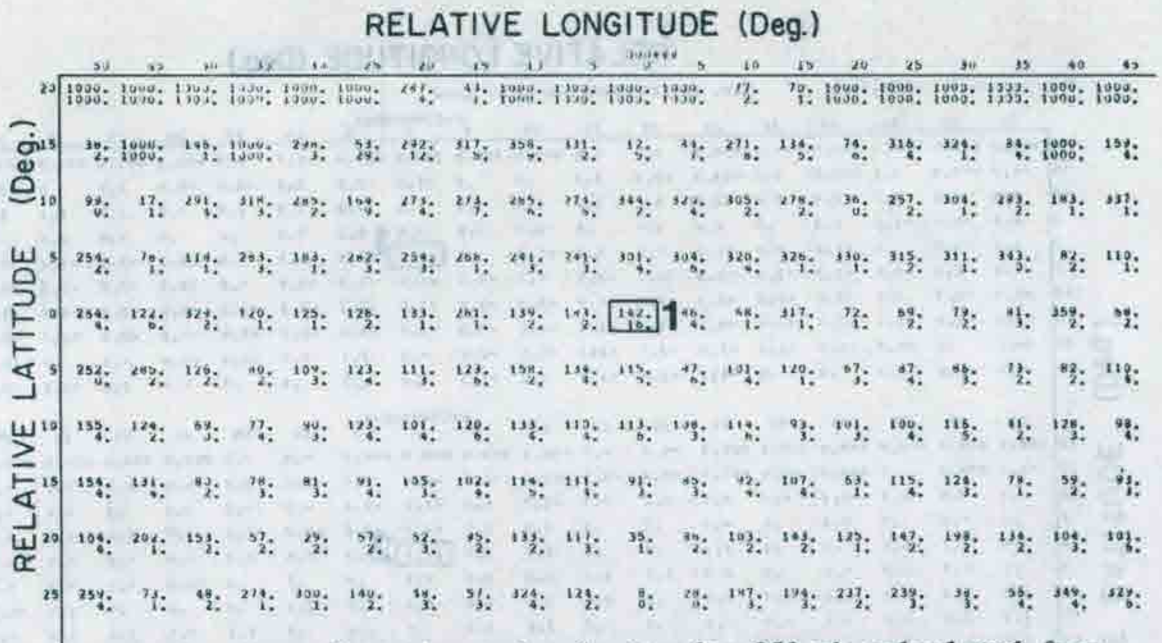

Fig. 5.17. Mean direction and velocity for 950 mb calculated from composited u and v components. The center grid box denoted ☐ 1 has a direction of 142° and a velocity of 16 m/s.

5.2.2 West Indies Rectangular Grid

The parameters output for this grid are listed in Table 5.5.

TABLE 5.5
West Indies Rectangular Grid Parameters

<u>Directly Composited</u>

Zonal Wind (u)	Meridional Wind (v)
Height (z)	Temperature (t)

<u>Derived</u>

Mean Wind Direction (DDD)	Mean Wind Velocity (VV)

<u>Derived Vertical Integration</u>

1000 to 100 mbs	1000 to 500 mbs	500 to 100 mbs
u,v	u,v	u,v
z,t	z,t	z,t

<u>900 and 200 mb Average</u>

u,v

<u>Thickness Values</u>

1000 to 100 mbs	1000 to 500 mbs	500 to 100 mbs

DIVERGENCEX10-6

	45	40	35	30	25	20	15	10	5	0	5	10	15	20	25	30	35	40
15	999.9	999.9	999.9	999.9	999.9	23.1	-9.9	999.9	999.9	999.9	999.9	3.3	-12.7	999.9	999.9	999.9	999.9	999.9
10	999.9	2.0	999.9	-6.2	-13.4	4.0	-1.5	-12.0	-7.8	-4.8	3.3	2.0	3.2	-1.0	.1	-.2	-1.1	999.9
5	-6.7	4.0	-1.4	-1.4	8.9	-2.8	-.3	-1.4	-1.5	-10.4	-3.5	-4.2	-1.5	.8	1.5	-1.6	-2.8	2.1
0	-2.4	3.3	-1.9	-.5	-2.7	1.9	-3.4	-1.1	-4.7	-7.2	3.7	.4	-1.3	-1.6	-2.4	-2.2	2.4	1.3
5	.2	-5.1	.3	-.7	-1.7	-1.1	-.5	.4	-2.5	6.1	-.6	2.3	.7	-3.7	-2.0	-.3	2.2	-5.1
10	-1.3	-.6	-2.6	1.6	1.0	-1.0	3.2	1.1	-.6	2.2	1.4	.5	1.3	-.9	-2.8	.4	1.4	-2.0
15	-.1	-1.6	-.4	.5	2.5	2.6	1.6	2.0	.6	3.1	.7	.8	.9	.2	-2.0	2.2	-1.6	-1.0
20	5.4	-1.0	-.5	-.3	-2.5	2.6	3.8	3.7	.9	.9	-1.3	-1.8	-.7	-.8	1.3	3.0	-1.6	-.7

VORTICITYX10-5

	45	40	35	30	25	20	15	10	5	0	5	10	15	20	25	30	35	40
15	999.9	999.9	999.9	999.9	999.9	12.8	1.9	999.9	999.9	999.9	999.9	6.8	1.1	999.9	999.9	999.9	999.9	999.9
10	999.9	-2.0	999.9	7.0	23.8	-15.4	-3.4	2.2	1.5	2.1	11.8	-2.9	4.9	6.2	-1.4	-.8	4.9	999.9
5	-4.4	-3.1	-2.5	-2.2	.8	-3.9	-4.9	-5.4	-8.3	-13.7	-5.9	-.2	.9	-1.2	-3.1	-1.9	-3.7	.3
0	1.2	-2.5	-3.3	-1.9	-5.6	-5.7	-1.4	-1.1	4.5	-9.9	-21.8	-6.1	-1.3	-2.4	-5.0	-3.9	-3.0	-.4
5	3.6	-.7	-2.9	.1	-1.8	-2.3	-4.7	-1.9	-3.0	1.7	-1.0	-3.7	-5.1	-2.4	-1.5	-2.1	1.5	-.7
10	-8.0	-2.7	-.4	1.0	.1	.0	3.4	-4.5	-.8	.9	2.9	-.8	-4.0	1.5	1.9	-1.5	.4	2.5
15	-1.2	-3.7	2.2	2.5	2.4	2.0	3.5	2.4	-.8	3.3	1.1	4.0	1.0	2.3	4.9	2.9	-7.4	-.1
20	2.7	-1.0	-.5	2.7	3.1	1.8	2.7	6.8	.2	1.6	3.4	5.7	3.1	1.7	6.6	1.0	-2.9	3.8

OMEGA

	45	40	35	30	25	20	15	10	5	0	5	10	15	20	25	30	35	40
15	0.0	0.0	0.0	0.0	0.0	48.5	-21.2	0.0	0.0	0.0	0.0	0.0	-51.3	0.0	0.0	0.0	0.0	0.0
10	0.0	-1.9	0.0	0.0	-21.1	-.0	-8.5	-17.1	-29.8	-23.0	23.1	-4.3	6.5	6.8	-3.7	10.5	.9	0.0
5	-27.7	.0	-6.3	-6.9	15.1	-14.8	-6.5	4.7	-16.4	-11.1	-13.7	-5.7	-2.3	-.9	-5.7	3.6	-6.7	-21.8
0	-22.8	4.2	1.7	4.1	4.2	.6	.9	1.3	-5.1	-17.9	-23.6	1.1	-9.0	-4.9	-10.3	-3.2	-12.0	6.1
5	10.6	-21.6	19.2	-10.1	5.6	-4.0	4.8	17.4	7.6	-13.4	.7	-.4	-10.8	-8.1	-6.7	-28.4	-1.3	5.5
10	-15.5	-10.8	8.5	-10.5	-13.3	2.9	20.2	-2.5	-10.3	19.8	4.8	-22.4	6.5	10.8	-17.4	-21.4	-1.7	-18.1
15	-1.2	-6.0	2.7	4.4	19.5	1.2	-2.1	5.3	-13.7	10.3	5.1	6.4	-10.2	2.7	7.1	-16.3	-29.4	-1.3
20	-.9	11.7	5.1	17.2	.9	4.9	13.5	-11.5	-27.7	-3.2	23.1	15.7	9.4	9.2	22.5	-11.5	23.0	31.1

Fig. 5.18. Divergence, vorticity and vertical velocity for 950 mb calculated from the composited u and v values and divergence. The center grid box values denoted by ☐ 1, 2, 3 are -7.2, $-9.9 \times 10^{-6}\ s^{-1}$, and -17.9 mb d^{-1} respectively. The form of this printout is similar to Fig. 5.16.

5.2.2a Directly Composited Parameters

The zonal wind (u-component), meridional wind (v-component), height (HT), and temperature (T) are composited on the grid at each level and displayed along with the associated case counts as shown in Figs. 5.19, 5.20 and 5.21. The u and v components are computed directly and also with the storm motion subtracted out (essentially the MOT system of the cylindrical composites). The values in the center grid boxes of Fig.

900 XU FAST STURMS 0 PERIOD SOUTH 15.0 58.0 15.0 58.0 98.8 9.1 9.1 -9.0 1.4

U-COMPONENT NATURAL

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	1.1	2.9	4.8	3.1	5.3	2.8	3.3	4.5	5.4	5.6	6.0	5.4	3.9	1.5	3.3	.4	13.0	4.2	999.0	999.0
21	-.1	1.4	1.7	1.3	1.0	1.5	2.2	3.1	3.9	4.2	3.7	3.1	2.4	4.5	5.8	3.0	999.0	-2.9	999.0	999.0
18	-1.1	-.1	.5	1.5	.8	.6	.8	1.4	2.2	1.7	4.3	4.4	5.2	2.4	-.6	2.2	2.8	2.7	2.1	999.0
15	-1.5	-1.1	-1.2	.1	1.3	.9	2.1	1.6	1.4	.4	2.1	2.6	4.3	5.2	4.2	2.8	-.6	-1.0	999.0	999.0
12	-3.3	-.5	-1.2	-1.9	.1	-.8	.1	-1.9	-.9	-1.4	-1.7	-4.6	-3.4	-6.0	999.0	999.0	999.0	999.0	999.0	999.0
9	-2.5	-4.1	-2.6	-3.3	-2.8	-2.9	-3.5	-5.0	-4.9	-6.0	-6.5	-6.9	-8.4	-9.4	-9.8	999.0	999.0	999.0	999.0	999.0
6	-3.5	-4.7	-5.3	-5.2	-5.7	-5.8	-5.9	-6.2	-7.6	-6.5	-6.1	-8.0	-8.7	-10.3	-8.0	-9.5	999.0	999.0	999.0	999.0
3	-4.3	-5.3	-6.1	-6.1	-7.7	-7.4	-7.4	-8.1	-8.5	-9.7	-9.6	-11.7	-12.9 **1**	-9.1	-7.2	-7.9	-10.1	-11.0	-7.5	999.0
0	-5.4	-4.8	-4.4	-6.6	-6.2	-5.9	-8.3	-7.5	-8.5	-6.6	-6.2	-7.2	[-9.2]	-9.2	-10.4	-7.9	-7.1	-6.3	-6.7	999.0
3	-3.2	-3.5	-7.7	-6.2	-7.0	-7.4	-6.0	-7.1	-8.2	-6.7	-5.5	-3.9	-1.2	-2.5	-7.6	-4.3	-7.2	-4.8	999.0	-3.5
6	-6.2	-3.8	-4.8	-4.9	-4.9	-6.0	-6.9	-4.4	-5.4	-8.8	-3.9	-1.9	-1.0	-4.5	-4.9	-3.7	999.0	-3.3	-2.9	999.0
9	-2.7	-3.5	-5.6	-5.3	-4.1	-3.5	-4.6	-7.5	-3.4	-1.7	-7.8	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0
12	999.0	-4.6	999.0	3.5	.9	999.0	-.5	-5.5	999.0	999.0	-3.9	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0
15	-6.9	-15.5	999.0	999.0	999.0	-8.0	-8.8	-8.9	-8.3	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0

V-COMPONENT NATURAL

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	-.8	1.6	1.7	1.5	-.2	.3	2.2	2.1	2.7	3.0	1.6	2.4	2.4	1.8	1.3	5.9	-5.2	-5.6	999.0	999.0
21	2.1	1.3	1.9	.4	2.0	1.9	2.6	3.4	2.8	2.8	3.0	1.0	.8	.9	-2.9	-2.1	999.0	.9	999.0	999.0
18	1.4	2.1	1.8	2.8	2.6	3.0	2.6	3.2	2.5	2.2	2.7	1.8	1.1	.4	-.0	-1.4	-.7	-3.3	-5.6	999.0
15	1.9	2.5	2.0	2.3	3.2	3.4	3.2	2.2	3.3	2.5	2.5	2.3	.5	.7	-.7	-1.8	-.8	1.7	999.0	999.0
12	2.8	2.6	.5	3.4	2.0	3.9	3.6	4.1	2.5	2.9	3.4	3.1	1.8	-.1	999.0	999.0	999.0	999.0	999.0	999.0
9	1.7	1.9	2.7	2.1	3.9	3.6	4.1	2.2	1.7	.8	1.7	.7	1.7	-.4	-1.9	999.0	999.0	999.0	999.0	999.0
6	1.9	-.6	.0	.5	1.1	1.8	3.7	2.3	1.2	.4	.0	-.4	-.0	.5	-1.6	-1.9	999.0	999.0	999.0	999.0
3	.2	.6	.1	1.0	1.2	2.5	1.5	.8	.2	-.6	-.9	-3.4	1.2 **2**	.9	.3	-.0	-4.2	2.9	2.6	999.0
0	.4	-1.3	-.1	-.8	.1	.6	-.0	-.4	-.9	-1.2	-3.5	-7.4	[-.5]	6.4	4.9	-.5	-2.3	-1.5	2.2	999.0
3	-.7	-2.9	-1.4	-.8	.8	-.2	.4	-1.3	-1.3	-2.0	-2.5	-2.1	3.1	3.0	4.1	2.0	1.5	.3	999.0	2.0
6	-3.8	-3.6	-2.6	-1.3	-2.7	1.6	1.3	-1.6	-.4	.8	-2.2	1.2	2.0	7.2	3.6	.9	999.0	1.2	.0	999.0
9	-3.0	-1.0	-4.7	2.7	-1.2	.0	1.1	-2.0	.4	-4.1	-4.5	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0
12	999.0	-3.9	999.0	-6.1	-5.9	999.0	-3.0	-2.3	999.0	999.0	.8	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0
15	-.9	-6.9	999.0	999.0	999.0	.4	-1.9	-1.4	-3.4	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0

NO CASES

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	23	30	30	42	38	38	31	33	34	27	24	16	13	8	6	3	1	1	0	0
21	36	41	39	39	50	45	44	29	26	25	18	18	11	8	2	2	0	1	0	0
18	43	45	48	50	38	37	40	38	28	18	14	13	3	4	4	4	3	3	1	0
15	48	46	49	46	36	39	36	30	28	19	14	8	8	4	4	2	2	1	0	0
12	26	40	42	42	36	28	18	25	14	15	11	8	4	1	0	0	0	0	0	0
9	35	28	26	31	27	29	23	20	14	15	14	5	6	5	1	0	0	0	0	0
6	20	25	33	26	29	26	27	20	15	13	16	16	11	8	5	4	0	0	0	0
3	14	11	14	15	26	24	30	28	22	24	16	18	8	8	8	7	5	4	2	0
0	10	12	15	14	16	16	17	13	13	14	14	10	[12] **3**	11	9	9	2	2	1	0
3	7	8	5	5	11	10	15	11	15	15	10	9	3	2	3	3	4	3	0	1
6	2	6	6	8	5	5	4	5	4	3	5	7	4	6	4	3	0	2	2	0
9	3	3	2	1	4	7	3	2	3	2	1	0	0	0	0	0	0	0	0	0
12	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
15	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0

Fig. 5.19. Standard form of the output for the u and v component for the West Indies rectangular grid at 950 mb. The values in the center grid box (0,0) denoted by [ ] 1, 2, 3, and -9.2 m/s, -.5 m/s, and 12 respectively. This grid box contains all soundings within 1 1/2^{0} latitude of the storm center. The form of this printout is similar to Fig. 5.16.

900 15.0 58.0 15.0 58.0 98.8 9.1 9.1 -9.0 1.4
XU FAST STORMS 0 PERIOD SOUTH

HT NATURAL

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	1043.	1043.	1042.	1049.	1044.	1038.	1043.	1038.	1051.	1057.	1067.	1070.	1053.	1040.	1053.	1078.	1062.	1068.	99999.	99999.
21	1041.	1041.	1043.	1038.	1047.	1050.	1053.	1049.	1058.	1060.	1060.	1084.	1087.	1079.	1072.	1082.	1122.	1117.	1068.	1087.
18	1049.	1044.	1043.	1038.	1048.	1050.	1055.	1067.	1066.	1062.	1081.	1081.	1076.	1089.	1091.	1107.	1093.	1089.	1064.	99999.
15	1047.	1046.	1045.	1048.	1048.	1047.	1058.	1059.	1075.	1067.	1080.	1086.	1102.	1110.	1112.	1127.	1116.	1089.	99999.	99999.
12	1051.	1051.	1048.	1049.	1049.	1057.	1059.	1069.	1069.	1069.	1073.	1077.	1100.	1093.	1163.	99999.	99999.	99999.	99999.	99999.
9	1049.	1043.	1051.	1044.	1048.	1054.	1054.	1055.	1069.	1065.	1070.	1078.	1081.	1086.	1082.	99999.	99999.	99999.	99999.	99999.
6	1043.	1042.	1041.	1046.	1043.	1047.	1051.	1054.	1049.	1048.	1053.	1052.	1051.	1053.	1066.	1072.	99999.	99999.	99999.	99999.
3	1036.	1015.	1038.	1038.	1041.	1042.	1042.	1049.	1050.	1048.	1049.	1046.	1043.	1 1038.	1049.	1054.	1059.	1061.	1057.	99999.
0	1035.	1029.	1034.	1032.	1035.	1036.	1041.	1038.	1038.	1040.	1037.	1028.	1016.	1034.	1044.	1047.	1029.	1038.	1052.	99999.
3	1015.	1018.	1016.	1033.	1035.	1025.	1028.	1035.	1031.	1027.	1021.	1032.	1022.	1033.	1034.	1044.	1028.	1039.	99999.	1022.
6	1032.	1009.	1011.	1027.	1008.	1026.	1030.	1025.	1020.	1045.	1034.	1021.	1016.	1018.	1038.	1032.	99999.	1023.	1033.	1032.
9	1016.	1028.	1005.	1005.	1022.	1027.	1021.	1047.	1030.	1014.	999.	1050.	1019.	1060.	99999.	99999.	99999.	99999.	99999.	99999.
12	99999.	1051.	1000.	1020.	1014.	1020.	1013.	1041.	970.	1040.	1040.	99999.	99999.	99999.	1025.	99999.	99999.	99999.	99999.	99999.
15	1019.	992.	1010.	1050.	99999.	1009.	1054.	1044.	1042.	99999.	99999.	99999.	99999.	99999.	99999.	99999.	99999.	99999.	99999.	99999.

NO CASES

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	29	34	34	45	40	39	32	36	38	29	26	18	17	8	8	6	2	3	0	0
21	43	47	44	44	55	49	47	30	28	26	20	22	18	13	5	3	1	1	2	3
18	52	52	57	53	43	39	43	38	29	19	14	13	3	6	6	5	3	4	1	0
15	54	55	53	46	38	41	37	30	28	19	15	9	9	5	4	2	2	1	0	0
12	29	40	43	43	36	30	22	26	14	16	11	8	4	1	1	0	0	0	0	0
9	36	31	27	33	28	30	24	20	16	16	15	6	7	5	1	0	0	0	0	0
6	21	27	36	30	33	28	27	20	16	13	16	18	12	8	5	4	0	0	0	0
3	15	15	17	17	30	26	35	30	22	24	17	18	12	9	9	7	5	4	2	0
0	10	12	15	15	16	17	17	13	15	14	14	10	12 2	13	9	9	2	3	1	0
3	8	9	7	6	11	10	17	12	15	15	10	10	3	2	3	3	4	3	0	1
6	4	7	7	9	7	6	5	8	4	5	5	8	4	7	4	4	0	2	2	1
9	3	3	3	4	7	10	5	2	3	3	2	2	2	1	0	0	0	0	0	0
12	0	2	1	2	2	1	2	4	1	1	1	0	0	0	1	0	0	0	0	0
15	1	2	1	1	0	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0

Fig. 5.20. Standard form of the output for height at 900 mb. The values in the center grid box (0,0) denoted by ☐1,2 are 1016 meters and 12 respectively. The form of this printout is similar to Fig. 5.16.

900 15.0 58.0 15.0 58.0 98.8 9.1 9.1 -9.0 1.4
XU FAST STORMS 0 PERIOD SOUTH

T NATURAL

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	19.3	19.0	18.1	18.6	18.6	18.1	17.8	18.0	17.6	18.7	18.8	18.9	17.9	17.5	17.6	17.9	14.6	15.3	999.0	999.0
21	20.9	20.7	20.8	19.6	19.9	19.6	19.0	18.7	18.7	19.8	19.2	19.3	18.7	19.4	20.0	19.1	16.7	19.0	17.3	16.6
18	20.8	20.5	20.7	20.8	21.0	20.2	20.0	20.0	20.2	19.8	20.0	20.1	21.1	18.8	18.2	19.1	19.1	18.6	14.8	999.0
15	21.4	21.0	20.8	20.4	19.9	19.9	20.7	20.3	20.4	19.7	20.0	20.1	20.1	19.0	18.7	18.9	18.9	18.4	999.0	999.0
12	20.5	21.4	20.2	20.3	20.4	20.2	20.4	20.6	20.7	20.1	20.3	20.7	20.9	20.3	16.9	999.0	999.0	999.0	999.0	999.0
9	20.1	20.8	20.8	20.7	20.9	20.4	20.8	20.7	20.5	20.6	20.2	20.4	20.5	19.9	20.2	999.0	999.0	999.0	999.0	999.0
6	20.3	20.5	20.6	20.5	20.8	20.7	20.2	20.9	20.5	21.4	20.8	20.6	20.7	19.5	19.5	19.2	999.0	999.0	999.0	999.0
3	20.8	20.6	20.7	21.2	21.2	20.8	21.1	20.7	21.1	20.7	20.7	20.9	20.8	20.7	20.0	19.6	19.6	19.5	19.6	999.0
0	21.1	20.8	20.7	21.1	20.5	20.4	20.3	20.2	20.8	20.6	20.4	20.7	[20.0] 1	20.2	20.6	19.8	19.0	19.6	20.0	999.0
3	20.5	21.2	20.7	20.6	21.1	20.5	21.0	20.3	20.3	20.0	21.4	20.4	21.4	20.4	20.9	20.9	20.4	19.7	999.0	17.7
6	21.0	20.2	21.3	21.0	21.3	20.0	20.1	20.6	21.0	21.1	19.5	20.9	20.6	22.3	20.6	21.4	999.0	20.6	20.6	21.4
9	19.9	21.8	20.0	20.8	20.6	20.9	20.4	19.7	19.3	21.2	24.4	999.0	20.6	999.0	999.0	999.0	999.0	999.0	999.0	999.0
12	999.0	19.3	999.0	20.8	19.4	999.0	20.2	19.8	999.0	999.0	19.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0
15	20.8	19.7	999.0	999.0	999.0	21.8	20.7	20.4	19.6	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0	999.0

NO CASES

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	24	30	31	44	40	39	32	36	38	29	26	18	17	8	8	6	2	3	0	0
21	37	44	41	39	50	46	45	30	28	26	20	22	18	13	5	3	1	1	2	3
18	45	46	48	50	41	38	43	38	29	19	14	13	3	6	6	5	3	4	1	0
15	48	50	49	46	38	41	37	30	28	19	15	9	9	5	4	2	2	1	0	0
12	27	40	43	42	36	30	22	26	14	16	11	8	4	1	1	0	0	0	0	0
9	35	31	27	33	28	30	24	20	16	16	15	6	7	5	1	0	0	0	0	0
6	21	26	34	28	31	28	27	20	16	13	16	18	12	8	5	4	0	0	0	0
3	15	12	16	16	30	24	34	30	22	24	17	18	12	9	9	7	5	4	2	0
0	10	12	15	15	16	17	17	13	15	14	14	10	[12] 2	13	9	9	2	3	1	0
3	7	8	6	5	11	10	17	12	15	15	10	10	3	2	3	3	4	3	0	1
6	3	6	6	8	6	5	4	5	4	3	5	8	4	7	4	4	0	2	2	1
9	3	3	2	1	4	7	3	2	3	3	1	0	1	0	0	0	0	0	0	0
12	0	1	0	1	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
15	1	1	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0

Fig. 5.21. Standard form of the output for temperature at 900 mb. The values in the center grid box (0,0) denoted by [ ] 1,2 are 20.0°C and 12 respectively. The form of this printout is similar to Fig. 5.16.

5.19 are denoted by □1, 2, 3 and are -9.2 m/s, -.5 m/s, and 12 respectively. The reference grid box (0,0) contains all soundings within 1.5^{o} latitude of the storm center. The values in the center grid box of Fig. 5.20 denoted by □1, 2 are 1016 meters and 12 respectively. The values in the center grid box of Fig. 5.21 are denoted by □1, 2 and are 20.0^{o}C and 12 respectively.

5.2.2b Derived Parameters

Mean wind direction (DDD), and mean wind velocity (VV) are calculated from the mean u and v components and displayed as shown in Fig. 5.22. The values in the center grid box denoted □ 1 are a direction of 87^{o} and a velocity of 9 m/s. Also calculated (but not shown) are vertical integrations of u, v, HT and T for levels from 1000 to 100 mbs, 1000 to 500 mbs and 500 to 100 mbs. In addition, the 900 and 200 mb average for the wind components is calculated. The 1000 to 100, 1000 to 500, and 500 to 100 mb thickness values are also calculated.

5.3 Special Cylindrical Composites

We have developed a special program to calculate information in cylindrical composites with regard to our cyclone motion studies. These special parameters are output in plan views and are listed in Table 5.6. Because tropical cyclones move in a myriad of directions three new parameters are calculated.

900 XU FAST STORMS 0 PERIOD SOUTH 15.0 58.0 15.0 58.0 98.8 9.1 9.1 -9.0 1.4

DDD+VV NATURAL

	36	33	30	27	24	21	18	15	12	9	6	3	0	3	6	9	12	15	18	21
24	305. 1.	241. 3.	251. 5.	244. 3.	272. 5.	265. 3.	230. 4.	245. 5.	243. 6.	242. 6.	255. 6.	246. 6.	238. 5.	221. 2.	248. 4.	184. 6.	292. 14.	323. 7.	999. 999.	999. 999.
21	177. 2.	225. 2.	221. 3.	254. 1.	205. 2.	218. 2.	221. 3.	222. 5.	234. 5.	236. 5.	231. 5.	252. 3.	251. 3.	259. 5.	297. 6.	305. 4.	999. 999.	108. 3.	999. 999.	999. 999.
18	141. 2.	177. 2.	195. 2.	209. 3.	197. 3.	191. 3.	198. 3.	204. 3.	222. 3.	218. 3.	237. 5.	248. 5.	258. 5.	260. 2.	89. 1.	303. 3.	284. 3.	320. 4.	340. 6.	999. 999.
15	142. 2.	157. 3.	149. 2.	182. 2.	202. 3.	195. 4.	213. 4.	216. 3.	203. 4.	188. 3.	220. 3.	229. 3.	263. 4.	262. 5.	279. 4.	302. 3.	35. 1.	149. 2.	999. 999.	999. 999.
12	130. 4.	168. 3.	113. 1.	151. 4.	184. 2.	168. 4.	182. 4.	155. 5.	160. 3.	155. 3.	153. 4.	123. 6.	118. 4.	89. 6.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.
9	124. 3.	115. 5.	136. 4.	123. 4.	144. 5.	141. 5.	140. 5.	114. 5.	110. 5.	98. 6.	105. 7.	96. 7.	102. 9.	88. 9.	79. 10.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.
6	119. 4.	82. 5.	90. 5.	95. 5.	101. 6.	107. 6.	122. 7.	110. 7.	99. 8.	94. 6.	90. 6.	87. 8.	90. 9.	93. 10.	79. 8.	79. 10.	999. 999.	999. 999.	999. 999.	999. 999.
3	93. 4.	96. 5.	91. 6.	100. 6.	99. 8.	109. 8.	102. 8.	96. 8.	91. 8.	87. 10.	85. 10.	74. 12.	95. 13.	102. 9.	92. 7.	90. 8.	68. 11.	105. 11.	109. 8.	999. 999.
0	94. 5.	75. 5.	88. 4.	83. 7.	91. 6.	96. 6.	90. 8.	87. 8.	84. 9.	80. 7.	61. 7.	44. 10.	87. 9. 1	125. 11.	115. 11.	87. 8.	72. 7.	77. 6.	108. 7.	999. 999.
3	78. 3.	50. 5.	80. 8.	82. 6.	97. 7.	88. 7.	93. 6.	80. 7.	81. 8.	73. 7.	65. 6.	62. 4.	159. 3.	140. 4.	119. 9.	115. 5.	102. 7.	43. 5.	999. 999.	120. 4.
6	59. 7.	47. 5.	62. 5.	75. 5.	61. 6.	105. 6.	101. 7.	70. 5.	86. 5.	95. 9.	60. 4.	123. 2.	154. 2.	148. 8.	126. 6.	104. 4.	999. 999.	110. 3.	90. 3.	999. 999.
9	41. 4.	73. 4.	50. 7.	117. 6.	74. 4.	90. 3.	104. 5.	75. 8.	96. 3.	23. 4.	60. 9.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.
12	999. 999.	50. 6.	999. 999.	330. 7.	351. 6.	999. 999.	10. 3.	67. 6.	999. 999.	999. 999.	102. 4.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.
15	83. 7.	66. 17.	999. 999.	999. 999.	999. 999.	93. 8.	78. 9.	81. 9.	68. 9.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.	999. 999.

Fig. 5.22. Standard form of the output of direction and velocity calculated from mean u and v components for 900 mb. The values in the center grid box denoted □1 are a direction of 87° and a velocity of 9 m/s. Form of output is similar to that of Fig. 5.17.

TABLE 5.6

Special Cylindrical Composite Parameters for Cyclone Motion Studies

ROT

Wind Component Parallel to the Direction of Storm Motion (V_P)	Wind Component Normal to the Direction of Storm Motion (V_N)

MOTROT

Wind Component Parallel to the Direction of Storm Motion with the Storm Motion Subtracted Out (V_{PM})	Wind Component Normal to the Direction of Storm Motion (V_N)

The cylindrical grid is used in ROTATED (ROT) coordinates so that octant 1 is always in the direction of cyclone movement. Each wind vector is resolved into a component parallel (V_P or VP) and one normal (V_N or VN) to the direction of cyclone movement as shown in Fig. 5.23. The V_P component can then be compared to the cyclone speed while the V_N component coupled with V_P can be used to associate the surrounding cyclone wind vector with the storm's movement. To study the surrounding cyclone wind field relative to the cyclone, a variation of the ROTATED (ROT) coordinate system is used in which the cyclone speed is subtracted from the V_P component of the wind before the composite is made. The composite value is then labeled as V_{PM}. The V_N component is unchanged since it is normal to the direction of cyclone movement. This is referred to as the MOTION-ROTATED (MOTROT) coordinate system. See Fig. 5.24.

The V_P, V_N, and V_{PM} are displayed in plan view as shown in Figs. 5.25 and 5.26. Figure 5.25 shows the V_P component for the ROT system. The octant 6 7-9^o radius value is 4.57 m/s and there are 15 soundings in the octant. Figure 5.26 shows the V_N component for the ROT and MOTROT system. The octant 6 7-9^o radius value is 1.42 m/s and there are

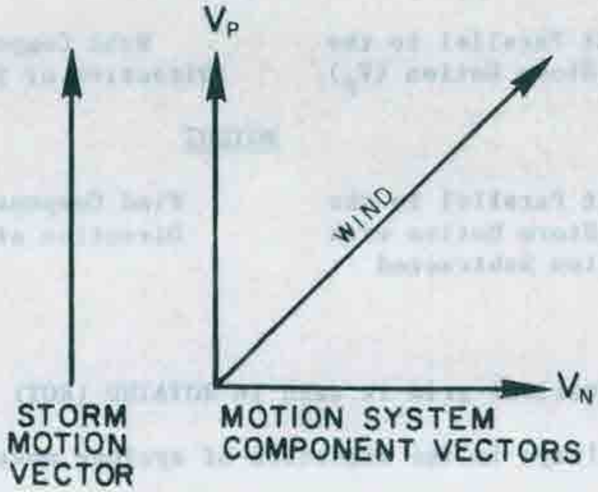

Fig. 5.23. Parallel (V_P) and perpendicular (V_N) components of a wind vector showing their relation to the storm motion vector.

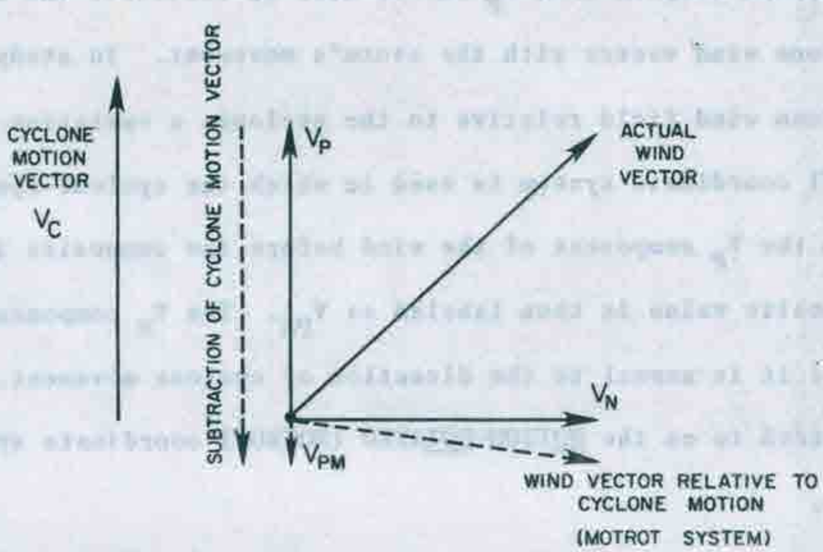

Fig. 5.24. Definition of V_{PM}, the wind component relative and parallel to the storm motion in the MOTROT coordinate system.

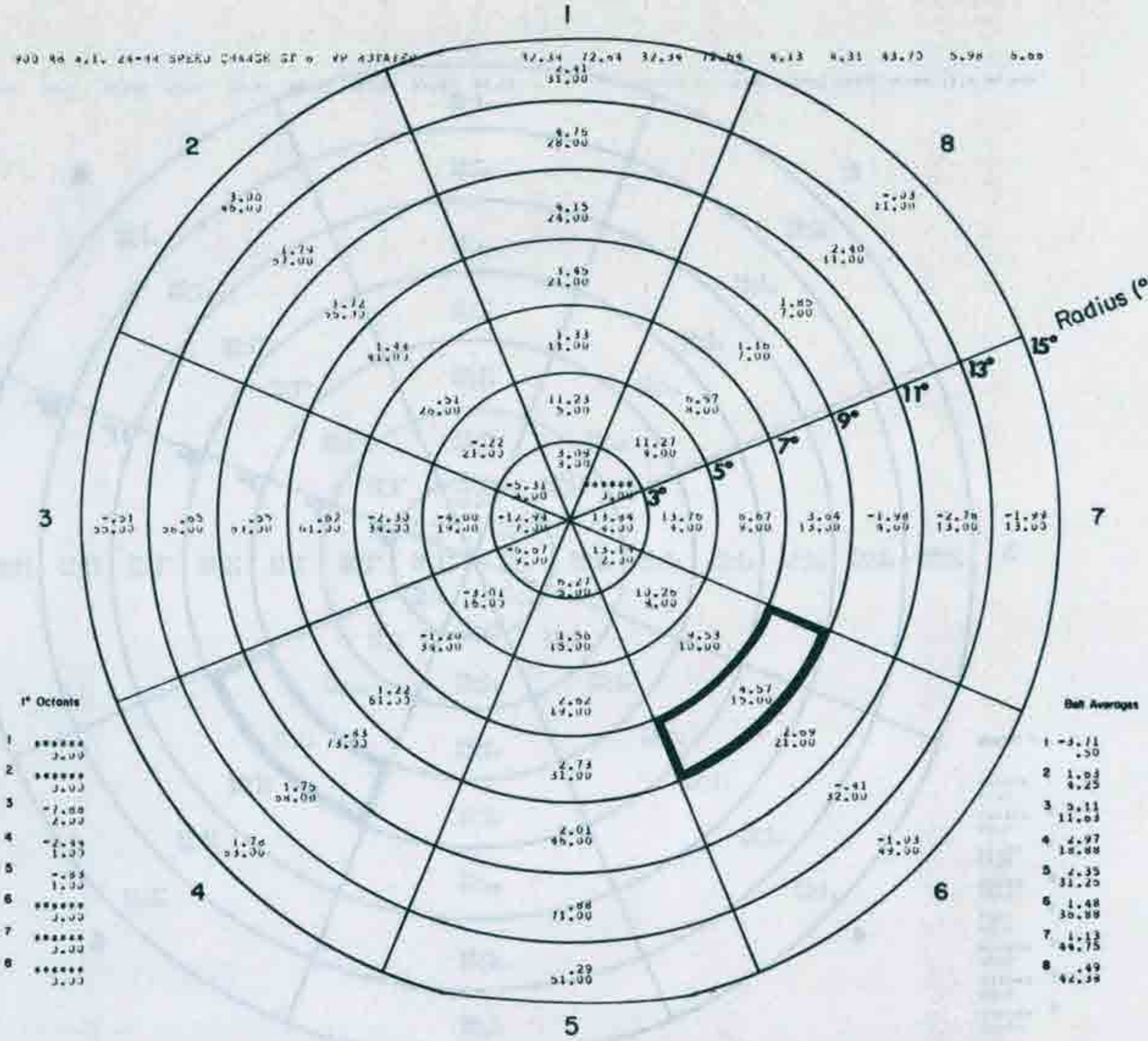

Fig. 5.25. Plan view of V_p ROT for a single level (950 mb). The octant 6, 7-9^o radius value (outlined) is 4.57 m/s and there are 15 soundings in the octant.

15 soundings in the octant. The composites are made at only 900, 700, 500, 300, 200 and 100 millibars. The average of 900 and 200 mbs, and the shear between 900 and 200 mbs is computed for all parameters except temperature. The surface to 100 mb integration is also calculated for all parameters.

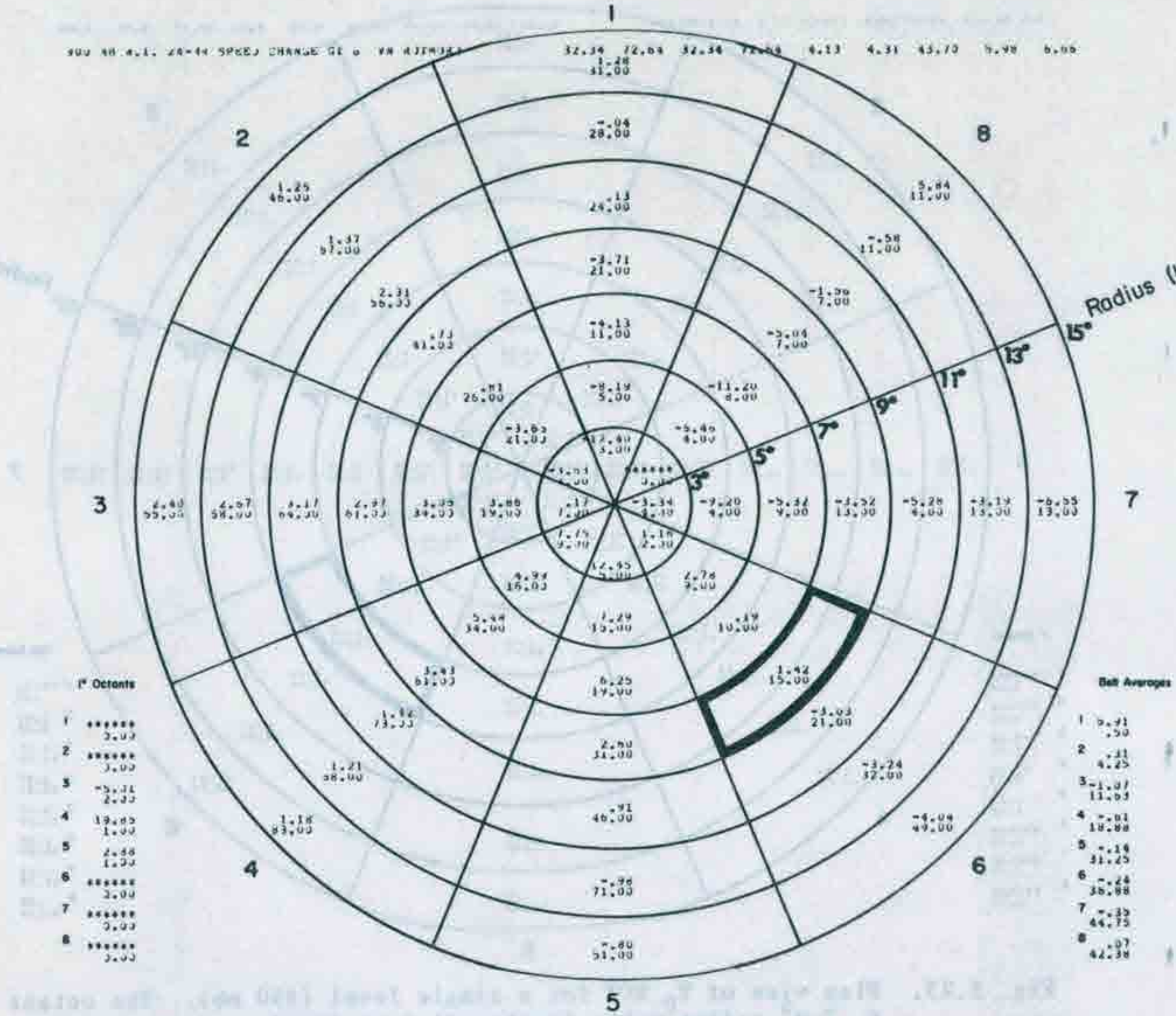

Fig. 5.26. Plan view of V_N ROT and MOTROT for a single level (900 mb). The octant 6,7–9° radius value (outlined) is 1.42 m/s and there are 15 soundings in the octant.

5.4 Smoothed Data Sets at NCAR

5.4.1 Smoothed Data

A second version of the composite data sets, which has been smoothed, is also available. At the present time, only 18 primary data sets have been processed with regard to our basic structure studies and 16 additional data sets with regards to our cyclone motion studies. Any of the composite data, however, can be easily run through the smoothing system.

The data are smoothed by using a cubic spline approximation on each of 18 pressure surfaces and for each variable. We use the subroutine SPLCC and SPLFE from the NCAR libraries, with 5 nodes in each horizontal direction and a grid 28^{o} by 28^{o} (a 14^{o} radius) and store the data on the TMS-4 (explained in Chapter 4). Five nodes appear to produce satisfactory results in most cases, but different values can be used upon request.

The primary motivation for smoothing is to facilitate the calculation of horizontal gradients both radially and between octants for derived quantities such as DIV, ω, and vorticity. Meteorological budgets can then more smoothly be determined at individual points. This is often more difficult with the raw data. The major disadvantage to using this smoothed data is that naturally sharp gradients tend to be reduced in strength and diffused over a slightly greater distance.

5.4.2 Smoothed Data Availability at NCAR

Currently, data sets mentioned in the prior section, both raw and smoothed forms, are on mass storage at NCAR. In some cases this may be the simplest and least expensive way to obtain copies of the composite data.

In order to transfer data from the CSU computers to the NCAR computers one must follow the procedure listed below:

1) Run job at CSU which places the required data in the jobs output file.

2) Upon arrival at the CSU Atmospheric Science Department PDP 11/34, the operator copies the output file to disk.

3) A program is executed on the 11/34 which prepares an NCAR job with appropriate job control language and deck structure.

4) The NCAR job is submitted; execution of this job copies the data to a mass storage device at NCAR.

5.5 Summary

All octant summations and case counts are stored on magnetic tape for all parameters. This storage of the data allows us to print extra copies of output if they are needed and also to make other calculations with the parameters.

The storage of the parameters also allows us to display the data in forms other than the standard ones if it is deemed necessary for completion of the research effort. The ways the data can be displayed and the calculations that can be made are limited only by the needs and imagination of the researcher. Figure 5.27 shows some of the printouts that have been generated for the storm stratifications that have been run to date. Figure 5.28 gives an example of the documentation sheet with pertinent information that is made up for each stratification that has been run. This sheet shows the purpose of the composite run, system intensity, location, number of soundings, type of output (wind, thermal budget, etc.), date of run, and other pertinent information.

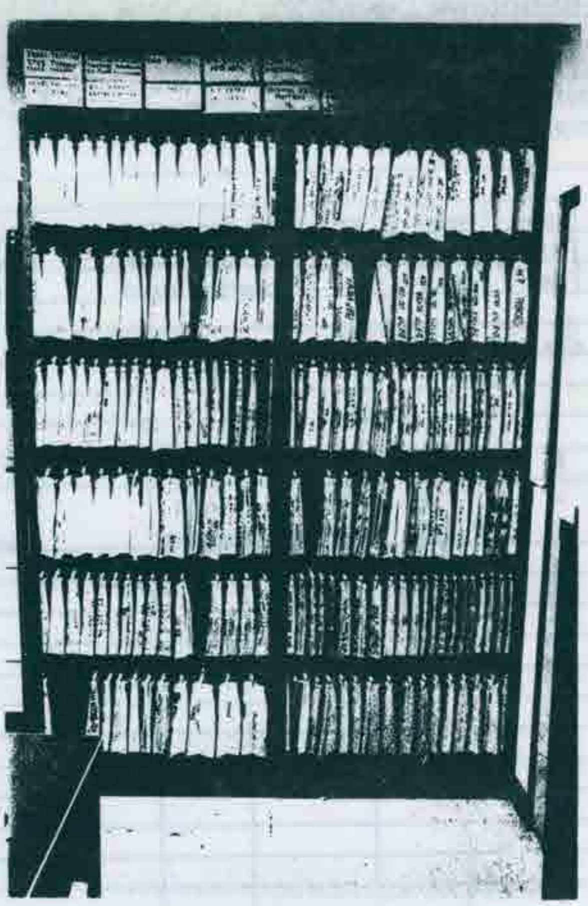

Fig. 5.27. Picture of a data rack showing some of the printouts that have been generated for storm stratifications run to date.

STRATIFICATION Atlantic D4 - Hurricane		ID. NO. 8
AUTHOR: John McBride		BLDG. LOCATION ATS 207
PURPOSE: STRUCTURE		RACK LOCATION 2-8
CRITERIA FOR STRATIFICATION: $V_{max} \geq 65$ kts		
POSITIONS MACHINE [X] HAND [X] PICKED	NO. STORMS:	NO. PERIODS:
DATA SAMPLE USED: W.I. some dates coastal stations		

NO. OF SNDGS.	WIND	TEMP	RH	MEAN CHARACTERISTICS	
500 mb 4°	412	411	389	LATITUDE 22.94	LONGITUDE 78.83
500 mb 10°	889	888	843	DIRECTION 130.09	SPEED 2.87/4.06

W.I. some dates coast GE 65 OC,I,L, Regions 1,2,3

OUTPUTS	ID	DATE RUN	OUTPUT LOCATION	NCAR SMOOTHED	COMMENTS
WIND	X	4/77			
WINOUT 1	X	10/77			
THERMO	1,2	3/77			
BUDGET	S	10/77			
PLAN WIND	X	7/78			
CROSS-WIND	X	5/77			
PLAN-THERMO					
CROSS-THERMO	X	5/77			
CHAN PLAN					

GENERAL COMMENTS:

Fig. 5.28. Documentation sheet that is made up for each run.

6. HURRICANE INNER-CORE RESEARCH AIRCRAFT FLIGHT DATA

Our research project personnel have spent considerable effort over the last 20 years in the evaluation of the NOAA National Hurricane Research Project inner hurricane aircraft flight data. Data are now available from two periods:

a) flights of 1957 to 1969 with B-50, DC-6, B-47, and B-57 aircraft where winds were determined from a Doppler Navigation system and

b) flights since 1975 where a new hierarchy of instrumentation is employed on P-3 aircraft of which the most notable change is the inertial navigation system which allows accurate horizontal and vertical wind measurements down to a space and time scale of approximately 100 meters and a few seconds.

Most of our analysis of hurricane data to this time has been with data set a). We are now beginning to work with data set b) and plan to do an extensive analysis of various topics with this new and unique information.

6.1 Data Set a)

Observational information from approximately 100 aircraft flight missions (533 separate radial leg flights into or out of hurricanes by B-50, B-47, DC-6 and B-57 aircraft) into twenty-two different hurricanes on forty-one storm days over a twelve year period (1957-1967, 1969) by aircraft of the NOAA Research Flight Facility is available on magnetic tape and has been extensively studied on our research project during the 1960's and early 1970's.

The National Hurricane Research Project (NHRP) was established in the middle 1950's at the instigation of Congress following the devastating flooding caused by hurricane Carol in the Connecticut Valley in 1954. Dr. Robert Simpson (former Director of the National Hurricane Center) was the driving force behind the initial organization and functioning of the NHRP. The first flights were accomplished in late 1956. Except for the year 1959 (during the change over from Air Force to civilian aircraft) an almost continuous monitoring of the hurricane by the Weather Bureau's (now NOAA's) Research Flight Facility (RFF) was accomplished in the decade from 1956 through 1966. From 1966-1967 onward the interest of NOAA has steadily shifted to hurricane modification and the typical radial or cloverleaf flight patterns have been modified.

Data set a) represents most of the processed inner core National Hurricane Research Laboratory Research Flight Facility (RFF) radial leg flight missions into tropical cyclones between 1957 and 1966. Some additional data for hurricane Beulah (1967) and Debbie (1969) are also included. The other approximately two-thirds of the RFF tropical cyclone flight data have not yet been processed or are unavailable in final processed form. Some of this latter unprocessed information is of less or marginal quality than that which has been processed.

At CSU we have chosen to portray this data along individual radial flight legs in 2 1/2 nautical mile (n.mi.) intervals from 5 to 50 n.mi. radius. Typically, 4 to 6 radial legs were flown at one level into and out of a tropical cyclone during a 6-8 hour period. These radial legs are listed separately and have been vortex averaged for each flight mission.

The majority of the data set a) missions were made into the hurricane eye and out again. This was repeated at individual flight levels four to six times with a rather even balance between the storm quadrants. Figures 6.1 to 6.4 show several typical flight patterns.

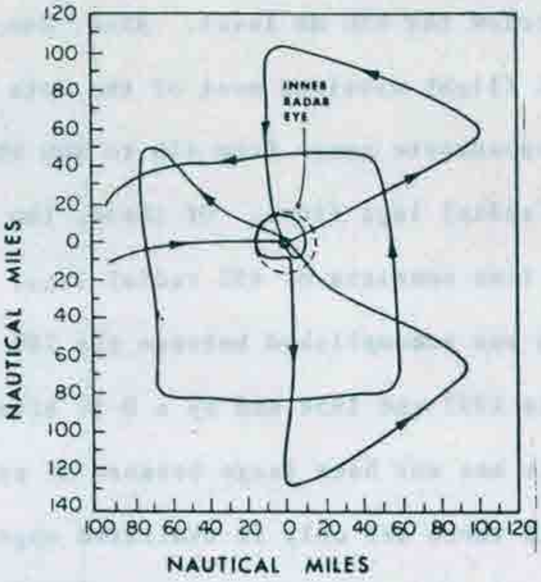

Fig. 6.1. Cleo 18 Aug. 1958, 560 mb.

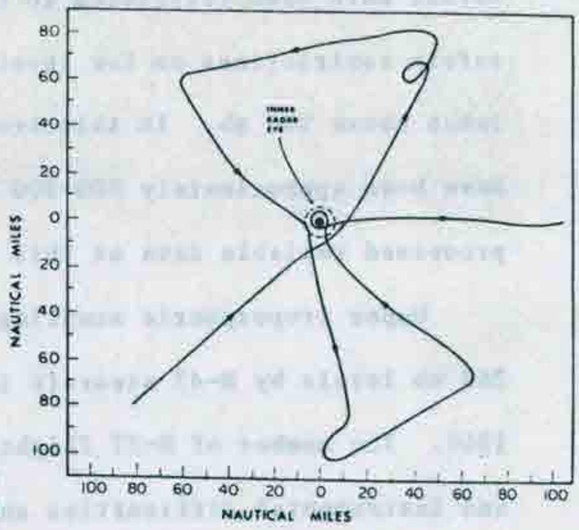

Fig. 6.2. Daisy 27 Aug. 1958, 620 mb.

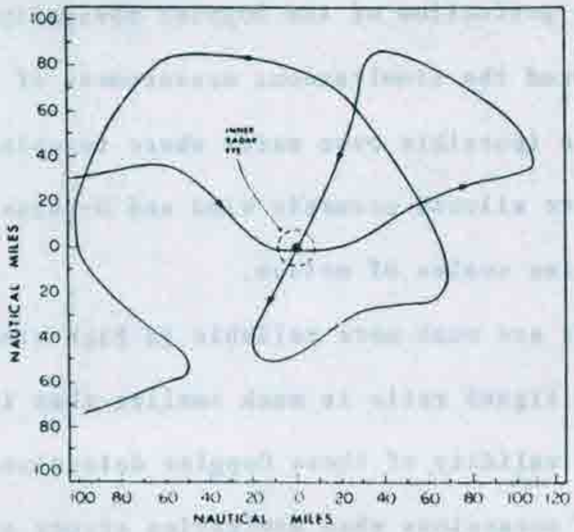

Fig. 6.3. Helene 26 Sept. 1958, 250 mb.

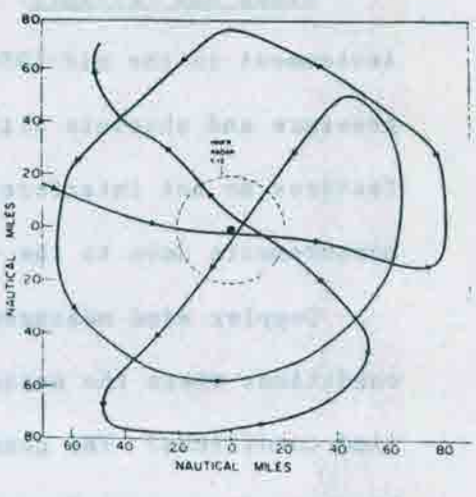

Fig. 6.4. Carla 10 Sept. 1961, 600 mb

Because these data have been gathered by prop aircraft flight levels have been restricted to below the 450 mb level. Also, due to safety restrictions on low level flight missions most of the data were taken above 900 mb. In this tropospheric range from 450 to 900 mb there have been approximately 700-800 radial legs flown. Of these, the processed reliable data at this time consists of 492 radial legs.

Upper tropospheric sampling was accomplished between the 180 and 260 mb levels by B-47 aircraft in 1957 and 1958 and by a B-57 after 1960. The number of B-57 flights has not been large because of range and instrumental difficulties and there are only 11 evaluated upper level missions (41 radial legs). Combining upper and lower levels there are 533 radial legs.

6.1.1 Character of the Measurements

<u>Winds and Pressure</u>. The perfection of the Doppler navigation instrument in the mid-1950's and the simultaneous measurement of pressure and absolute altitude (possible over water where terrain features do not interfere) have allowed accurate wind and D-value measurements down to the cumulus scales of motion.

Doppler wind measurements are much more reliable in high wind conditions where the noise to signal ratio is much smaller than in weak wind conditions. The general validity of these Doppler determined winds has been demonstrated on many occassions when navigation errors after many hours of flight proved to be but a few nautical miles.

<u>Temperature</u>. The vortex temperature measurements have shown a good reliability except for measurements directly within cumulus clouds where wet bulb biasing is believed, by some scientists, to still be a problem. It is possible to obtain an independent check on the observed inward

radial temperature gradients by measurement of the pressure level thickness changes when simultaneous double level missions were flown. When compared the hydrostatically calculated temperature gradients and the directly measured temperature gradients generally proved to be quite close.

Processing of Data. The data reduction, cross checking, navigation corrections, hydrostatic consistency checks, etc., that had to be made at the Miami Hurricane Research Center and at CSU have required a rather lengthy and painstaking evaluation procedure. This large data sample a) flight information is now available for additional scrutiny.

6.1.2 Data Collection and Accuracy

Discussions of the instruments and aircraft used in data sample a) have been given by Hilleary and Christensen (1957), Hawkins et al. (1962), Reber and Friedman (1964) and Friedman et al. (1969a, 1969b).

After a flight into a storm has been completed, the raw data are composited with respect to the moving storm center by computer. These data are then processed to give the plane's distance from the storm center, the actual tangential wind (VAT), the actual radial wind (VAR), the relative tangential wind (VRT), the relative radial wind (VRR), the D-value (D) and the adjusted temperature (TADJ) at that radius. The actual winds include the effects of storm motion whereas the relative winds have had the storm motion subtracted fom the data. The adjusted temperature is the observed temperature adjusted to a constant pressure surface using typical hurricane lapse rates. A typical printout of data for one flight mission is shown in Fig. 6.5.

These data are unique in that simultaneous wind, temperature and pressure measurements are available down to the cumulus scale. Over

STORM	DATE	PRES ALT FEET	MB.	TIME INTERVAL	IN /OUT	LAT/LONG	ID

STORM SPD	DIR	TRUE HDG	OCTANT NOTH/STM	AZMTH ANGLE	IN RDR EYERAD	CENT PRES	MAX WINDS ACTUAL	REL	RADIUS MAX WD

/CARLA / 610909 / 4780 / 859 / 2110-2127 / 0 / 24 / 91 / 512 /

/ 8 / 310 / 15 / N / 3 / 15 / 21W0 / 948 / 111 / 104 / 17.5

RADIUS	VAT	VAR	VRT	VRR	D-VALUES	TADJ
5.0	21	13	13	12	-1980	22.4
7.5	32	3	24	0	-1960	22.7
10.0	53	-2	42	-4	-1930	22.4
12.5	65	1	58	-2	-1850	22.2
15.0	87	5	81	2	-1750	22.1
17.5	111	11	104	7	-1630	21.9
20.0	102	1	95	-2	-1560	21.8
22.5	96	-9	88	-13	-1450	21.0
25.0	91	-14	84	-18	-1410	21.0
27.5	91	-9	84	-13	-1330	21.0
30.0	85	-5	80	-10	-1290	20.5
32.5	83	-2	76	-5	-1240	20.9
35.0	84	-13	76	-16	-1210	21.2
37.5	81	-5	74	-7	-1200	20.8
40.0	76	9	68	1	-1180	20.8
42.5	77	-6	67	-8	-1160	20.6
45.0	79	-1	70	-3	-1150	20.8
47.5	80	-1	72	-3	-1110	20.8
50.0	81	1	74	0	-1080	20.8

/CARLA / 610909 / 4780 / 859 / 2052-2108 / 1 / 24 / 91 / 514 /

/ 8 / 310 / 60 / SW / 4 / 240 / 21W0 / 948 / 86 / 93 / 22.5

RADIUS	VAT	VAR	VRT	VRR	D-VALUES	TADJ
5.0	-2	-3	6	0	-1940	23.3
7.5	2	-8	9	-6	-1920	23.1
10.0	24	-2	31	0	-1910	22.9
12.5	59	2	66	10	-1900	22.1
15.0	77	10	83	3	-1830	22.0
17.5	90	7	88	6	-1710	21.6
20.0	91	6	89	5	-1620	21.3
22.5	86	9	93	7	-1520	21.1
25.0	75	-2	83	-6	-1440	21.0
27.5	74	-6	82	-8	-1310	20.9
30.0	71	-12	78	-14	-1230	20.8
32.5	66	-6	73	-6	-1190	21.5
35.0	62	-4	69	-7	-1140	21.2
37.5	54	-3	61	-5	-1120	21.8
40.0	57	-5	64	-7	-1060	21.2
42.5	55	-5	62	-7	-1050	21.0
45.0	52	-4	60	-5	-1040	20.9
47.5	56	-7	63	-6	-1040	20.4
50.0	55	-6	63	-6	-1030	20.2

/CARLA / 610909 / 4780 / 859 / 2229-2240 / 0 / 24 / 91 / 513 /

/ 3 / 310 / 100 / E / 5 / 100 / 21W0 / 948 / 98 / 95 / 20.0

RADIUS	VAT	VAR	VRT	VRR	D-VALUES	TADJ
5.0	10	2	8	8	-2050	22.7
7.5	19	3	17	9	-2030	22.5
10.0	34	3	32	3	-1990	22.4
12.5	50	-4	47	2	-1960	22.3
15.0	76	3	75	0	-1850	22.1
17.5	99	7	86	14	-1790	22.3
20.0	98	-8	95	-2	-1650	22.0
22.5	97	-9	94	-3	-1650	21.8
25.0	91	-11	88	-5	-1520	21.6
27.5	90	-17	86	-11	-1440	20.7
30.0	86	-20	83	-14	-1380	20.6
32.5	81	-17	79	-12	-1290	20.8
35.0	78	-16	75	-11	-1240	20.9
37.5	79	-19	76	-14	-1230	20.7
40.0	999	999	999	999	999	999.0
42.5	999	999	999	999	999	999.0
45.0	999	999	999	999	999	999.0
47.5	999	999	999	999	999	999.0
50.0	999	999	999	999	999	999.0

/CARLA / 610909 / 4780 / 859 / 2211-2226 / 1 / 24 / 91 / 515 /

/ 8 / 310 / 140 / NW / 1 / 315 / 21W0 / 948 / 101 / 100 / 17.5

RADIUS	VAT	VAR	VRT	VRR	D-VALUES	TADJ
5.0	2	-5	2	-12	-2020	22.8
7.5	13	-6	13	-13	-1990	22.7
10.0	26	-11	27	-17	-1890	22.5
12.5	75	-6	76	-10	-1840	22.3
15.0	96	-10	96	-16	-1790	21.7
17.5	101	-14	100	-22	-1740	21.6
20.0	92	-17	91	-19	-1570	20.9
22.5	84	-8	84	-15	-1490	20.8
25.0	80	-15	79	-21	-1420	21.0
27.5	79	-11	78	-19	-1350	20.7
30.0	72	-19	71	-16	-1270	21.1
32.5	69	-7	69	-15	-1200	21.0
35.0	67	-11	66	-17	-1190	20.9
37.5	63	-11	62	-18	-1170	20.5
40.0	63	-6	62	-13	-1130	20.5
42.5	62	1	61	-6	-1090	20.6
45.0	63	-2	62	-8	-1060	20.5
47.5	67	-7	66	-14	-1000	20.6
50.0	63	-3	62	-10	-950	21.3

Fig. 6.5. A typical printout of the data set a) flight data which has been processed at CSU. This printout shows the information for four 859 mb flight level radial legs into and out of Hurricane Carla on 9 September 1961. Data is portrayed by 2.5 n mi radius interval.

land, where terrain features obscure D-value measurements, this is not possible. The simultaneous pressure and wind measurements allow examination of gradient wind balances. Where double level flights were made, an examination of the vertical wind shears and cylindrical thermal wind balances can be made.

Table 6.1 lists the twenty-two hurricanes, the forty-one storm days, the number of radial legs (total - 533), the pressure levels at which the data were collected, the maximum actual winds at flight levels, the central pressures, etc., for the storms used in this study. Hurricane Hannah's data for 1959 was obtained by Air Force research planes.

Besides the information listed in Table 6.1 several other types of information are available. These include the time interval during which the data were obtained, the ground track of the aircraft, the octant in which the aircraft was flying both with respect to (w.r.t.) geographic north and w.r.t. storm motion, and whether the plane was flying towards or away from the storm center. This allowed investigation of the data to see if individual parameters exhibited any systematic differences between data gathered by inward penetration as opposed to outward penetration of the eye wall. Results showed that there are no systematic differences.

Contained in the data sample are twenty days on which simultaneous multilevel flights were made. In order to be representative, each flight level was required to have at least four approximately equally spaced radial legs and the data at each level had to be taken within a reasonable time interval of each other i.e., 5-6 hours. This greatly reduces the number of usable multiple level flights. These multiple

TABLE 6.1

Storms, dates, levels, etc., used in this study. The letters following the inner radar eye are: A - approximate, WD - well defined, P - poor. Intensity change means D(Deepening), S(Steady), and F(Filling).

1-Carrie	15 Sept 57	30	310/11	S	963	80	(22)	---	610	6	1	1
						84	(22)	---	525	4	2	3
						54	(35)	---	240	2	3	5
	17 Sept 57	35	65/8	S	978	84	(32)	25A	680	6	4	7
						42	(47)	25A	240	6	5	9
2-Cleo	18 Aug. 58	33	15/13	S	972	86	(22)	17	800	6	1	11
						82	(22)	17	560	6	2	13
						49	(50)	17	240	5	3	15
3-Daisy	27 Aug. 58	29	25/5	D	942	109	(10)	6	620	6	1	17
		"			943	69	(10)	6	250	4	2	19
	28 Aug. 58	33	0/17	F	950	101	(20)	---	620	6	3	21
4-Helene	25 Sept 58	29	335/6	D	982	76	(27)	15	800	6	1	23
	26 Sept 58	30	315/9	D	948	99	(25)	9	800	8	2	25
						97	(20	9	800	1	3	28
						119	(15)	9	560	5	4	30
						81	(12)	9	250	4	5	32
5-Hannah	01 Oct. 59	31	335/11	S	959	95	(20)	---	700	4	1	34
	02 Oct. 59	34	75/8	S	959	96	(22)	---	700	4	2	36
	04 Oct. 59	37	85/10	S	955	108	(30)	---	700	6	3	38
6-Donna	04 Sept 60	17	290/15	S	952	120	(12)	---	600	2	1	40
	07 Sept 60	22	270/9	S	935	129	(22)	10-13WD	760	4	2	42
						128	(15)	13WD	620	4	3	44
	09 Sept 60	23	305/10	S	930	131	(15)	---	800	2	4	46
7-Anna	21 July 61	13	280/16	S	983	98	(12)	---	700	9	1	48
8-Carla	08 Sept 61	23	300/6	D	964	98	(32)	31WD	850	4	1	51
						96	(35)	31WD	700	4	2	53
	09 Sept 61	24	310/8	D	948	109	(22)	21WD	850	4	3	55
						111	(17)	21WD	850	4	4	57
						94	(22)	22WD	700	4	5	59

TABLE 6.1 (cont'd)

	10 Sept 61	27	300/8	S	940	96	(20)	20A	600	6	6	61
	11 Sept 61	28	340/6	S	940	102	(15)	---	600	4	7	63
9-Esther	16 Sept 61	23	295/13	D	935	128	(12)	10A	800	8	1	65
						109	(12)	10A	470	9	2	68
						106	(12)	10A	470	5	3	71
	17 Sept 61	24	300/10	S	940	112	(10)	---	800	5	4	73
						108	(10)	---	800	2	5	75
						108	(10)	---	800	3	6	77
10-Ella	10 Oct. 62	31	65/8	D	966	102	(30)	30	900	8	1	79
						89	(40)	30	600	8	2	82
11-Beulah	23 Aug. 63	21	340/8	D	962	82	(17)	13	800	5	1	85
	24 Aug. 63	24	350/7	F	961	100	(25)	13A	800	10	2	87
						108	(20)	13A	520	13	3	90
12-Flora	03 Oct. 63	17	330/9	D	936	135	(8)	8-9	700	14	1	94
						122	(10)	8	650	12	2	98
	10 Oct. 63	28	50/25	S	970	117	(42)	25	700	12	3	101
						101	(50)	25	650	15	4	104
13-Cleo	23 Aug. 64	17	275/12		---	133	(7)	---	700	13	1	108
					---	126	(7)	---	650	16	2	112
14-Dora	05 Sept 64	24	320/10	D	966	98	(27)	8-15	700	7	1	116
					960	95	(25)	18	600	6	2	119
	07 Sept 64	28	285/10	S	963	75	(25)	14	700	6	3	121
					960	89	(50)	14	700	8	4	123
					960	88	(25)	14	650	16	5	126
	08 Sept 64	29	285/12	S	963	88	(35)	17P	700	4	6	130
					962	82	(40)	14	650	2	7	132
	09 Sept 64		280/10	S	965	82	(42)	25A	860	5	8	134
						80	(35)	25A	700	6	9	136
						69	(30)	25A	600	2	10	138
15-Gladys	17 Sept 64	24	300/9	S	954	111	(12)	13	900	6	1	140
					950	102	(15)	13	700	4	2	142
					945	107	(15)	13	700	2	3	144
			300/10		945	105	(15)	13	560	4	4	146

TABLE 6.1 (cont'd)

16-Hilda	01 Oct. 64	24	310/5	D	950	110	(12)	10	900	4	1	148
					947	109	(12)	7-9	750	5	2	150
					950	90	(15)	7	650	4	3	152
						90	(12)	9	500	7	4	154
		24	310/5			47	(15)	9	180	2	5	157
	02 Oct. 64	26	0/5	F	956	103	(20)	9	900	4	6	159
						89	(35)	9	700	2	7	159
						93	(40)	9	650	4	8	163
						50	(27)	9	200	2	9	165
17-Isbell	14 Oct. 64	24	35/11	S	970	108	(10)	13	850	6	1	167
						102	(12)	13	700	7	2	169
						87	(20)	13	570	1	3	177
18-Betsy	03 Sept 65	25	315/10	S	952	98	(22)	13-28	750	6	1	174
						100	(25)	10-15	650	6	2	176
						91	(17)	10	500	6	3	178
						56	(37)	10	200	4	4	180
	05 Sept 65	29	180/3	F	973	93	(37)	28	900	2	5	182
					968	75	(40)	10	800	2	6	184
		25				72	(37)	10	650	2	7	186
		29			970	57	(22)	10	500	4	8	188
						47	(42)	10	200	4	9	190
19-Inez	27 Sept 66	16	275/10	D	962	108	(5)	5	750	6	1	192
						104	(7)	5	650	6	2	194
					971	74	(12)	5	500	6	3	196
					962	46	(25)	5	200	4	4	198
20-Inez	28 Sept 66	17	275/12	D	934	142	(5)	4	950	6	1	200
					928	150	(7)	7	750	6	2	202
					934	126	(7)	4	650	6	3	204
			275/14		930	137	(7)	7	500	5	4	206
					934	67	(15)	7	200	4	5	208
21-Beulah	18 Sept 67	22	295/11	D	967	78	(12)	7	950	4	1	210
						80	(20)	7	850	4	2	212
22-Debbie	18 Aug. 69	24	300/1	S	971	93	(22)	--	650	4	1	214
	20 Aug 69	25	305/11	S	950	99	(22)	--	650	4	2	216
					954	99	(12)	--	650	4	3	218

TABLE 6.2

Storms, dates and flight levels for the 20 storm days on which multilevel flight missions were made.

Storm	Date	Approximate Flight Levels (mb)
Carrie	15 Sept 1957	610, 525
	17 Sept 1957	680, 240
Cleo	18 Aug 1958	800, 560, 240
Daisy	27 Aug 1958	620, 250
Helene	26 Sept 1958	800, 560, 250
Donna	7 Sept 1960	760, 620
Carla	8 Sept 1961	850, 700
	9 Sept 1961	850, 700
Beulah	24 Sept 1963	800, 520
Flora	3 Oct 1963	700, 650
	10 Oct 1963	700, 650
Dora	5 Sept 1964	700, 600
	9 Sept 1964	860, 600
Gladys	17 Sept 1964	900, 700, 560
Hilda	1 Oct 1964	750, 650, 500
Isbell	14 Oct 1964	800, 700
Betsy	3 Sept 1965	750, 650, 200
	5 Sept 1965	500, 200
Inez	27 Sept 1966	750, 650, 500, 200
Beulah	18 Sept 1967	950, 850

level flights are listed in Table 6.2. Examination of these flights can be used as a check of the vertical wind shears and the degree of cylindrical thermal wind balance, and other features requiring knowledge of the vertical wind shear.

Vertical Distribution of Data. Figure 6.6 shows the distribution of the data in the vertical. The number of radial legs at each level and the pressure level which the data best represent is indicated. Using this information a five level mean symmetric storm can be constructed.

Various CSU research papers or reports by Gray, 1962, 1965a, 1965b, 1966, 1967; Shea, 1972; Shea and Gray, 1973; Gray and Shea, 1973, 1976 (references given in Chapter 8) give more detailed descriptions of hurricane data set a) and how we have evaluated the information.

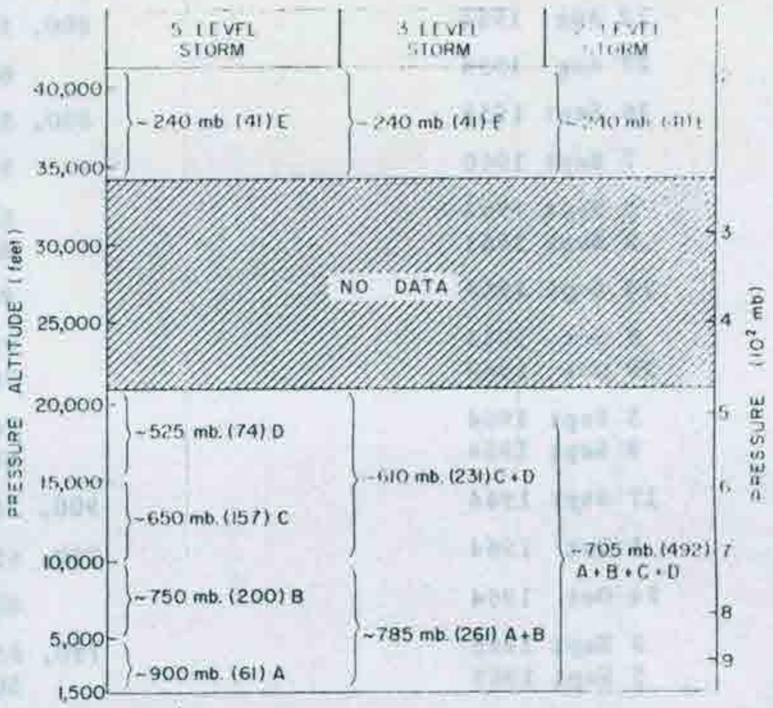

Fig. 6.6. Distribution of radial leg data in the the vertical. The number in parenthesis is the number of radial legs between the pressure layers indicated. The center of these layers are indicated.

6.2 New P-3 Aircraft Data -- Data Set b)

We have recently received magnetic tapes containing all of the NOAA National Hurricane Research Laboratory (NHRL) processed P-3 aircraft data (as of October 1981) of the research flights since 1975. We have 23 flight tapes (courtesy of the NOAA NHRL) involving 8 hurricanes on approximately 30 separate days on which 50 flight missions were flown at approximately 200 separate flight levels along about 800 individual radial leg penetrations into or out of tropical storms. These newer P-3 aircraft have many advanced instrumental capabilities like the inertial navigation system and special higher quality radar than the aircraft used on earlier flights. We plan to study various aspects of this newer flight data set to shed more light on the processes of inner-core hurricane intensity change and motion as they are related to outer hurricane region wind and pressure changes.

6.3 Discussion

A number of conclusions have emerged from the data set a) research missions:

1) Although the general structure and dynamics of the typical hurricane can be well specified by the flight data, large differences (in motion, radius of maximum winds, eye wall convection, asymmetry, etc.) exist between separate storms. The individual hurricane at a particular time typically has a complicated structure and dynamic character which is often substantially different from the mean hurricane circulation.

2) The hurricane flight data, overall, appear to be of high quality. The observational quality cannot, however, be well judged by those who have worked only with some portions of the data. Because the structure of each storm can be so different from the average, one must work with many of the storms and make many instrumental and dynamic consistency checks, etc. before the data's limitations can be ascertained.

3) There appears to be much more meaningful research which can be accomplished with these hurricane flight data.

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Gray, W. M. and D. J. Shea, 1977: Data summary of NOAA's Hurricane Inner Core Radial Leg Flight Penetrations 1957-1967, 1969. Atmos. Sci. Paper No. 257, Colo. State Univ., Ft. Collins, CO, 245 pp.

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Hilleary, D. T. and F. E. Christensen, 1957: Instrumentation of the National Hurricane Research Project Aircraft. National Hurricane Res. Project Rept. No. 11, 61 pp. (Available from NOAA Weather Bureau, Miami office.)

Reber, C. and H. Friedman, 1964: Manual of meteorological instrumentation and data processing of the research flight facility. US Weather Bureau. (Available from Miami office.)

7. OTHER AVAILABLE TROPICAL OCEANIC DATA SETS

Our project has been performing tropical meteorological research at CSU since the early 1960's. A number of auxillary oceanic data sets have been assembled during this period which offer important supplementary background data to assist in our tropical cyclone compositing research. To fully understand the tropical cyclone in its oceanic setting one must have an understanding of the physical processes associated with cumulus convection, air-sea interaction, planetary boundary layer phenomena, and many other topics. A number of auxillary data sets have consequently been assembled on our CSU project which impact upon the overall tropical cyclone problem in either a direct or indirect way. Some of these auxillary data sets available are:

1) GARP Atlantic Tropical Experiment (GATE) of 1974. We have made extensive analysis of the GATE observational data from a variety of points of view -- see our project's GATE analyses reports and published papers by W. Frank (1978, 1979, 1980), McBride and Gray (1980a, 1980b), Dewart (1978), and Grube (1978) referenced in Chapter 8. Our project has available on magnetic tape all GATE ship individual rawinsonde data. Rawinsonde data are also available as individual sounding deviations from particular ship phase means and in a variety of other ways. GATE satellite, radar, rainfall, and surface data are also available. Analyses have been made on special squall line events, warming-cooling, and moistening-drying events associated with various aspects of GATE convective activity, etc. A variety of energy and moisture budgets have also been made. Our project participated in the GATE experiment from Dakar.

2) Barbados Oceanographic and Meteorological Experiment (BOMEX) Data of 1969. We have all the rawinsonde and special surface observations for this ocean-atmosphere experiment available on magnetic tape and/or in hard copy. Gray and a number of his project personnel were involved in this experiment from Barbados. We made special aircraft boundary layer flights during the BOMEX period.

3) Line-Island Experiment (LIE) of 1967. Our research project has available the rawinsonde and surface observation data from this experiment. We were participants in this experiment.

4) Marshall Island Atomic Test 6-hour Sounding Data of 1956 and 1958. We have available the special 6 hourly sounding data from this Atomic Test experiment during 1956 and 1958.

5) First GARP Global Experiment (FGGE) of 1978-1979. Our project has recently purchased all the FGGE year European Center for Medium Range Weather Forecasting (ECMWF) global 850 mb and 250 mb mercator tropical weather maps (30°N to 30°S) for this experiment. Maps are available every 12 hours with 6 hourly maps available during the intensive SOP periods. Figures 7.1 and 7.2 show an example of a portion of this analysis for the western Pacific for one time period in January 1979. We are planning on an extensive analysis of these maps to study individual case tropical cyclone genesis, intensity change, and motion. Over 2000 separate global tropical maps are on hand and we have also collected once-a-day visual and IR pictures from the five synchronous satellites which operated during the FGGE year.

We also plan to obtain 80-85 magnetic tapes which contain the data for the ECMWF 12-level analysis for the FGGE period.

6) Oceanic Boundary Layer Pibal and Rawin Soundings. All US National Climatic Center, Asheville, oceanic rawin and pibal data on the variation of the wind in the lowest two km over the oceans have been assembled for the 16-year period of 1949-1964. Data include over 80,000 ship rawin and pibal observations from merchant ships which took rawins or pibals, data from weather ships, military ships -- every kind of ocean vessel which took upper air soundings. Figure 7.3 shows the location of these oceanic soundings. For instance, over 5000 observations are available between 10 and 20° latitude. This ship rawin-pibal information has been stratified by latitude, season, wind direction, wind speed, and in other ways. These data have been used primarily to study the oceanic boundary layer. See the report by Gray (1972) and Gray and Mendenhall (1974) listed in Chapter 8 for more background information.

7) Microfilm Weather Maps. Nearly all of the conventional Miami weather map analyses for hurricanes from 1957 onward (with a 1-2 year lag) are available on our project in microfilm form. The Joint Typhoon Warning Center hand drawn map analyses from Guam are also available for various periods over the last 10 years. In addition, the microfilm maps of the Darwin/Australia Bureau of Meteorology Tropical Center analyses are available since 1972. Darwin performs a twice a day hand analysis of six pressure levels from 40°N to 40°S

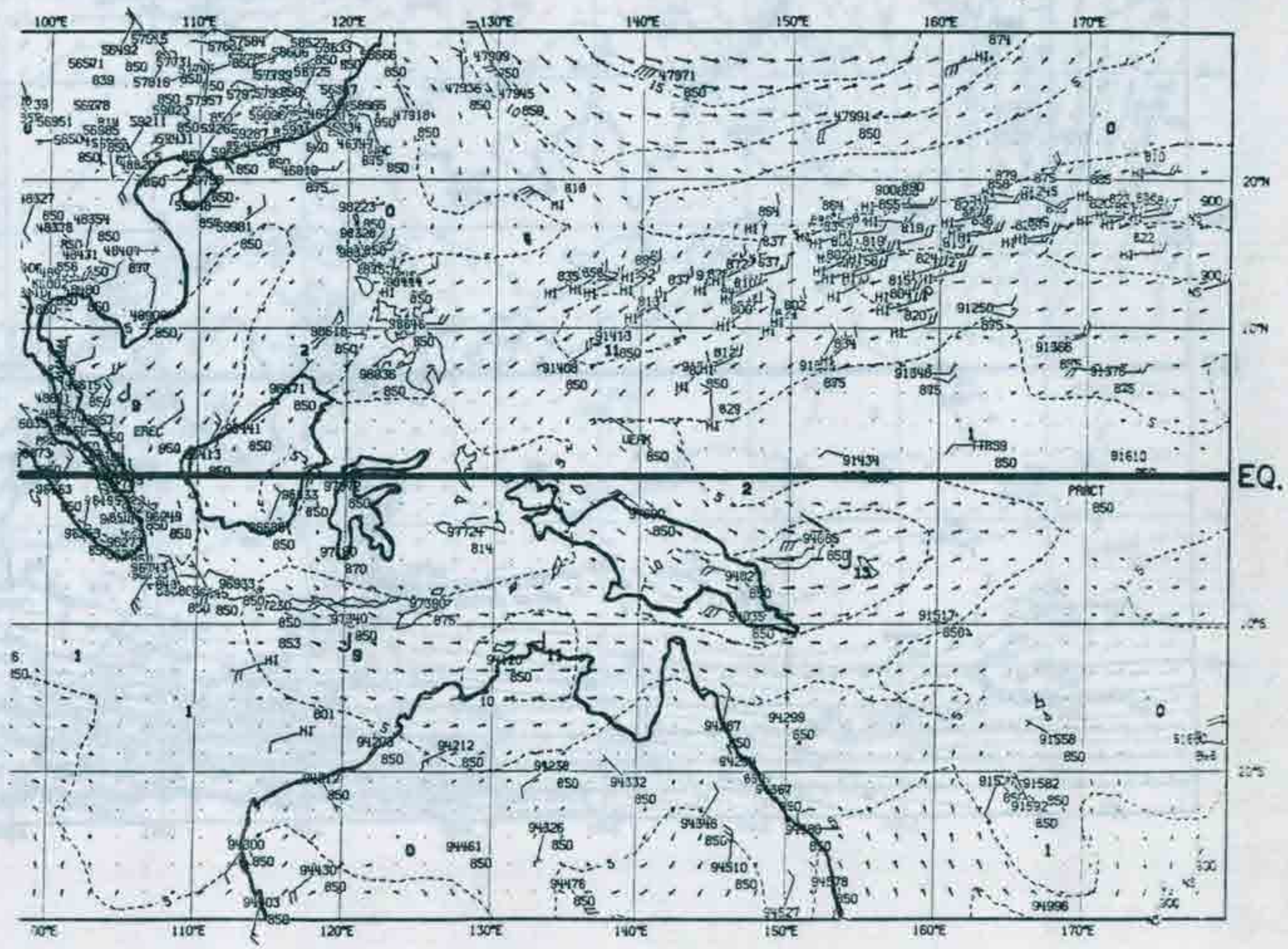

Fig. 7.1. ECMWF 850 mb analysis for a portion of the tropical west Pacific for 19 January 1979 at 00Z.

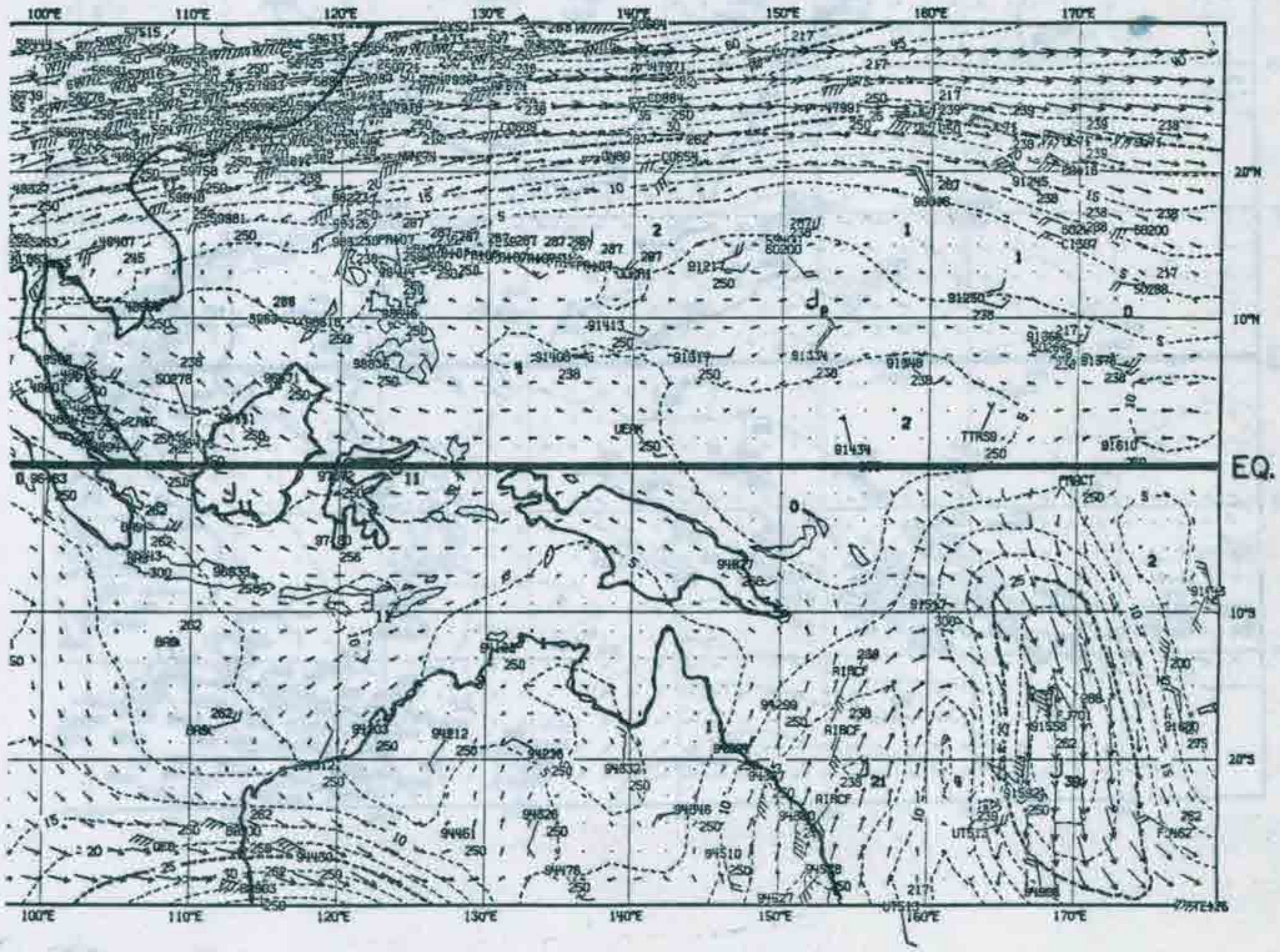

Fig. 7.2. Same as Fig. 7.1 except for the 250 mb level.

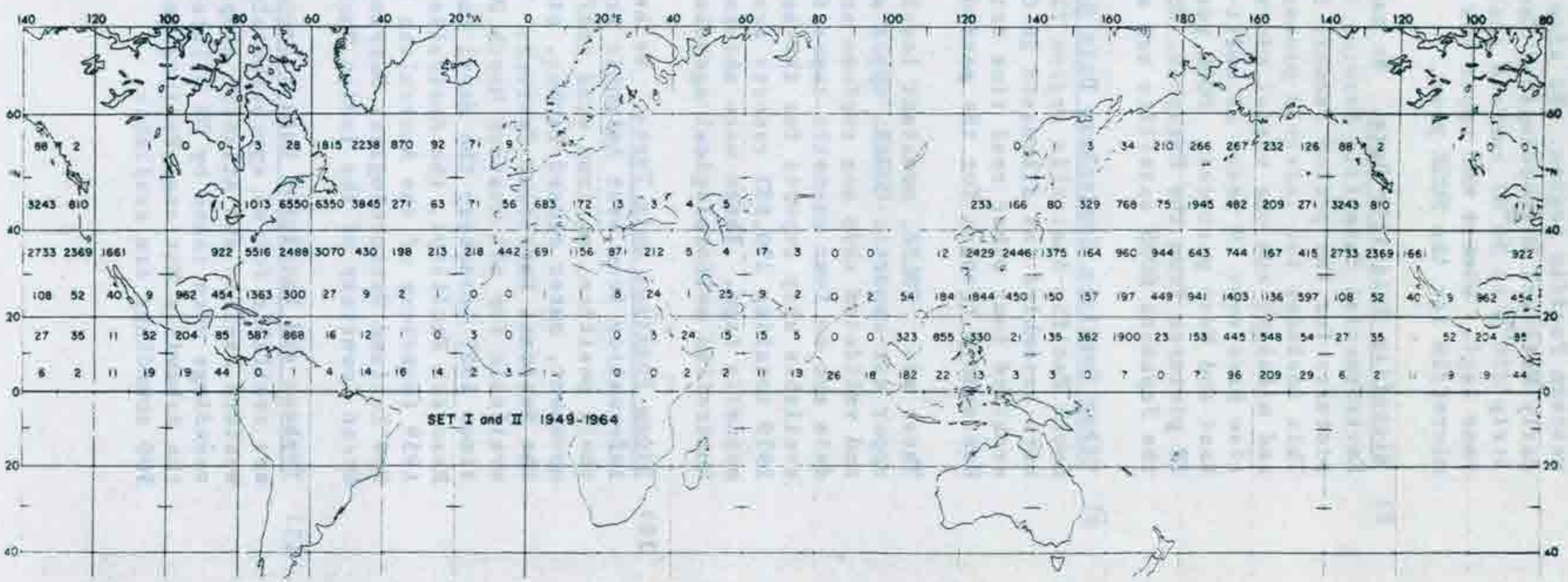

Fig. 7.3. Distribution of ship pibal and rawin data for combined period of 1949–1964.

and 70°E to the Dateline. Four surface maps are drawn daily. These maps are overall the best analyses available for the western Pacific region. We also have microfilm copies of the daily National Meteorological Center (NMC) tropical global strip (30°N to 50°S) surface analysis since 1972 (with 1-2 year lag). Global NMC upper air analysis is available on microfilm for the FGGE year.

8) Microfilm Satellite Data. We have the National Environmental Satellite Service (NESS) full disc satellite pictures for the period January 1975 through December 1980. This includes two infrared pictures per day around local noon and midnight and one visual picture around local midday. We also have over 10 years of multi-times a day hard copy GOES East and West pictures. FGGE year full disc daily visual and IR pictures from the European, US, special Indian Ocean, and the Japanese GOES satellite are also available.

9) Other Southern Hemisphere Data Sets. In addition to the South Pacific-Australia region 22 year rawinsonde data we have assembled (as discussed in Chapter 3) we have also archived four other real time data sets from the Southern Hemisphere tropics for the period 1972-1979.

These are: COLBA, constant level balloon observations; ship upper air reports; CODAR, upper air reports from aircraft; and validated ship sea surface and air temperatures. These data are on four magnetic tapes in standard WMO code. All available ship reports for the southwest Pacific from 1957-1979 totaling 270,887 reports are also archived on a single magnetic tape. These were obtained from the New Zealand and Australian meteorological agencies.

10) Storm Position Data Tapes. We have on magnetic tape information from west Atlantic tropical cyclones as regards their position, maximum wind and/or central pressure, movement, outer closed isobar, etc. since 1957 (courtesy of the National Hurricane Center). Similar information is also available for all western North Pacific tropical cyclones since 1957 (courtesy the Naval Environmental Prediction Research Facility), the Australian-South Pacific storms since 1959 (courtesy of the Australian Bureau of Meteorology and New Zealand Meteorological Service) and in the North Indian Ocean (courtesy of the Indian Bureau of Meteorology).

11) Typhoon and Hurricane Center Dropsonde Data. Dropsonde data are available for an approximately 20-year period from all western Pacific and Atlantic tropical storms on which such soundings were taken by US Military aircraft and recorded at the Asheville National Weather Records Center. Approximately 300 soundings are available.

12) Hourly Rainfall Data. We have hourly rainfall data for all US western Pacific class-A weather stations for most of the 1960's and 1970's.

13) Prominent Tropical Disturbances Which Did Not Form Tropical Storms. We have a number of different data sets in the Atlantic and the western North Pacific of prominent well developed tropical disturbances (as observed by the satellite) which did not develop into tropical cyclones. These form the standard of reference for comparison with similar early stage tropical disturbances which later became tropical cyclones.

14) BT Data. We also have on file Navy hydrographic office bathythermograph (BT) data over the entire global tropical ocean (30°N to 30°S) which have been averaged by season and 5° Marsden square for a 15-20 year period.

15) Indian Daily Weather Maps. Daily weather maps for a seven year period in the North Indian Ocean are also available. These maps have been prepared by the Indian Meteorology Office.

16) Diurnal Observations. We have developed an extensive collection of oceanic tropical meteorological data that is arranged to portray the large diurnal cycle in deep tropical convection which appears to be occurring at most global tropical locations. Figure 7.4 shows some of the stations and time zones which have gone into this diurnal data set.

Supplementary Data Sets Over the US. Although our project research has concentrated on the tropics, we have also gathered other various middle-latitude data sets over the US. Among these data sets are:

a) A rawinsonde data set with multi-year observations which have been interpolated on a 2°-grid over the eastern two-thirds of the US to study boundary layer process (Hoxit, 1974, 1975 - reference in Chapter 8) - see Fig. 7.5.

b) The National Severe Storm Laboratory (NSSL) data tape of severe weather phenomena over the US.

c) Various classes of severe weather and tornado proximity soundings over the US (see Wills, 1969; Maddox, 1975) including all available hurricane spawned tornado soundings up until 1973 (see Novlan and Gray, 1973). We also have a collection of severe thunderstorm wind gusts throughout the US (see Walters, 1975). These severe weather and tornado reports are listed in Chapter 8.

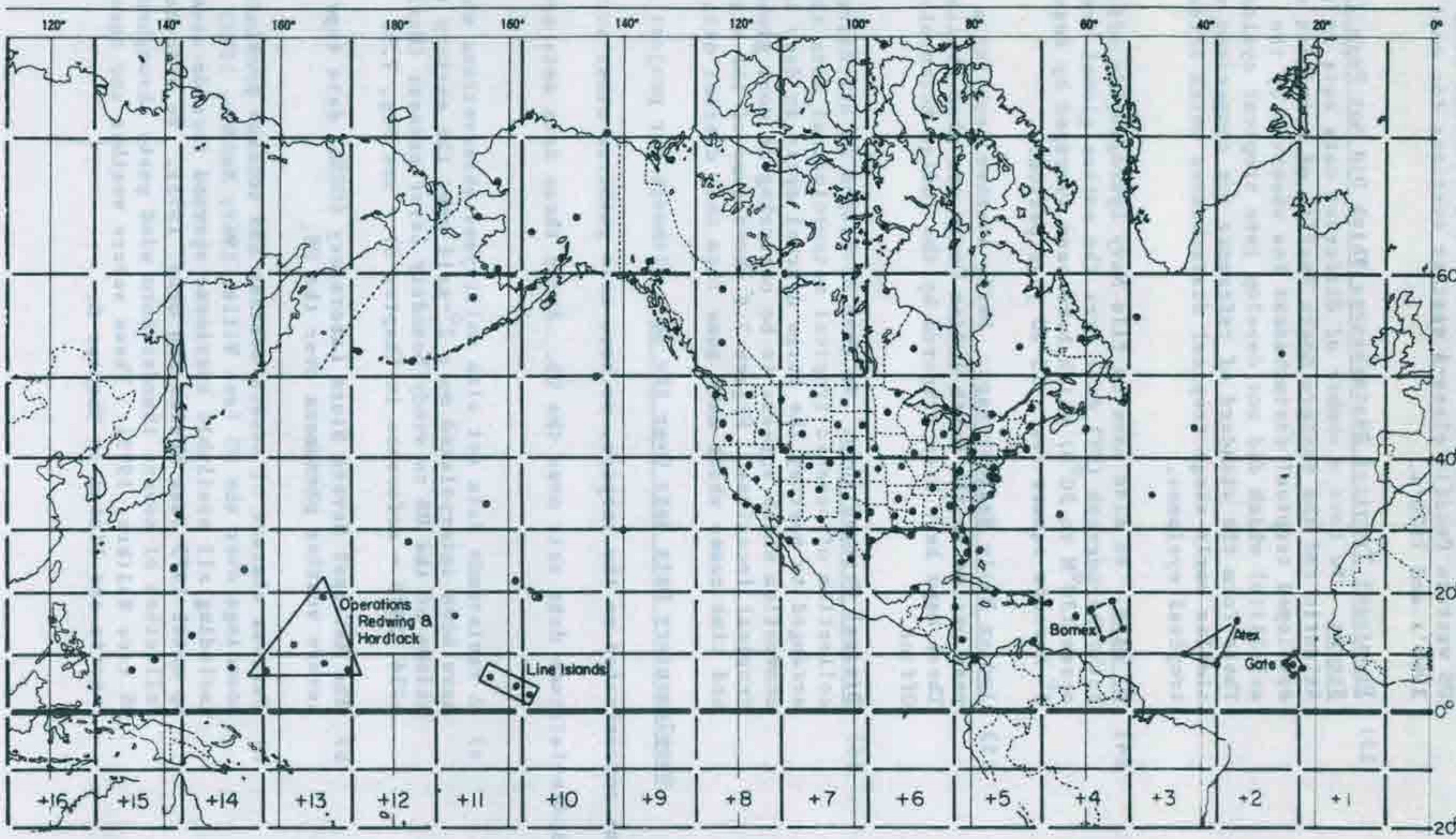

Fig. 7.4. Location of radiosonde data network and special oceanic tropical experiments used in our diurnal study. The numbers located at the bottom of the map identify the various time zones of the 00 and 12Z soundings.

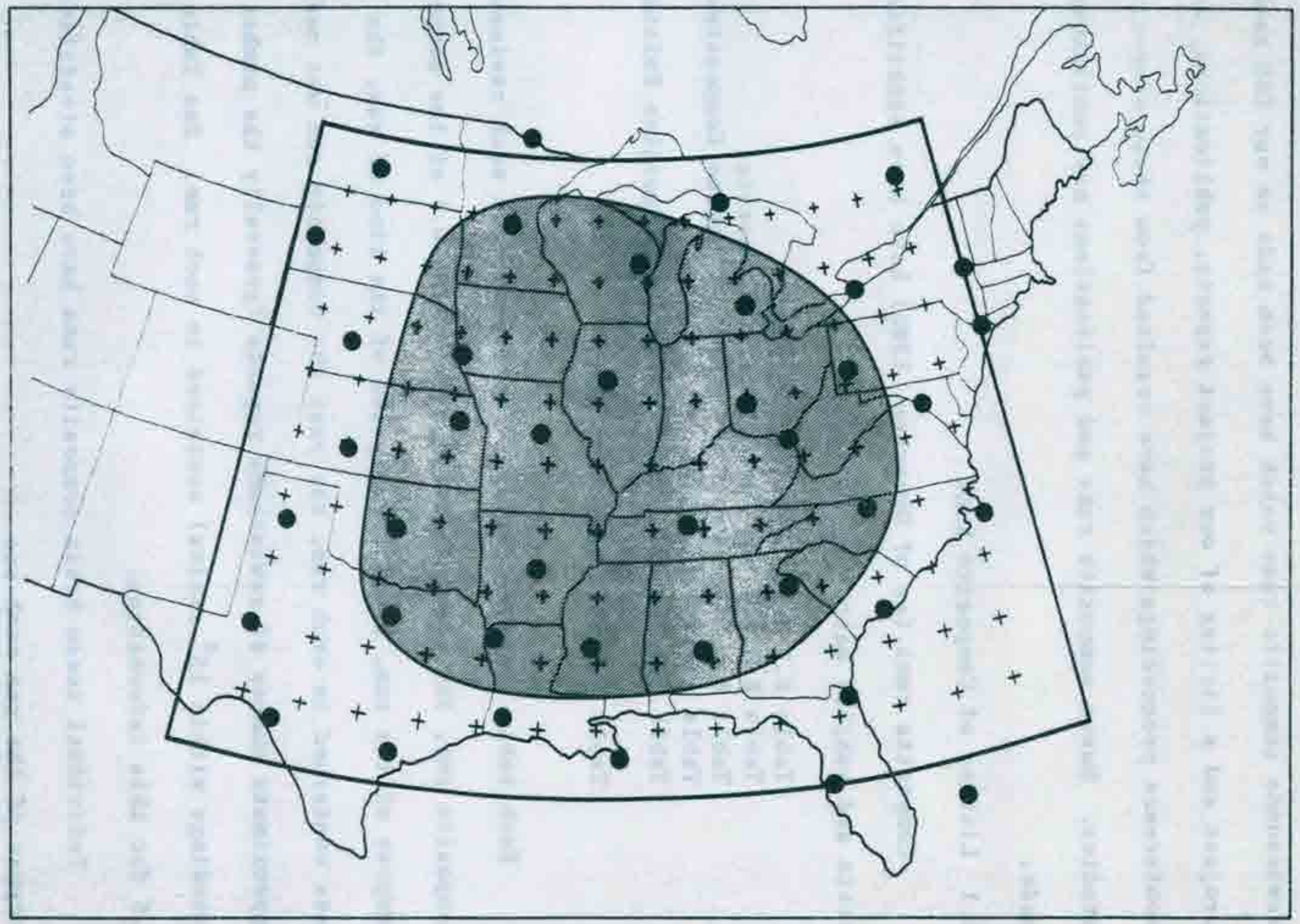

Fig. 7.5. Radiosonde network. Data from stations outside the shaded area were utilized only to calculate the horizontal derivatives of temperature for the 19 interior stations. The superimposed 2° latitude - 2° longitude grid was used in all horizontal analyses.

8. SUMMARY OF COMPOSITE RUNS AND PROJECT REPORT PUBLICATIONS TO DATE

This chapter contains a listing of the tropical cyclone and related rawinsonde composite runs which have been made on our CSU research project and a listing of our project reports, publications, and conference proceedings which have resulted from these compositing studies. Newer composite runs and publications are continuously being made.

8.1 Listing of Composite Runs

Composite runs (as of December, 1981) have been stratified by ocean basin and subject matter as follows:

Table 8.1 West Atlantic Composites
Table 8.2 Western North Pacific Composites
Table 8.3 South Pacific-Australian Region Composites
Table 8.4 Cyclone Motion Composites
Table 8.5 Special Cross-Hemisphere Composites Related to Tropical Cyclone Genesis
Table 8.6 GATE composite runs

Each table contains pertinent information on each rawinsonde composite run, the identification number (ID No.) of the composite, the purpose of the run, brief description of the kind of run, the years of data contained in each run, the year the composite run was made, and the approximate number of rawinsonde reports (generally the number of soundings within 15^{o} radius) contained in each run. See Tables 8.1 to 8.6 for this information.

Individual ocean basin composite runs have been stratified by the purpose of the run such as:

Tropical Cyclone Structure (Structure)
Tropical Cyclone Genesis (Genesis)
Tropical Cyclone Intensity Change (Intensity Change)
Tropical Cyclone Motion (Motion)
Tropical Cyclone Moisture and Energy Budget (Moisture and

and Energy Budgets)

Cross Hemisphere Influences on Tropical Cyclone Genesis (Cross Hemp. Genesis)

Diurnal Influences (Diurnal)

Other information to interpret these tables are as follows:

- WI is West Indies
- WP is Western North Pacific
- SPA is South Pacific-Australian Region
- (D) denotes a deepening tropical cyclone or weather system
- (F) denotes a filling tropical cyclone or weather system
- D1 denotes a pre-typhoon or pre-hurricane early stage cloud cluster with maximum sustained winds of less then 10 m/s.
- D2 denotes a more advanced pre-typhoon or pre-hurricane cloud cluster than D1 with maximum sustained winds of about 10 m/s or a tropical depression.
- D3 developing tropical cyclone with maximum sustained winds of about 20 m/s.
- D4 tropical cyclone of typhoon or hurricane intensity
- N1 prominent non-developing cloud cluster
- N2 non-developing easterly wave
- N3 non-developing depression or cyclone.

The approximate total number of tropical cyclone soundings now available on magnetic tape within 15^{o} latitude of tropical systems and those expected to be available in the next few years:

a) West Atlantic
   Now available - 1.5 million
   Likely available within 1-2 years - about 2.0 million

b) Western North Pacific
   Now available - 18,000
   Likely available within 1-2 years - about 200,000

c) South Pacific-Australian Region
   Now available - 2.0 million

The quantity of this data availability may be appreciated when one realizes that the entire ship array of the oceanic GATE experiment has but ~ 5,000 soundings. It took 2-3 years before the international data exchanges and technical processing of the GATE data were completed and research could proceed with these data sets. By contrast, our CSU project has available in stratified form relative to tropical weather systems about a thousand times the number of soundings which are

TABLE 8.1

Western Atlantic Tropical Cyclone Composite Runs

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius
1	Genesis-ATN1	1961-1974	1977	3155
2	Genesis-ATN1-00Z	1961-1974	1977	1378
3	Genesis-ATN1-12Z	1961-1974	1977	1777
4	Genesis-ATN2	1968-1974	1978	2760
5	Genesis-ATN2-00Z	1968-1974	1977	1089
6	Genesis-ATN2-12Z	1968-1974	1977	1671
7	Genesis-ATN3	1967-1974	1977	898
8	Genesis-ATD1	1961-1974	1978	714
9	Genesis-ATD2	1961-1974	1978	2168
10	Genesis-ATD2-00Z	1961-1974	1977	1103
11	Genesis-ATD2-12Z	1961-1974	1977	1065
12	Structure-ATD2 Westward(225-315)	1961-1974	1977	1418
13	Intensifying-ATD3	1961-1974	1977	2447
14	Intensifying-Diurnal-ATD3-00Z	1961-1974	1977	1142
15	Intensifying-Diurnal-ATD3-12Z	1961-1974	1977	1305
16	Intensifying-ATD3 Westward(225-315)	1961-1974	1977	1311
17	Intensity Change ATD4(D),(<30°)	1961-1974	1978	2881
18	Intensity Change ATD4(D),all lat.	1961-1974	1978	2672
19	Structure-ATD4	1961-1974	1977	4721
20	Structure-Diurnal ATD4-00Z	1961-1974	1977	2430
21	Structure-Diurnal ATD4-12Z	1961-1974	1977	2291
22	Statistics-ATD4-Even Days	1961-1974	1980	2447
23	Statistics-ATD4-Odd Days	1961-1974	1980	2274
24	Intensity Change-Atlantic Filling,(<30°N)	1961-1974	1978	1918
25	Intensity Change-Atlantic Filling,(all lat.)	1961-1974	1978	1958
26	Genesis-Depression (<35 kts)*	1961-1974	1977	4742
27	Genesis-Diurnal Depression-00Z*	1961-1974	1977	2295
28	Genesis-Diurnal Depression-12Z*	1961-1974	1977	2447
29	Structure-Tropical Storm (35<V<65 kts)*	1961-1974	1977	2301

TABLE 8.1 (continued)

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15^{o} Radius
30	Structure-Diurnal Tropical Storm-00Z*	1961-1974	1977	1119
31	Structure-Diurnal Tropical Storm-12Z*	1961-1974	1977	1181
32	Structure->35 kts, Region 1	1961-1974	1977	2526
33	Structure->35 kts, Regions 2A,3	1961-1974	1977	4776
34	Structure->65 kts, Region 1*	1961-1974	1977	1586
35	Structure->65 kts, Region 2A*	1961-1974	1977	2194
36	Structure->65 kts, Region 3*	1961-1974	1977	1221
37	Structure->65 kts, Region 1,2A and 3*	1961-1974	1977	6137
38	Environment Without Storm-00Z	1967-1968	1978	12859
39	Environment Without Storm-12Z	1967-1968	1978	12043
40	Clear Region-Diurnal 12Z-(Day-12 hrs)	1967-1968	1978	2191
41	Clear Region-Diurnal 00Z-(Day)	1967-1968	1978	3909
42	Clear Region-Diurnal 12Z-(Day+12 hrs)	1967-1968	1978	4382

TABLE 8.1 (continued)

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15^o Radius
43	Small/Medium Tropical Storm (TSSM)Lat $\leq 45^oN$ ROCI** $\leq 3^o$ Lat 34 kt $\leq V_{max} \leq$ 63 kt	1957-1977	1981	9401
44	Large Tropical Storm (TSLR) Lat $\leq 45^oN$ ROCI** $< 4^o$ Lat 34 kt $\leq V_{max} \leq$ 63 kt	1957-1977	1981	2792
45	Small/Medium Hurricane (HUSM) Lat $\leq 45^oN$ ROCI** $\leq 3^o$ Lat $V_{max} \geq$ 64 kt	1957-1977	1981	8606
46	Large Hurricane North (HULN) $25^oN<Lat \leq 45^oN$ ROCI** $\geq 4^o$ Lat $V_{max} \geq$ 64 kt	1957-1977	1981	5280
47	Large Hurricane South (HULS) Lat $\leq 25^o$ N ROCI** $> 4^o$ Lat $V_{max} \geq$ 64 kt	1957-1977	1981	1464

(*): Excludes land codes Lo, 1, 2, 3, 5
Includes I, L, 9, 8, 7, 6.

** ROCI denotes Radius of Outer Closed Isobar

TABLE 8.2

Western North Pacific Tropical Cyclone Composite Runs

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius
1	Genesis-All Clusters	1961-1970	1975	7206
2	Genesis-Early Years Clusters	1961-1965	1975	3127
3	Genesis-Later Years Clusters	1966-1970	1975	4005
4	Genesis-Diurnal 00Z Clusters	1961-1970	1975	2419
5	Genesis-Diurnal 12Z Clusters	1961-1970	1975	2154
6	Genesis-Longitude > 145°E Cluster	1961-1970	1975	2683
7	Genesis-Longitude < 145°E Clusters	1961-1970	1975	1878
8	Genesis-June to October Clusters	1961-1970	1975	3561
9	Genesis-November to May Clusters	1961-1970	1975	1012
10	Genesis-Systems Moving West(240-300°)	1961-1970	1975	2587
11	Genesis-Other Directions(310-090°)	1961-1970	1975	1603
12	Genesis-All Developing Systems to Become Tropical Cyclones	1961-1970	1975	1710
13	Genesis-Trade Wind Developing Cases	1961-1970	1975	939
14	Genesis-ITCZ Developing Cases	1961-1970	1975	4579
15	Genesis-Non-developing Clusters (O)-All Year	1961-1970	1975	4736
16	Genesis-Non-developing Clusters (OO)-June-Nov.	1961-1970	1975	1901
17	Genesis-Non-developing Clusters (OO)-00Z	1961-1970	1975	967
18	Genesis-Non-developing Clusters (OO)-12Z	1961-1970	1975	939
19	Genesis-Developing Cluster Stage 1-All	1961-1970	1975	821
20	Genesis-Developing Cluster Stage 2-All	1961-1970	1975	2081
21	Genesis-Developing Cluster Stage 2-00Z	1961-1970	1975	1131
22	Genesis-Developing Cluster Stage 2-12Z	1961-1970	1975	951
23	Genesis-Developing Cluster Stage 3-All	1961-1970	1975	1766

TABLE 8.2 (Continued)

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15^o Radius
24	Genesis-Developing Cluster Stage 4-All	1961-1970	1975	2492
25	Genesis-Developing Cluster Stage 4-00Z	1961-1970	1975	1288
26	Genesis-Developing Cluster Stage 4-12Z	1961-1970	1975	1204
27	Structure-Type1 - P_c <980mb, Lat.<30^o,June to Oct.	1961-1970	1975	6581
28	Structure-Type1 - P_c <980mb, Lat.<30^o,Oct. to May	1961-1970	1975	1395
29	Intensity Change-Type A-All Case Deepening Storms at some time P_c < 970 mb	1961-1970	1978 1981	2621
30	Intensity Change-Type A Deepening Storms at some time P_c < 970 mb Lat. < 20^{o}N	1961-1970	1975	1536
31	Intensity Change-Type A Deepening Storms at some time P_c < 970 mb Lat. > 20^{o}N	1961-1970	1975	Miss.
32	Intensity Change-Type A Early Deepening P_c between 980-1000 mb Later Storm P_c <970 mb Lat. < 20^{o}N	1961-1970	1975	1451
33	Intensity Change-Type A Early Deepening P_c between 980-1000 mb Later Storm P_c <970 mb Lat. > 20^{o}N	1961-1970	1975	439
34	Intensity Change-Sustained Filling Tendency Lat.<20^{o}N	1961-1970	1975	1029
35	Intensity Change-Sustained Filling Tendency Lat.>20^{o}N	1961-1970	1975	2542
36	Intensity Change-Type A-Early Deepening Lat. < 30^{o}N	1961-1970	1975	2621
37	Intensity Change-Type A-All Periods of Deepening Lat.<30^{o}N	1961-1970	1975	1856
38	Intensity Change-Sustained Filling-All Time Periods Lat. < 30^{o}N	1961-1970	1975	3572
39	Intensity Change-Type B Lat. < 20^{o}N	1961-1970	1975	821
40	Intensity Change-Type B Lat. > 20^{o}N	1961-1970	1975	996
41	Intensity Change-Type B Lat. < 30^{o}N	1961-1970	1975	1822
42	Structure-All Systems P_c > 1000 mb	1961-1970	1975	2132

TABLE 8.2 (Continued)

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius
43	Structure-All Cyclones P_c between 980-1000 mb	1961-1970	1975	5473
44	Structure-All Cyclones P_c between 950-980 mb	1961-1970	1975	4956
45	Structure-All Cyclones P_c < 950 mb	1961-1970	1975	3020
46	Structure-Type B-All Cases	1961-1970	1979	1857
47	Genesis-WPN1-New Stage 00-Non genesis	1961-1970	1977	1901
48	Genesis-WPD1-New Stage Erickson Non-developing from Satellite data	1961-1970	1979	366
49	Structure-Pre-typhoon Cluster-WPD2	1961-1970	1977	2053
50	Intensity Change-Deepening Tropical Storm-WPD3(D)	1961-1970	1979	1863
51	Structure-Tropical Cyclone Stage-WPD3	1961-1970	1977	2509
52	Intensity Change-Deepening Typhoon-WPD4(D)	miss	miss	miss.
53	Structure-Typhoon-WPD4	1961-1970	1977 1979	8257
54	Intensity Change-Filling Typhoon-WPD4(F)	1961-1970	1978	3566
55	Structure-Super Typhoon WPD5	1961-1970	1979	3122
56	Structure-Typhoon Lat. < 30°N	1961-1970	1978	9180
57	Very Rapidly Deepening Cyclone (40 mb/d)-24 hrs Before Deepening Starts	1961-1970	1979	135
58	Very Rapidly Deepening Cyclone (40 mb/d)-at time Deepening Starts	1961-1970	1979	258
59	Very Rapidly Deepening Cyclone (40 mb/d)-24 hrs After Deepening Starts	1961-1970	1979	208
60	Moisture and Energy Budgets Non-developing Cluster-12Z (night)	1969-1973	1979	90
61	Moisture and Energy Budgets Non-developing Disturbance 12Z (night)	1969-1973	1978	984
62	Moisture and Energy Budgets WPD1-12Z (night)	1961-1970	1977 1978	922
63	Moisture and Energy Budgets WPD2-12Z (night)	1961-1970	1977-1978	934

TABLE 8.2 (Continued)

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15^o Radius
64	Moisture and Energy Budgets WPD3(D)-12Z (night)	1961-1970	1978	866
65	Moisture and Energy Budgets WPD4-12Z (night)	1961-1970	1978	1204
66	Moisture and Energy Budgets WPD4(D)-12Z (night)	1961-1970	1978	1429
67	Moisture and Energy Budgets WPD4-12Z (night)	1961-1970	1978	4067
68	Moisture and Energy Budgets WPD4-(F)-12Z (night)	1961-1970	1978	1642
69	Moisture and Energy Budgets WPD5-12Z (night)	1961-1970	1978	1536
70	Moisture and Energy Budgets One day after Cloud Cluster -12Z (night)	1968-1969	1975	4382
71	Diurnal Influences-Average without respect to weather system (background) July-Oct.-00Z (day)	1967-1968	1978	12,392
72	Diurnal Influences-Average without respect to weather system (background) July-Oct.-12Z (night)	1967-1968	1978	11,239
73	Diurnal Influences-Clear Region-00Z (day)	1967-1968	1978	2160
74	Diurnal Influences-Clear Region-12Z (night after)	1967-1968	1978	2109
75	Diurnal Influences-Clear Region-12Z (night before)	1967-1968	1978	2160
76	Small Tropical Storm (TSSM) ROCI $\leq 3^o$ Lat $P > 980$ mb	1961-1970	1981	3208
77	Medium Tropical Storm (TSME) $4^o \leq$ ROCI $\leq 5^o$ Lat $P > 980$ mb	1961-1970	1981	2530
78	Large Tropical Storm (TSLR) ROCI $\geq 6^o$ Lat $P > 980$ mb	1961-1970	1981	1156
79	Small Typhoon (TYSM) ROCI $\leq 3^o$ Lat $P \leq 980$ mb	1961-1970	1981	1782
80	Medium Typhoon (TYME) $4^o \leq$ ROCI $\leq 5^o$ Lat $P \leq 980$ mb	1961-1970	1981	3280
81	Large Typhoon (TYLR) ROCI $\geq 6^o$ Lat $P \leq 980$ mb	1961-1970	1981	3609

TABLE 8.2 (Continued)

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius
82	NWPREC I1 Recurving, Intensifying Tropical Cyclone, 995>P>980 mb	1961-1970	1981	542
83	NWPREC I2 Recurving, Intensifying Tropical Cyclone, 980>P>960 mb	1961-1970	1981	625
84	NWPREC I3 Recurving, Intensifying Tropical Cyclone, P<960 mb	1961-1970	1981	874
85	NWPREC F Recurving, Filling Tropical Cyclone, P<960 mb	1961-1970	1981	1151

TABLE 8.3

South Pacific-Australian Region Tropical Cyclone Composite Runs (to this date)*

I.D. No.	Purpose of Run	Description of Run	Year of Data	Year of Run	Total Soundings Inside 15^o Radius
AUSTREC1	Structure	As NWPREC1	1958-1979	1981	1959
AUSTREC2	Structure	Cyclones P < 980 mb Intensifying Before or at Recurvature	1958-1979	1981	2847
AUSTREC3	Structure	Cyclones P < 980 mb. Filling at or After Recurvature	1958-1979	1981	1595

*20-30 Additional south Pacific-Australian region composite runs will be made by the summer of 1982.

TABLE 8.4

Rawinsonde Composite Runs Used to Study Tropical Cyclone Motion

A. Northwest Pacific Ocean

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius at 500 mb
100	Latitude > 20°N	1961-1970	1975	~5000
101	Latitude < 20°N	1961-1970	1975	~5000
M102	Slow Cyclone (1-3 m/s)	1961-1970	1975	~3000
M103	Moderate Cyclone (4-7 m/s)	1961-1970	1975	~3000
M104	Fast Cyclone (> 7 m/s)	1961-1970	1975	~3000
M105	Westward (250-310°)	1961-1970	1975	~3000
M106	Northward (310-350°)	1961-1970	1975	~3000
M107	Eastward (350-60°)	1961-1970	1975	~3000
108	Weak (980-1000 mb)	1961-1970	1975	~3000
109	Intense (950-980 mb)	1961-1970	1975	~3000
110	Very Intense (< 950 mb)	1961-1970	1975	~3000
111	Deepening N of 20°N	1961-1970	1975	~5000
112	Deepening S of 20°N	1961-1970	1975	~5000
113	Filling N of 20°N	1961-1970	1975	~5000
114	Filling S of 20°N	1961-1970	1975	~5000
115	Small Tropical Storm	1961-1970	1980	3206
116	Medium Tropical Storm	1961-1970	1980	2529
117	Large Tropical Storm	1961-1970	1980	1165
118	Small Typhoon	1961-1970	1980	1786
119	Medium Typhoon	1961-1970	1980	3284
120	Large Typhoon	1961-1970	1980	3613
M121	Left-turning Cyclones T-48hr.	1961-1970	1979	38
M121	Left-turning Cyclones T-36hr.	1961-1970	1979	62
M121	Left-turning Cyclones T-24hr.	1961-1970	1979	163
M121	Left-turning Cyclones T-12hr.	1961-1970	1979	269
M121	Left-turning Cyclones T-0 hr.	1961-1970	1979	279
M121	Left-turning Cyclones T+12hr.	1961-1970	1979	263
M121	Left-turning Cyclones T+24hr.	1961-1970	1979	154

TABLE 8.4 (Continued)

A. Northwest Pacific Ocean

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius at 500 mb
M122	Straight-Moving Cyclones T-48hr.	1961-1970	1979	31
M122	Straight-Moving Cyclones T-36hr.	1961-1970	1979	113
M122	Straight-Moving Cyclones T-24hr.	1961-1970	1979	217
M122	Straight-Moving Cyclones T-12hr.	1961-1970	1979	291
M122	Straight-Moving Cyclones T-0 hr.	1961-1970	1979	290
M122	Straight-Moving Cyclones T+12hr.	1961-1970	1979	296
M122	Straight-Moving Cyclones T+24hr.	1961-1970	1979	285
123	Right-turning Cyclones T-48hr.	1961-1970	1979	162
123	Right-turning Cyclones T-36hr.	1961-1970	1979	224
123	Right-turning Cyclones T-24hr.	1961-1970	1979	444
123	Right-turning Cyclones T-12hr.	1961-1970	1979	507
123	Right-turning Cyclones T-0 hr.	1961-1970	1979	534
123	Right-turning Cyclones T+12hr.	1961-1970	1979	514
123	Right-turning Cyclones T+24hr.	1961-1970	1979	409

TABLE 8.4 (Continued)

B. West Atlantic Ocean

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15^{o} Radius at 500 mb
201	Latitude > 18^{o}N	1961-1974	1977	2560
202	Latitude < 18^{o}N	1961-1974	1977	4462
M203	Slow Cyclone (1-3 m/s)	1961-1974	1977	4882
M204	Fast Cyclone (> 3 m/s)	1961-1974	1977	6479
M205	Northward ($316-45^{o}$)	1961-1974	1977	4685
M206	Westward ($225-315^{o}$)	1961-1974	1977	4372
207	Small Tropical Storm	1957-1977	1981	9388
208	Large Tropical Storm	1957-1977	1981	2787
209	Small Hurricane	1957-1977	1981	8574
210	Large Hurricane N of 25^{o}N	1957-1977	1981	5246
211	Large Hurricane S of 25^{o}N	1957-1977	1981	1444
M212	Left-turning Cyclones T-48hr.	1961-1974	1978	78
M212	Left-turning Cyclones T-36hr.	1961-1974	1978	235
M212	Left-turning Cyclones T-24hr.	1961-1974	1978	336
M212	Left-turning Cyclones T-12hr.	1961-1974	1978	368
M212	Left-turning Cyclones T-0 hr.	1961-1974	1978	420
M212	Left-turning Cyclones T+12,24hr.	1961-1974	1978	839
M213	Straight-moving Cyclones T-48hr.	1961-1974	1978	215
M213	Straight-moving Cyclones T-36hr.	1961-1974	1978	301
M213	Straight-moving Cyclones T-24hr.	1961-1974	1978	504
M213	Straight-moving Cyclones T-12hr.	1961-1974	1978	655
M213	Straight-moving Cyclones T-0 hr.	1961-1974	1978	678
M213	Straight-moving Cyclones T+12,24hr.	1961-1974	1978	1390

TABLE 8.4 (Continued)

B. West Atlantic Ocean

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius at 500 mb
201	Latitude > 18°N	1961-1974	1977	2560
202	Latitude < 18°N	1961-1974	1977	4462
M203	Slow Cyclone (1-3 m/s)	1961-1974	1977	4882
M204	Fast Cyclone (> 3 m/s)	1961-1974	1977	6479
M205	Northward (316-45°)	1961-1974	1977	4685
M206	Westward (225-315°)	1961-1974	1977	4372
207	Small Tropical Storm	1957-1977	1981	9388
208	Large Tropical Storm	1957-1977	1981	2787
209	Small Hurricane	1957-1977	1981	8574
210	Large Hurricane N of 25°N	1957-1977	1981	5246
211	Large Hurricane S of 25°N	1957-1977	1981	1444
M212	Left-turning Cyclones T-48hr.	1961-1974	1978	78
M212	Left-turning Cyclones T-36hr.	1961-1974	1978	235
M212	Left-turning Cyclones T-24hr.	1961-1974	1978	336
M212	Left-turning Cyclones T-12hr.	1961-1974	1978	368
M212	Left-turning Cyclones T-0 hr.	1961-1974	1978	420
M212	Left-turning Cyclones T+12,24hr.	1961-1974	1978	839
M213	Straight-moving Cyclones T-48hr.	1961-1974	1978	215
M213	Straight-moving Cyclones T-36hr.	1961-1974	1978	301
M213	Straight-moving Cyclones T-24hr.	1961-1974	1978	504
M213	Straight-moving Cyclones T-12hr.	1961-1974	1978	655
M213	Straight-moving Cyclones T-0 hr.	1961-1974	1978	678
M213	Straight-moving Cyclones T+12,24hr.	1961-1974	1978	1390

TABLE 8.4 (Continued)

B. West Atlantic Ocean

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15° Radius at 500 mb
M214	Right-turning Cyclones T-48hr.	1961-1974	1978	162
M214	Right-turning Cyclones T-36hr.	1961-1974	1978	257
M214	Right-turning Cyclones T-24hr.	1961-1974	1978	475
M214	Right-turning Cyclones T-12hr.	1961-1974	1978	624
M214	Right-turning Cyclones T-0 hr.	1961-1974	1978	662
M214	Right-turning Cyclones T+12,24hr.	1961-1974	1978	1363
M215	Rapid Slow-down Cyclones	1961-1974	1980	338
M216	Slow-down Cyclones	1961-1974	1980	946
M217	No-speed-change Cyclones	1961-1974	1980	3504
M218	Speed-up Cyclones	1961-1974	1980	820
M219	Rapid Speed-up Cyclones	1961-1974	1980	1557

TABLE 8.4 (Continued)

C. South Pacific-Australian Region

I.D. No.	Purpose of Run and Description	Year of Data	Year of Run	Total Soundings Inside 15^o Radius at 500 mb
M301	Eastward ($40-150^o$)	1958-1970	1980	2463
M302	Westward ($210-320^o$)	1958-1970	1980	3175

*20-25 additional south Pacific/Australian data runs are being made during the spring and summer of 1982.

TABLE 8.5

Special Cross-Hemispheric Composites Related to Tropical Cyclone Genesis

Large Scale Composite Runs

I.D. No.	Purpose of Run	Description	Region	Year of Data	Area of Composite ^{o}long.x^{o}lat.	Year of Run	Number of Soundings
1	Cross-Hemp. Genesis	Three days before Atlantic Tropical Cyclone(T.C.) Genesis	W. Atlantic	1958-1971	50x30	1980	2309
2	Cross-Hemp. Genesis	One day before Atlantic T.C. Genesis	W. Atlantic	1958-1971	50x30	1980	2065
3	Cross-Hemp. Genesis	Three days before Southern Hemisphere (SH) T. C. Genesis Wind Field Only	S.Pacific-Australian	1972-1979	90x40	1981	9152
4	Cross-Hemp. Genesis	One day before SH T.C. Genesis Wind Field Only	S.Pacific-Australian	1972-1979	90x40	1981	8884
5	Cross-Hemp. Genesis	Quiet periods in SH Wind Field	S. Pacific-Australian	1972-1979	90x40	1981	25,060
6	Cross-Hemp. Genesis	During Cyclone Periods in SH Wind Fields	S. Pacific-Australian	1972-1979	90x40	1981	32,504
7	Cross-Hemp. Genesis	Three days before Northern Hemisphere (NH) T.C. Genesis Wind Fields Only	S. Pacific-Australian	1972-1979	90x40	1981	7376
8	Cross-Hemp. Genesis	One day before NH T.C. Genesis Wind Field Only	S. Pacific-Australian	1972-1979	90x40	1981	7888
9	Cross-Hemp. Genesis	Quiet periods in the NW Pacific Wind Fields Only	S. Pacific-Australian	1972-1979	90x40	1981	19,796

TABLE 8.5 (Continued)

Large Scale Composite Runs

I.D. No.	Purpose of Run	Description	Region	Year of Data	Area of Composite ^{o}long.x^{o}lat.	Year of Run	Number of Soundings
10	Cross-Hemp. Genesis	During Cyclone Periods of the NW Pacific Wind Fields Only	S. Pacific-Australian	1972-1979	90x40	1981	30,772
11	Cross-Hemp. Genesis	Three days before T.C. Genesis in Australian Region (AR) Wind Field Only	NW Pacific	1972-1979	90x25	1981	1240
12	Cross-Hemp. Genesis	One day before T.C. Genesis in AR Wind Fields Only	N.W. Pacific	1972-1979	90x25	1981	1440
13	Cross-Hemp. Genesis	During quiet Periods in AR Wind Fields Only	N. W. Pacific	1972-1979	90x25	1981	4960
14	Cross-Hemp. Genesis	During Periods of T.C. Activity in AR Wind Fields Only	N. W. Pacific	1972-1979	90x25	1981	5456
15	Cross-Hemp. Genesis	Three days before T.C. Genesis in NW Pacific Wind Fields Only	N. W. Pacific	1972-1979	90x25	1981	1315
16	Cross-Hemp. Genesis	One day before T.C. Genesis in NW Pacific Wind Fields Only	N. W. Pacific	1972-1979	90x25	1981	1420

TABLE 8.5 (Continued)

Large Scale Composite Runs

I.D. No.	Purpose of Run	Description	Region	Year of Data	Area of Composite ^{o}long.x^{o}lat.	Year of Run	Number of Soundings
17	Cross-Hemp. Genesis	During Quiet Periods in the NW Pacific Wind Fields Only	N. W. Pacific	1972-1979	90x25	1981	3472
18	Cross-Hemp. Genesis	During periods of T.C. Activity in NW Pacific	N. W. Pacific	1972-1979	90x25	1981	3751
19	Cross-Hemp. Genesis	One day before T.C. Genesis in AR Wind and Thermal Parameters	S. Pacific-Australian	1958-1979	90x40	1981	2805
20	Cross-Hemp. Genesis	During quiet Periods in the AR Wind and Thermal Parameters	S. Pacific-Australian	1958-1979	90x40	1981	5629
21	Cross-Hemp. Genesis	One day before T.C. Genesis in NW Pacific Wind and thermal Parameters	S. Pacific-Australian	1958-1979	90x40	1981	2760
22	Cross-Hemp. Genesis	During quiet Periods in the NW Pacific Wind and Thermal Parameters	S. Pacific-Australian	1958-1979	90x40	1981	5869

TABLE 8.6

GATE RAWINSONDE OBSERVATIONS

Individual Soundings, Averages, Deviations and Composites

Individual Soundings

ID. No.	Description	No. of Soundings
	Individual Soundings All Ships	
1	Phase 1	1373
2	Phase 2	1440
3	Phase 3	2027

Averages

ID. No.	Description
4	All Time Period Phase Mean Averages by Ship
5	All Time Period All GATE Averages by Ship
6	00Z,06Z,12Z,18Z Combined Phase Mean Average by Ship
7	00Z,06Z,12Z,18Z Combined All GATE Average by Ship
8	Individual Time Period PhaseMean Average by Ship 00Z,03Z,06Z,09Z,12Z,15Z,18Z,21Z
9	Individual Time Period All GATE Average by Ship 00Z,03Z,06Z,09Z,12Z,15Z,18Z,21Z
10	All Time Period Phase Mean Averages - A/B and B Array
11	All Time Period All GATE Averages - A/B and B Array
12	00Z,06Z,12Z,18Z Combined Phase Mean Averages - A/B and B Array
13	00Z,06Z,12Z,18Z Combined All GATE Averages - A/B and B Array
14	Individual time Period Phase Mean Averages 00Z,03Z,06Z,09Z,12Z,15Z, 18Z - A/B and B Array
15	Individual Time Period All GATE Averages 00Z,03Z,06Z,09Z,12Z,15Z, 18Z - A/B and B Array

Deviations

ID. No.	Description
16	Individual Sounding-Deviations from Phase Mean by Ship
17	Diurnal Time Period - Deviations from Phase Mean by Ship - 00Z,03Z,06Z,09Z, 12Z,15Z,18Z
18	Diurnal Time Period Deviations from All GATE Mean by Ship 00Z,03Z,06Z,09Z,12Z,15Z,18Z

TABLE 8.6 (Continued)

Deviations

19	Diurnal Time Period Deviations from 00Z,06Z,12Z,18Z Combined Phase Mean by Ship 00Z,03Z,06Z,09Z,12Z,15Z,18Z
20	Diurnal Time Period Deviations from 00Z,06Z,12Z,18Z Combined All GATE Mean by Ship 00Z,03Z,06Z,09Z, 12Z,15Z,18Z
21	Diurnal Time Period Deviations from Phase Mean by Scale 00Z,03Z,06Z,09Z,12Z,15Z,18Z,21Z
22	Diurnal Time Period Deviations from All GATE Mean by Scale 00Z,03Z,06Z,09Z,12Z,15Z,18Z,21Z
23	Diurnal Time Period Deviations from 00Z,06Z,12Z,18Z Combined Phase Mean for A/B and B Arrays - 00Z,03Z,06Z, 09Z,12Z,15Z,18Z
24	Diurnal Time Period Deviations from 00Z,06Z,12Z,18Z Combined All GATE Mean for A/B and B Arrays - 00Z,03Z, 06Z,09Z,12Z,15Z,18Z

Composites

ID No.	Purpose	Description
25	Individual Time Period Variation	Individual Time Period Analysis by Scale (Frank, 1979)
26	Squall Dynamics Cluster Structure	Life Cycles of GATE Squall Lines and Clusters (Frank, 1978)
27	Diurnal Variations	Diurnal Variability of Disturbed and Suppressed Conditions (Dewart, 1978) and McBride and Gray, 1979)
28	Convection Induced Tempeature Change	Rain and No Rain Comparisons (Grube, 1979)
29	Convection Induced Temperature Change	Before Rain, During Rain, After Rain Events (Grube, 1979)
30	Convection Induced Temperature Change	Pre-Warming, Warming, Post-Warming Events Squall and No Squall (Grube, 1979)
31	Convection Induced Temperature change	Pre-Cooling, Cooling, Post-Cooling Events Squall and No Squall (Grube, 1979)

Additional Data

32	Individual Time Period Rainfall

available from the GATE ship data.

8.2 Project Reports, Publications, and Conference Proceedings to Date

Summary of W. M. Gray's CSU research project reports, publications and conference proceedings since 1965. A majority of these reports and publications have made use of the rawinsonde compositing techniques here being advocated.

a) Project reports
b) Publications
c) Conference Proceedings

Project Conference Presentations are not included in this list.

a) W. M. GRAY'S FEDERALLY SUPPORTED RESEARCH PROJECT REPORTS SINCE 1967

CSU Dept. of Atmos. Sci. Report No.	Report Title, Author, Date, Agency Support
104	The Mutual Variation of Wind, Shear and Baroclinicity in the Cumulus Convective Atmosphere of the Hurricane (69 pp.). W. M. Gray. February 1967. NSF Support.
114	Global View of the Origin of Tropical Disturbances and Storms (105 pp.). W. M. Gray. October 1967. NSF Support.
116	A Statistical Study of the Frictional Wind Veering in the Planetary Boundary Layer (57 pp.). B. Mendenhall. December 1967. NSF and ESSA Support.
124	Investigation of the Importance of Cumulus Convection and Ventilation in Early Tropical Storm Development (88 pp.). R. Lopez. June 1968. ESSA Satellite Lab. Support.
Unnumbered	Role of Angular Momentum Transports in Tropical Storm Dissipation over Tropical Oceans (46 pp.). R. F. Wachtmann. December 1968. NSF and ESSA Support.
Unnumbered	Monthly Climatological Wind Fields Associated with Tropical Storm Genesis in the West Indies (34 pp.). J. W. Sartor. December 1968. NSF Support.
140	Characteristics of the Tornado Environment as Deduced from Proximity Soundings (55 pp.). T. G. Wills. June 1969. NOAA and NSF Support.
161	Statistical Analysis of Trade Wind Cloud Clusters of the Western North Pacific (80 pp.). K. Williams. June 1970. ESSA Satellite Lab. Support.
---	A Climatology of Tropical Cyclones and Disturbances of the Western Pacific with a Suggested Theory for Their Genesis/Maintenance. W. M. Gray. NAVWEARSCHFAC Tech. Paper No. 19-70 (225 pp.). November 1970. (Available from US Navy, Monterey, CA). US Navy Support.
179	A diagnostic Study of the Planetary Boundary Layer over the Oceans (95 pp.). W. M. Gray. February 1972. Navy and NSF Support.
182	The Structure and Dynamics of the Hurricane's Inner Core Area (105 pp.). D. J. Shea. April 1972. NOAA and NSF Support.
188	Cumulus Convection and Larger-scale Circulation, Part I: A Parameteric Model of Cumulus Convection (100 pp.). R. E. Lopez. June 1972. NSF Support.

CSU Dept. of Atmos. Sci. Report No.	Report Title, Author, Date, Agency Support
189	Cumulus Convection and Larger-scale Circulations, Part II: Cumulus and Meso-scale Interactions (63 pp.). R. E. Lopez. June 1972. NSF Support.
190	Cumulus Convection and Larger-scale Circulations, Part III: Broadscale and Meso-scale Considerations (80 pp.). W. M. Gray. July 1972. NOAA-NESS Support.
195	Characteristics of Carbon Black Dust as a Tropospheric Heat Source for Weather Modification (55 pp.). W. M. Frank. January 1973. NSF Support.
196	Feasibility of Beneficial Hurricane Modification by Carbon Black Seeding (130 pp.). W. M. Gray. April 1973. NOAA Support.
199	Variability of Planetary Boundary Layer Winds (157 pp.). L. R. Hoxit. May 1973. NSF Support.
200	Hurricane Spawned Tornadoes (57 pp.). D. J. Novlan. May 1973. NOAA and NSF Support.
212	A Study of Tornado Proximity Data and an Observationally Derived Model of Tornado Genesis (101 pp.). R. Maddox. November 1973. NOAA Support.
219	Analysis of Satellite Observed Tropical Cloud Clusters (91 pp.). E. Ruprecht and W. M. Gray. May 1974. NOAA-NESS Support.
224	Precipitation Characteristics in the Northeast Brazil Dry Region (56 pp.). R. P. L. Ramos. May 1974. NSF Support.
225	Weather Modification through Carbon Dust Absorption of Solar Energy (190 pp.). W. M. Gray, W. M. Frank, M. L. Corrin, and C. A. Stokes. July 1974.
234	Tropical Cyclone Genesis (121 pp.). W. M. Gray. March 1975. NSF Support.
---	Tropical Cyclone Genesis in the Western North Pacific (66 pp.). W. M. Gray. March 1975. US Navy Environmental Prediction Research Facility Report. Tech. Paper No. 16-75. (Available from the US Navy, Monterey, CA). Navy Support.
241	Tropical Cyclone Motion and Surrounding Parameter Relationships (105 pp.). J. E. George. December 1975. NOAA Support.

CSU Dept. of Atmos. Sci. Report No.	Report Title, Author, Date, Agency Support
243	Diurnal Variation of Oceanic Deep Cumulus Convection. Paper I: Observational Evidence, Paper II: Physical Hypothesis (106 pp.). R. W. Jacobson, Jr. and W. M. Gray. February 1976. NOAA-NESS Support.
257	Data Summary of NOAA's Hurricane Inner-Core Radial Leg Flight Penetrations 1957-1967, and 1969 (245 pp.). W. M. Gray and D. J. Shea. October 1976. NSF and NOAA Support.
258	The Structure and Energetics of the Tropical Cyclone (180 pp.). W. M. Frank. October 1976. NOAA-NHEML, NOAA-NESS and NSF Support.
259	Typhoon Genesis and Pre-typhoon Cloud Clusters (79 pp.). R. M. Zehr. November 1976. NSF Support.
Unnumbered	Severe Thunderstorm Wind Gusts (81 pp.). G. W. Walters. December 1976. NSF Support.
262	Diurnal Variation of the Tropospheric Energy Budget (141 pp.). G. S. Foltz. November 1976. NSF Support.
274	Comparison of Developing and Non-developing Tropical Disturbances (81 pp.). S. L. Erickson. July 1977. US Army Support.
77-01	Tropical Cyclone Research by Data Compositing (70 pp.). W. M. Gray and W. M. Frank. July 1977. Navy Support.
277	Tropical Cyclone Cloud and Intensity Relationships (154 pp.). C. P. Arnold. November 1977. US Army and NHEML Support.
297	Diagnostic Analyses of the GATE A/B-scale Area at Individual Time Periods (102 pp.). W. M. Frank. November 1978. NSF Support.
298	Diurnal Variability in the GATE Region (80 pp.). J. M. Dewart. November 1978. NSF Support.
299	Mass Divergence in Tropical Weather Systems, Paper I: Diurnal Variation; Paper II: Large-scale Controls on Convection (109 pp.). J. L. McBride and W. M. Gray. November 1978. NOAA-NHEML Support.
78-01	New Results of Tropical Cyclone Research from Observational Analysis (108 pp.). W. M. Gray and W. M. Frank. June 1978. Navy Support.

CSU Dept. of Atmos. Sci. Report No.	Report Title, Author, Date, Agency Support
305	Convection induced temperature change in GATE (128 pp.). P. G. Grube. February 1979. NSF Support.
308	Observational Analysis of Tropical Cyclone Formation (230 pp.). J. L. McBride. April 1979. NOAA-NHEML, NSF, and NEPRF Support.
	Tropical Cyclone Genesis - Numerical Modeling Inferences (152 pp.). W. A. Fingerhut. September 1980. NSF Support.
	Tropical Cyclone Structure and Intensity Change. Ewin Núñez. October 1980. NSF and NOAA-NHEML Support.
333	Tropical Cyclone Intensity Change - A Quantitative Forecasting Scheme. K. M. Dropco. May 1981. NOAA Support.
340	The Role of the General Circulation in Tropical Cyclone Genesis. Geoff Love. April 1982. NSF Support.
341	Tropical Cyclone Movement and Surrounding Flow Relationships. Johnny C. L. Chan and W. M. Gray. April 1982. ONR Support.
342	Environmental Circulation Conditions Associated with Tropical Cyclones Experiencing Fast, Slow and Looping Motions. Jianmin Xu and W. M. Gray. May 1982. ONR Support.
343	Tropical Cyclone Structure and Intensity Change. E. Nunez. May 1982. NSF and NOAA Support.
344	Vertical Rearrangement of Tangential Momentum in Tropical Cyclones. Cheng Shang Lee. May 1982. ONR Support.
---	Tropical Cyclone and Related Meteorological Data Sets Available at CSU and Their Utilization. W. M. Gray, E. Buzzell, G. Burton, G. Holland and Other Project Personnel. February 1982. NSF, ONR, NOAA, NEPRF Support.

b) Publications Since 1962

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c) Conference Proceedings Since 1969

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9. EXAMPLE OF SOME BASIC FINDINGS FROM OUR PROJECT'S RECENT RAWINSONDE COMPOSITING EFFORTS

We have, we believe, documented a number of significant features about tropical storms and tropical weather systems that could not have generally been obtained in any way other than through the compositing methodology. Such research findings or documentation of processes are:

1) With regard to tropical cyclone structure:

a) The horizontal scale of the tropical cyclone is very large. Detectable cyclone influences extend radially outward to 15^{o} or more.

b) Typhoons, hurricanes and south Pacific-Australian region tropical cyclones, although basically similar to each other, do exhibit some important structural differences.

c) The horizontal scale of the cyclonic flow of the typical hurricane-typhoon is largely independent of its inner-core intensity.

d) The deep layer inflow occurring in tropical cyclones at outer radii has now been well established. Classical tropical cyclone theory presumes a strong shallow inflow layer in the lowest levels, a similar outflow layer just below the tropopause, and no significant inflow in the middle levels. This type of flow appears reasonably valid at inner radii, but beyond 3^{o} radius mid-level inflow (800-300 mb) becomes increasingly important. Roughly one-half of the inflow beyond 4-5^{o} radius occurs above 800 mb. There are large implications in this observation for a basic physical understanding of these storm systems.

e) The tropical cyclone's required inward transport of angular momentum at outer radii is to a large extent a result of eddy influx of relative angular momentum and eddy influx of earth angular momentum. The relative angular momentum influx is actually an eddy export of negative angular momentum in the upper level outflow jets. The relative angular momentum budget (M_r) of the tropical cyclone beyond 4-5^{o} radius is very much dependent upon the influx of eddy earth momentum. Poleward moving cyclones overtake their environmental flow so that there is a poleward to equatorward blow through of the cyclone. This imports eddy earth momentum and helps maintain the outer 4-12^{o} radius circulation against conservation of absolute angular momentum requirements that specify that the cyclonic circulation should decrease as a cyclone moves poleward.

f) Vertical mass recycling is very large below 400 mb in the tropical cyclone and is fundamental to the simultaneous maintenance of the mass, moisture, and total energy budgets of the cyclone. This vertical recycling is accomplished primarily by convective updraft and downdraft processes.

g) The vertical momentum transports occurring in the average tropical weather system or storm by small scale convective processes can be solved for as a residual. Such convectively induced momentum rearrangement occurs primarily as a down-gradient process. We have solved for tangential friction (F_θ) as a residual in our composited tropical cyclone rawinsonde data sets. A general consistency is found in all the developing data sets. F_θ is positive at lower and upper tropospheric levels and negative at middle levels at radii less than about 5-7^o where rainband convection is prevalent. It is believed that such sub-grid scale tangential friction is a result of deep cumulus induced vertical rearrangement of horizontal momentum. We are finding that the incorporation of such cumulus momentum influences is necessary to the proper numerical modelling of tropical cyclone genesis and tropical cyclone structure.

h) There are distinctive large-scale environmental flow patterns in which big and small sized tropical cyclones form. The relation between the surrounding flow and the motion of little vs. big cyclones is surprisingly much the same.

i) Correlation between vorticity and convergence in the tropical cyclone's boundary layer is weak.

j) Tropical cyclones export large amounts of kinetic energy (KE) in their upper tropospheric outflow layer. Approximately half or more of this export is accomplished by horizontal eddy processes (or correlation of KE' with V_r'). Tropical cyclones also export sizable amounts of moist static energy. This allows for the direct calculation of surface energy fluxes when net radiational cooling is known. Surface energy fluxes are often significantly larger than those specified by the bulk aerodynamic formula.

k) Cb overshooting. The regions of tropical cyclones beyond the eyewall exhibit substantial amounts of 'apparent warming' in the upper troposphere due to warm air advection. To balance energy budget computations it is necessary to hypothesize substantial downward eddy fluxes of moist static energy at these levels, presumably the result of cumulonimbus overshooting. Parameterization schemes without Cb overshoot cooling cannot treat the energetics of the tropical cyclone's upper layers in a realistic fashion.

2) With regard to the tropical cyclone's surface energy flux:

a) The tropical cyclone's surface energy flux can be solved for as a residual in the h-budget. Evaporation can be well estimated as a residual in the combined h, and q budgets. About two-thirds of the hurricane or typhoon's precipitation inside 6^{o} radius is a result of evaporation inside that radius. For the weaker pre-typhoon cloud cluster this figure is about 50 percent. Such large local evaporation has not been previously documented.

b) The bulk-formula $[\rho_o C_E |V_o| (q_s - q)]$ for surface evaporation can significantly underestimate surface energy flux in tropical cyclone situations. This is believed due to the enhanced local surface energy flux caused by the tropical storm's special Cb and towering cumulus cloud bands which produce enhanced downdrafts.

3) With regard to tropical cyclone genesis:

a) Tropical cyclone genesis will not occur unless large-scale environmental processes are favorable. An intense region of cumulus convection cannot, without a supporting favorable environment, develop into a tropical cyclone.

b) Documentation of how generally ineffective the process of condensation heating is for direct and sustained tropospheric temperature change. Regions of intense and deep penetrative convection do not generally cause direct tropospheric temperature increase. What tropospheric temperature change that does occur is typically dissipated in a few hours through outward gravity wave export. Tropospheric temperature increase (and surface pressure fall) appears to result primarily from an adjustment of the pressure or mass fields to previously established supergradient wind fields. These findings are not in agreement with the original CISK hypothesis ideas on tropospheric warming.

c) The primary observable distinguishing parameter for tropical cyclone development from disturbance stage is the outer radius tangential winds at lower (~ 900 mb) and upper tropospheric levels (~ 200 mb). Radial wind, temperature, and moisture show much less distinguishing power between disturbances which develop and those which do not.

d) The passage of opposite hemisphere winter baroclinic systems can have a profound influence on the establishment of favorable large-scale wind patterns about a monsoon trough which leads to the activation of tropical cyclone genesis.

e) Tropical cyclone genesis requires deep layer inflow so that the observed deep tangential wind increases of the intensifying cyclone can be maintained. This is likely a fundamental factor in tropical cyclone genesis

4) With regard to tropical cyclone intensity change:

a) Tropical cyclone intensity change and cyclone genesis is heavily influenced by the presence or absence of deep layer baroclinicity on the poleward side of the storm or cloud cluster. The presence of deep layer baroclinicity usually causes cyclones to weaken. Intensifying cyclones or cloud clusters do not have deep-layer baroclinicity on their poleward sides. By contrast, upper tropospheric baroclinicity, as experienced by a Tropical Upper Tropospheric Trough (TUTT), is generally favorable for cyclone genesis and cyclone intensification.

b) We are observing significant differences in the gradient and thermal wind balances between intensifying and filling tropical cyclones at radii of about 3-9^{o}. Intensifying systems have 20-30% more supergradient (or less subgradient) winds than filling systems. These differences are also related to the observed thermal wind imbalances we are finding in these cyclones. Intensifying systems typically have 10-30% higher vertical wind shear (for thermal wind balance) than corresponding horizontal temperature gradient. The opposite is true for filling cyclone systems. These gradient and thermal wind differences are most pronounced to the poleward side of the cyclone. They are hypothesized to result from cumulus momentum rearrangement and/or surrounding cyclone environmental flow changes associated with trough-ridge passages, etc. It may be possible for the new satellite observational systems to measure such changes.

c) Filling storms show less low level potential buoyancy of the inflowing air than deepening storms. The inflow is predominantly from the northwest in both cases but is relatively cool and dry at the surface for the filling storms.

d) Filling storms tend to have maximum upper level outflow to the northeast associated with an upper level trough north-northwest of the storm. Outflow to the southwest is weaker. Deepening tropical cyclones have maximum upper level outflow to the southwest and only weak outflow to the northeast.

e) A comparison of developing and weakening cyclones using newly developed angular momentum budget equations applied to both composite and case study data have indicated that large scale environmental modulation seems to be as important or perhaps more important than inner region effects in both cyclogenesis and in short period intensity changes. In particular, the results indicate that inner core intensity changes are preceeded by distinct flow field variations at 6-10^{o} latitude radius wind. The poleward movement of a cyclone and its response to its environmental 'steering current' are intimately coupled with its likely intensification, and the position and movement of a cyclone relative to surrounding circulation features must be taken into account in any discussion of their mutual interaction.

5) With regard to tropical cyclone motion:

a) Our new rawinsonde compositing methods are, in a general way, quantitatively verifying the tropical cyclone steering flow hypothesis for a variety of different cyclone motion stratifications and ocean basins. Cyclone motion is best associated with the surrounding cyclone middle tropospheric 5-7^{o} radius mean wind and/or the surrounding 5-7^{o} radius surface to 300 mb (inflow layer) mean wind.

b) Tropical cyclones have a distinctive motion of about 10-20^{o} to the left of and faster than their surrounding 5-7^{o} radius middle tropospheric environmental steering current. Westward moving cyclones, however, show very little leftward deviation from their environmental flow. The more poleward or the more east the system goes the more it deviates to the left of its steering current.

c) Tropical cyclone motion is very well related to right vs. left quadrant tangential wind asymmetry across the cyclone. Cyclone motion is well specified by horizontal advection of absolute vorticity.

d) We are finding distinct surrounding cyclone parameter variations which indicate cyclone turning motion and speed change 24-36 hours before it takes place.

6) With regard to diurnal variations:

a) A large, nearly two to one, day vs. night diurnal variation in the troposphere's vertical motion which occurs within tropical weather systems is well shown in our data sets. Such a large diurnal variation is also present in the subsidence regions between the weather systems. This diurnal variation is primarily manifested in a diurnal variation in Cb convection and deep layer subsidence. We believe this to be quite a new and unique observational finding which has much implication for future modeling of the atmosphere. It is hypothesized that this quite striking diurnal variation is a result of day vs. night variations in net tropospheric cooling. We believe this is a fundamentally important observation in throwing light on how the troposphere's circulation responds to radiational cooling. There is no way that a vertical circulation response such as this could have been discovered except through the rawinsonde composite methodology.

(This is only a short summary. For more information on results from our tropical cyclone data sets the reader should refer to the references listed in the previous chapter or consult a general summary of our tropical cyclone research results which is contained in the WMO publication of 1981 titled 'Recent Advances in Tropical Cyclone Research from Rawinsonde Composite Analysis', 407 pp. by the first author.

10. DESIRED FUTURE RESEARCH AND SOFTWARE DEVELOPMENT

10.1 Desired Future Calculations

There are a number of potentially profitable research directions in the tropical weather system area which we are poised to exploit with the massive data sets we now have available at CSU. Some of these research topics which we are very eager to pursue are:

1) Additional statistical studies to more precisely demonstrate the validity of the rawinsonde compositing philosophy and to verify objectively which parameters, levels, etc. best relate to tropical storm and weather system behavioral differences. We are being assisted in this statistical study by Professors P. Mielke and K. Berry of the CSU Department of Statistics.

2) More study of how single case weather systems can be handled at individual time periods once the overall background physics of these weather systems (as derived from knowledge gained from composite studies) are known. We plan to use the various individual time period ECMWF FGGE data sets for this purpose. We will also attempt to use various individual time period NMC products.

3) One of the great apparent strengths of rawinsonde compositing is the ability to specify differences between two composited weather systems which show different behavior. It is probable that any systematic errors that may be present in one composite are also present in the other composite. Such systematic errors can likely be eliminated by subtracting one composite from the other. This subtraction technique allows us to determine just what are the most significant parameter differences which exist between composited weather systems exhibiting different behavior characteristics. We will continue to exploit this composite difference approach to determine the significant parameter differences between a whole spectrum of weather system behavior classes such as developing vs. non-developing weather systems, intensifying vs. filling cyclone systems, recurving vs. non-recurving cyclones, etc.

4) Further development of our research on ocean-air energy exchange through simultaneous solving of the moist-static energy and moisture budgets and the testing of the validity of the bulk formula. We need to determine how surface energy flux variations are related to variations of other tropospheric conditions besides the surface wind. Our composited rawinsonde data sets are especially applicable to this topic.

5) We will study the elusive relationship of the vertical variation of boundary layer wind in tropical storm conditions through an analysis of the large sample of surface and upper air merchant and military ship data we have recently acquired.

6) More thoroughly study the apparent large and significant diurnal variation of the troposphere's vertical circulation. This has been a significant finding of our past 5-6 years of rawinsonde data compositing. The four per day rawin observations available in the southwest Pacific/Australian region will be very valuable for such an analysis.

7) Study the differences in gradient and thermal wind balances between various classes of tropical weather systems by subtracting the observed wind-pressure and thermal wind imbalances of one system from another.

8) More thoroughly study the basic structure and the momentum, energy, and moisture budgets of the monsoon trough throughout the western Pacific and southeast Asia with our rawinsonde data and satellite cloud information.

9) Study the feedback influence of cumulus convection on temperature, moisture and momentum alteration from both an individual case and a rawinsonde composite point-of-view. This will hopefully lead to important background information on how such convective processes may be parameterized in terms of the measureable large-scale parameters.

10) Study the likely influences tropical cyclones have on alterations of middle-latitude westerly wave patterns. We will continue our study of the similar but opposite influence of the middle latitudes on ITCZ enhancement and tropical cyclone genesis.

11) Study the processes which lead to Tropical Upper Tropospheric Trough (TUTT) and upper level cold core low formation, maintenance, and decay.

12) Study hurricane inner-core variability (as determined from the NOAA NHRL research flights) as it is related to outer hurricane parameter variability.

13) Special study of tropical cyclones of 'small' vs. 'large' horizontal extent.

14) More thorough study of tropical cyclone motion characteristics such as fast vs. slow motion, right vs. left turning cyclones, stalling and looping cyclones, steering flow relationships, etc. From this motion analysis we will attempt to develop new forecasting schemes for tropical cyclone motion.

15) More thorough studies of tropical cyclone intensity change especially cyclones undergoing rapid deepening and filling.

16) Thorough and more complete study of the tropical cyclone genesis question. What is the relevant physics? How can a better forecast of tropical cyclone genesis and non-genesis be made?

17) What are the characteristics of tropical cyclones which become intense storms vs. those cyclones whose central pressure did not become deeper than 980 or 990 mb.

10.2 Desired Future Software Development

In addition to the writing of software programs to make the various calculations discussed in the previous section, there are other new programs that need to be written and enhancements made to our existing programs to simplify their usage and maximize their efficiency. If new calculation methods and techniques are not continuously developed and existing programs improved our utilization of these valuable data decks will be impaired.

One of the primary enhancements to be made to existing programs is the development of an all inclusive program that will simultaneously calculate wind, thermal, and motion parameters (as discussed in Chapter 5). Until recently this was not possible due to size limitations on the CSU computer system. These size limitations have been alleviated with a recent expansion of the CSU systems. Development of an all inclusive program will be extremely cost effective since we will only have to process the data once instead of up to three separate times (the present method) to calculate wind, thermal and motion parameters. Any new calculations needed and improved techniques and methods would be continuously added to this master program. The budget calculations would still have to be made separately since they require mass-balanced wind fields which have to be calculated in the first program.

New programs are also being developed and existing programs modified to make all calculations for the southwest Pacific-Australian region. Most calculations so far in this region have only been made on wind parameters. We have only recently finished constructing the thermodynamic data sample. One of the primary differences between the south Pacific-Australian region and the other regions is the need for totally different I/O routines because of differences in data structure. A separate wind program will be maintained for this region in order to take advantage of the four-a-day wind soundings which are available in this region but not available in the west Atlantic or northwest Pacific.

When we eventually develop the North Indian Ocean data set we will also have to develop a new set of somewhat different programs to properly fit the different data formats, different stations and geographic pecularities of this region.

We also plan to develop a standardized rectangular grid program for use in all basins and all parameters. Our rectangular grid development so far has been directed toward making use of specific parameter calculations in the northwest Pacific and West Indies based on data availability. This new rectangular program will be developed maintaining the flexibility in the current rectangular programs to vary grid size, and center location.

Although most of the currently used programs have been generalized for ease of use and to minimize duplication within the different basins, a number of individual region changes have to be made. Each basin and each data sample has different stations at different locations and time periods which have to be handled. Sign difference in east to west longitude change between the Eastern and Western Hemisphere must be accounted for. The same problem exists with the latitude differences between the Northern and Southern Hemisphere. The ocean basins have a differing number of data levels in the vertical. This set of programs will only be improved through continued usage and enhancement. Ways of merging the different regional data sets for general studies and for comparison purposes will also be developed.

12.3 Other Desired Software Developments

1) Graphical Software Packages. We need to put much more effort into development of graphical software packages. This would reduce the costs of some of our present output data analysis and make our data analysis more efficient. We hope to make extensive use of the NCAR graphical software packages and to develop a few new software packages to meet our own special graphic needs for output that the NCAR system does not have. We have yet to take advantage of the recent developments in computer graphic systems.

2) Incorporation of Global Data Analysis Into Our Tropical Weather System Studies. We hope to put more efforts into individual weather system analysis. As the surrounding large-scale influences are being found to be more and more important in tropical weather system behavior we very much want to concentrate more on individual case analysis. To this end we will start using the National Meteorological Center (NMC) global data analysis outputs and the European Center for Medium Range Weather Forecasting (ECMWF) daily analysis which will be available in the NCAR data archives. We are planning to make extensive use of the ECMWF First GARP Global Analysis (FGGE) analysis which is also available from NCAR.

   The proper incorporation of these individual time period global data sets into our CSU tropical analysis scheme will require additional special software development.

3) Jet Aircraft Winds. Develop new software programs to properly incorporate all available relevant upper tropospheric jet aircraft wind reports into our rawinsonde composite analysis.

4) Satellite Wind Data. Develop new programs to incorporate all available relevant geosynchronous satellite derived lower and upper tropospheric wind information into our rawinsonde composite analysis.

5) Satellite Sounder Temperature Information. Develop programs for the incorporation of the new satellite sounder mean-layer temperature and temperature gradient information that is now becoming available from the new VAS satellite system and from some of the polar orbiting satellites.

6) Surface Ship Data. Develop new software programs to properly handle all of the surface merchant and military ship data we have recently obtained.

11. DATA AVAILABILITY TO OTHER RESEARCH GROUPS

Since we now have what we consider to be the most complete tropical cyclone data set that is available anywhere, we are willing to make specialized data runs (at cost) of portions of these various data sets for other researchers. If we are able to more fully develop the data sets that we are presently working on we will be in an even more favorable position to aid other observationally oriented scientists and numerical modelers.

The cost of supplying this specialized data would be the cost of labor, computer time, and materials involved. Duplication of the output from a run already made is a relatively inexpensive task. Making new runs on already existing software would involve the increased cost of program time to set up the stratification and the additional computer time to run the sample. Costs are, to a considerable extent, based on the size of the stratification. The most expensive aspect of making new data runs for other scientists would be the costs involved in developing and testing new software programs. Additional software could likely be developed cheaper at CSU than elsewhere because we already have such software development experience.

Supplying raw data (soundings) would depend on the number of tapes and number of soundings desired. A direct copy of a particular tape would only require the cost of the tape, a little computer and labor time, and mail costs. A request for specific stations or time periods would cost more due to programming time and increased computer costs. Another cost might be the labor efforts involved in converting the data for use between a 60 bit machine and a 32 bit machine, if such a change is required.

All requests for data or runs will be responded to on an individual case basis. Information can be obtained by contacting William M. Gray (303-491-8681) or Edwin J. Buzzell (303-491-8526) or writing to one of us at our Department address:

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

12. DISCUSSION

The archiving of historical (since about 1957) rawinsonde and other data around tropical cyclones (as we are attempting to do here at CSU) has been recommended by the World Meteorological Organization Work Group on Tropical Meteorology for a number of years. Other scientists agree that this is a necessary first step to the understanding of these storm systems. The problem has been to find willing meteorologists who have the resources and who are willing to expend the necessary effort to accomplish the building of such tropical cyclone data sets. This is not the most glamorous of scientific endeavors. We, nevertheless, believe it to be a fundamental first step to a true understanding of these storm systems and also to the ultimate improvement in forecasting these weather systems. The research findings discussed in Chapter 9 could not have been accomplished in any way other than through the rawinsonde compositing type of research approach.

We are, of course, not the first group to utilize the data compositing methodology for the study of tropical meteorological phenomena. Hughes (1952) used this approach to verify the large boundary layer inflow occurring in tropical cyclones. Riehl (1954) has often used this methodology to describe many tropical phenomena. Yanai et al. (1973) and their UCLA research group have successfully utilized rawinsonde compositing to specify the vertical distribution of convective energy and moisture transports within the ITCZ region of the Pacific. Reed (1971, 1978) and his University of Washington research group have shown that rawinsonde compositing can be beneficially used to define and describe the structure and dynamics of the tropical easterly wave. Many other meteorologists have successfully employed this methodological approach.

We would like to encourage numerical modeling groups to utilize our data samples for model initialization and the testing of their model outputs. A beginning attempt along these lines has been made by Pfeffer and Challa (1981) who have used a portion of our data to initialize their tropical cyclone development model. We encourage other numerical modelers to make use of our data samples.

It is important that the meteorological research community apply more pressure on the meteorological agencies of tropical countries to render their countries' rawinsonde data available on magnetic tape for the last 15-20 years, and also that these data be freely exchanged. It is most unfortunate that many tropical countries still do not put their upper air data onto magnetic tape.

An additional point to be emphasized is the much superior quality of individual station serial data on which consistency checks have been made. The development of rawinsonde composite data sets from this type of rawinsonde data is very much superior to developing a tropical cyclone rawinsonde data set from data obtained directly over the GTS circuits where:

1) so much data processing must be accomplished at each time period before you obtain the relatively few relevant pieces of information which you need and

2) errors due to line noise and teletype punching inaccuracies are present.

Our experience at going the GTS route to develop a composite data set (as we have in the Indonesia region) indicates a requirement for much too large an expenditure of effort. In many cases this type of rawinsonde development may be prohibitive.

It should be emphasized that the oceanic wind and height fields we have obtained from our rawinsonde analyses are considered to be significantly superior to the interpolated wind and height fields obtained from the usual meteorological center objective analysis which, by necessity, has employed a large degree of smoothing. Most tropical cyclone forecast schemes have been devised with interpolated data which are often significantly less accurate than the directly measured parameters of the rawinsonde.

It is also important that one research team study storm data from more than one ocean basin. There are significant differences in ocean basin environments. Generalizations derived from one ocean basin may often not be as valid in other regions. Multi-basin studies also allow for better verification of physical processes which are important to all storm regions. Thus, if a particular physical process is separately observed in all ocean basins it can then be more confidently accepted as a fundamental physical process of the system being studied.

It is very important that as much of the complete research cycle as possible from data collection, processing, research synthesis, and publication be accomplished within one research group at one location. Data processing and research should not be separated. Continuous alterations and reruns of data samples must be made as a consequence of the findings of earlier runs. One learns how good his data are and develops insights into their meaning only by comparing them with other data sets and by continuously testing and altering his computational techniques and physical hypotheses. These research insights feed directly back and lead to new and innovative ways of collecting and processing other data. The testing of physical processes derived from data analyses in numerical models can likely best be accomplished within the confines of one research team where some degree of synthesis between model and data insights are attempted.

There has already been a considerable investment of Federal research funds over the last decade to the establishment of our group's expertise in this line of research. It is hoped that funds will continue to be available so that this type of rawinsonde compositing research endeavor can be properly maintained.

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13. ACKNOWLEDGEMENTS

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