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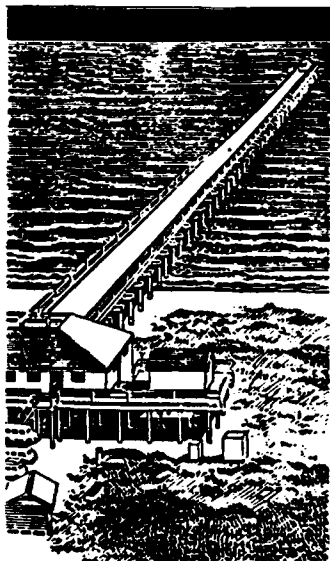
US Army Corps
of Engineers

UNIFIED PROGRAM FOR THE SPECIFICATION OF HURRICANE BOUNDARY LAYER WINDS OVER SURFACES OF SPECIFIED ROUGHNESS

by

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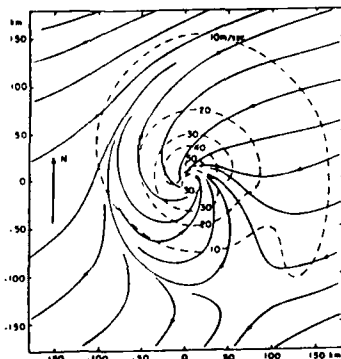


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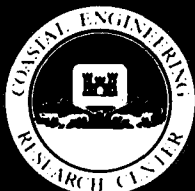
September 1992
Final Report

Approved For Public Release; Distribution Is Unlimited

Prepared for DEPARTMENT OF THE ARMY
US Army Corps of Engineers
Washington, DC 20314-1000

Under Work Units 12114 and 32683
Contract No. DACW39-78-C-0100

Monitored by Coastal Engineering Research Center
US Army Engineer Waterways Experiment Station
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REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE September 1992		3. REPORT TYPE AND DATES COVERED Final report
4. TITLE AND SUBTITLE Unified Program for the Specification of Hurricane Boundary Layer Winds Over Surfaces of Specified Roughness				5. FUNDING NUMBERS
6. AUTHOR(S) Vincent J. Cardone, Catherine V. Greenwood, J. Arthur Greenwood				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Oceanweather, Inc. 5 River Road, Cos Cob, CT 06807				8. PERFORMING ORGANIZATION REPORT NUMBER Contract Report CERC-92-1
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) USAE Waterways Experiment Station, Coastal Engineering Research Center, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; US Army Corps of Engineers, Washington, DC 20314-1000				10. SPONSORING / MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) A method is developed to specify the surface stress and the wind speed and direction in the planetary boundary layer of a tropical cyclone from meteorological storm parameters available for historical hurricanes. The method is based upon a numerical primitive-equation model of the planetary boundary layer in a moving tropical cyclone. The complete time history of the evolution of the surface wind field is described from a series of characteristic wind field states calculated at discrete times in a storm's history by the steady-state model. A surface drag formulation, based upon a contemporary similarity model (Arya 1977), coupled with a roughness parameter specification for a water surface consistent with Cardone's (1969) law, is incorporated into the numerical model and found to produce a consistent description of the integrated planetary boundary layer wind, the surface stress and its direction, and the wind speed and direction at anemometer level. The surface winds calculated in several recent hurricanes are found to be in excellent agreement with available, representative surface wind measurements made from offshore platforms and data buoys.				
14. SUBJECT TERMS Hurricanes Tropical storms Wind fields Numerical modeling Win's				15. NUMBER OF PAGES 201
				16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT	

13. (Concluded).

Transformations based upon an equilibrium planetary-boundary-layer similarity model are developed to specify the surface wind over terrain of specified roughness, including lake surfaces, from the over-water wind-field solution. Calculated over-land and over-lake winds are compared to the limited measurements available for several recent storms. Agreement is generally good.

The method is incorporated in a computer program, which provides surface winds on a variable-resolution rectangular grid. This report includes program documentation and sample grid results for a test simulation performed on Hurricane Betsy (1965).

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PREFACE

This report describes the methods incorporated in a computer program developed to provide hurricane surface wind fields. The wind fields can be used in wave and surge modeling activities. The report also serves to document the computer program delivered as part of the study.

The work described in this report was originally performed under Work Unit No. 12114, "Wave Information Studies," Coastal Field Data Collection Program. Publication of the report is funded by Work Unit No. 32683, "Wind Estimation for Coastal Modeling," Coastal Research Program. Both programs are sponsored by Headquarters, US Army Corps of Engineers (HQUSACE). Messrs. John H. Lockhart, Jr., and John G. Housley were the HQUSACE Technical Monitors. Ms. Carolyn M. Holmes of the Coastal Engineering Research Center (CERC), US Army Engineer Waterways Experiment Station (WES), was Program Manager. Drs. Jon M. Hubertz and Edward F. Thompson were the Principal Investigators of Work Unit Nos. 12114 and 32683, respectively.

This study was conducted under Contract No. DACW39-78-C-0100 by Oceanweather, Inc., Cos Cob, Connecticut, and provided to CERC on October 31, 1979. This report is the original contract report provided to CERC. It is being published as a CERC Contract Report at this time because CERC has used and continues to use the study results extensively to estimate wave growth in hurricanes. This report provides an important historical basis for present CERC practice. The hurricane wind model described in this report has recently been modified under Work Unit No. 32683 and included in CERC's Coastal Modeling System (Instruction Report CERC-91-1). Both work units are under the direct supervision of Dr. Martin C. Miller, Chief, Coastal Oceanography Branch, and Mr. H. Lee Butler, Chief, Research Division, and under the general supervision of Mr. Charles C. Calhoun, Jr., Assistant Director, CERC, and Dr. James R. Houston, Director, CERC.

The authors express their appreciation to the technical contract monitor at the time the work was performed, Dr. Robert W. Whalin, and to the late Dr. Charles E. Abel, both of WES, for their support, assistance and patience throughout the course of the work. The authors also acknowledge the role of the late Dr. John Wanstrath, who recognized the critical need for improved wind field models in hurricane surge modelling, and whose intense interest

stimulated the initiation of this research study.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
degrees (angle)	0.01745329	radians
feet	0.3048	metres
knots (international)	0.5144444	metres per second
miles (US nautical)	1.852	kilometres

A UNIFIED PROGRAM FOR THE SPECIFICATION OF HURRICANE BOUNDARY
LAYER WINDS OVER SURFACES OF SPECIFIED ROUGHNESS

PART I: INTRODUCTION

Statement of Problem

1. Specification of the wind velocity and vector wind stress near the sea surface in tropical cyclones is required for the description of ocean surface phenomena (such as ocean currents, the storm surge, and surface gravity waves) related to such cyclones. Dynamical-numerical computer-based models to describe such phenomena continue to be developed: for example, the work of Jelesnianski (1970) and Wanstrath et al. (1976) on the open coast surge, Forristall (1974) on currents, Cardone et al. (1976) on waves, and Wanstrath (1978) on the surge, including coastal flooding.

2. In most studies very simple descriptions of the hurricane wind field have been used to drive very complicated ocean response models. This disparity has hindered further refinement and validation of ocean response models and has limited the defensibility of climatological series, design criteria, and like results based upon the application of such models. The lack of near-surface wind measurements in hurricanes serves as an excuse for applying simple wind models: in fact, the most widely applied empirical model, discussed below, of surface marine wind distribution in hurricanes is calibrated against wind measurements made in a lake during the passage of a single storm.

3. In recent years, however, great progress has been made in our understanding of the basic physical and dynamical characteristics of tropical cyclones, including the part of such storms relevant to this discussion: the planetary boundary layer (PBL). Further, a series of measurement programs, both public and private, employing offshore oil and gas production platforms, automated data buoys, and low-flying aircraft, have made available a wealth of data on wind structure in the PBL in

tropical cyclones.

4. Cardone et al. (1976), exploiting this recent progress, developed a method for specifying the surface wind field in hurricanes over the ocean by applying a dynamical-numerical model of the PBL in hurricanes. The method, requiring as input only a description of the surface pressure field and specification of storm motion and latitude, has been used to model the surface wind field in nearly every major hurricane to affect the Gulf of Mexico or the East coast of the United States in the past decade (Camille, 1969; Delia, 1973; Eloise, 1975; Belle, 1976). At least one representative series of wind measurements over water was available in each of those storms to validate the method for the intended environment (open water) and the intended parameter (time-averaged winds at a specific height). Those studies confirm that the model is able to give a convincing numerical representation of how friction, latitude, storm motion, and the shape and intensity of the sea-level pressure pattern in a severe storm interact to produce an asymmetrical vertically integrated flow in the PBL. The model, however, includes an empirically based scaling law to relate the integrated boundary layer wind to the effective 19.5 meter level wind. Further, the surface stress distribution in the numerical solution has not been validated.

5. The purpose of the study reported here is to generalize the method so that it can be applied to specify surface wind and wind stress in hurricanes in a self-consistent way not only over the open sea but over waters typical of the near-shore environment, over inland bodies of water (lakes), and over terrain of varying roughness in general (e.g. open marshland, dense forest, cities). Such a capability is required for the application of surge models which treat the open-coast storm tide and inland flooding of coastal areas (e.g. the Mississippi delta and Lake Pontchartrain area) or those applied to surge studies of large inland bodies of water (e.g. Lake Okeechobee).

6. The goal of this study was the development of an efficient algorithm, implemented as a computer program free from proprietary constraints, that can be used to specify hurricane-generated surface winds and wind stresses, in historical storms or hypothetical storms, from the

kind of meteorological information available for historical storms.

Review of Prior Methods

7. Considered theoretically, the problem of surface wind specification in tropical cyclones is to solve the basic equations of hurricane-scale circulation, subject to appropriate initial and boundary conditions. As a part of the system of equations, consider the primitive equations of motion in cylindrical coordinates r , λ , z , with origin at the center of the cyclone, for u and v , the (horizontal) tangential and radial components of the wind:

$$\begin{aligned} \rho \left\{ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial r} + \frac{v}{r} \frac{\partial u}{\partial \lambda} + w \frac{\partial u}{\partial z} - f v - \frac{v^2}{r} \right\} \\ = \frac{\partial \rho}{\partial r} + \frac{\partial \tau_{zr}}{\partial z} + \left\{ \frac{\partial \tau_{rr}}{\partial r} + \frac{1}{r} \frac{\partial \tau_{\lambda r}}{\partial \lambda} + \frac{\tau_{rr} - \tau_{\lambda\lambda}}{r} \right\} \end{aligned} \quad (1a)$$

$$\begin{aligned} \rho \left\{ \frac{\partial v}{\partial t} + u \frac{\partial v}{\partial r} + \frac{v}{r} \frac{\partial v}{\partial \lambda} + w \frac{\partial v}{\partial z} + f u + \frac{uv}{r} \right\} \\ = \frac{1}{r} \frac{\partial \rho}{\partial \lambda} + \frac{\partial \tau_{z\lambda}}{\partial z} + \left\{ \frac{\partial \tau_{r\lambda}}{\partial r} + \frac{1}{r} \frac{\partial \tau_{\lambda\lambda}}{\partial \lambda} + \frac{2\tau_{r\lambda}}{r} \right\} \end{aligned} \quad (1b)$$

where w is the vertical component of the wind and the τ 's are the radial, tangential, and vertical eddy stresses of the tangential and radial velocity components.

8. Lack of knowledge how to solve equations (1), in particular lack of knowledge how to specify the eddy stresses, has until rather recently prevented a straightforward application of the primitive equations to the study of tropical cyclones. Practical demands, however, dictated the development of surface wind models as early as the late 1940's and the early 1950's. Even today the most widely applied method for wind specification derives from a procedure first published in a se-

ries of reports of the U.S. Weather Bureau, Hydrometeorological Section, during the 1950's. This method, hereafter referred to as the HP (Hydro-meteorological-Parametric) method, may be considered a three-parameter method: it requires knowledge of only three quantities related to a storm's structure, to specify the entire areal distribution of surface wind.

9. The basic steps involved in the HP method are the following:

- a. Assume that the sea-level pressure distribution in a tropical cyclone is symmetric; specify pressure as a function of radius r ,

$$p(r) = p_0 + \Delta p e^{-R/r},$$

where p_0 is the central pressure (at the eye), Δp is a storm pressure anomaly, and R is a scale radius related to the radius of maximum wind.

- b. Compute the profile of gradient wind as a function of radius: this step basically solves the u equation of motion for the steady-state, frictionless, locally horizontally homogenous solution:

$$u_{gr} + \frac{u^2}{fr} = \frac{1}{\rho f} \frac{\partial p}{\partial r}.$$

- c. Attempt to compensate for neglect of *all* other terms by reducing the gradient wind to the equivalent wind over water at 10 meters, using a reduction of the form

$$u_{10}/u_{gr} = F(r/R)$$

where F varies from .865 at the radius of maximum wind to about .60 at the periphery of the storm.

- d. Add asymmetry to the storm by vectorially adding 50% of the storm's forward motion V_f to the right side of the storm and subtracting 50% from the left side.
- e. Partition the reduced winds into tangential and radial components by specifying an inflow angle that is a function of r/R alone; in effect, this step attempts to compensate for the neglect of all physical effects contained in the v equation of motion.

10. The function F was derived from pressure and wind measurements made in and around Lake Okeechobee, Florida, during the passage of two hurricanes in 1949 and 1950; in fact, the constant .865 was chosen

from measurements in that single storm deemed more representative.

11. An attempt to solve by graphical means a less simplified version of equations (1), proposed by Myers and Malkin (1961), was applied to the determination of the wind field in hurricane Helene, 1958, by Schauss (1962). The study of Myers and Malkin (1961) was the first to demonstrate the dynamical inconsistencies in the HP method, especially the fallacy that superposition of storm motion on a circularly symmetric wind field can produce the right/left asymmetry observed in hurricanes. Schauss (1962) represented the eddy stresses in terms of friction coefficients which in turn were estimated indirectly from sea-level pressure analyses and ships' wind observations in hurricane Helene. An important element of Schauss' study was the realization that the pressure field about tropical cyclones is not axisymmetric. Schauss varied Δp and R by quadrant; he found that he could reliably estimate the quadrantal variation from conventional coastal measurements and marine pressure data, even though Helene remained offshore, east of the East coast of the United States.

12. The method of Myers and Malkin and Schauss is not, to our knowledge, in use today; the HP method, however, is in widespread use in design studies, climatological studies, and real-time forecast systems. Variants of the HP method are described by Patterson (1972) and Bretschneider (1976); the latest version is documented in Memorandum HUR7-120, Hydrometeorology Branch, Office of Hydrology, NOAA.

Relevant Recent Research

13. Much of our current basic knowledge of the structure, dynamics, and energetics of tropical cyclones has been generated only within the past 10 or 15 years. This progress is a result of two factors: first, an extensive data base has been created as a result of the program of reconnaissance by NOAA research aircraft begun in the late 1950's; second, models of the tropical cyclone, based upon numerical integration of the primitive equations, have provided new insight into the basic dynamical and thermodynamic processes operative in tropical cyclones.

14. As a result of analysis of the reconnaissance data, the general distribution of pressure, wind, and temperature throughout the free atmosphere above the friction layer in the inner core of hurricanes has been revealed. Shea and Gray (1973), for example, composited all aircraft data obtained between 1957 and 1969, and derived the distribution of the mean tangential and radial components of actual winds at various levels including the 900 mb level, the level closest to the boundary layer. Their analysis suggested that at that level, the asymmetry in the tangential component exceeds the forward motion of the storm, and that the radial (inflow) component is not symmetrically distributed about the storm axis, as is assumed in the HP model.

15. In the area of numerical modelling, at least a dozen distinct prognostic models have been developed since 1964. Anthes (1974) summarized numerical models down to about 1972, several of which continue to be further developed today. Changes have been mainly in the use of increased horizontal and vertical resolution and in parametrizing the effects of cumulus convection.

16. Models of the prognostic type are designed to study the dynamics and energetics of tropical cyclones, to expose the mechanisms of hurricane formation from incipient tropical disturbances, to study the sensitivity of the tropical cyclone to boundary conditions at the lower boundary (in particular sea surface temperature), and to assess the prospective influence of various proposed schemes for artificially modifying such cyclones (e.g. cloud seeding near the eye wall). Such models typically can not be used directly to specify the distribution of surface wind or wind stress in hurricanes, because the models suffer from relatively low horizontal resolution, crude parametrization of the boundary layer, and time-dependent integration schemes: in fact, the models were designed not as diagnostic tools, but rather to describe the evolution of the circulation from an arbitrary set of initial conditions.

17. Recently there has been greater emphasis on the boundary layer of tropical cyclones in hurricane research: this is because the boundary layer is an important dynamical component of the total circulation in cyclones; additionally, much of the new knowledge gained within

the past decade about the structure of the surface and planetary boundary layers of the atmosphere over the sea can be profitably applied to the boundary layer in hurricanes. Elsberry et al. (1974) obtained realistic solutions for the temperature and moisture distribution within the boundary layer of an axisymmetric storm by applying the marine PBL model of Cardone (1969), originally developed for application to the extra-tropical atmosphere. More recently, Moss and Rosenthal (1975) estimated the vertical exchange rates of momentum, heat, and cloud mass in the boundary layer of hurricanes by combining the boundary layer model of Deardoff (1975) with the roughness parameter formulation of Cardone (1969). Anthes and Chang (1978) used a new parameterization of the planetary boundary layer in an axisymmetric numerical hurricane model to study the response of a hurricane boundary layer to changes of sea surface temperature.

18. In this study, a diagnostic model of the hurricane PBL, developed originally by Chow (1971) and applied later by Cardone et al. (1976), is modified to produce a consistent description of the vertically integrated wind in the PBL, the surface drag and the wind speed and direction at anemometer height in a moving hurricane with asymmetric horizontal wind distribution over water. Equilibrium PBL theory is used to extend the surface wind description to terrain of specified roughness. The wind model is incorporated in a computer program to provide a gridded temporal and spatial history of the surface wind for use in surge models.

PART II: THE HURRICANE PBL MODEL

Review of Chow's (1971) Vortex Model

19. As time dependent numerical hurricane models have been extended to three dimensions, it has become necessary to find efficient numerical schemes of solving the primitive equations on the high resolution grids required and to give more emphasis to the asymmetry of planetary boundary layer flow. The latter is important because frictionally induced convergence in the boundary layer (Ekman pumping) is an important mechanism in organizing moist convection and triggering the instability responsible for the development of tropical cyclones. Those requirements served as the principal motivation for Chow's study.

20. Chow's model concerned the planetary boundary layer (PBL) only and sought the solution for the wind field and horizontal convergence in the PBL of a moving tropical cyclone from the equations of motion. The pressure field in the boundary layer was prescribed and fixed, so that there would be no gravity waves excited in the numerical solution. This facilitated the use of a nested grid system, which allowed grid spacings as small as 5 km near the hurricane inner region without sacrifice of overall computational efficiency.

21. The model is based upon the equation of horizontal motion, vertically averaged through the depth of the PBL, written in coordinates fixed to the earth as

$$\frac{d\vec{V}}{dt} + f|\mathbf{k} \times \vec{V} = -\frac{1}{\rho} \nabla p + \nabla \cdot (K_H \nabla \vec{V}) - \frac{C_D}{h} |\vec{V}| \vec{V} \quad (2)$$

where

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \vec{V} \cdot \nabla;$$

$\frac{\partial}{\partial t}$ is the time change local to the fixed coordinates; ∇ the two-dimensional del operator; $\vec{V}$ the vertically averaged horizontal velocity; f the Coriolis parameter; $|\mathbf{k}|$ the unit vector in the vertical direction; ρ the mean air density; p the pressure; K_H the horizontal eddy viscosity coefficient; C_D the drag coefficient; h the

depth of the planetary boundary layer. It is assumed that the vertical advection of momentum is small compared to the horizontal advection and can be neglected and that the shearing stress vanishes at the top of the PBL.

22. The pressure is prescribed as the sum of p_c and $\bar{p}$;

$$p = p_c + \bar{p}$$

where p_c , not necessarily axisymmetric, is the pressure field representing the tropical cyclone and assumed to translate with the storm at a specified speed $\vec{v}_c$; and $\bar{p}$ is a large scale pressure field which may be specified by the corresponding constant geostrophic flow, $\vec{v}_g$, as

$$f|K \times \vec{v}_g = -\frac{1}{\rho} \nabla \bar{p} \quad (3)$$

With this pressure specification, equation (2) may be written:

$$\frac{d\hat{\vec{v}}}{dt} + f|K \times (\hat{\vec{v}} - \hat{\vec{v}}_g) = -\frac{1}{\rho} \nabla p_c + \nabla \cdot (K_H \nabla \hat{\vec{v}}) - \frac{C_D}{h} |\hat{\vec{v}}| \hat{\vec{v}} \quad (4)$$

With respect to a moving Cartesian coordinate system (x, y) whose origin is located at the moving low center of p_c , equation (4) is transformed into

$$\frac{d\vec{v}}{dt} + f|K \times (\vec{v} - \vec{v}_g) = -\frac{1}{\rho} \nabla p_c + \nabla \cdot (K_H \nabla \vec{v}) - \frac{C_D}{h} |\vec{v} + \vec{v}_c| (\vec{v} + \vec{v}_c)$$

where

$$\frac{d}{dt} = \left(\frac{\partial}{\partial t}\right)_c + \vec{v}_c \cdot \nabla$$

$$\left(\frac{\partial}{\partial t}\right)_c = \frac{\partial}{\partial t} + \vec{v}_c \cdot \nabla$$

$$\vec{v} = \hat{\vec{v}} - \vec{v}_c$$

$$\vec{v}_g = \hat{\vec{v}}_g - \vec{v}_c$$

$\vec{V}$ is now the horizontal wind relative to the low center; $\vec{V}_g$ the effective geostrophic flow relative to the low center; and $(\frac{\partial}{\partial t})_c$ the time change local to the moving coordinates.

23. Chow solves equation (5) in component form

$$\frac{\partial u}{\partial t} = fv - Au - Pu + Hu - Fu \quad (5a)$$

$$\frac{\partial v}{\partial t} = -fu - Av - Pv + Hv - Fv \quad (5b)$$

where

$$Au = u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y}$$

$$Av = u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y}$$

$$Pu = fv_g + \frac{1}{\rho} \frac{\partial P_c}{\partial x}$$

$$Pv = -fu_g + \frac{1}{\rho} \frac{\partial P_c}{\partial y}$$

$$Hu = \frac{\partial}{\partial x} (K_H \frac{\partial u}{\partial x}) + \frac{\partial}{\partial y} (K_H \frac{\partial u}{\partial y})$$

$$Hv = \frac{\partial}{\partial x} (K_H \frac{\partial v}{\partial x}) + \frac{\partial}{\partial y} (K_H \frac{\partial v}{\partial y})$$

$$Fu = \frac{C_D}{h} [(u + u_c)^2 + (v + v_c)^2]^{\frac{1}{2}} (u + u_c) \quad (6a)$$

$$Fv = \frac{C_D}{h} [(u + u_c)^2 + (v + v_c)^2]^{\frac{1}{2}} (v + v_c) \quad (6b)$$

24. The general formulation is completed with the specification of the form of C_D , K_H and the boundary condition at the outermost boundary of the grid. Following Smagorinsky (1963)

$$K_H = 2\kappa^2 \left(\frac{\Delta}{2}\right)^2 |\text{Def}|$$

where $|\text{Def}|$ is the total deformation, Δ is the mesh size and κ is a non-dimensional constant ($\kappa = .4$ is assumed). The drag coefficient was assumed to increase linearly with wind speed

$$C_D = (0.5 + 0.6 |\vec{V}|) \times 10^{-3} \quad (\vec{V} \text{ in m/sec}) \quad (7)$$

At the outermost boundary of the grid, the acceleration and the horizontal diffusion of momentum are neglected, implying a balance between Coriolis force, pressure gradient force and the surface frictional force

$$f|K \times (\vec{V} - \vec{V}_g) = -\frac{1}{\rho} \nabla p_c - \frac{C_D}{h} |\vec{V} + \vec{V}_c| (\vec{V} + \vec{V}_c)$$

25. The computational grid is a rectangular nested grid system consisting of five nests, within each of which the mesh is constant. Figure 1 shows the inner three nests in one quadrant of the grid system; if the mesh size of the innermost nest is say 5 km, the second through fifth mesh sizes are 10, 20, 40, and 80 km respectively, and the entire grid covers an area of $(1600 \text{ km})^2$.

26. The details of the finite difference formulation and of the computational scheme are given by Chow (1971) and will not be repeated in detail here. Basically, a combination of diagonal and ordinary upstream differencing is used for spatial derivatives in order to reduce computational errors in the calculation of the advection terms and at the intermesh boundaries. The computation starts with an initial guess field consisting of the gradient wind components (computed from p_c). At each grid point, the equations (5) are integrated forward in time until the acceleration $(\partial \vec{V} / \partial t)_c$ is tolerably small. For an innermost grid mesh of size 5 km, the time step is 60 sec. Chow found that 800

iterations (equivalent to 13 hours 20 min) were sufficient to achieve a steady state solution.

27. Chow studied the accuracy of the numerical scheme by obtaining numerical solutions for a frictionless ($K_H, C_D = 0$) stationary ($\vec{V}_c = 0$) vortex in gradient balance. The pressure field was axisymmetric and defined by the well known exponential pressure law

$$p_c = p_o + \Delta p e^{-R_p/r} \quad (8)$$

where p_o is storm central pressure, Δp is the storm pressure anomaly, R_p is the scale radius and r is the radial distance from the eye.

For the test storm ($\Delta p = 50$ mb, $R = 40$ km), the truncation error decreased with the spacing of the inner nest mesh size. For a spacing of 5 km, the numerical solution for the radial and tangential components is compared to the analytical gradient-wind solution, which of course contains only a tangential component, in Figure 2. It is seen that the truncation error appears only in the radial component and serves to introduce a small inward-directed radial component.

28. Figure 3 shows the integrated boundary layer wind solution found by Chow for the same test storm but with friction, storm motion (10 m/sec) and a steering gradient of 10 m/sec aligned with the motion. The pattern is remarkably realistic, at least qualitatively, and displays considerable asymmetry in both speed and direction. In several sensitivity experiments Chow deduced that, at least for the test storm, friction and storm motion effects combine non-linearly to produce a strongly asymmetric inflow pattern. Storm motion is primarily responsible for front-back asymmetry in wind speed, while the asymmetric pressure field in the steering-flow case is mainly responsible for the left-right asymmetry in wind speed. These characteristics of the hurricane PBL wind field were proposed much earlier by Myers and Malkin (1961) on the basis of graphical integration of a vector equation of motion similar to equation (2), without lateral friction, but including both tangential and normal vertical friction forces.

A Consistent Surface Stress Parameterization

The model of Cardone et al. (1976)

29. Cardone et al. (1976) adapted Chow's model in order to specify hurricane surface winds in historical storms. While Chow's model provided a good qualitative description of the PBL wind field, Cardone et al. found it necessary to modify the model in several ways in order to attain good quantitative agreement between the modelled winds in real hurricanes and the limited amount of measured wind data available.

30. The model calibration rested mostly on the wind record measured on an oil rig directly in the path of Camille, 1969; at the time, this wind trace was believed to be the only existing accurate wind record representative of the surface boundary layer over open sea in a well-documented extreme hurricane.

31. The first modification made was to generalize the storm input parameter specification scheme adopted by Chow. The 3-parameter scheme, requiring only ΔP , R , and $\vec{V}_c$, was retained; as was the 4-parameter scheme, which adds an ambient geostrophic ($\vec{V}_g$) pressure gradient directed normal to the storm track, a so-called steering flow. A 5-parameter scheme allowed the angle between the storm track and the ambient gradient to be varied. Finally the option to specify Δp and R in equation 8 by storm quadrant was added, providing up to an 11-parameter scheme. The motion and pressure parameters, along with storm latitude, completely defined the integrated boundary-layer wind solution for a given storm.

32. The calibration against Camille data, and to a lesser extent Carla wind direction information, involved two major modifications to the model. First, it was necessary to modify the boundary layer depth formulation. Chow had assumed a constant depth of 1 km. In the modified version, the depth was allowed to increase toward the storm center from a minimum depth of 1 km at the storm periphery to nearly 2 km in the vicinity of the eye wall of intense storms. This modification primarily affected the directional properties of the integrated boundary-layer wind solution.

33. Second, since the model was needed to drive a wave prediction model which required wind data at 20 meter elevation, the wind speed calibration incorporated a scaling law to reduce the integrated boundary-layer wind to 20 meters. The law was found to be dependent on wind speed, with low winds reduced only slightly and winds of 50 m/sec reduced by about 60%.

34. The modified vortex model has been applied to the specification of the time history of surface winds in many historical storms (Ward et al., 1979) and in many recent storms which have affected the U.S. coast (Cardone and Ross, 1977; Ross and Cardone, 1977; Cardone and Ross, 1978). Since most hurricanes are not strictly in steady state (though the calibration storm Camille was remarkably so), a wind time history in a given storm is interpolated from several characteristic states computed from the vortex model, on the implicit assumption that there is a rapid mutual adjustment between the wind field and pressure field in hurricanes. The simulated storms all included some direct PBL wind data measured from offshore platforms, data buoys or aircraft. The model appears to provide a good surface wind description for a fairly wide range of storm types.

Shortcomings

35. Recent theoretical and field studies of the structure of the PBL in hurricanes have revealed several shortcomings in the modified model described above. First, with regard to the depth of the PBL, the evidence now suggests a much lower height than 1-2 km as assumed above. Moss (1978) studied the PBL turbulence structure from aircraft measurements for a peripheral portion of Eloise, 1975; the data support a PBL height of about 650 meters.

36. Moss and Rosenthal (1978) estimated PBL variables in two intense storms by applying Deardoff's (1972) PBL parameterization scheme to bulk data to compute the surface exchange coefficients. Cardone's (1969) relation for the roughness length was used and found to provide drag coefficients in reasonable agreement with previous estimates. The calculation included the estimation of the PBL depth under the assumption that the top of the PBL coincides with the cloud base, which was

taken as the lifting condensation level of surface air. Figure 4 shows the PBL depth calculated for the storms studied. A depth of 600-700 meters characterized both storms except near the eye wall where the depth lowers to about 500 meters. Finally, Chang (1977) added a PBL parametrization of contemporary formulation to a time dependent multilevel primitive equation model and derived the radial distribution of the PBL height in both steady and unsteady cyclones. Figure 5 shows that in the steady-state hurricane the depth varies between 380 and 450 m with the PBL height lifted slightly near the eye wall. The PBL height was not found to exceed these heights significantly in the several unsteady cases studied.

37. Another inconsistency in the model results from the retention of the drag law, equation (7), used by Chow. That law is actually intended for use with marine wind data at standard height (10 m). Since the drag coefficient decreases with increasing height in the PBL, the use of (7) with vertically integrated winds implies overestimation of the surface drag. In addition, new evidence (Figure 6) for the behavior of the 10 m drag coefficient; C_{10} , at sea reported by Garratt (1977) supports a Charnock-type roughness law

$$z_0 = a \frac{u_*^2}{g} \quad (9)$$

where z_0 is the roughness parameter, u_* is friction velocity and g is the gravitational constant. The Charnock constant a proposed was .0144 though the value is sensitive to the value assumed for the Kármán constant in the PBL model applied.

38. The scaling law adopted by Cardone et al. (1976) apparently compensates for the shortcomings noted above, at least insofar as the specification of the 20 meter wind speed is concerned. However, the computed surface wind is not consistent with the surface drag, which itself is likely to be incorrect. The integrated boundary-layer wind therefore is also likely to be in error in a given storm and is not suitable for the extension of the model solution to surfaces of arbitrarily specified roughness as required in this study.

39. In the next section, a revised PBL parameterization is adopted and shown to provide an accurate and consistent PBL wind and stress representation within the vortex model.

The revised PBL parameterization

40. A new framework for parameterization of the fluxes of momentum, heat and moisture in the PBL has been developed within the past decade, beginning mainly with the work of Blackadar and Tennekes (1968) and Zilitinkevich (1969). The parametric relations result from the matching of mean profiles of wind, temperature, and moisture predicted by surface and outer-layer similarity theories for a PBL in which the flow is assumed to be horizontally homogeneous and quasi-stationary.

41. A particularly convenient form of the parameterization, first proposed by Deardoff (1972), expresses the PBL fluxes in terms of layer-averaged mean PBL properties. Deardoff's parameterization, combined with Cardone's roughness parameterization, was found by Moss and Rosenthal (1977) to provide reasonable results for hurricanes. The parameterization adapted here is taken from Arya's (1977) update of Deardoff's scheme.

42. The general form of the parametric relations may be written

$$\frac{ku}{u_*} = - (\ln \hat{z}_0 + A_m) \quad (10a)$$

$$\frac{k v}{u_*} = - B_m \text{ sign } f \quad (10b)$$

$$k(\theta_v - \theta_0)/\theta_* = - (\ln \hat{z}_0 + C_m) \quad (10c)$$

$$k(q - q_0)/q_* = - (\ln \hat{z}_0 + D_m) \quad (10d)$$

where u and v are the vertically integrated (as in equation 5) horizontal wind components (in the direction of the surface shear and perpendicular to it, respectively), θ_v and q are the mean layer virtual potential temperature and specific humidity, respectively, $\hat{z}_0$ is the roughness parameter normalized by the PBL height (z_0/h), k is von Kármán's constant, θ_* is a potential temperature scale expressed in

terms of the heat flux H , q_* is a specific humidity scale involving the moisture flux, and A_m , B_m , C_m , D_m are universal functions of dimensionless similarity parameters.

43. The Monin-Obukov length L may be expressed in terms of θ_* and u_* since

$$L = \frac{-U_*^3 \theta_v \rho c_p}{kgH} = \frac{-U_*^2 \theta_v}{g\theta_*} \quad (11)$$

44. There exist two competing theories for the form of universal functions. In one theory, known as Rossby-number similarity theory, the boundary layer height is uniquely determined by u_*/f and L . For the near neutral hurricane PBL, that theory predicts the PBL to increase as the ratio u_*/f increases toward the center of storms, in apparent contradiction to observation.

45. In the generalized theory, the depth of the PBL, h , is specified as an independent variable. Arya (1977) presents updated expressions for the similarity functions in terms of this generalized theory as follows:

$$A_m = \ln\left(-\frac{h}{L}\right) + \ln \frac{fh}{u_*} + 1.5$$

$$B_m = 1.8 \frac{fh}{u_*} e^{.2h/L}$$

$$\frac{h}{L} \leq -2 \quad (12)$$

(unstable)

$$C_m = \ln(-h/L) + 3.7$$

$$A_m = -.96(h/L) + 2.5$$

$$B_m = .80(h/L) + 1.1$$

$$\frac{h}{L} \geq +2 \quad (13)$$

(stable)

$$C_m = -2.0(h/L) + 4.7$$

For near-neutral conditions, $-2 < h/L < 2$, A_m , B_m , C_m are assumed to be given by linear interpolation between the above computed values at $h/L = \pm 2$.

46. In terms of the similarity relations (10), the drag coeffi-

cient with respect to the integrated PBL wind is

$$C_d = \frac{k^2}{[(\ln \hat{z}_0 + A_m)^2 + B_m^2]} \quad (14)$$

while the angle β , between the surface wind and the integrated PBL wind is

$$\beta = \tan^{-1}(v/u) \quad (15)$$

47. To incorporate the similarity theory in the hurricane model, two cases were considered:

- a. Land. In a PBL over land, the following parameters are prescribed: f , z_0 , h , $\theta_v - \theta_0$. The parametric relations then define the following functions

$$C_d = F_1(|\vec{V}|)_{f, z_0, h, \theta_v - \theta_0} \quad (16)$$

$$\beta = F_2(|\vec{V}|)_{f, z_0, h, \theta_v - \theta_0} \quad (17)$$

- b. Water. Over water, the roughness parameter is not known but can be expressed in terms of u_* through a Charnock-type relation (equation 9) or the form proposed by Cardone (1969). The parametric relations can then be solved for

$$C_d = F_3(|\vec{V}|)_{f, h, \theta_v - \theta_0} \quad (18)$$

$$\beta = F_4(|\vec{V}|)_{f, h, \theta_v - \theta_0} \quad (19)$$

48. Arya (1977) gives solutions graphically only for the condition $fh/u_* = 1$, in which case C_d and β can be expressed, for a given latitude, in terms of z_0 and a bulk Richardson number. In this form, the theory is an updated version of Deardoff's scheme, which did not include dependence of A_m , B_m , C_m , D_m on fh/u_* . In general, however, fh/u_* or z_0 are not known a priori; equations (10-15) are solved by iteration starting from an initial guess on u_* .

49. In order to avoid the prohibitive computational expense of solving equations 10-15 iteratively at each grid point within the numerical vortex model, the assumptions are made that over water the air-sea

temperature difference and boundary layer height can be considered to be invariant over the domain of the storm. In view of the preceding discussion on h , this appears to be a reasonable approximation. Except for hurricanes crossing major ocean-current boundaries, the assumption of horizontal homogeneity of $\theta_v - \theta_o$ also seems reasonable, especially for Gulf of Mexico and lower U.S. East Coast hurricanes. Little is known about the characteristics of the PBL in hurricanes over land. However, given the high level of turbulent mixing there in hurricanes, it is reasonable to assume that an adiabatic lapse rate is established and that at least in the near-coastal zone, the boundary layer depth is close to that assumed for the over-water case.

50. Given the above conditions, the parametric relations F_1 , F_2 , F_3 , F_4 can be found once for a given storm by iteration, and expressed in terms of tables. In practice, the upwind and crosswind drag coefficients, the ratio $u_x/|\vec{V}|$ and the angle, β , between the surface wind and the integrated wind are computed for $|\vec{V}| = 0.8(.8)80$ m/s and tabled. Values for intermediate wind speeds are found by linear interpolation.

Test results for the general parameterization

51. The behavior of the over water drag coefficient for typical hurricane conditions ($\theta_v - \theta_o = -2^\circ\text{C}$, $h = 650$ m, $f = 10^{-4}$) according to the general parameterization is shown in Figure 7. The over water cases are computed for two separate values of the Charnock constant: .0144 and .035. The former value was recommended by Garratt (1977). However, in this model, $k = .35$, to be consistent with the Arya formulation, and $a = .035$ provides a better fit to the 10 meter drag coefficient measurements analyzed by Garratt. The drag coefficient for the land case is for a roughness parameter of .08 m, a boundary layer depth of 650 m and neutral stability. For comparison, Figure 7 also includes the form adopted by Chow.

52. While it is reasonable to expect the new theory to yield drag coefficients lower than equation (7), the magnitude of the decrease and the form of the wind dependence seen was surprising. The revised parameterization was tested in the numerical vortex model with the Camille

inputs used in the study of Cardone et al. (1976). The revised solution was referred to 20 meters by solving

$$v_{20} = \frac{u_*}{k} \ln \left(\frac{20}{z_0} \right)$$

where u_* and z_0 are determined by the numerical model, since for typical hurricane conditions, stability effects can be neglected in the surface layer.

53. Figure 8 compares the new solution and that derived by Cardone et al. Clearly, the general parameterization is underestimating the surface stress and therefore the surface wind. The difficulty with the general Arya formulation was traced to the dominating influence of the scale-height ratio fh/u_* on the similarity variables. This parameter was added by Arya mainly to describe the relative influence of the Coriolis force in an Ekman-type layer over a wide range of latitudes. In a hurricane, however, the parameter varies over two orders of magnitude because of the variation of u_* over an extreme range (typically 0-200 cm/sec) over a short distance. Considering the highly curved nature and spatial inhomogeneity of the flow in the hurricane PBL, that parameter is apparently irrelevant. Its influence was controlled therefore by restricting the solution to $fh/u_* = 1$.

54. The results of restricting the scale-height ratio to unity were dramatic. The revised dependence of drag coefficient on wind speed is shown in Figure 7 and the revised 20-meter wind profiles in Camille, for two boundary layer heights ($h = 650, 325$ m) are shown in Figure 8. The comparisons of modelled and measured wind speeds at Rig 50 in Camille for three PBL heights are shown in Figure 9. In the range of $h = 325-650$ m, the new theoretical calculation fits the measurements as well as the calibrated solution of Cardone et al. (1976).

Properties of the over-water solution

55. The final PBL parameterization chosen for the over-water case consists of the Arya (1977) parameterization, with the scale height ratio restricted ($fh/u_* = 1$) and with the crosswind drag term retained both in the calculation of the surface stress in the numerical solu-

tion and in the derivation of surface-layer wind direction from the integrated boundary-layer wind direction. The Charnock constant, a , is assignable as is the value of k . However, since a value of k of .35 is consistent with Arya's model, an a of .035 provides a better fit to Garratt's (Figure 6) drag coefficient data than the value suggested by Garratt.

56. The properties of the new over-water hurricane wind model solution are most directly seen in the relatively simple case of a stationary, symmetric vortex. The solution may then be compared more readily to the gradient wind. This is done in Figure 10 for a stationary symmetric vortex with the scale radius ($R_p = 12$ n.mi)* and pressure anomaly ($\Delta p = 105$ mb) of Camille. Note that the comparisons are only made at and outside the radius of maximum wind, since inside that radius, truncation errors remain fairly large for a small storm such as Camille.

57. The vortex model predicts integrated PBL winds which are supergradient within a radius of about $3 \times R_p$. The 20-meter winds, however, vary from 75 to 85% of the gradient wind. The surface inflow reaches a maximum of 25° at a radius of about $5 \times R_p$ and decreases sharply at the eye wall. These features are entirely consistent with those deduced by Shea and Gray (1973) from composited low level aircraft data in hurricanes. Comparisons of modelled and measured winds over water in several recent storms will be presented in a later section.

Numerical Experiments over Mixed Terrain

58. The similarity PBL theory as modified above may be easily applied to the specification of C_D and β in the hurricane PBL over land. For a neutral PBL, the revised theory predicts that C_D and β are functions only of z_0 . For h of 500 m, some typical values of C_D (β) are 1.78×10^{-3} (13.6°) for $z_0 = .04$ m and 2.54×10^{-3} (16.3°) for $z_0 = .16$ m.

59. The revised theory was tested in two ways. First, the numerical model was solved for the steady state wind field in a stationary

* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 4.

symmetric intense hurricane situated entirely over homogeneous terrain. While this case is unrealistic, it was intended to provide an indication of the sensitivity of the numerical solution to a greatly increased drag. Second, the solution was sought for the more realistic case of an intense hurricane situated at the coast with terrain of homogeneous roughness under the northern half of the storm and open sea beneath the southern half. The storm was stationary since only in such a case is the numerical model, formed in a moving coordinate system, rigorous.

60. Solutions typical of both cases are shown in Table 1 where they are compared to the open-sea solution discussed above. The cases were run with symmetric stationary Camille inputs. The all-land case returned a symmetric solution as expected. The case shown is for $z_0 = .08$ m, which is typical of open, level, countryside with low vegetation. Within about 200 km of the eye, the integrated PBL wind is found to be larger than the open-sea case, though surface winds are slightly lower. The inflow angle is about 50% greater than the open-sea solution. In effect, the increased surface drag results in a more intense vortex for a given pressure field, reflecting the well known dual role of friction in tropical cyclones. In nature, decreased evaporation is largely responsible for hurricane decay over land, and rapid decrease in PBL winds.

61. Two typical examples of the mixed land/sea solution are shown in Table 1. The solutions in these cases were quite asymmetrical. In general, the solution over-land matched quite closely the solutions found in strictly over land cases for comparable z_0 . However, over-water, the solution departed significantly from the reference over-water case. In particular, for all values of land roughness attempted, the PBL winds over water downwind of land increased to values above the all-water case, thus causing the formation of a distinct wind maximum in the left rear quadrant (with respect to north) of the storm.

62. In Table 1, the vertically integrated winds over sea in the mixed land/sea solution are taken along a radial extending south from the storm center. For a land z_0 of .04 m the maximum wind over water

Table 1

Comparison of over water, over land, and mixed terrain radial wind speed profiles in vortex model numerical solutions for a stationary, symmetric storm with pressure profile parameters $\Delta p = 105$ mb, $R_p = 12$ n.mi., and modified ($f_h/U_* = 1$) Arya (1977) similarity PBL parameterization.

R	V_g	Over water		Over land $z_0 = .08m$		Half land/sea $z_0 = .04m$		Half land/sea $z_0 = .32m$	
		$ \vec{V} $	V_{20}	$ \vec{V} $	V_{20}	$ \vec{V} _{sea}$	$ \vec{V} _{land}$	$ \vec{V} _{sea}$	$ \vec{V} _{land}$
800	6.9	7.2	7.2	7.3	5.1	7.3	7.3	7.1	7.3
400	20.6	20.2	19.7	18.6	13.0	20.3	19.0	20.3	17.5
200	42.3	41.2	34.9	37.9	26.5	41.5	38.7	41.8	35.5
100	66.5	67.0	53.5	64.5	45.1	69.0	64.7	70.4	61.0
50	90.7	94.2	72.7	97.2	67.9	100.2	91.7	104.9	88.6
40	97.6	102.4	78.3	108.1	75.5	110.0	99.3	116.9	95.1
30	105.2	108.4	82.4	116.9	81.7	116.7	104.6	129.4	98.9
20	111.2	112.5	85.2	117.0	81.8	116.9	109.6	133.9	103.5

Explanation of table:

- R radial distance from hurricane center (km)
- V_g magnitude of the gradient wind
- $|\vec{V}|$ integrated boundary layer wind speed
- V_{20} 20 meter wind speed
- $|\vec{V}|_{sea}$ in mixed terrain solution, the over-sea values are taken from radial over sea extending out from eye (at coast) normal to coastline.
- $|\vec{V}|_{land}$ as above except radial extended over land

All wind speeds are expressed in knots.

is increased about 5% over the all-water case, and about 15% for a land z_0 of .32 m. Even greater increases were found in the left rear quadrant. A similar experiment for actual Camille inputs (not shown) led to comparable results, showing an unrealistic speed maximum in the left rear quadrant, whereas the nominal over-water Camille solution displayed a maximum in the right hand quadrant.

63. It is difficult to explain the precise cause of the anomalous model behavior in the mixed-terrain case. Test cases were run with modified over-land drag laws derived from Rossby-number similarity theory but no change in the basic structure of the solution was noted. The solution was verified to be steady-state in trial integrations carried out for 1600 rather than 800 iterations of the vortex model. Indeed, the behavior might be attributed to the basic model formulation, which forces a steady state solution unrealistically. However, in an experiment with a three-level, three-dimensional nested-grid numerical model, reported by Moss and Jones (1978), behavior similar to that found here has been seen in a simulation of an intense hurricane approaching the coastline. In their integration, it was noted that as the hurricane approached the coastline, even though the sea-level pressure in the storm began to rise, a transient wind-speed maximum greater than found in the all-water control case was established over water on the landward side of the vortex and extending to the left side of the circulation (looking down the track toward land).

64. Moss and Jones attribute the anomalous behavior of the wind field near landfall to changes in the pressure field induced by greatly increased inflow in the part of the wind field over land. In our simulation, however, the anomalous behavior is present even though the pressure field is fixed. More likely, the behavior is caused by the simplified treatment of the PBL vertical structure and the neglect of boundary-layer-adjustment processes which occur on vertical scales of the order of the depth of the PBL and on horizontal scales of the order of the grid spacing.

65. Basic knowledge of the behavior of the PBL flow across discontinuities in roughness is in a remarkably inchoate state.

The theories fall into two classes: (1) those which treat surface boundary layers only (e.g. Elliott, 1958); (2) those which treat the Ekman layer as a whole. Nearly all the available field data are restricted to the former case: there is considerable evidence that upon crossing a change in surface roughness, the wind profile is modified from below as a new (internal) boundary layer grows in thickness at a rate which depends upon stability and roughness. As a crude rule, the new boundary layer is established to a height given by one tenth the distance to the upwind change in roughness. If we were to extend this rule to the hurricane PBL, whose height is typically 500 m, we would expect the flow to adjust within 5 km. However, the more general Ekman-layer adjustment theories (e.g. Taylor, 1969) suggest a more complicated process, in which the wind-speed profile near the surface adjusts rapidly as in the surface-layer theories, but in which the surface stress, the turbulence structure and the wind direction take much longer (by nearly an order of magnitude) to attain equilibrium with the new surface. The theory and scant available data (Jensen, 1978) suggest also that the process is not symmetrical with respect to roughness transitions with the adjustment from rough to smooth conditions taking place at a slower rate than from smooth to rough. It appears therefore that the basic process of PBL adjustment in hurricanes needs to be better understood before the simulation of PBL flow across discontinuities within numerical hurricane models can be improved.

Equilibrium Theory Terrain Transformations

Empirical Evidence

66. The numerical experiments described above indicated that the numerical model could not of itself provide reliable wind fields over terrain of arbitrary roughness. This raised three questions:

- (a) are fetch effects near roughness discontinuities important enough to be accounted for empirically in the specification of surface winds in hurricanes?
- (b) can over-land PBL winds be prescribed from the over water numerical solution?

- (c) are winds over lakes such as Pontchartrain and Okeechobee different from winds over open water, apart from fetch effects, other factors being equal?

67. Extensive empirical studies of the effect of fetch on winds over water downwind of the coastline have been reported by Richards et al. (1966) and Phillips and Irbe (1976), who processed large data sets obtained around and in the Great Lakes. Both studies employed the same analytical method. Extensive series of simultaneous surface wind measurements from coastal land stations and downwind ships and buoys were paired and stratified by wind speed, fetch, and stability. Both studies employed the same fetch and stability classes. The stability was parametrized by the temperature difference (land air minus lake water).

68. The problem of concern here is the adjustment of the surface wind over a shallow inland lake of the dimensions of lakes Pontchartrain and Okeechobee (fetch < 40 n.mi) in hurricane conditions. The latter are characterized by winds > 8 m/sec and near-neutral stability. The data of Phillips and Irbe, and Richards et al., in those wind-speed and stability categories are plotted in Figure 11. Clearly, up to a fetch of at least 40 n. mi., no significant trend with fetch is evident in the wind-speed ratio (over-land ÷ over-water). The ratio tends to be slightly larger for the more recent study, because the over-water winds in the recent study were measured at 3 meter height while in the study of Richards et al. the anemometer height was 10 meters. Since the first fetch class covered the range 0-5 n.mi., the implication is that the wind speed over the lake in the indicated classes and at heights up to 10 m attained equilibrium with the lake surface within the first few miles of the coast. This behavior is consistent with the height-to-fetch ratio of 1:10 noted above for surface layer adjustment.

69. It should be noted that, in both of the studies cited, a dependence of the wind ratio on fetch is proposed. The dependence however appears mainly in data from low wind speed (< 8 m/sec) classes and very stable or unstable stability classes. The fetch dependence therefore probably is caused by an adjustment of the turbulence in the PBL due to changes in stability rather than in surface roughness and is therefore

not likely to be important in the hurricane environment.

70. An interesting corroborative piece of evidence has been provided recently by remote sensing data. The Seasat mission has proved that the marine surface wind speed as might be measured at 10 m height from say a data buoy, can be measured by a radar scatterometer to an accuracy of 1 m/s or better. The radar backscatter cross-section of the sea surface (σ_0) therefore appears to be mainly dependent on surface stress and wind speed (Jones et al. 1978). Ross and Jones (1978) reported several aircraft experiments in which a scatterometer was flown directly downwind off the U.S. East Coast in moderately strong offshore wind conditions. The σ_0 measurements were plotted versus fetch (Figure 12), beginning within 1 km of the shoreline. There was found to be no fetch dependence at least to 40 km offshore, which suggests that the surface stress, the friction velocity, and the surface wind speed adjusted quickly to the surface roughness.

71. The above studies all suggest strongly that the adjustment scale for near-surface wind speed in strong-wind, near-neutral conditions is a few kilometers at most, which is a small distance compared to the dimensions of lakes Okeechobee and Pontchartrain. A dependence of wind speed on fetch may therefore be omitted. The situation with regard to wind direction is not as clear. There are no comparable field data for the adjustment of PBL wind direction across a roughness discontinuity. The available theories suggest a much longer adjustment scale. In the adopted scheme, no fetch-dependent adjustment for wind direction is incorporated; however, the case is allowed whereby the wind speed adjusts to the lake roughness immediately while throughout the lake, the wind direction is computed in accordance with the roughness of the terrain surrounding the lake (subroutine BREEZE/SPECIAL). This is correct if the adjustment scale for wind direction in the PBL is larger than the lake dimension. Field measurements are required to test this hypothesis.

72. Apart from fetch considerations, the surface winds over a large lake in hurricanes might be different from equivalent over-ocean winds because of differences in the surface roughness between a lake and

open sea. That is, the drag coefficient over a lake might be different from the drag coefficient over open sea, particularly for uniformly shallow lakes in which the surface wave structure can be expected to differ significantly for a given wind from deep-water surface waves. Unfortunately, the correct drag formulation for a shallow lake is much less certain than for the sea. Whitaker, Reid and Vastano (1973) have inferred a drag law for Lake Okeechobee which is quite different from the form proposed by Garratt. The scheme adopted below therefore includes the allowance for the specification of over-lake winds relative to an altered lake specification of surface roughness.

The Transformation Model

73. In this section a simple model is proposed to derive the surface wind and stress over terrain of arbitrary roughness from the numerical wind-field solution computed exclusively from the revised over-water drag formulation. The approach is to employ equilibrium PBL theory to relate the over-water integrated PBL wind to the flow at the top of the PBL and then to employ a consistent equilibrium model to compute the surface wind stress from the wind at the top of the PBL for terrain (including lakes) of arbitrarily specified roughness. The model proposed assumes that the PBL over land or inland lakes in a hurricane is neutrally stratified.

74. The transformations are derived quite simply from consideration of the alternate forms of the similarity FBI theory adapted in this study. To parameterize the surface drag in the numerical vortex model we applied equations 10a and 10b which relate the stress to the integrated PBL wind. Alternatively (Arya, 1977), the surface drag may be referenced to the wind at the top of the PBL u_h, v_h :

$$\frac{ku_h}{u_*} = - (\ln \hat{z}_0 + A) \quad (20a)$$

$$\frac{kv_h}{u_*} = - B \text{ sign } f \quad (20b)$$

or to the surface geostrophic wind components

$$\frac{ku_g}{u_*} = - (\ln \hat{z}_0 + A_0)$$

$$\frac{kv_g}{u_*} = - B_0 \text{ sign } f$$

As noted by Arya, A_0 and B_0 may be expected to differ from A and B due to the presence of baroclinicity and also in very low latitudes where winds are strongly geostrophic. In hurricanes, baroclinicity in the PBL may be ignored, but the flow at the top of the PBL is more nearly in gradient balance. The effects of curvature on A , B have not been studied, but the success achieved with the similarity PBL theory in the over water case suggests that such effects are not large. In this model, differences between A , B and A_0 , B_0 are ignored.

75. The relationship between A_0 , B_0 and A_m , B_m is given by Arya (1977) as derived from the equations of mean motion for a barotropic atmosphere in which the momentum flux is assumed to vanish at $z = h$:

$$A_m = A_0 \quad (21a)$$

$$B_m = B_0 - k (fh/u_*)^{-1} \quad (21b)$$

For the restricted case of $fh/u_* = 1$, which we have adopted only for the purposes of attaining a workable parameterization, it can be shown simply from equations 10, 20 and 21 that the flow at the top of the PBL, $z = h$, is related to the vertically integrated flow through

$$u_h = u \quad (22a)$$

$$v_h = v - u_* \quad (22b)$$

In the coordinate system adopted (see Figure 13), v_m is negative, u_* is always positive so the wind speed at the top of the PBL is always larger than and turned clockwise (in the Northern Hemisphere) with respect to the mean layer wind $\vec{V}$.

76. Given the wind at the level h , the consistent similarity theory defined by equations 20a and 20b may be solved for the surface stress and surface layer wind in a neutral PBL over terrain of specified roughness z_0 . For a neutrally stratified PBL, A_0 and B_0 are reduced simply to constants (1.39, $1.95 + k$, respectively). If z_0 is a constant, as say over a homogeneous land surface, u_* may be obtained directly from equations 20a and 20b. However since over a lake, the roughness probably depends on u_* , z_0 may in general be prescribed in terms of u_* using the general form proposed by Cardone (1969).

$$z_0 = C_1 u_*^{-1} + C_2 u_*^2 + C_3 \quad (23)$$

where C_1 , C_2 , C_3 are constants to be chosen to impose a desired drag law. (For example, for a Charnock law, $C_1 = C_3 = 0$, $C_2 = a/g$; for land, $C_1 = C_2 = 0$, C_3 is the roughness parameter for the terrain type).

77. The implementation of the above model in the specification of hurricane surface wind fields over terrain of arbitrary roughness or lakes is coded as subroutine UPDOWN, which allows for the calculation of transformations for up to six terrain categories, for each of which roughness constants C_1 , C_2 , C_3 have been specified. The procedure followed is:

- a. Given the integrated boundary layer wind u , v and the conditions of a given hurricane over water (h , $\theta_a - \theta_0$, f , k , a) compute u_* from the revised over water similarity parameterization.
- b. From equations 22a, 22b, compute the wind speed and direction at level h , the top of the PBL.
- c. For each terrain roughness, specified in terms of equation 23, use the neutral similarity model (20a, 20b) to compute the friction velocity appropriate to the terrain roughness, u_{*t} , the ratio $u_{*t}/|\vec{v}|$, and the angle between the surface stress and the integrated wind. The ratio and the turning angle are computed for $|\vec{v}| = 0.8(.8)80.0$ m/sec, for each roughness category and stored for use in the specification of surface winds in a given simulation over a grid covering different terrain types.

78. The overall behavior of the transformations is exemplified in Figure 14, which shows the ratio of surface wind speeds at 20 meters (over-land + over-sea) and the difference between the over-land and over-sea inflow angle for two terrain roughnesses: .04m, .32m. For comparison, Figure 14 shows the results for the wind-speed ratio derived from numerical mixed-terrain and over-water solutions for a symmetric stationary vortex (radius and pressure drop as in Camille). To arrive at the indicated quantities, the surface wind speed and direction along a radial extending north of the eye over land in the mixed terrain case was referenced to the (symmetrical) solution along the radial for open ocean. It should be recalled that in the mixed-terrain solution, the wind field over land looked quite reasonable. Apparently, that solution can be retrieved quite simply from the over-water solution using the equilibrium model described above. It is also interesting to note that the form of the dependence shown in Figure 14 conforms quite closely to the empirical wind-speed ratio derived from measurements in hurricanes in and around Lake Okeechobee (U.S. Weather Bureau, Hydrometeorological Section, 1954).

Results for Test Storms

79. In this section, the results of calculations of the entire history of the surface wind field in selected hurricanes are checked at measurement locations at which representative surface wind measurements are available. Indeed, the storms were chosen because over-water wind measurements and, in some cases, representative over-land wind measurements were available, and because extensive analyses of storm pressure and track characteristics had been performed in previous studies. Results are presented for hurricanes Camille, 1969; Betsy, 1965; Delia, 1973; Belle, 1976; Anita, 1977; and the Lake Okeechobee (LO) storm of 1949. Comparisons against over water winds are made in Camille, Delia, Belle, and Anita. A limited evaluation of over-land and over-lake winds in Camille and the LO storm is made. Finally, sample results for Betsy are presented without comparison against measurements, as no represen-

tative measured winds over land or lake are available in that storm.

Camille

80. Hurricane Camille played a crucial role in the calibration of the method developed by Cardone et al. (1976), because at that time, the wind trace in Camille from Rig 50 was deemed to be the only extant representative over-water wind trace in an intense hurricane. Indeed, the empirical law developed by Cardone et al. to scale integrated boundary layer winds to standard anemometer height was based largely on that wind trace. In the present scheme, the assignable model parameters are physical quantities related to fundamental properties of the planetary boundary layer model (PBL height, stability, roughness parameter formulation). Also, the method provides the wind speed as might be measured at any height in the constant-stress surface boundary layer, which in hurricanes may extend to a height of at least 50 meters.

81. The comparison of measured and modelled wind speed at Rig 50 at measurement height in Camille is shown in Figure 15. The agreement is at least as good as that achieved by Cardone et al. (1976). Results for two boundary-layer heights are shown. The numerical solutions differ little, except near the eye, where the lower height ($h = 500$ m) matches the peak measured wind better. This may reflect the fact that near the eye of intense hurricanes, the PBL height lowers slightly. Since the solutions differ little outside the eye, it is perhaps prudent to use a PBL height of 500 m in simulations of strong storms in the Gulf of Mexico.

82. To generate modelled surface-wind time histories at land sites requires knowledge of the roughness parameter representative of the terrain. Typical z_0 values for various terrain types have been given by several workers (e.g. Figure 16 after ESDU 72026, 1972). The roughness parameter is very sensitive to the terrain type within a few kilometers of a given measurement site, and therefore often varies significantly with wind direction at a site. For the sites at which winds have been measured in the selected hurricanes, the roughness parameter has not been determined experimentally. We therefore depict modelled time histories covering a reasonable range of roughness parameters at

land sites. Also, with the exception of the lakefront comparison in Camille, comparisons are restricted to only those measurement times at which the anemometer was recorded on strip chart, from which 30-minute-average wind speed and direction could be extracted.

83. Figure 17 compares measured and modelled winds at Keesler Air Force Base, Biloxi, Mississippi. The anemometer at Keesler is mounted 16 feet above the runway surrounded by fairly level terrain but with the coast less than a block away to the southeast. The anemometer measured winds up to the time of eye landfall at 0000 CDT. Measured wind directions support an over land trajectory up to about 2300 CDT and an over water trajectory thereafter. The modelled wind history for z_0 of .16 m, compares favorably with the measurements up to 2300 CDT; after which the measurements agree better with an equivalent over-water history (also shown in Figure 17). Modelled wind direction is generally within 20° of that measured.

84. The anemometer at Burwood CGS, Southwest Pass, is in a complex environment, with at least some influence of land to be expected, especially for wind directions between northwest and northeast. The wind comparisons in Figures 18 and 19 show better agreement in wind direction for an assumed over-water exposure. For wind speed, however, over-land histories agree better, but the effect of a shift in wind direction to an off-water direction (1800-2000 CDT) can clearly be seen in the measured wind speed.

85. Since fetch effects are not built into the present model, the Burwood and Keesler comparisons present worst-case examples of limitations of the present scheme. Nevertheless, the results appear accurate enough for specification of over-land winds in the coastal zone.

86. An important function of the present model is to specify winds over Lake Pontchartrain in hurricanes. The scheme adopted includes the provision for the specification of winds over the lake different from winds over open water in two ways. First, surface wind speeds may be computed relative to a z_0 specified for lakes which differs from the Charnock law assumed over water. Second, the program accommodates the condition, discussed earlier, whereby the surface layer

wind speed and stress are assumed to adjust to the lake roughness on length scales small compared to the lake width, but the PBL wind direction is governed by the roughness of that terrain upwind of the lake.

87. There is virtually no data on the roughness properties of Lake Pontchartrain. Whitaker, Reid and Vastano (1973) have deduced a drag law for Lake Okeechobee which differs substantially in level and wind dependence from equation 9. Their form was fit to equation 23, and was used to provide test wind histories at measurement sites around and in the lakes in the test simulations. (The form of equation 23 does not provide a particularly accurate fit to the odd form proposed by Whitaker et al., but is within about 20% over the range 10-50 m/s.)

88. The model was used to specify surface wind speed at the location and measurement height of Lakefront Airport, New Orleans, in Camille, for both water and lake roughness laws (Figure 20). The wind direction was computed for the water z_0 and for the special case described above, assuming an upwind terrain roughness of 1 m. Observed 1-minute hourly surface winds from the airport station are also plotted. Quantitative comparison of wind speeds is not warranted because the measurement is poorly averaged and the measurement site may not be representative of over-lake conditions. The reported wind directions should be more representative; the comparisons there suggest that there may indeed be a larger inflow angle for winds over Lake Pontchartrain in hurricanes than returned by the nominal over-water or over-lake transformation. Higher quality measurements in the lake in storm conditions are required to verify this possibility.

89. Figure 20 also shows the wind speed over downtown New Orleans, at 85 feet, calculated with a z_0 of 1 m. Time-averaged measured winds are not available for comparison.

Delia

90. Forristall et al. (1977), using the method of Cardone et al. (1976), ran a simulation of hurricane Delia in order to produce a wind field as accurate as possible, permitting the simulation of the surface wind and current at Buccaneer tower, offshore of Galveston, Texas. Thus

the storm parameters and track were adjusted, within their range of uncertainty, to produce best agreement between measured and modelled winds at the tower. Those storm parameters and track were used, without alteration, as input data to the present scheme and the wind field was computed. The boundary layer height was specified as 500 m.

91. The comparison of measured and modelled wind speed and direction in this storm is shown in Figures 21 and 22. The agreement in wind speed and direction is generally excellent, except for about an $10\text{-}20^\circ$ excess of inflow in the modelled wind directions. Slight alteration of the input parameters and track of this poorly organized highly erratic storm would probably have provided even better agreement.

Belle

92. The wind and wave fields in hurricane Belle have been modelled by Cardone and Ross (1979), using both the methods of Cardone et al. and simpler parametric schemes. Belle moved rapidly up along the east coast. As it did so, the central pressure rose sharply and the eye diameter increased. This storm, therefore, provides a critical test of the present method, which simulates such time changes in terms of a series of steady-state numerical solutions.

93. The center of Belle passed directly over two NOAA data buoys, one EB15 located offshore South Carolina; the other, EB41, located east of New Jersey. As for the Delia simulation, the storm input parameters and storm track determined by Cardone and Ross (1979) was used without alteration to drive the present model. Four steady-state solutions were utilized to attempt to accomodate the rapid changes in storm intensity, shape and speed.

94. The modelled and measured time histories are compared at sensor height at EB15 and EB41, in Figures 23, and 24. Agreement is generally excellent. The departure between modelled and measured wind direction early in the EB41 history is related to the presence of a frontal trough of low pressure which was located off the New Jersey coast and which distorted the pattern of isobars in the forward quadrants of the storm.

Lake Okeechobee Storm of 1949

95. The Lake Okeechobee storm of 1949 has been the subject of much past study. It is particularly important because winds were measured over the lake with calibrated anemometers mounted at 10 meters height. The wind data had been reduced to 10-minute averages by the Hydrometeorological Section, U.S. Weather Bureau. For the comparisons shown in this study, the data were reduced further to 30-minute averages, to be more consistent with the implied averaging interval of modelled winds.

96. Storm input parameters were specified as objectively as possible from the data published on this storm. While there is considerable storm data from the lake stations, there remains some uncertainty in the precise storm track; particularly east of the Florida coast and as the storm recurved northwest of the lake. There is also some uncertainty in the filling rate. In our simulation, no filling is applied until just after the eye of the hurricane has crossed the lake. Storm pressure input parameters ($p_o = 954$ mb, $R = 22$ n.mi.) prior to the filling stage were taken directly from Graham and Hudson (1960), while the steering flow was estimated from historical Northern Hemisphere Surface Analyses. The four-parameter (Δp_c , R , V_c , V_g) pressure initialization scheme was adopted since the storm appeared to translate in the direction of the steering flow. There did not appear to be sufficient data in this storm to estimate Δp and R by quadrant. Storm track was taken from published track charts, though it is not clear whether the track relates to the pressure center or the center of surface wind circulation.

97. Surface winds were measured reliably at two locations within the lake, stations 14 and 16, shown in Figure 25. The same figure shows the path of the storm schematically. Surface winds were computed for two roughness categories: (1) the over-water Charnock law; (2) the roughness specification, equation 23, with constants consistent with the Lake Okeechobee drag law of Whitaker et al. (1973).

98. Measured and modelled winds at the lake stations are shown in Figures 27 and 28. The histories cover the period from about 8 hours before the occurrence of maximum wind on the lake, at which time the

storm center was between Nassau, Bahamas and West Palm Beach, Florida, and the 8-10 hour period after the occurrence of maximum winds, when the storm was filling rapidly and recurving northward over central Florida.

99. The wind speed comparisons show that in general the lake roughness histories compare better with the measurements than the over-water specification. There is one serious discrepancy between modelled and measured wind speeds: this occurs over a two-hour period just after the occurrence of maximum winds, when the modelled winds show a significant drop before rejoining the measurement history. The measurements also show a drop but to a much lesser degree. The double maximum suggests that the stations "entered" the eye briefly on the western side of the hurricane and that this affect was accentuated in the simulation perhaps because the offset between the wind circulation center and the pressure center was larger in the numerical model than actually occurred. Another possibility is that the pressure field in this storm was simply more complex than could be described by three parameters.

100. The modelled wind directions agree well with measurements at Station 14 in the forward quadrant of the storm and at Station 16 in the rear quadrant of the storm; otherwise systematic departures of 20-40° are evident. The sense of the discrepancy is that there is less inflow than modelled in the forward quadrants and more inflow than modelled in the rear quadrants, over the lake. Frictional effects associated with the presence of roughness boundaries are not as likely to be the cause of systematic effects of this nature as are differences between the actual large scale pressure field in this storm and the one simply modelled.

Betsy

101. Hurricane Betsy served to test the complete history program, including the specification of surface wind fields over a rectangular high resolution grid, each hour, throughout a 24-hour history run. Input data and sample output fields are included in Appendix C.

102. As a part of the test, surface wind histories were calculated at several locations around Lake Pontchartrain. Figure 28 displays sample wind histories for Lake Pontchartrain at Lakefront (open water

roughness), Lake Pontchartrain at Lakefront (Whitaker et al. lake roughness), New Orleans Moisant Airport ($z_0 = .16$ m) and the U.S. Weather Bureau Office city office, New Orleans ($z_0 = 1$ m). No attempt is made to compare these calculated histories to measurements.

Anita

103. Hurricane Anita was one of the most intense hurricanes of historical record to cross the Gulf of Mexico. The storm formed in the east central Gulf of Mexico on August 28, 1977 and moved west-southwestward into Mexico on September 02, 1977, sparing populated areas from its fury. Anita passed about 50 n.mi. north of NOAA buoy EB04 on the 30th as a poorly organized but deepening tropical storm and about 10 n.mi. south of EB71 early on September 01. As the storm moved past EB71, it was much better organized and undergoing explosive development. The general path of the storm and the time history of central pressure are shown in Figure 29.

104. Four steady-state solutions were generated for Anita, corresponding to the storms' parameters at the times indicated in Figure 29. The radius to maximum wind in Anita contracted from 30 n.mi at the time of the first solution to 15 n.mi. at the last solution. The four solutions were used to interpolate winds in space to the buoy locations over a 48 hour period.

105. The modelled wind series at the locations of the buoys are compared to the winds measured at 20 meter height in Figures 30 and 31. At EB04, the agreement is surprisingly good considering the poorly organized nature of the storm during the period shown. Agreement is generally very good also at EB71. As suggested by the Belle test, the steady-state model provides reasonably good simulations even when applied to storms undergoing rapid changes in intensity and structure.

PART III: THE COMPUTER PROGRAM

Program Description

. The program task which produces tropical storm wind histories at specified locations is divided into two main programs. The first, SNAP, produces snapshot wind fields on a nested grid and writes them onto an output data file from which the second program, HIST, obtains nested-grid wind fields for each hour of the storm's history, using linear interpolation if necessary. HIST then gets and prints the wind history at each measurement station specified, and, if requested, writes the wind history for a different grid onto an output data file.

. The programs were written in Fortran V and were run on a UNIVAC 1108 computer. Each snapshot takes approximately 6 minutes of computer time, and execution of program HIST usually takes less than 3 minutes. Some mass storage is required, the amount varying with the number of snapshots, the number of interpolations between snapshots, the length of the history, and whether or not winds are to be interpolated to an output grid; 250,000 words is sufficient for most storms. Substitution of tapes for mass storage is possible, but efficiency would be decreased.

. Program SNAP is composed of:

MAIN

- Together with its subprograms, produces one or more snapshot wind fields on a nested grid according to card input specifications. It prints the computed winds and writes them onto an output file, and it optionally prints corresponding pressure fields and initial guess winds. MAIN itself reads all input cards, calls subroutine CCROSS which sets up tables, calls BLOWUQ which controls computation of the winds, and writes the final snapshot wind fields onto the output file.

SUBROUTINE AANGEL

- Converts grid components (UN, VN) of integrated wind to speed (VTN) and direction (ANG) for all points of the $21 \times 21 \times 5$ wind grid. In addition, if

the switch variable $I20 \neq 0$, AANGEL reduces the speed (VTN) to a height of 19.5 m; TWIST, the necessary correction to ANG, is computed by interpolating the array TURN; u_* is computed by interpolating the array UXV containing u_*/V_m ; anemometer wind is computed from u_* (called UXX in the code) by the usual logarithmic profile.

Arguments: input, typing implicit
 $I20$: Flag, if non-zero winds are reduced to 19.5 meters.

- SUBROUTINE ABCC - Computes Arya's A_m , B_m , C_m (called AM, BM, CM in the FORTRAN program) and UV, the square of the integrated wind speed, all as functions of the friction velocity u_* . This is passed in common from CCROSS at location $UX(K123)$, where $K123 = 1, 2$, or 3 at various stages of the iteration. The code is slightly more general than needed in the hurricane model, catering for unstable, neutral, and stable wind profiles (indexed by the sign of HL). In computing A_m and B_m , the ratio f_h/u_* is taken equal to unity.
- SUBROUTINE BLOWUQ - Controls computation and printing of all output on the nested grid. It is called once for each snapshot wind field.
- SUBROUTINE CCROSS - Computes the upwind and crosswind drag coefficients, the ratio u_*/V_m , and the angle between surface wind and integrated wind, for all $V_m = 0.8(0.8)80.0$. Values for intermediate V_m are linearly interpolated when required (lines 72-83 of COMQUT; lines 27-37 of AANGEL). The computation implements Arya's theory. The numerical method is an initial guess at u_* , followed by an iterative series of corrections by inverse interpolation. The iterations proper, and the computation of Arya's A_m , B_m , C_m , take place in subroutine ABCC.
- SUBROUTINE COMQUT - Solves equations which determine the final wind fields on the nested grid. For each snapshot, COMQUT is called as many times as specified in input NAME3. At each calling a grid level is specified, and computation is done on that level

and all finer-meshed levels only, so that wind computation on the innermost nest only is computed NM times.

Arguments: input, typing implicit

LEVEL: Input $1 \leq \text{LEVEL} \leq 5$.

Grid distance is doubled at each increase of LEVEL. Computation is done on all grid levels $\leq \text{LEVEL}$.

SUBROUTINE GRAD - Computes the radial and tangential gradients $\partial P / \partial r$ and $r^{-1} \partial P / \partial \theta$ of an exponential pressure field and converts them to rectangular gradients $\partial P / \partial x$ and $\partial P / \partial y$.

Mathematical Method:

1. Compute polar coordinates $(r, \cos \theta, \sin \theta)$ of the $21 \times 21 \times 5$ grid points.
2. Convert direction of track to radians.
3. Convert forward speed to meters per second.
4. Compute x- and y- components of forward speed. The method here divides into two cases: circularly symmetric pressure field ($\text{JA}(6) = 0$) and quadrantal pressure field ($\text{JA}(6) \neq 0$).

A: Circularly symmetric pressure field.

The governing equation

$$P = P_0 + \Delta P \exp(-R/r) \quad (*)$$

yields on differentiation

$$\partial P / \partial r = \Delta P R r^{-2} \exp(-R/r).$$

5. Convert R to kilometers.
6. Compute P.
7. Compute $\partial P / \partial r$, $\partial P / \partial x$, $\partial P / \partial y$.

B: Quadrantal pressure field.

ΔP , prescribed in four quadrants, is expanded as the trigonometric polynomial

$$a_0 + a_1 \cos \theta + a_2 \sin \theta + [a_3 \cos 2\theta]$$

and then smoothed by removing the

bracketed term. R is similarly expanded and smoothed. Substituting these trigonometric polynomials in (*) yields

$$P = P_0 + (a_0 + a_1 \cos \theta + a_2 \sin \theta) \exp(-[b_0 + b_1 \cos \theta + b_2 \sin \theta]/r)$$

and the radial and tangential gradients

$$\partial P / \partial r = (a_0 + a_1 \cos \theta + a_2 \sin \theta)(b_0 + b_1 \cos \theta + b_2 \sin \theta) r^{-2} \times \exp(-[b_0 + b_1 \cos \theta + b_2 \sin \theta]/r)$$

$$r^{-1} \partial P / \partial \theta = [r^{-1}(-a_1 \sin \theta + a_2 \cos \theta) + r^2(b_1 \sin \theta - b_2 \cos \theta)] \times \exp(-[b_0 + b_1 \cos \theta + b_2 \sin \theta]/r)$$

8. Convert R to kilometers in each quadrant.
9. Compute ΔP to millibars in each quadrant.
10. Compute the coefficients in trigonometric polynomials.
11. Compute $\partial P / \partial r$ and $r^{-1} \partial P / \partial \theta$.
12. Compute $\partial P / \partial x$ and $\partial P / \partial y$.

Arguments: none

Variables (not in common):

AD	$\partial P / \partial r$, $r^{-1} \partial P / \partial \theta$, $\partial P / \partial x$, $\partial P / \partial y$
AE,AF,AG,AH	Temporary storage
AP, CR, CD	Coefficients in trigonometric polynomials
AT,CT	Direction cosines of motion of storm
BA,BC	JA, floated and converted to metric units
BP	Temporary storage
DEG	Radian measure of 1 deg.

IC, ID, IE, Do-loop indexes
 IG, IH
 LU Logical unit number of
 standard print unit
 S45 Circular sine of 45°

SUBROUTINE OUTBY1 - Sets outer boundary winds for the next time level. It is called once for each cycle of wind computation and grid level if the grid level is not the outermost computed at that time.

Arguments: typing implicit

NEST: Input - grid level at which boundary to be set.

SUBROUTINE OUTBY2 - Sets outer boundary winds for the same time level. It is called once for each cycle of wind computation for the coarsest meshed grid level being computed at that time unless that grid level is the outermost in the entire grid.

Arguments: typing implicit

NEST: Input - grid level at which boundary to be set.

SUBROUTINE OUTFLO - Operates on the entire field of $21 \times 21 \times 5$ wind vectors, rotating every vector clockwise (in the northern hemisphere) by 8° . Extensive numerical experiment with earlier versions of the hurricane wind model has indicated that the finite difference scheme used leads to excessive inflow; the 8° rotation approximately removes that bias.

SUBROUTINE OUTQUT - Controls printing of winds on nested grid.

Arguments: input, typing implicit

I20: Passed on to subroutine AANGEL.

If I20 $\neq$ 0, wind speed will be adjusted to 19.5 meters.

NAME: 4-character name of storm

IDENT: 4-character identification of type of field (INIT or SNAP)

NSEQ: Snapshot sequence number.

SUBROUTINE PXYM - Receives the pressure gradients computed in GRAD, divides them by the density, and rearranges them in the order demanded by BLOWUQ. It then computes the gradient wind from the radial pres-

sure gradient to provide initial values for COMQUT.

Mathematical Method:

The gradient wind is given by Hess (1959, p. 183) as

$$C = -\frac{1}{2}fr + \left[\left(\frac{1}{2}fr \right)^2 + \rho^{-1}r \frac{\partial p}{\partial r} \right]^{\frac{1}{2}} (*)$$

For large r , $(*)$ expresses C as the difference of two nearly equal terms, and so it is advisable to compute the equivalent expression

$$C = \frac{\rho^{-1}r \frac{\partial p}{\partial r}}{\frac{1}{2}fr + \left[\left(\frac{1}{2}fr \right)^2 + \rho^{-1}r \frac{\partial p}{\partial r} \right]^{\frac{1}{2}}}$$

where f is the Coriolis acceleration and ρ is the density of the atmosphere.

1. Coriolis, computed in SNAP, is passed in C_1 . Note that the latitude is taken as a constant throughout the cyclone; this approximation is inappropriate between $\pm 5^\circ$ of latitude.
2. Divide $\partial p / \partial x$ and $\partial p / \partial y$ by ρ . 1.15×10^{-3} is the density; 1×10^{-4} is a conversion factor from mb/km to newtons/m³.
3. Compute gradient wind. BC contains r in km, and the factor 1000 converts r to meters.
4. Resolve gradient wind into x - and y - components.
5. If steering flow is used, add $(W_c \times F)$ to the vector $\rho^{-1}\Delta P$.

Arguments: none

Variables (not in common):

AG,AH,AI	Temporary storage
I	Index variable for X
J, MJ	Index variable for Y
NEST	Index variable for nest (counted from inside out)
FADE	Attenuation factor for steering flow

SUBROUTINE SHORE - Sets the land/sea table for the nested grid. It is currently set to 'sea' throughout.

SUBROUTINE TVEL - Prints the contents of arrays VTN and ANG on the grid level indicated as well as on the next coarser grid level.
Arguments: Input, typing implicit

VTN: The top number in each pair of numbers printed is taken from this array. It is printed with the decimal moved one place to the right.

ANG: The bottom number in each pair of numbers printed is taken from this array.

NBASE: 4-character heading information

IDENT: 4-character heading information

KSEQ: Header information, 4-digit integer number.

LV: Finer-meshed (lower numbered) grid level to be printed at this call to TVEL.

I20: Flag, controlling printing of the legends "reduced" and "not reduced".

Note heading:

[NBASE] [IDENT] [KSEQ] LEVEL LV+1..

. Program HIST is composed of:

MAIN

- Produces winds at specified measurement stations for each hour of a storm's history. If requested, it will also interpolate winds to a grid. After card input has been read and tables have been set up, it writes all unique nested-grid winds (i.e. all snapshots plus all interpolated fields) on a temporary file in the order needed. It next loops through the list of stations and, using the temporary file just written, finds and prints the winds for each station throughout the storm's history. Then, if requested, it interpolates winds to another grid for each hour of the storm's history, prints the winds on the grid for any hours indicated, and writes the fields onto an output file.

SUBROUTINE ABCCC - (Called by UXKV) Operates exactly the same algorithm as ABCC (called by CCROSS). The only difference in coding is that ABCCC references the common block /C57/, defined in program HIST.

SUBROUTINE BREEZE - Given LA0, L00, ROT, LA1, L01, DX, STHT, and LANSEA in common block D1, BREEZE determines the wind at point LA1, L01 at height STHT on the nested grid wind field in array XX in common block D2 and returns the wind data in W1, TH1, D, AL, and UST of common block D1.

Mathematical Method:

Let a, b, c be the sides of a spherical triangle, and α, β, γ the angles opposite; define $s = \frac{1}{2}(a + b + c)$.

Then

$$\begin{aligned} \text{hav } c &= \text{hav } (a - b) \\ &+ \sin a \sin b \text{ hav } \gamma; \end{aligned}$$

$$\tan^2 \frac{1}{2}\alpha = \frac{[\sin(s - b) \sin(s - c)]}{[\sin(s - a) \sin s]} (*)$$

1. Compute distance and bearing. If c is very small, $(s - a)$ and $(s - b)$ are nearly zero, and eq. (*) is unsuitable for computation; the bearing can then be computed without sen-

sible error by solving a plane triangle.

2. Reduce bearing to rectangular grid.
3. Reduce distance to kilometers.
4. Compute rectangular coordinates.
5. Search for the smallest rectangular grid in whose interior the point lies. If point lies without fifth nest, no wind has been computed; set wind to zero.
6. Interpolate components of wind, using bivariate linear interpolation:

$$\phi(x + f_1 \Delta x, y + f_2 \Delta y)$$

$$= (1 - f_1)(1 - f_2) \phi(x, y)$$

$$+ (1 - f_1) f_2 \phi(x, y + \Delta y)$$

$$+ f_1(1 - f_2) \phi(x + \Delta x, y)$$

$$+ f_1 f_2 \phi(x + \Delta x, y + \Delta y)$$
7. Compute wind speed and reduce to anemometer height. The factor 3600/1852 converts from m/sec to knots; the MIN function assures that the anemometer wind is never greater than the integrated wind.
8. Compute wind direction and reduce to true south.

Arguments: none

Variables: All variables except temporary storage are annotated in the program listing.

SUBROUTINE INVJD - Is the inverse of the function JULIAN. Given the Julian date, it returns the month, day, and year.

Arguments:

J: Input-Julian date, type integer

M: Output-Month, type integer

D: Output-Day, type integer

Y: Output-Year, type integer

FUNCTION JULIAN - Returns the Julian date.

Arguments:

MO: Month, type integer
DA: Day, type integer
YR: Year, type integer

SUBROUTINE PRLAKE - Is a grid-dependent subroutine and must be changed or replaced if the output grid is changed. It prints winds for each grid point, with speed on top, direction in the middle, and terrain code on the bottom.

Arguments: Input, typing implicit
NBASE: 4-character name of storm;
KHR: Integer sequence number of hour of storm;
ISTART: First hour of storm, corresponds to KHR = 1. Format is YYMMDDHH;
IZONE: 3-character time zone of ISTART;
WIND: As on output file 20;
LSTAB: Terrain code table for output grid;
MAXI: Number of longitudes in output grid;
MAXJ: Number of latitudes in output grid.

Note: The grid currently used uses unequally spaced meridians and parallels; printed map is distorted.

SUBROUTINE RDGRID - Is a grid-dependent subroutine and must be replaced or altered if the output grid is changed. Its function is to read latitude, longitude, and terrain code for each grid point and store them in arrays ZLA, ZLØ, and LSTAB respectively. It is called only if winds are to be interpolated to an output grid.

Arguments: typing implicit
ZLA: Output - latitudes in radians ordered south to north.
ZLØ: Output - west longitudes in radians, ordered west to east.
LSTAB: Output - terrain codes for all grid points; the first subscript increases eastward, the second increases northward.
MAXI: Input - number of longitudes in grid.

MAXJ : Input - number of latitudes
in grid

SUBROUTINE UPDOWN - Computes the ratio u_*/V_m and the angle between surface wind and integrated wind, all for $V_m = 0.8(0.8)80.0$, for terrains other than open ocean. The program consists of two parts: "UP" (lines 8-19) and "DOWN" (the rest of the code). UP computes U_m and V_{TOP} (components of wind at the top of the boundary layer), $VW2$ (squared wind speed at top), and $TARN$ (tan of angle between integrated wind and wind at top). The computation in UP uses quantities computed in UXXV (open ocean) and is consistent with Arya's theory. The assumption is now made that wind at the top of the boundary layer in a hurricane does not "see" the terrain below, so that the surface wind over any terrain can be computed by working UP and then DOWN. DOWN follows a logic similar to UXXV: Arya's A_0 and B_0 are constants (neutral wind profile); the roughness length is computed as

$$Z_0 = AZ/u_*^2 + BZu_* + CZ.$$

SUBROUTINE UXXV - Computes the ratio u_*/V_m , the angle between surface wind and integrated wind and the cosine and sine of this angle, all for $V_m = 0.8(0.8)80.0$. Values for intermediate V_m are linearly interpolated when required (line 73-82 of BREEZE). The computation implements Arya's theory. The numerical method is an initial guess at u_* , followed by an iterative series of corrections by inverse interpolation. The iteration proper, and the computation of Arya's A_m , B_m , C_m , take place in subroutine ABCCC. UXXV works the part of the algorithm of CCROSS (called from SNAP) pertaining to sea, i.e. $LS = 2$. The computations in UXXV are valid for open ocean only; all other terrains are treated in subroutine UPDOWN.

Remarks

. In all arrays dimensioned $21 \times 21 \times N$, where N is a multiple of 5, the 1st dimension increases eastward, the 2nd dimension increases northward, and the 3rd dimension, grid nest, increases with grid spacing. Grid spacing doubles with each increasing nest level.

. Logical unit numbers for the card reader and printer are 5 and 6, respectively, on the system under which these programs were run. These unit numbers are set by a DATA statement into variables LR and LP in programs HIST and SNAP, and the printer unit is set into LU in subroutines GRAD and TVEL.

. Equivalences between snapshot input parameters and array JA in COMMON block C2 of program SNAP:

<u>JA</u>	<u>NAME</u>	<u>TYPE</u>
1	ITRACK	I
2	EYELAT	R
3	EYLONG	R
4	DIREC	R
5	SPEED	R
6	IQUAD	I
7	EYPRES	R
8	RADIUS(1)	R
9	RADIUS(2)	R
10	RADIUS(3)	R
11	RADIUS(4)	R
12	PFAR(1)	R
13	PFAR(2)	R
14	PFAR(3)	R
15	PFAR(4)	R

Explanation of program organization charts:

Rectangular box	- program element
Cut-off corner	- punched card image
Diamond	- printer
Barrel	- mass storage
Rounded ends	- program stop

Table 2

Files

<u>Description</u>	<u>Unit Number</u>	<u>Size</u>	<u>Program SNAP</u>	<u>Program HIST</u>	<u>Save</u>
Card Reader	5		Input	Input	
Printer	6		Output	Output	
Snapshot Wind Fields on Nested Grid	13	4436 Words each Record (Snapshot)	Output	Input	✓
Ordered Unique Wind Fields on Nested Grid	10	4411 Words each Record (Wind Field)		Work	
Hourly Wind Fields on Output Grid	20	Grid-dependent, 3855 Words each Record (Hour) for Test Grid		Output	✓

Records in files 10, 13, and 20 are written with Fortran unformatted WRITE statements. There are file marks after the last data records in output files 13 and 20.

Table 3

Card InputDescription and order within programs of card input groups

<u>Program</u>	<u>Seq. Number</u>	<u>Name* (If Namelist)</u>	<u>Number/Remarks</u>	<u>Description</u>
SNAP	1	NAME1	1	Processing control
SNAP	2	NAME2	1	Parameters in roughness law (usually constant)
SNAP	3	NAME3	1 for each wind snapshot	Parameters describing wind field
HIST	1	NAME4	1	Storm identification, also grid parameters if winds are to be inter- polated to an output grid
HIST	2	NAME5	1	Terrain coefficients and number of types of terrain other than open ocean
HIST (RDGRID)	3		Only if grid conversion	Longitudes and latitudes of grid points. Card count, format and ordering of data must agree with subroutine RDGRID.
HIST (RDGRID)	4		Only if grid conversion	Code for type of terrain at each grid point. Card count, format, and ordering of data must agree with subroutine RDGRID.

* Namelist is not a construction recognized by the current FORTRAN standard (ANSI X3.9-1978).
Appendix A contains an account of Namelist as used in this program.

Table 3 (concluded)

<u>Program</u>	<u>Seq. Number</u>	<u>Name (If Namelist)</u>	<u>Number/Remarks</u>	<u>Description</u>
HIST	5(or 3)		One card for each station where wind history is needed, terminated by end-of-file	Station location and height at which measurements taken.
HIST	6(or 4)		One card for each hour of storm history, terminated by end-of-file	Location of eye of storm, snapshot identification

Table 4

Program SNAP namelist input

<u>Namelist Name</u>	<u>Variable Name</u>	<u>Size in Words</u>	<u>Units</u>	<u>Type</u>	<u>Default Value</u>	<u>Description</u>
NAME1	IB	1		I		Switch variable: 0 suppresses printing of pressures and initial winds.
	NZ	1		I		Number of snapshot wind fields to compute
NAME2	DTH	2	°K	R	0,-2.	1: Air-land temperature difference 2: Air-sea temperature difference
	HH	1	m	R	650.	Boundary layer height over water
	ZOLAND	1		R	.08	Roughness length over land
	GARR	1		R	.0144	Charnock's constant
	PTH	1	°K	R	300.	Potential temperature
	K35	1		R	.35	Karman's constant

Table 4 (continued)

<u>Namelist Name</u>	<u>Variable Name</u>	<u>Size in Words</u>	<u>Units</u>	<u>Type</u>	<u>Default Value</u>	<u>Description</u>
NAME3	SGW	1	m/sec	R		Surface geostrophic wind of ambient flow
	AN1	1	deg	R		Direction of SGW, counterclockwise from snapshot x-axis
	NAME	1		H		4-character name of storm
	EYELAT	1	deg	R		North latitude of eye of storm
	EYLONG	1	deg	R		West longitude of eye of storm; for reference only
	DIREC	1		R		Direction of track of storm, clockwise from north. See ITRACK for units.
	SPEED	1	kn	R		Forward speed of storm
	EYPRES	1	mb	R		Pressure at eye of storm
	RADIUS	4	nm	R		Exponential pressure profile scale radius in 4 quadrants. If the pressure field is circularly symmetric (IQUAD = 0) input is required for the first quadrant only
	PFR	4	mb	R		Far field pressure in 4 quadrants. If the pressure field is circularly symmetric (IQUAD = 0) input is required for first quadrant only.
	NM	1		I	800	Number of times to cycle wind computation in innermost grid nest
	DX	1	km	R	5.	Grid spacing of innermost nest
	ST12	1	km	R	0.	Distance from axis to $\frac{1}{2}$ magnitude of SGW

(continued)

Table 4 (concluded)

<u>Namelist Name</u>	<u>Variable Name</u>	<u>Size in Words</u>	<u>Units</u>	<u>Type</u>	<u>Default Value</u>	<u>Description</u>
NAME3	ITRACK	1		I	0	If 0, DIREC in degrees; if 1, DIREC in points of 11.25 degrees
	IQUAD	1		I	0	Indicator for quadrants of pressure field: 0, circularly symmetric pressure field; 1, 1st quadrant is right front; 2, 1st quadrant is forward

Table 5

Program HIST Namelist Input

<u>Namelist Name</u>	<u>Variable Name</u>	<u>Size in Words</u>	<u>Type</u>	<u>Description</u>
NAME4	NBASE	1	H	4-character name of storm - must be same as 1st SNAP namelist NAME3, item NAME
	ISTART	1	I	Starting time of storm, format YYMMDDHH
	IZONE	1	H	3-character time zone of ISTART
	ICNVRT	1	I	Flag: if non-zero, winds will be interpolated to an output grid, and grid data must be input
	NPRT	1	I	Interval in hours at which to print winds on output grid. If zero, winds will be printed only for hours so flagged in the history table
NAME5	LAKE	1	I	Number of types of terrain in addition to open ocean. $0 \leq \text{LAKE} \leq 5$
	ZCOEFF	15	R	3 coefficients in formula relating Z_o to U^* for all terrains except open ocean. Dimensioned (3,5).

Table 6
Program HIST Fixed Format Card Input

- 1) Station location and data: One card for each measurement station, format (5I4,F6.1,1X,I3)
 1. Degrees of north latitude
 2. Minutes of latitude
 3. Degrees of west longitude
 4. Minutes of longitude
 5. Terrain code, same codes as grid terrain code table
 6. Station height in meters
 7. Station number (for identification only)

- 2) History: One card for each hour, format (6I4,F8.4,2I4)
 1. Degrees of north latitude of eye of storm
 2. Minutes of latitude of eye
 3. Degrees of west longitude of eye
 4. Minutes of longitude of eye
 5. Sequence number of 1st snapshot wind field to be used for this hour
 6. Sequence number of 2nd snapshot wind field to be used for this hour (blank if no interpolation this hour)
 7. Interpolation distance between 1st and 2nd snapshots (blank if (6) is blank)
 8. Clockwise rotation of snapshot in degrees
 9. Flag: non-zero if output grid wind field is to be printed

Table 7

Input Cards with Data Defining Program HIST Test Output Grid

- 1) 5 cards with 62 west longitudes in the form DDMM and progressing from west to east. Each card, except the last has 15 longitudes and a sequence number in format 16I5. The last card is blank filled between the last data field and the sequence number.
- 2) 3 cards with 31 latitudes progressing from south to north. Form and format are the same as those of the longitude cards.
- 3) 31 cards of terrain code. Each card is for one latitude, and cards are ordered from south to north. The format is 2I3, for degrees and minutes of latitude, then 2X,62I1, where the 62I1's are one-digit numeric terrain codes for each longitude and progress from west to east. As used in the test grid for Lake Pontchartrain, the codes are as follows -
 - 1: open ocean
 - 2 lake
 - 3: marsh
 - 4: plains
 - 5: woods
 - 6: cities

Table 8

COMMON BlocksProgram SNAP

<u>Block Name</u>	<u>Variable Name</u>	<u>Size in Words</u>	<u>Units</u>	<u>Source</u>	<u>Disposition</u>	<u>Description</u>
C1	NAME	1		Input NAME3	Snapshot wind data file	4-character name of storm
	NSNAP	1				Sequence number of wind snapshot
	DX	1	km	Input NAME3	Snapshot wind data file	Grid spacing of innermost nest
	DT	1	sec			Time increment for computation of winds in innermost nest
	F	1				Coriolis force
	SGW	1	m/sec	Input NAME3	Snapshot wind data file	Surface geostrophic wind of ambient flow
	AN1	1	deg	Input NAME3	Snapshot wind data file	Direction of SGW counterclockwise from snapshot x-axis
	UC	1	m/sec			X-component of velocity of storm movement
	VC	1	m/sec			Y-component of velocity of storm movement
	UG	1	m/sec			X-component of surface geostrophic wind
	VG	1	m/sec			Y-component of surface geostrophic wind
	CS	1	m/sec			Speed of storm movement
	NM	1		Input NAME3		Number of times to cycle wind computation in innermost grid nest
	IB	1		Input NAME1		Flag: if zero, do not print pressure field or initial wind

Table 8 (continued)

Block Name	Variable Name	Size in Words	Units	Source	Disposition	Description
[C1]	ST12	1	km	Input NAME3	Snapshot wind data file	Distance from axis to $\frac{1}{2}$ magnitude of SGW
C2	JA	15		Input NAME3	Snapshot wind data file	See program SNAP output data file record description, page . Also note equivalence list in remarks, page .
	AB	6615				Work array, 1st third, $\partial\rho/\partial x$; 2nd third, $\partial\rho/\partial y$; last third, $\partial\rho/\partial r$
	AC	3087				Dimensioned $21 \times 7 \times 21$. Location in grid defined by 1st and 3rd subscripts. If 2nd subscript, N, is 1, value is cosine of angle of grid point; if 2, value is sine of angle of grid point; if 3-7, value is radius in meters of point in nest N-2.
C3	U	2205	m/sec			Work array, x-component of boundary layer wind at previous time level
	V	2205	m/sec			Work array, y-component of boundary layer wind at previous time level
	UN	2205	m/sec		Snapshot wind data file	X-component of boundary layer wind
	VN	2205	m/sec		Snapshot wind data file	Y-component of boundary layer wind
	PX	2205				Work array, $\partial\rho/\partial x$
	PY	2205				Work array, $\partial\rho/\partial y$
	VTN	2205	kn			Work array, holds wind speeds to be printed
	ANG	2205	deg			Work array, holds wind directions to be printed

(Continued)

Table 8 (continued)

Block Name	Variable Name	Size in Words	Units	Source	Disposition	Description
[C3] C4	LW	2205				Land/sea table: 1 for land, 2 for sea
	CDR	400				Work array, dimensioned 100 x 2 x 2. Drag coefficients: CDR(I,1,1) is upwind component of drag coefficients over land, when integrated wind speed is (.8*I) m/sec. CDR(I,2,1) is crosswind component over land CDR(I,1,2) is upwind component over ocean CDR(I,2,2) is crosswind component over ocean
	UXV	200				Work array, dimensioned 100 x 2. UXV(I,1) is $\frac{U_*}{V_m}$ over land, when
	TURN	200	rad			$V_m = (.8*I)$ m/sec UXV(I,2) is the same over ocean Work array, dimensioned 100 x 2. TURN(I,1) is the angle between surface wind and integrated wind, over land, when integrated wind speed is (.8*I) m/sec. TURN(I,2) is the same over ocean
C5	FLAT	1				Coriolis force
	PTH	1	°K	Input NAME2	Snapshot wind data file	Potential temperature
	DTH	2	°K	Input NAME2	Snapshot wind data file	(1) Air-land temperature difference (2) Air-sea temperature difference

(continued)

Table 8 (continued)

Block Name	Variable Name	Size in Words	Units	Source	Disposition	Description
[C5]	HH	1	m	Input NAME2	Snapshot wind data file	Boundary layer height over water
	ZOLAND	1		Input NAME2		Roughness length over land
	LS					Index variable
	VV	100	m/sec			Vertically integrated wind speeds. VV(I) at point I = .8m/sec $\times$ I
	UX	3	m/sec			Latest 3 values of U* in an iterative loop
	UV	3	$\frac{m^2}{sec^2}$			Latest 3 values of integrated wind speed corresponding to U*
	DUV	3	$\frac{m^2}{sec^2}$			Interpolated value of wind speed squared minus desired value squared
	K35	1		Input NAME2	Snapshot wind data file	Karman's constant, type real
	K2	1				$K35^2$, type real
	G	1				Acceleration of gravity = 9.806 m/sec ²
	GA	1	$\frac{sec^2}{m}$			Charnock's constant divided by G
	DEN	1				Used in stability length computation
	VV2	1	$\frac{m^2}{sec^2}$			VV(I) ² for current I
	HL	1				HH/stability length
	K123	1				Index variable
	Z0	1	m			Roughness length
						(continued)

Table 8 (continued)

Block Name	Variable Name	Size in Words	Units	Source	Disposition	Description
[C5]	ZLOG	1				Log (ZO/HH)
	AM	1				Constant in Arya's logarithmic scale law
	BM	1				Constant in Arya's logarithmic scale law
	CM	1				Constant in Arya's logarithmic scale law
	FF	1	sec ⁻¹			Coriolis parameter. Retained for consistency with other versions of CCROSS; not used in this program.
<u>Program HIST</u>						
C57	PTH	1	°K	Snapshot wind data file		Potential temperature
	DTH	1	°K	Snapshot wind data file		Air-sea temperature difference
	HH	1	m	Snapshot wind data file		Boundary layer height over water
	ZCOEFF	15		Input NAMES		3 coefficients in formula relating Z_0 to U_* for all terrains except open ocean, where Garratt's formula is used
	LAKE	1		Input NAMES		Number of terrains other than open ocean. Integer, 0-5
	VV	100	m/sec			Vertically integrated wind speeds at point I: $(VV(I) = I \times .8 \text{ meters/sec})$
	UX	3	m/sec			Latest 3 values of U_* in an iterative loop

(continued)

Table 8 (continued)

Block Name	Variable Name	Size in Words	Units	Source	Disposition	Description
[C57]	UV	3	m ² /sec ²			Latest 3 values of square of integrated wind speed corresponding to U*
	DUV	3	m ² /sec ²			Difference between squares of interpolated value of wind speed and desired value
	K35			Snapshot wind data file		Karman's constant, type real
	K2					K35 ² , type real
	G	1	m/sec ²			Acceleration of gravity: 9.806 constant
	GA	1	sec ² /m			Charnock's constant divided by G
	DEN		mKsec ⁻²			Temporary variable used in stability length computation
	VV2		m ² /sec ²			VV(I) ² for current I
	HL					HH/stability length
	K123					Index variable
	Z0		m			Roughness length
	ZLOG					LOG(Z0/HH)
	AM					Correction terms in Arya's logarithmic scaling law
	BM					Correction terms in Arya's logarithmic scaling law
	CM					Correction terms in Arya's logarithmic scaling law
	UXV	600				U*/VV for each I, terrain type

(continued)

Table 8 (continued)

Block Name	Variable Name	Size in Words	Units	Source	Disposition	Description
[C57]	TURN	600	rad			Turning angle between surface wind and integrated wind for each I, terrain type
	COST	100				Cosine of TURN for current terrain
	SINT	100				Sine of TURN for current terrain
	LA0	1	rad			Latitude of storm eye at current hour, type real
	LO0	1	rad			West longitude of storm eye at current hour, type real
	ROT	1	deg			Clockwise angle to rotate snapshot wind field
	LA1	1	rad			Latitude of 1 point at which wind is wanted, type real
	LO1	1	rad			West longitude of point of which wind is wanted, type real
	DX	1	km	Snapshot wind data file		Grid spacing of innermost nest
	STHT	1	m			Height of measurement at current location
	LANSEA	1				Indicated sea or type of terrain for current location
	W1	1	kn			Wind speed at current location
	TH1	1	deg			Meteorological wind direction
	D	1	km			Distance between locations LA0, LO0 and LA1, LO1

(continued)

Table 8 (concluded)

Block Name	Variable Name	Size in Words	Units	Source	Disposition	Description
[D1]	AL	1	deg			Bearing of point LA1,LO1, from point LA0,LO0, clockwise from north
	UST	1	m/sec			Friction velocity at current location
D2	XX	4410		Snapshot wind data file		Winds on nested grid at current hour
D3	NSNAP1	100				1st wind snapshot sequence number
	NSNAP2	100				2nd wind snapshot sequence number (0 if none)
	PCT	100				Interpolation distance between snapshots NSNAP1 and NSNAP2
	IPI	100				Flag: non-zero if listing of winds on output wanted
	NHT	1				Number of hours in storm history
	INTVN	1				Not used
	INTVI	1	hours			Interval at which to print winds on output grid
LGRID*	ILAT	31				List of output grid latitudes, south to north, in the format DDMM
	ILONG	62				List of output grid west longitudes, west to east, in the format DDMM

*Not in main program, in subroutines RDGRID and PRLAKE only.

Table 9

Description of Program HIST arrays not in COMMON

Station data arrays - all dimensioned 100

MAD	Location, from card input - degrees of north latitude
MAM	Location, from card input - minutes of latitude
MMOD	Location, from card input - degrees of west longitude
MOM	Location, from card input - minutes of longitude
LLAKE	Terrain code, from card input
STAHT	Height in meters, from card input
KSTA	Station number (identification), from card input
YLA	Latitude in radians
YLO	Longitude in radians

History table arrays - all dimensioned 100

NAD	Location of eye of storm, from card input - degrees of north latitude
NAM	Location of eye of storm, from card input - minutes of latitude
NOD	Location of eye of storm, from card input - degrees of west longitude
NOM	Location of eye of storm, from card input - minutes of longitude
IROT	Grid rotation angles, from card input
KDATE	Date in form YYMMDD
KTIME	Hour of KDATE
JSEQ	Sequence numbers of nested grid winds on work file

Output grid data arrays as used with test grid

ZLA	List of latitudes of grid points, south to north, in radians
ZLO	List of west longitudes of grid points, west to east, in radians

Table 9 (concluded)

ZANG	Deviation between true north and grid north for each grid point - zero throughout test grid
LSTAB	List of terrain codes of grid points.

Other arrays

XY	Dimensioned $21 \times 21 \times 10$. Contains 2nd snapshot wind field when needed
----	---

Table 10

Program Stops

<u>Program</u>	<u>Stop Number</u>	<u>Interpretation</u>
SNAP	999*	Normal completion of run
HIST	999*	Normal completion of run
HIST	5	Error in reading station or history input card
HIST	146	Error in reading mass storage work file of wind fields on nested grid
HIST	444	Snapshot interpolation distance out of range (< 0 or > 1).
HIST	515	Input card and snapshot data file storm identifications are different
HIST	516	Too many station input cards (> 100)
HIST	517	Too many history input cards (> 100)
HIST (RDGRID)	21	Error in reading grid longitude card
HIST (RDGRID)	23	Error in reading grid latitude card
HIST (RDGRID)	51	Error in reading grid terrain code card

* If running a FORTRAN that requires STOP number to be octal, substitute 777.

Table 11

Output Data File Record DescriptionSnapshot wind field record from program SNAP

<u>Variable Name</u>	<u>(Dimension)</u>	<u>Size</u>	<u>Accumulated Word Count</u>	<u>Units</u>	<u>Applicable Format*</u>	<u>Description</u>
UN	(21,21,5)	2205	2205	m/sec	F4.1	X-component of boundary layer wind 1st dimension increases with increasing x 2nd dimension increases with increasing y
VN	(21,21,5)	2205	4410	m/sec	F4.1	Y-component of boundary layer wind 3rd dimension (grid nest) increases with grid spacing
NAME		1	4411		A4	4-character name of storm
DX		1	4412	km	F3.0	Grid spacing of innermost nest
JA	(15)	15	4427		I1	1: Indicator for coding of (4) If 0, (4) in degrees; if 1, (4) in points of 11.25 degrees. 2: North latitude of eye of storm 3: West longitude of eye of storm 4: Direction of track of storm, clockwise from north 5: Forward speed of storm 6: Indicator for quadrants of pressure field

* Format appropriate for printing this variable or array.

Table 11 (continued)

Variable Name	(Dimension)	Size	Accumulated Word Count	Units	Applicable Format	Description
[JA]						
						0 - circularly symmetric pressure field 1 - 1st quadrant is right front 2 - 1st quadrant is forward
				mb	F6.1	7: Pressure at eye of storm
				nm	F4.0	8-11: Exponential pressure profile scale radius in four quadrants. If JA(6) is zero, JA(9) - JA(11) may not contain valid data
				mb	F5.0	12-15: Far field pressure in four quadrants. If JA(6) is zero, JA(13) - JA(15) may not contain valid data
SGW	1	4428		m/sec	F3.0	Surface geostrophic wind of ambient flow
AN1	1	4429		deg	F4.0	Direction of SGW counterclockwise from snapshot x-axis
ST12	1	4430		km	F5.1	Distance from axis to $\frac{1}{2}$ magnitude of SGW
DTH	2	4432		°K		(1) Air-land temperature difference (2) Air-sea temperature difference
HH	1	4433		m		Boundary layer height over water
GARR	1	4434				Charnock's constant
PTH	1	4435		°K		Potential temperature
K35	1	4436				Karman's constant, type real
(continued)						

Table 11 (concluded)

Test output grid wind field record from program HIST

Variable Name	(Dimension)	Size	Accumulated Word Count	Units	Applicable Format	Description
NBASE		1	1		A4	4-character name of storm
KHR		1	2		I3	Sequence number of hour of storm
ISTART		1	3		I8	Starting time of storm in format YYMMDDHH (Time at which KHR=1)
IZONE		1	4		A3	Time zone of ISTART
IMAX		1	5		I2	Longitudinal dimension of output grid
JMAX		1	6		I2	Latitudinal dimension of output grid
GRIDHT		1	7	m	F6.1	Height to which wind speeds are scaled
NAD		1	8		I3	Location of eye of storm - degrees of north latitude
NAM		1	9		I2	Location of eye of storm - minutes of latitude
NOD		1	10		I4	Location of eye of storm - degrees of west longitude
NOM		1	11		I2	Location of eye of storm - minutes of longitude
WIND	(2, MAX1, MAXJ) (3844 for test grid)		11+2*MAXI*MAXJ (3855 for test grid)			Wind at specified height on wave grid. If 1st subscript is 1, value is wind speed in knots. If 1st subscript is 2, value is direction in degrees toward which wind blows counterclockwise from north

Printed Output

. Program SNAP initially prints card input data and finally prints an end-of-job message. For each snapshot it prints card input data pertinent to that snapshot, a pressure field and an initial guess wind field if requested, and a final snapshot wind field on the nested grid. Snapshot wind speeds are printed in tenths of knots, directions are meteorological, and west is at the top of the page. Each snapshot is printed both with wind speeds as computed and with wind speeds scaled to 19.5 meters.

. Program HIST prints card input data, the wind history at each requested station, wind fields on the output grid for hours requested, and an end-of-job message. Output grid wind speeds are in knots and directions are meteorological. Terrain types are indicated by blank for type 1, '#' for 2, '=' for 3, '-' for 4, '+' for 5 and '\$' for 6.

Table 12

Program Changes Needed for a New Output Grid

- 1) Subroutine RDGRID
- 2) Subroutine PRLAKE
- 3) COMMON block LGRID (used in RDGRID and PRLAKE only)
- 4) In program Hist:
 - a) Parameters MAXI, MAXJ, and IGRDHT, where MAXI is the longitudinal dimension of the grid, MAXJ is the latitudinal dimension, and IGRDHT is its height in tenths of meters.
 - b) ZLA, ZLO become two-dimensional if rows and columns do not fall on latitude, longitude lines, and the settings of LA1 and LO1 in the DO 111 and DO 110 loops will be affected
 - c) Array ZANG, the angle between true meridian and grid meridian, may become non-zero.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

. A method is developed to specify the surface stress and the wind speed and direction in the planetary boundary layer of a tropical cyclone from meteorological storm parameters available for historical hurricanes. The method is based upon a numerical primitive-equation model of the planetary boundary layer in a moving tropical cyclone. The complete time history of the evolution of the surface wind field is described from a series of characteristic wind field states calculated at discrete times in a storm's history by the steady-state model.

. A surface drag formulation, based upon a contemporary similarity model (Arya, 1977) coupled with a roughness parameter specification for a water surface consistent with Cardone's (1969) law, is incorporated into the numerical model. As a result, the model was found to produce a consistent description of the integrated planetary boundary layer wind, the magnitude and direction of the surface stress, and the wind speed and direction at anemometer level, without recourse to arbitrary, empirical calibration schemes. The surface winds calculated in several recent hurricanes are found to be in excellent agreement with available, representative surface wind measurements made from offshore platforms and data buoys.

. Transformations based upon an equilibrium planetary-boundary-layer similarity model are developed to specify the surface wind over terrain of specified roughness, including lake surfaces, from the over-water wind-field solution. Calculated over-land and over-lake winds are compared to the limited measurements available for several recent storms. Agreement is generally good.

. The principal limitation of the model is the neglect of fetch effects in the adjustment of the PBL across roughness discontinuities. Adjustments in near-surface wind speed, however, are believed to occur sufficiently rapidly that accuracy over homogeneous terrain and lakes the size of Pontchartrain and Okeechobee should not be significantly limited. The adjustment scale for wind direction, however, might be much larger.

. The principal obstacle to further development and evaluation of the method developed here is the lack of high-quality measurements of surface winds over the lakes of interest in well documented storms. As part of an intensive field program conducted in Lake Pontchartrain by the U.S. Army Corps of Engineers during the past year, wind data was apparently collected at several points in the lake during the passage of two hurricanes (Bob and Frederick, 1979). Even though only the peripheral parts of those storms were sampled, it is strongly recommended that those measurements be carefully processed and that the method developed in this study be applied to those storms.

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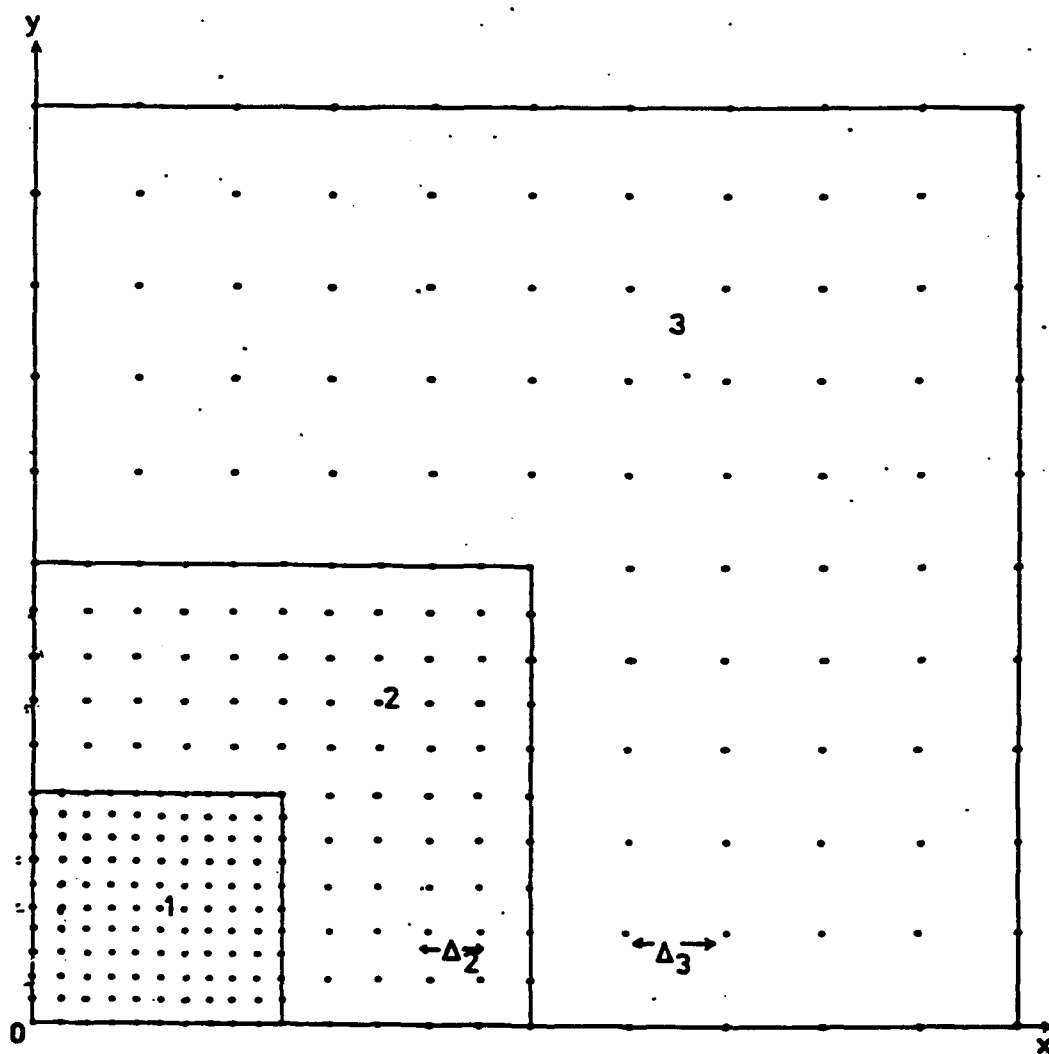


Figure 1. Grid points of the inner three grids in one quadrant of the nested grid system. The center of the grid system is indicated by 0 (from Chow 1971)

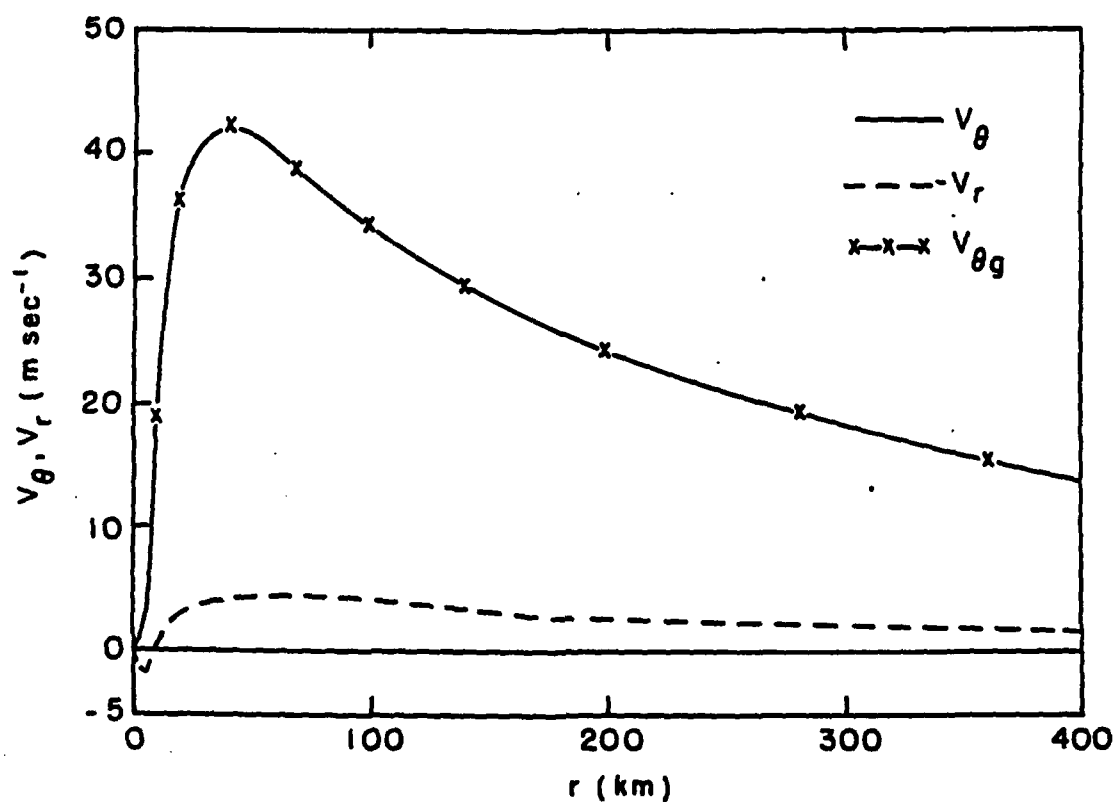


Figure 2. Radial distribution of tangential velocity (V_θ) and radial velocity (V_r) for a frictionless, symmetrical, stationary storm given by $\Delta p = 50$ mb and $R = 40$ km, computed from Chow's numerical model. Analytical (gradient wind solution) solution ($V_{\theta g}$) for specified pressure field is shown (from Chow 1971)

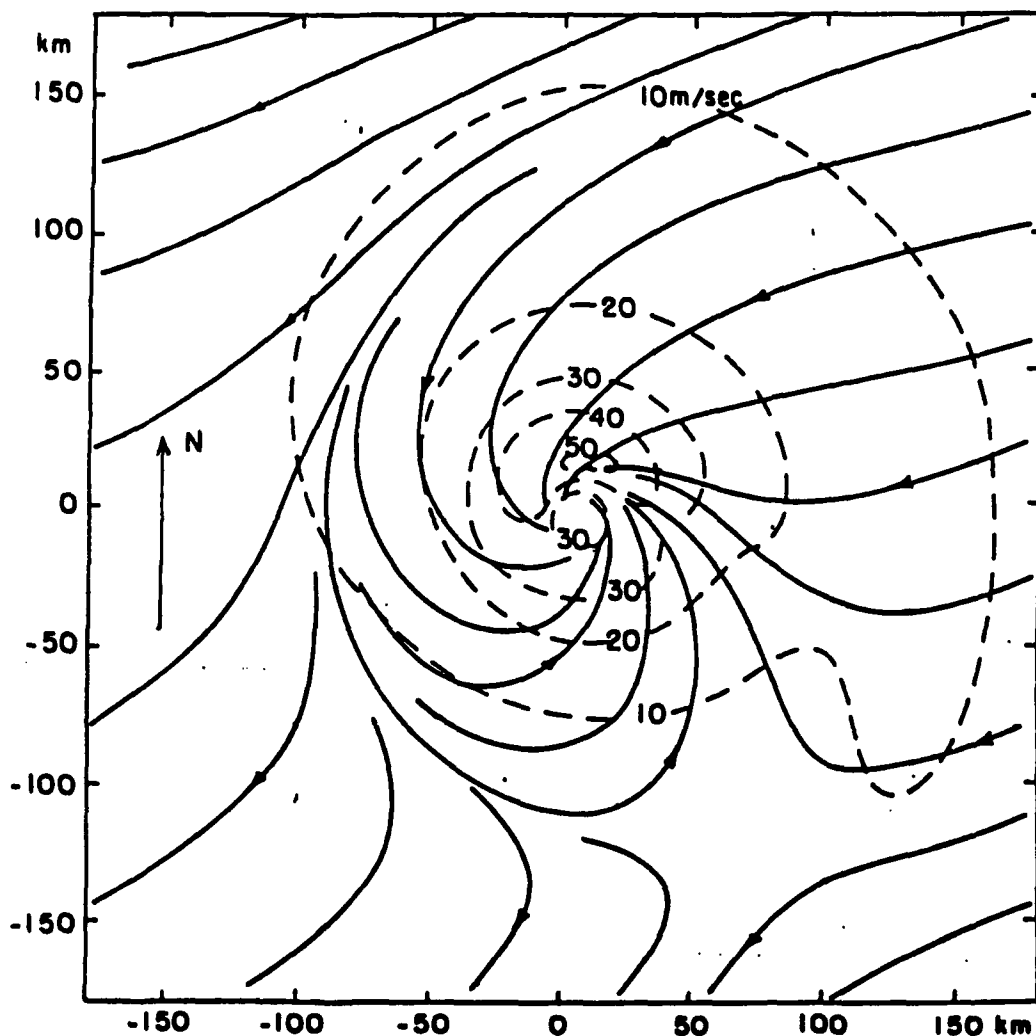


Figure 3. Streamlines (solid lines) and isotachs (dashed lines) of the steady-state solution for the vertically integrated boundary layer wind in a mature tropical cyclone moving westward at 10 m/sec, in a westerly steering flow (10 m/sec), from the model of Chow (1971)

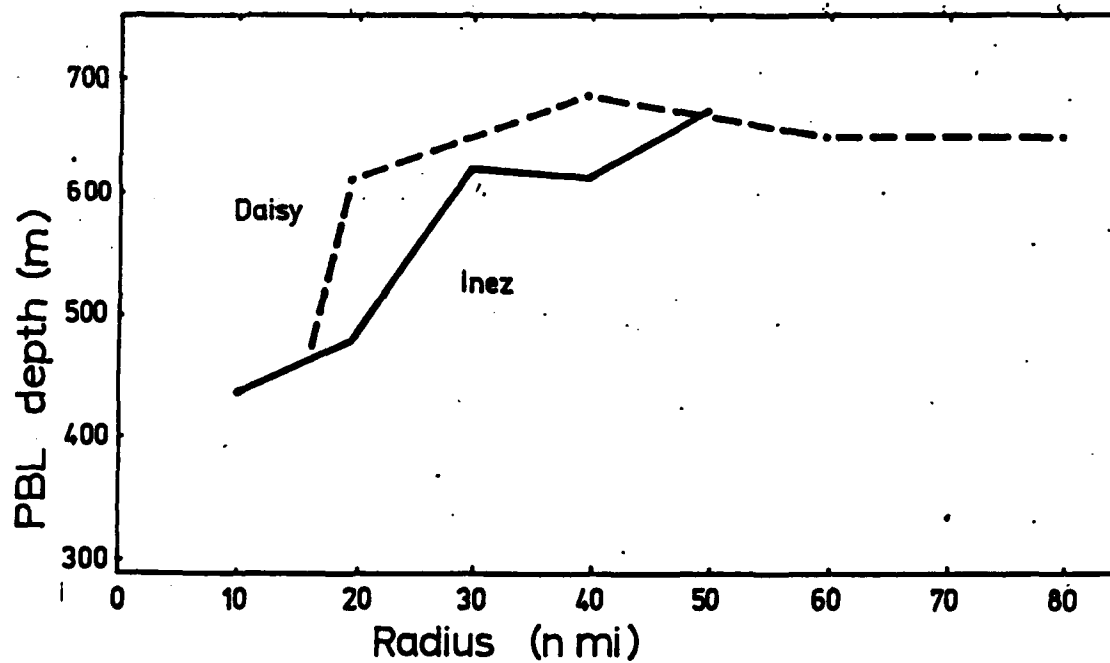


Figure 4. Computed depth of the planetary boundary layer versus radial distance from the eye for Hurricanes Daisy (1958) and Inez (1966) (from Moss and Rosenthal 1975)

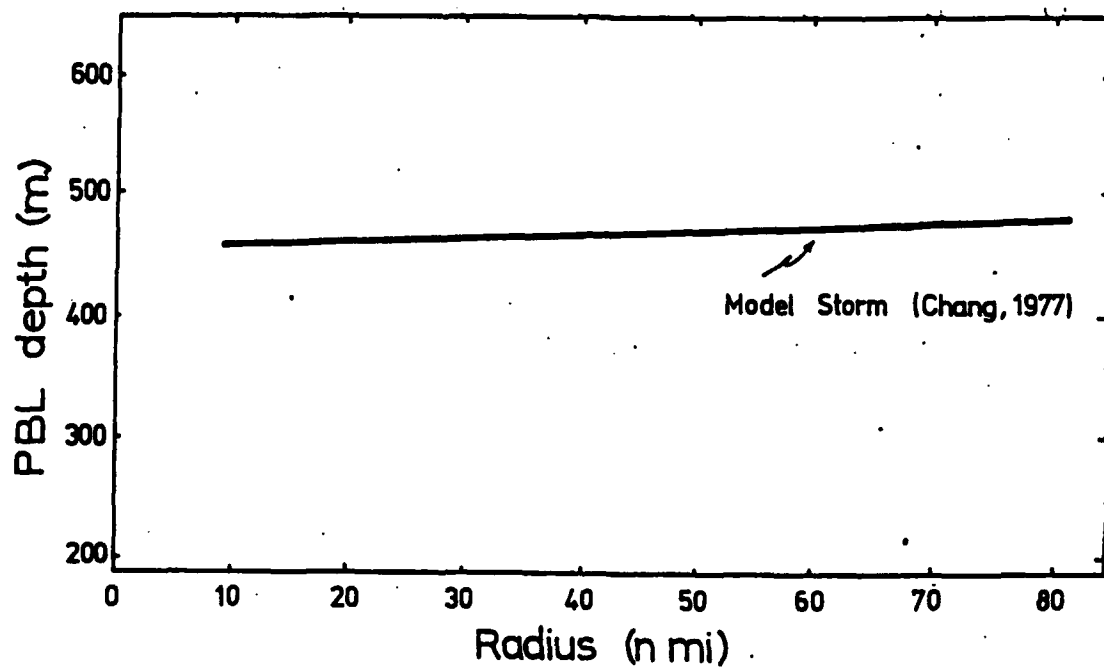


Figure 5. Computed depth of the planetary boundary layer in a mature, steady-state tropical cyclone (from Chang 1977)

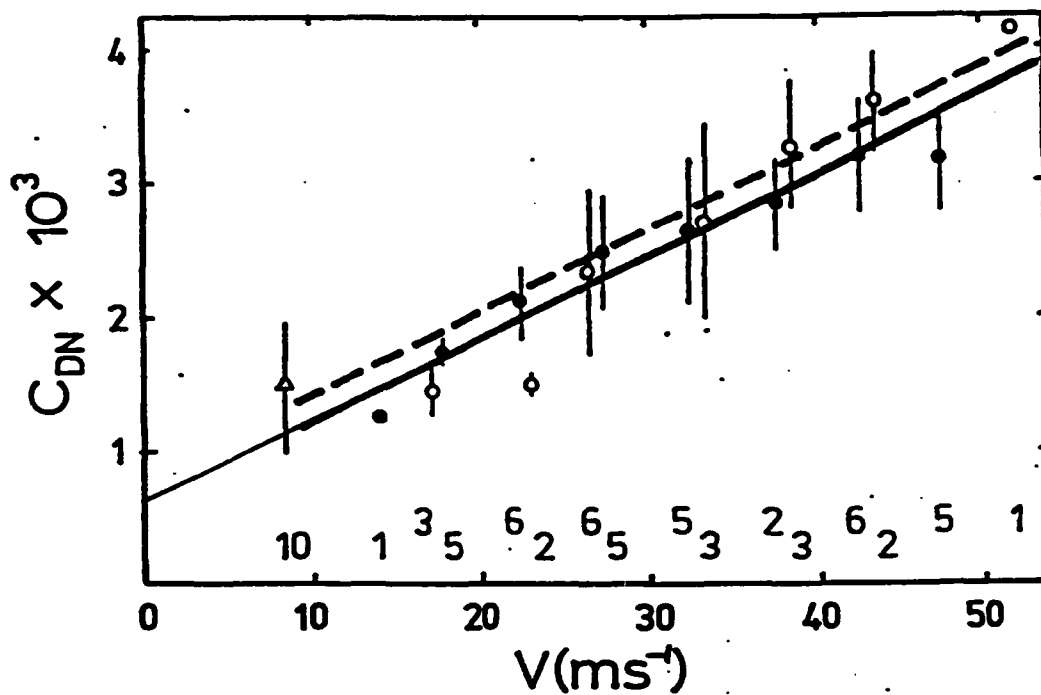


Figure 6. Garratt's (1977) collection of mean values of the drag coefficient as a function of wind speed at the 10-m height for 5-m/sec intervals, based on individual data from hurricane studies ($\circ$), wind flume experiments ($\bullet$), and vorticity/mass budget analysis (Δ). Vertical bars refer to the standard deviation of individual data for each mean, with the number of data used in each mean shown below each mean value immediately above the abscissa scale. The dashed curve represents the variation of the 10-m neutral drag coefficient C_{DN} with wind speed based on

$$z_0 = a \frac{u_*^2}{g}$$

with $a = 0.0144$ and a value of the barrier constant k of 0.41. The solid curve represents the variation with $a = 0.035$ and $k = 0.35$

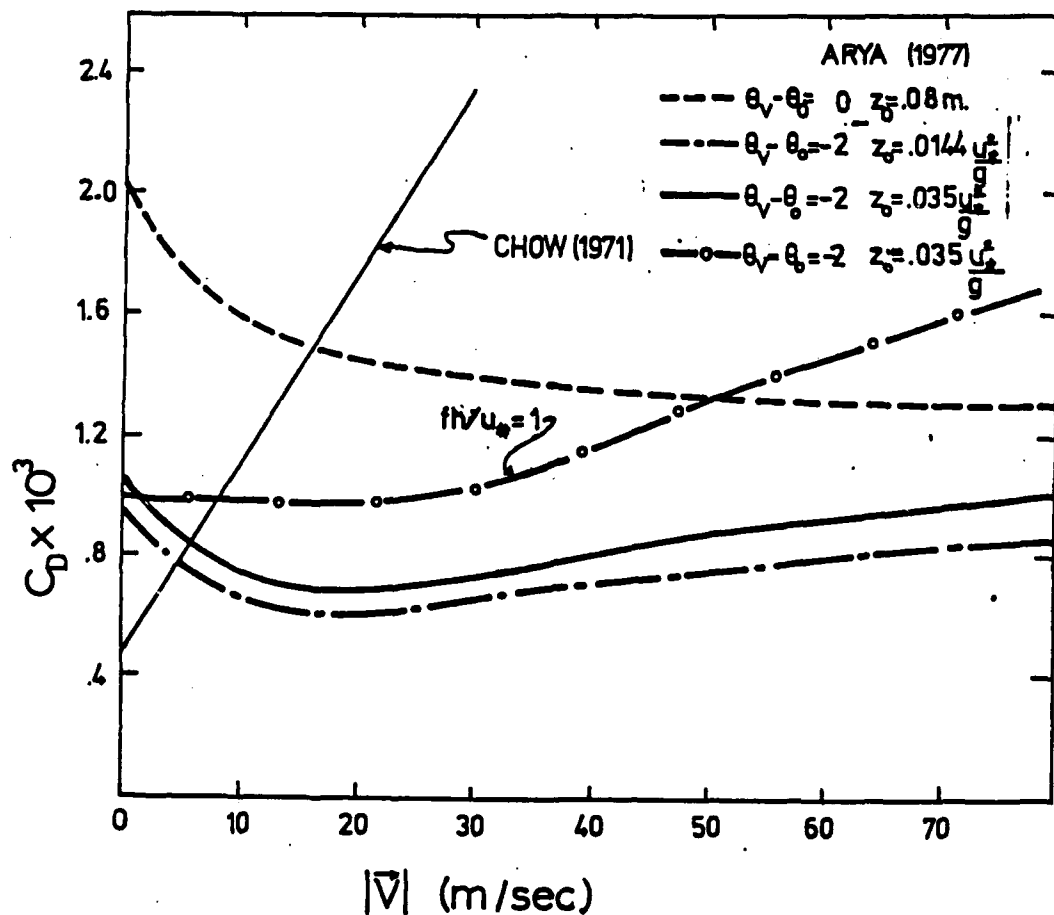


Figure 7. Drag coefficient with respect to the vertically integrated planetary boundary layer wind versus integrated boundary layer wind from Arya's model for alternate air-sea temperature and roughness parameter specifications and/or the case of restricted scale/height ratio. The form used by Chow (1971) is shown for comparison

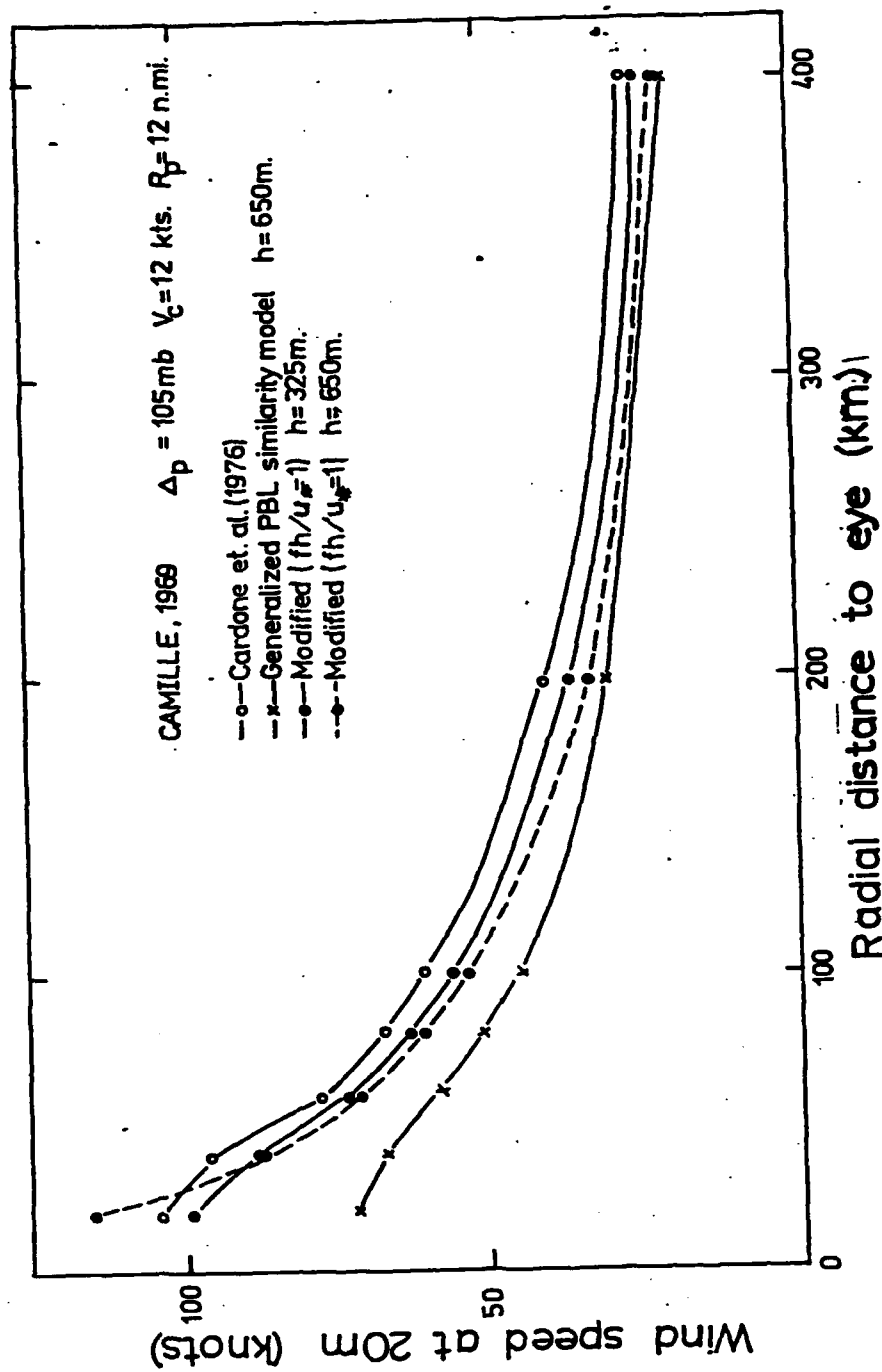


Figure 8. Predictions of 20-m wind speed versus radial distance to eye in Camille from the model of Cardone et al. (1976) and from the model with revised PBL stress law

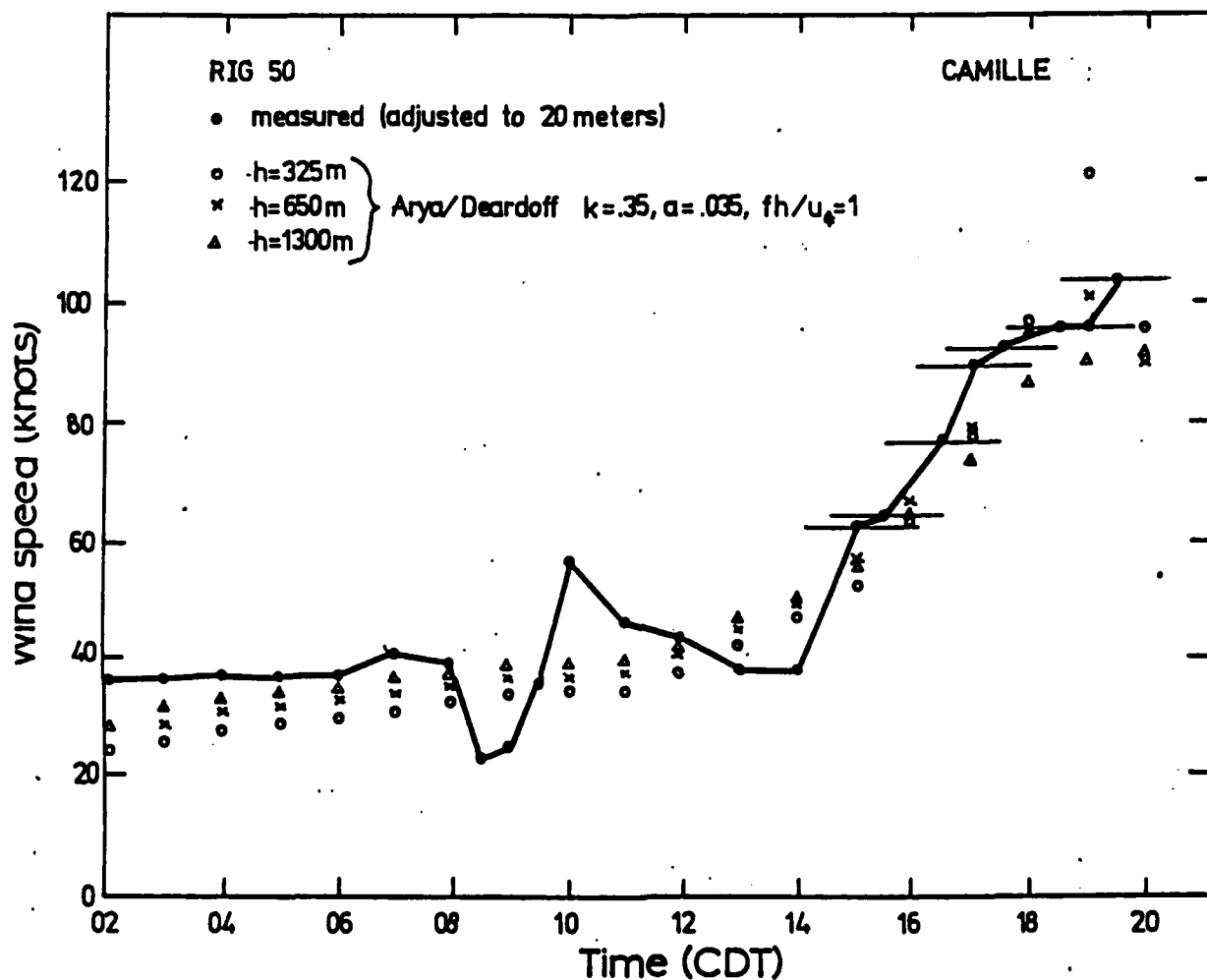


Figure 9. Comparison of modelled and measured surface wind speed at Rig 50 in Camille for vortex model with modified similarity model drag law and alternate boundary layer heights

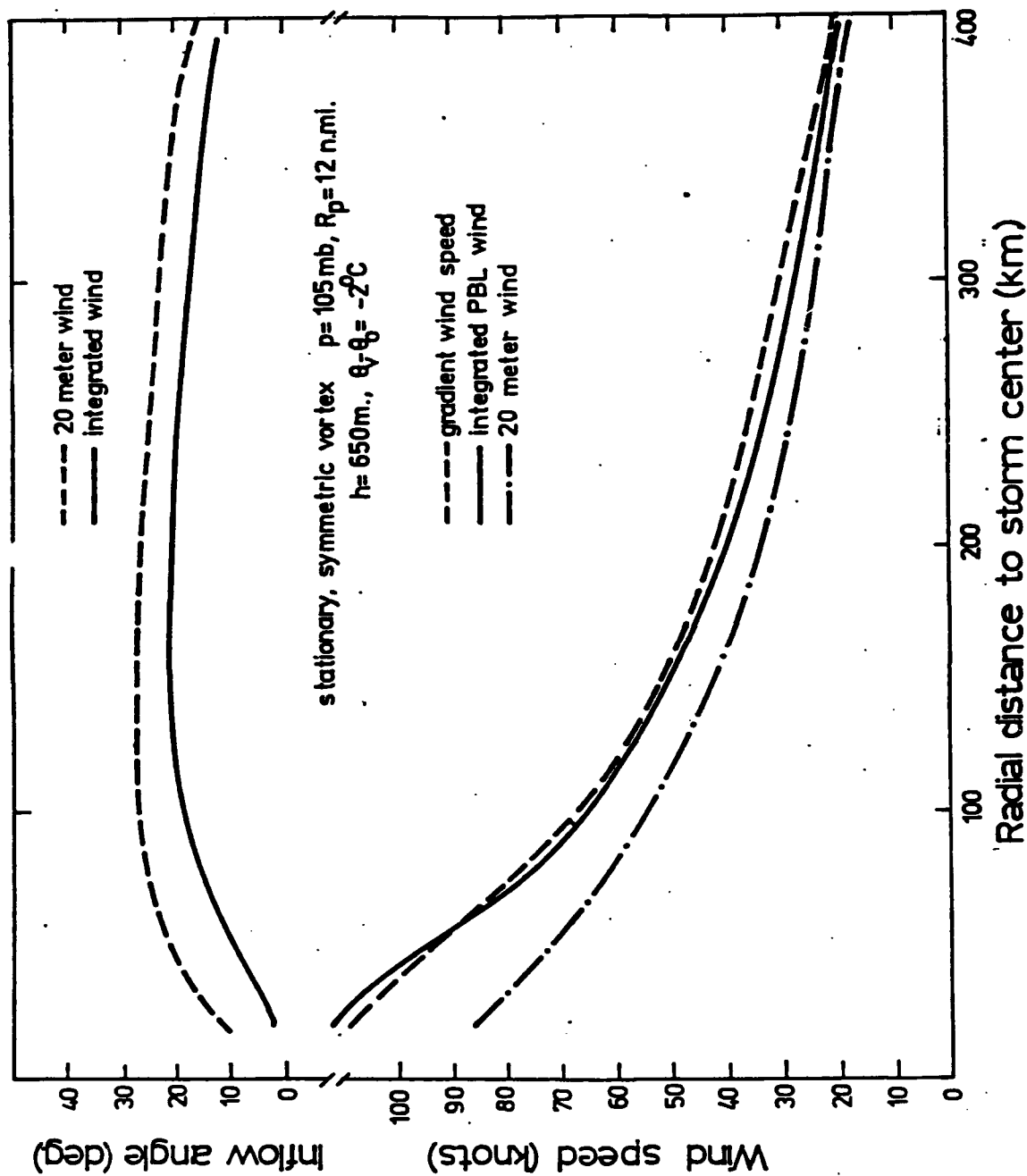


Figure 10. Radial profile of gradient wind speed, integrated PBL wind speed, 20-m wind speed, inflow angle of integrated and surface wind for a severe, stationary, symmetric hurricane

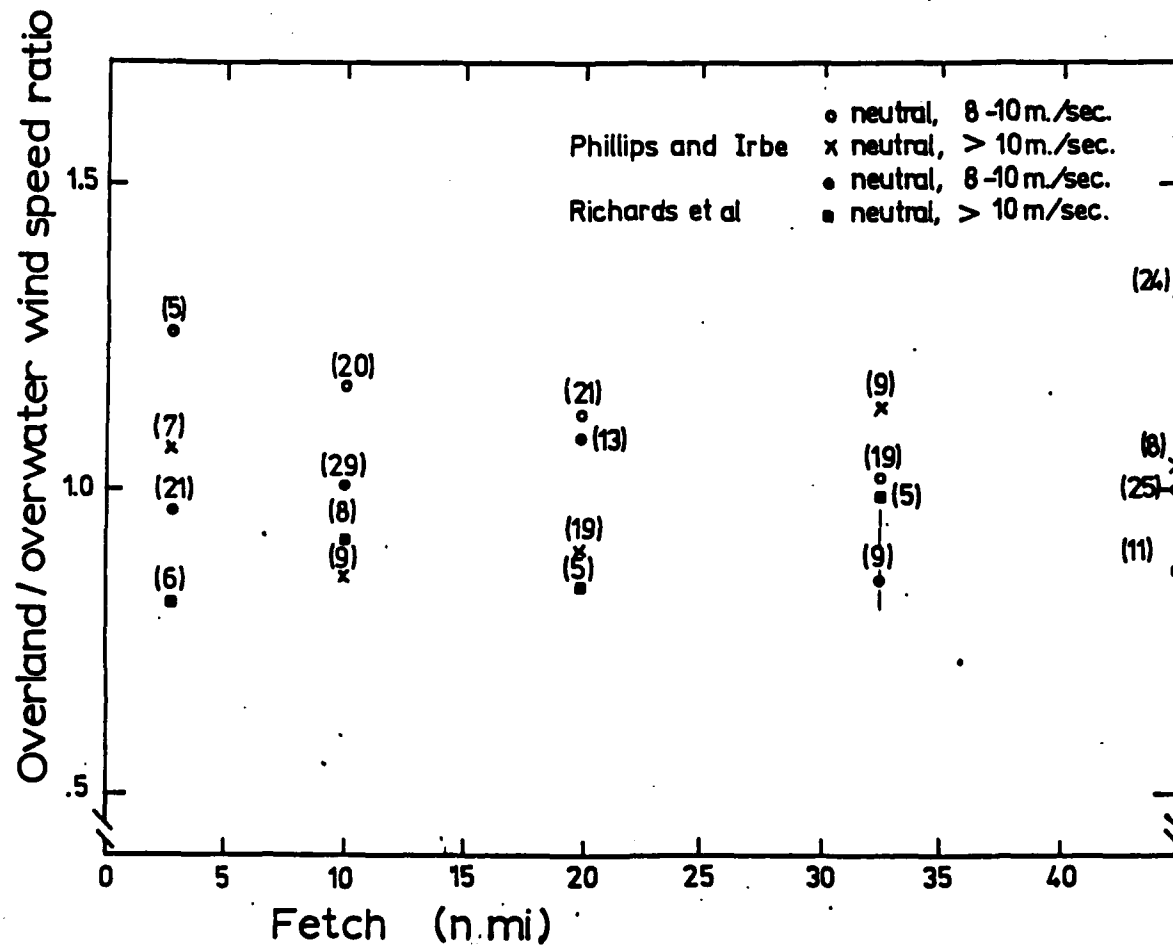
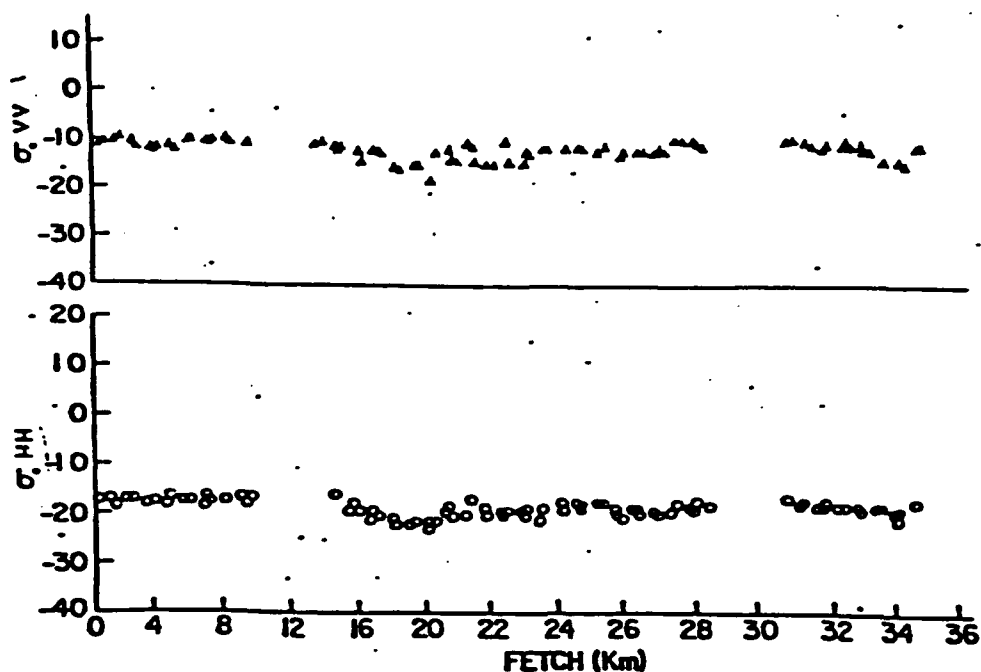
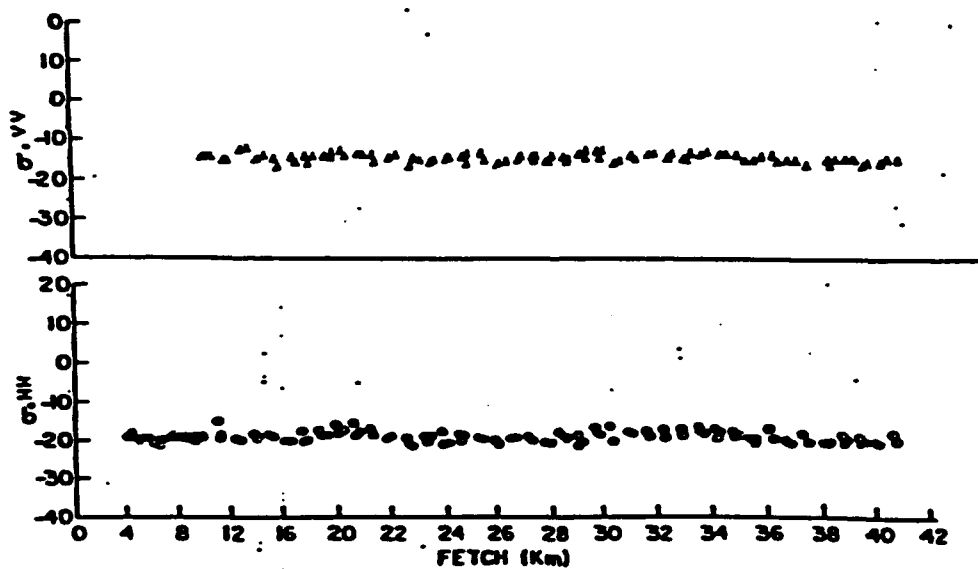


Figure 11. Ratio of overland/over-water wind speed versus fetch for near neutral moderate-high wind speed data of Richards et al. (1966) and Phillips and Irbe (1977)



Radar scattering cross section σ_0 as a function of fetch at an incidence angle of 40° . Surface wind speeds were 9.0 m s^{-1} .



Radar scattering cross section σ_0 as a function of fetch at an incidence angle of 53° . Surface wind speeds were 13.0 m s^{-1} .

Figure 12. Radar scattering cross section σ_0 as a function of fetch at an incidence angle of 40° for wind speeds of 9.0 m/sec (above) and an incidence angle of 53° for wind speeds of 13.0 m/sec (below)

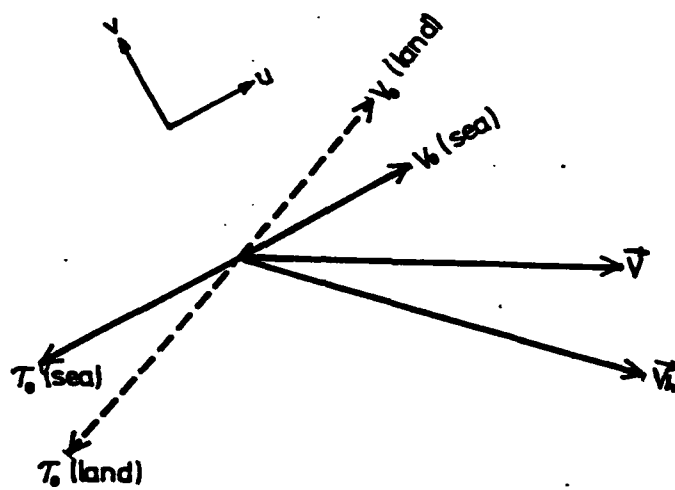


Figure 13. Coordinate system and relationship of wind stress components in the equilibrium model PBL over rough and smooth (sea) terrain

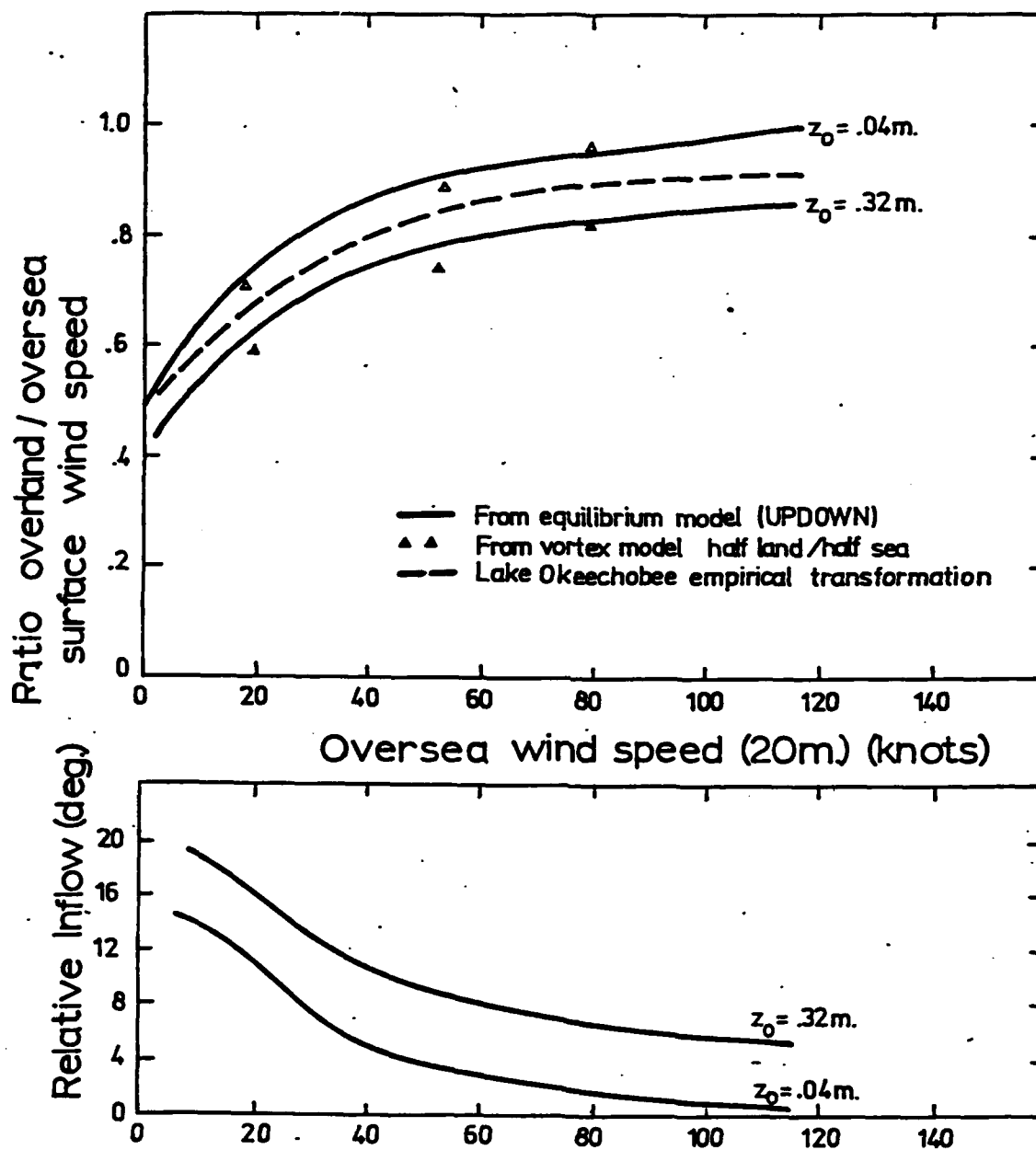


Figure 14. Ratio of the surface wind speed at the 20-m height overland to over sea (above) and the difference between the overland and over-sea inflow angle (below) from the equilibrium PBL model for two terrain roughnesses, from the numerical vortex model and the empirical wind speed ratio derived from measurements in hurricanes at Lake Okeechobee

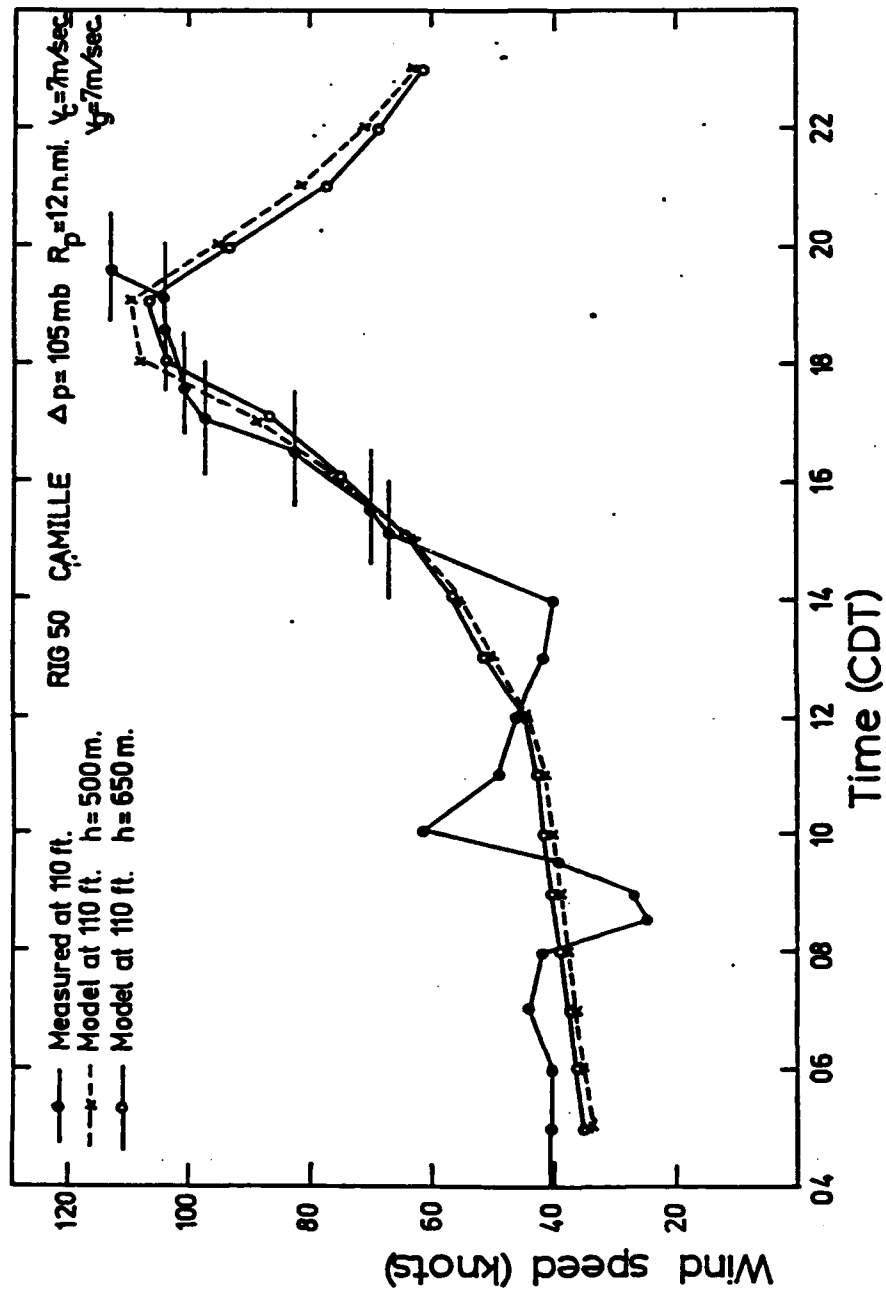


Figure 15. Comparison of measured and modelled wind speed at Rig 50 at measurement height in Camille

16 Z_0 Values for Typical Terrain Types (After ESDU 72026, 1972)

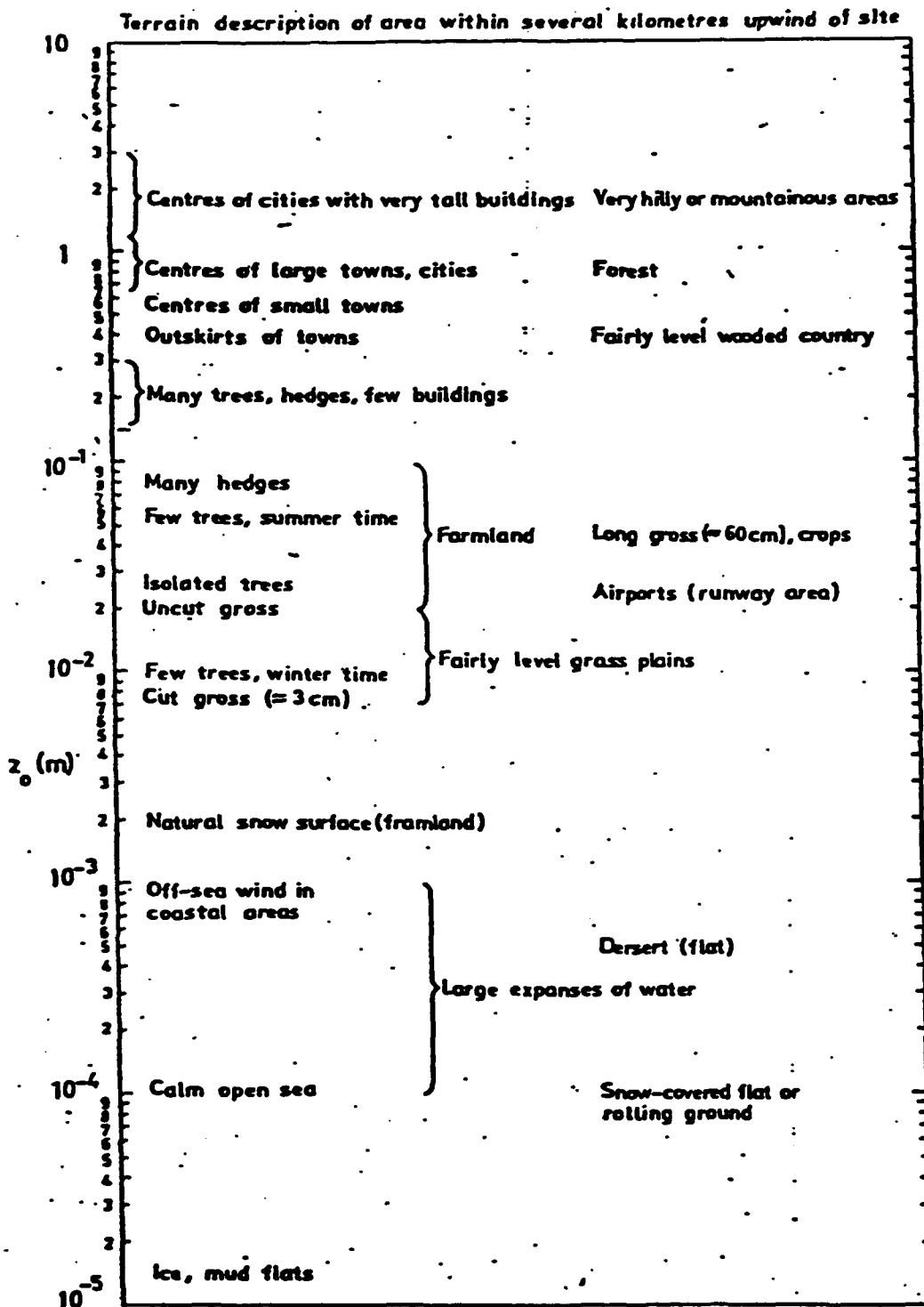


Figure 16. Roughness parameter values for typical terrain types (after ESDU 72026, 1972)

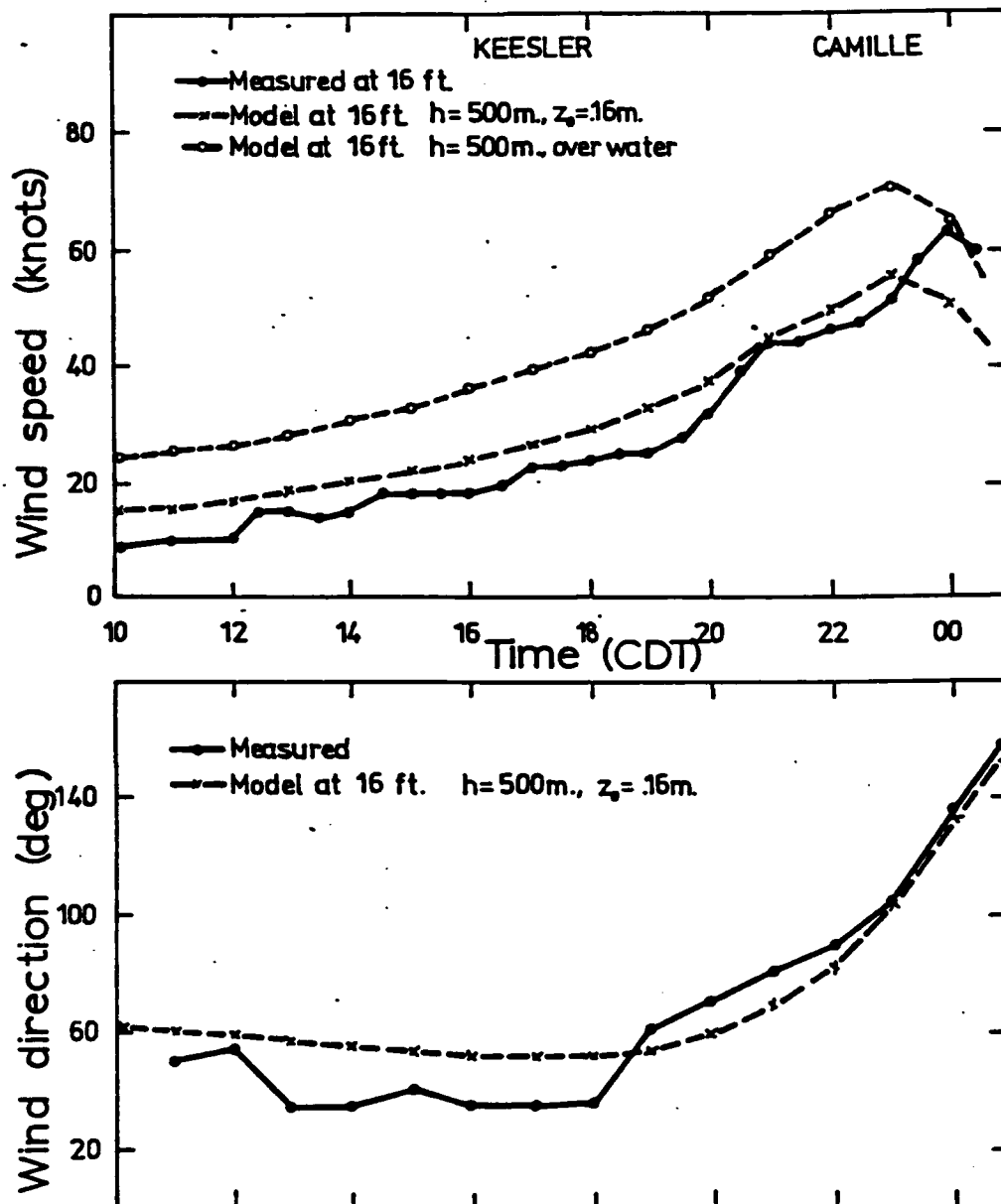


Figure 17. Comparison of measured and modelled winds at Keesler Air Force Base, Biloxi, MS, in Camille

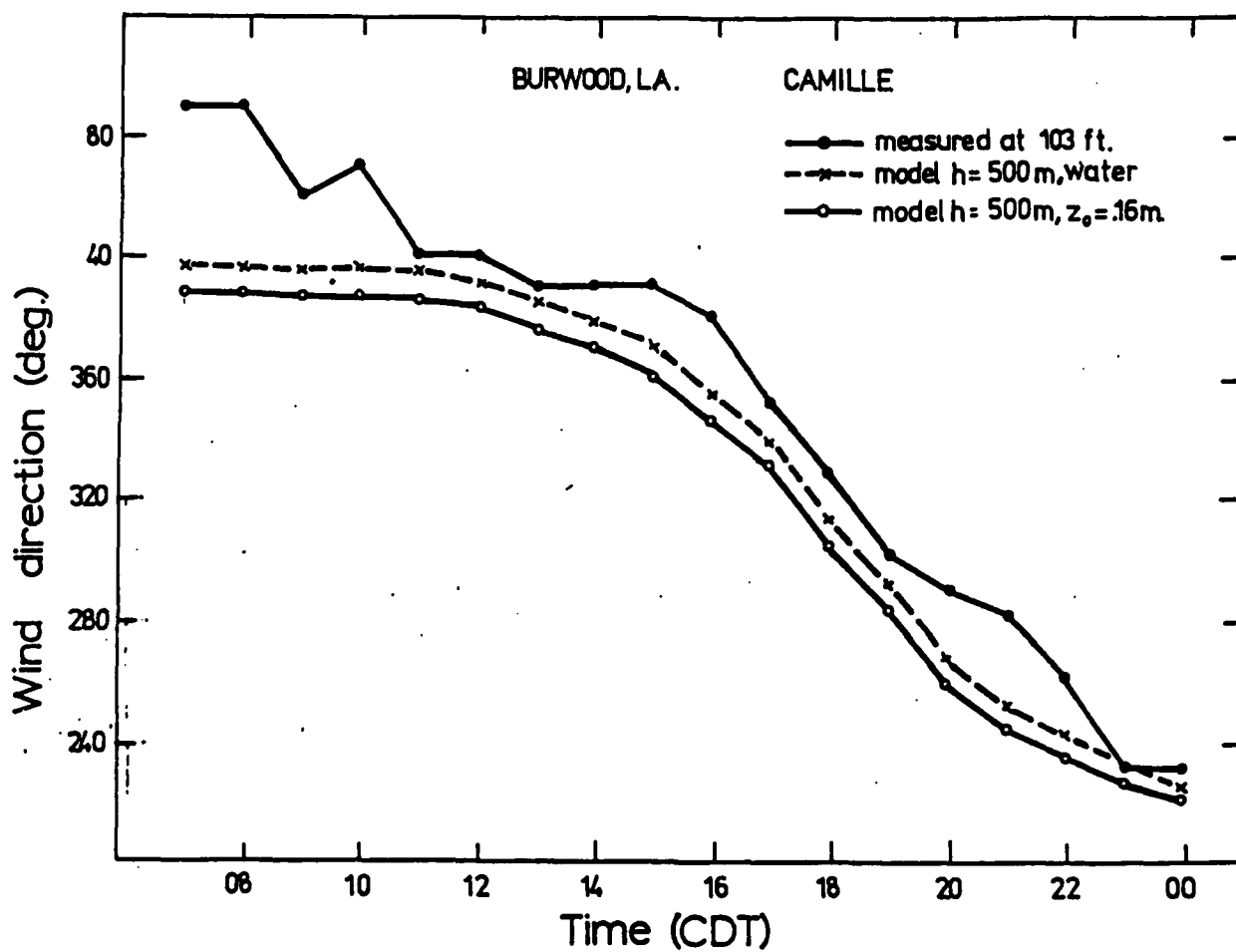


Figure 18. Comparison of measured and modelled wind direction at Burwood, LA, in Camille

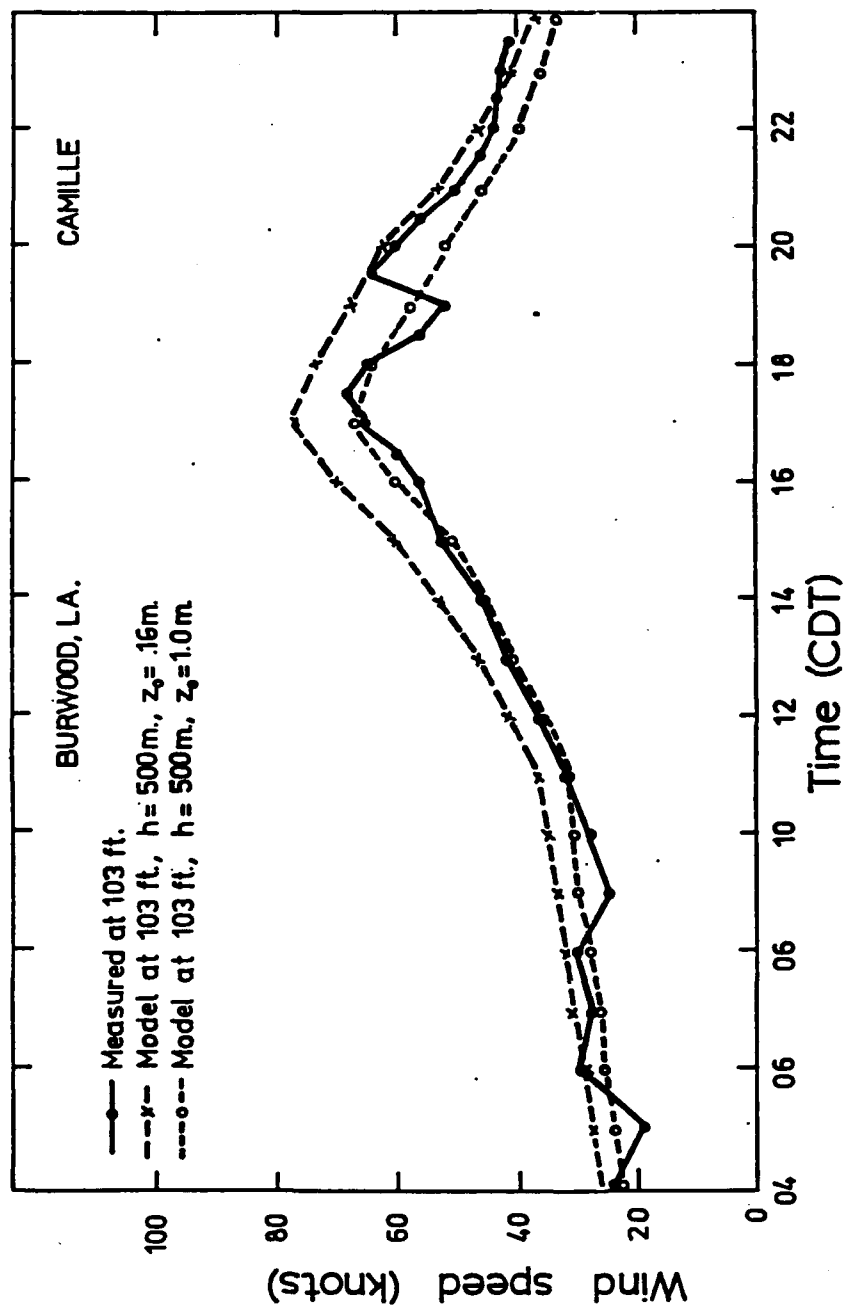


Figure 19. Comparison of measured and modelled wind speed at Burwood, LA, in Camille

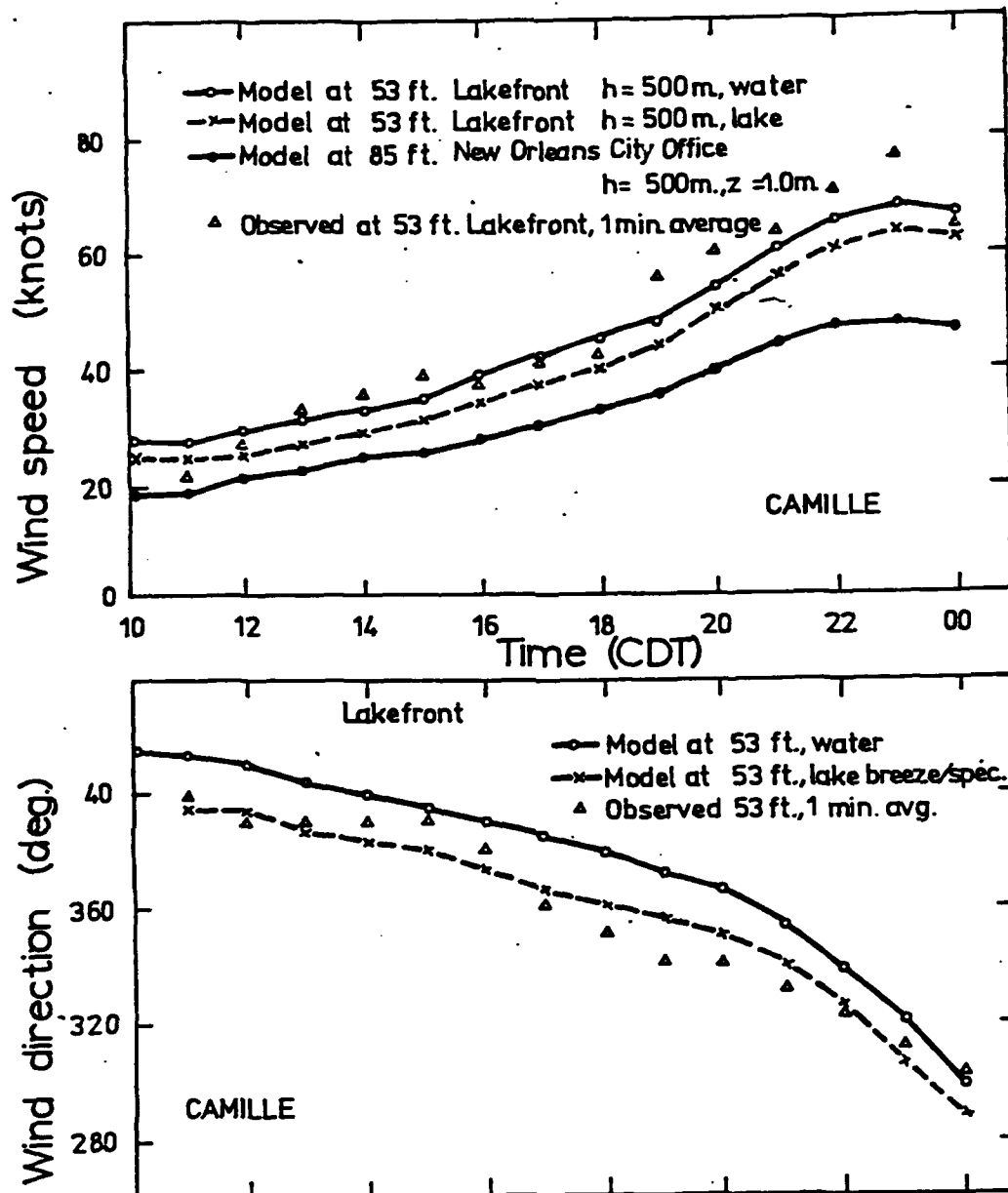


Figure 20. Comparison of measured and modelled wind speed (above) and wind direction (below) at New Orleans Lakefront Airport in Camille. Modelled wind at New Orleans for roughness parameter of 1 m shown

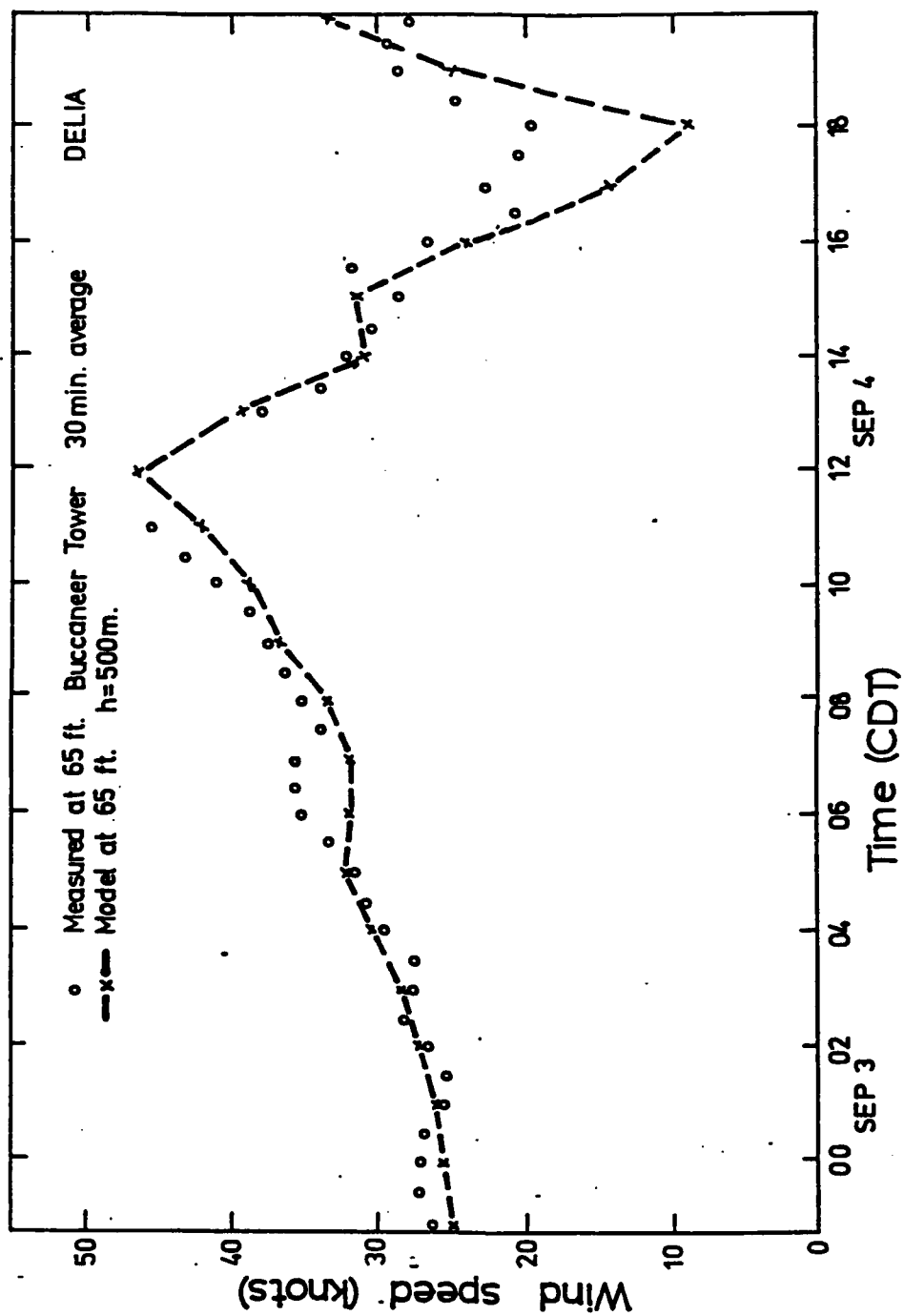


Figure 21. Comparison of measured and modelled wind speed at Buccaneer Tower in Delia

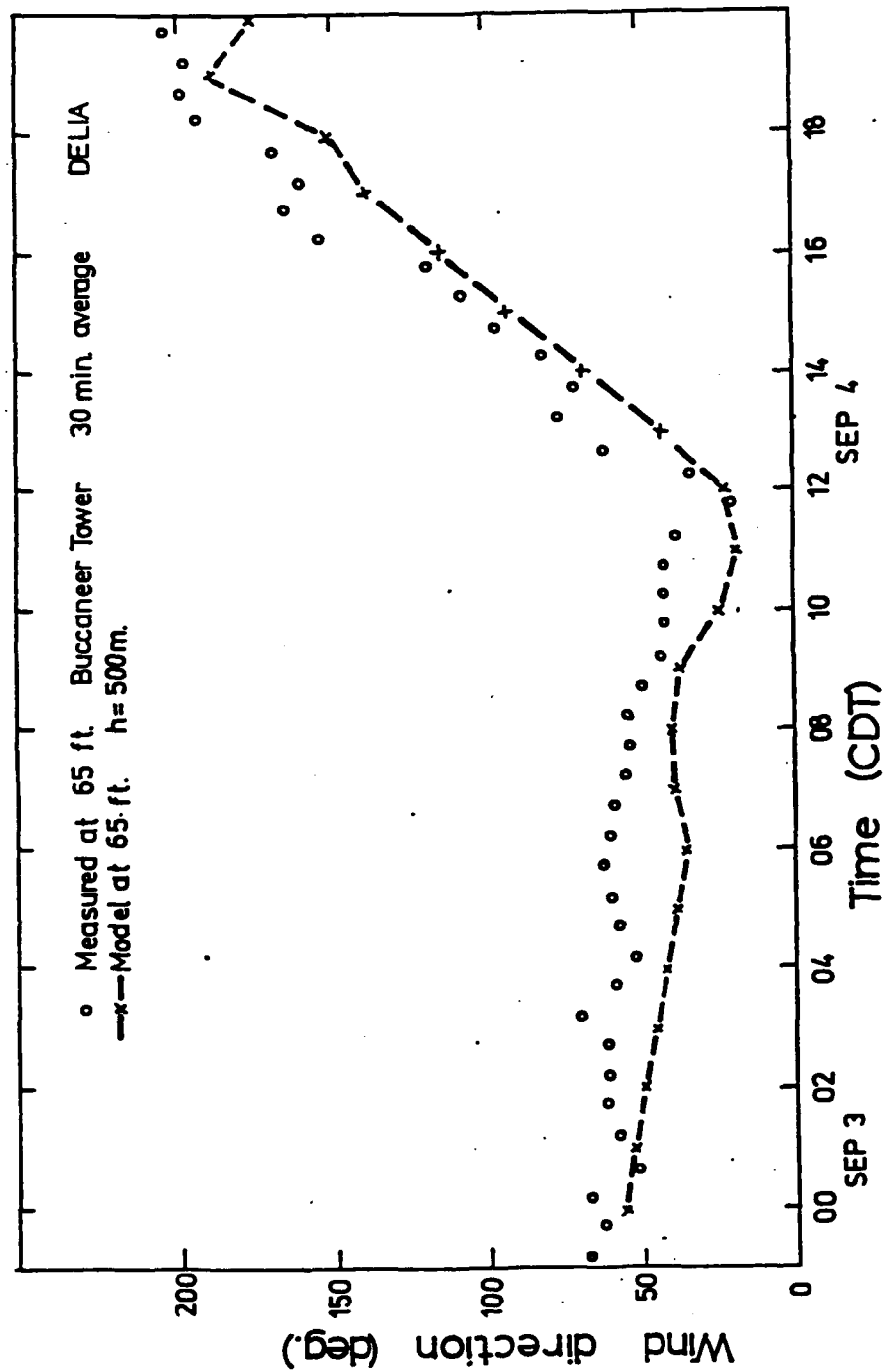


Figure 22. Comparison of measured and modelled wind direction at Buccaneer Tower in Delia

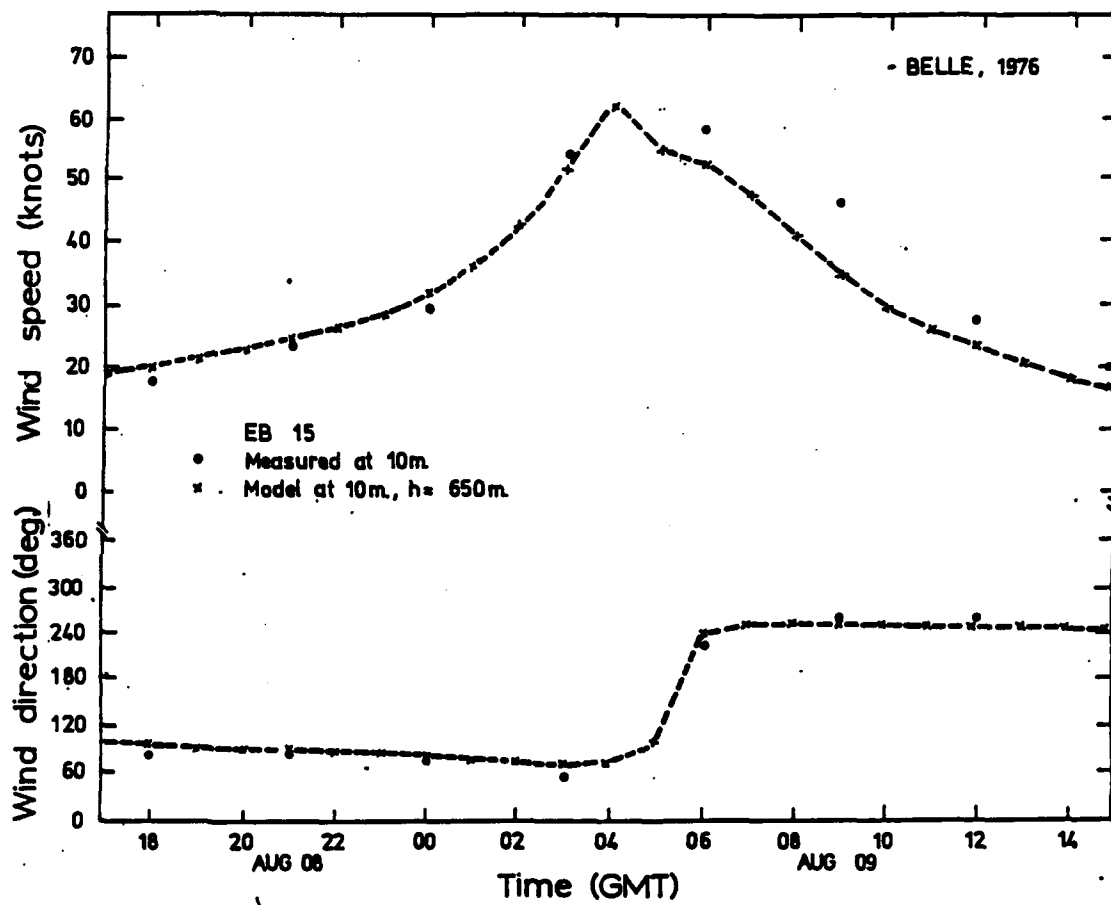


Figure 23. Comparison of measured and modelled wind speed and direction at buoy EB15 in Belle

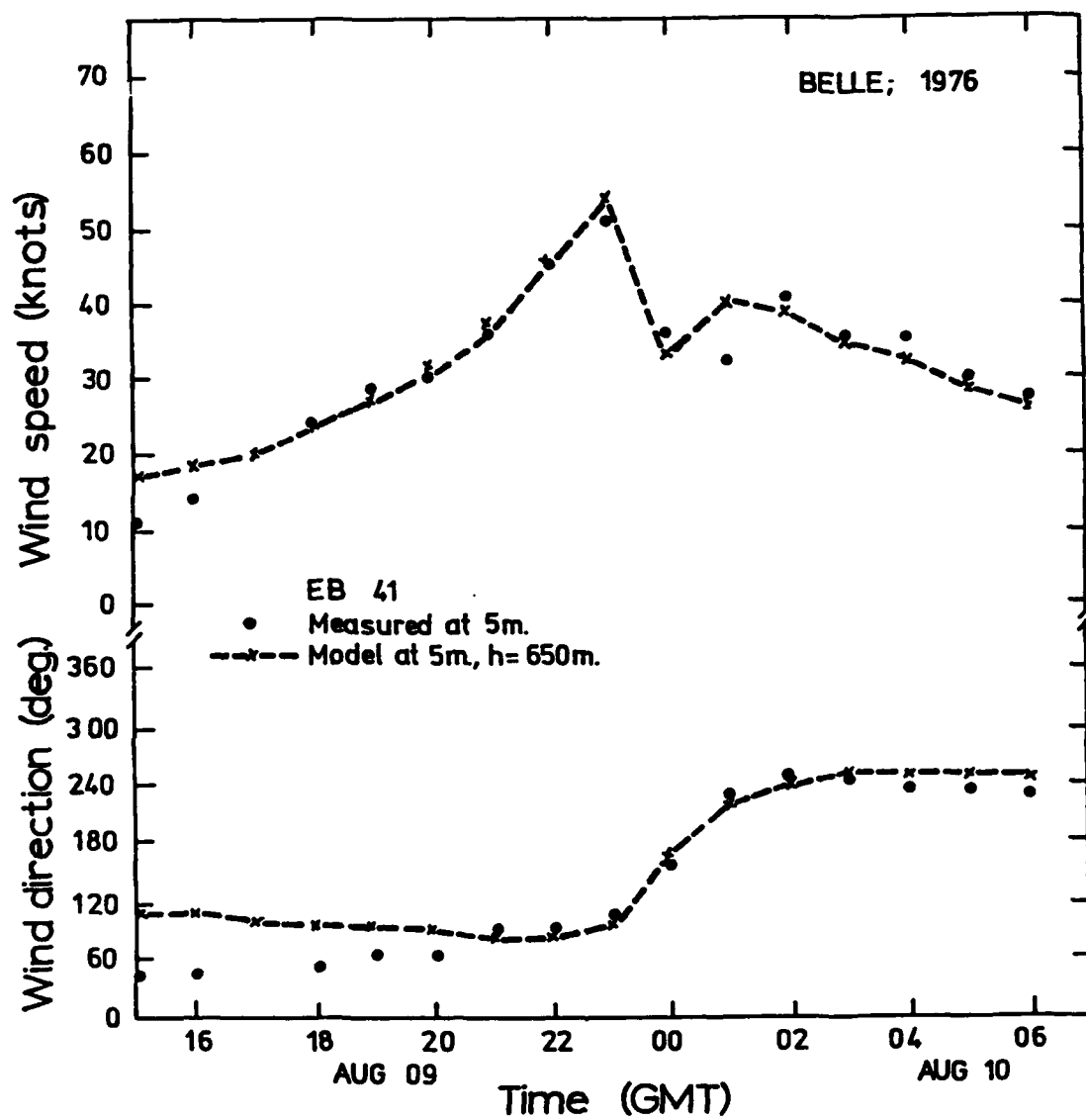


Figure 24. Comparison of measured and modelled wind direction at buoy EB41 in Belle

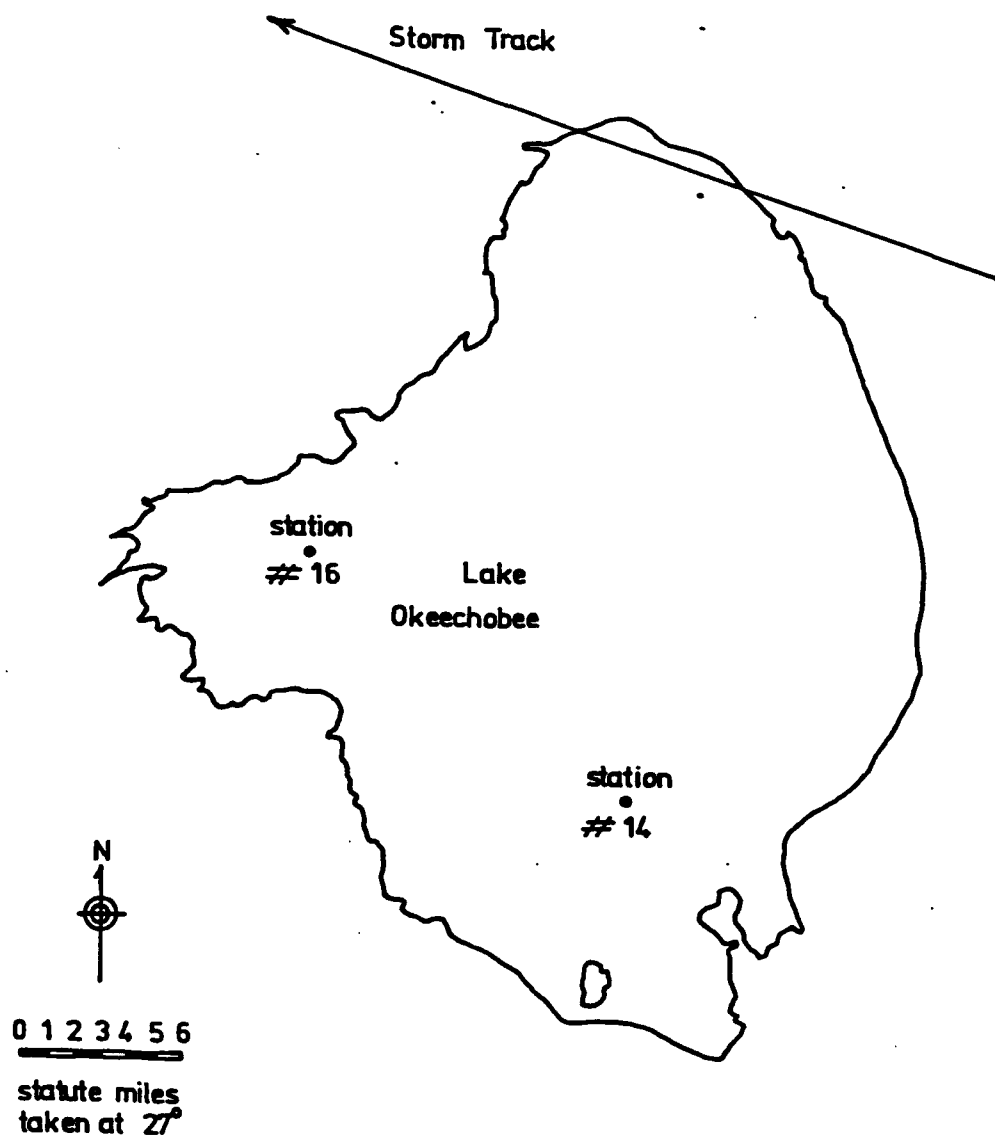


Figure 25. Location of measurement stations in Lake Okeechobee and path of the 1949 Lake Okeechobee hurricane

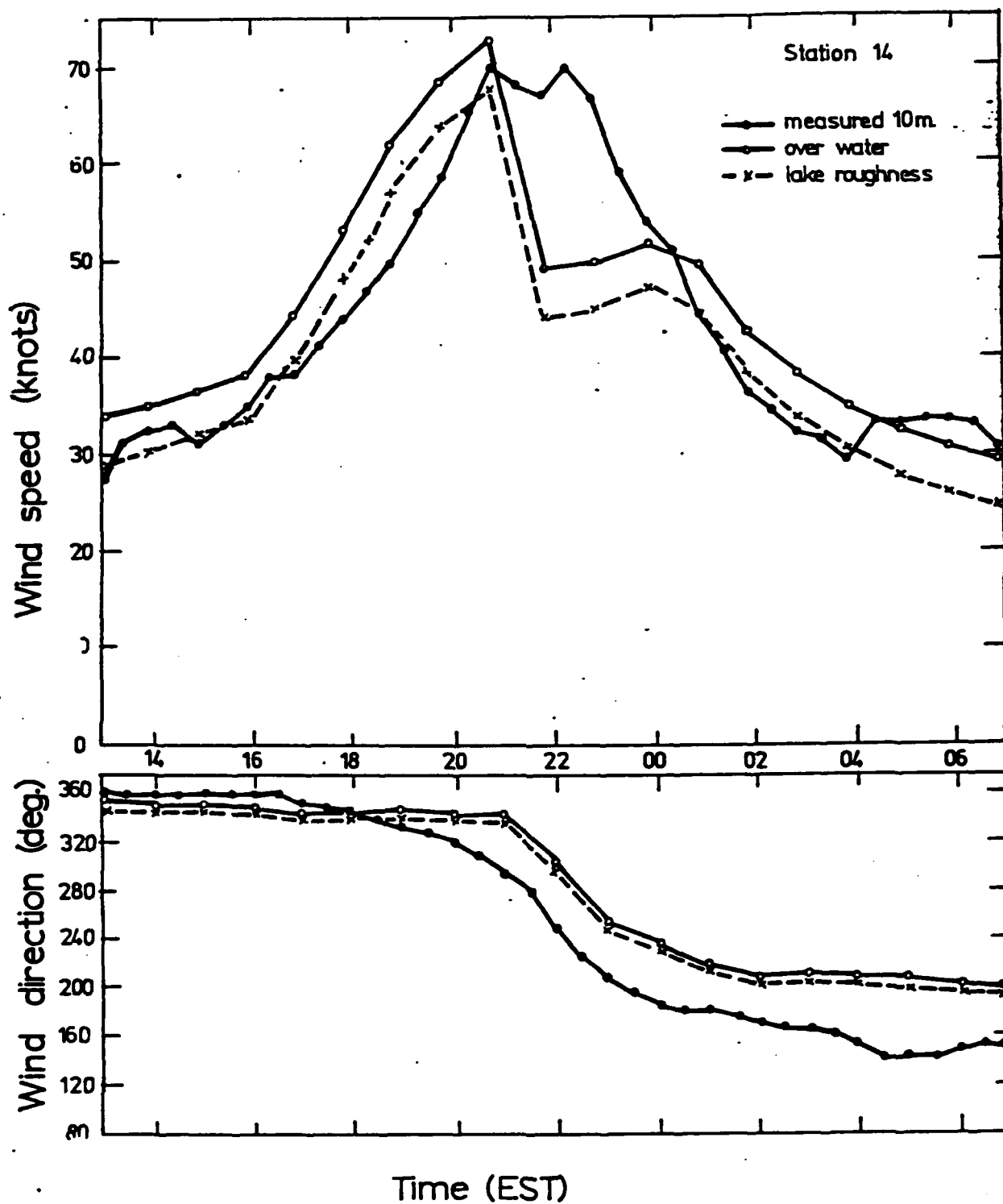


Figure 26. Comparison of measured and modelled wind speed and direction at station 14 in the 1949 Lake Okeechobee hurricane

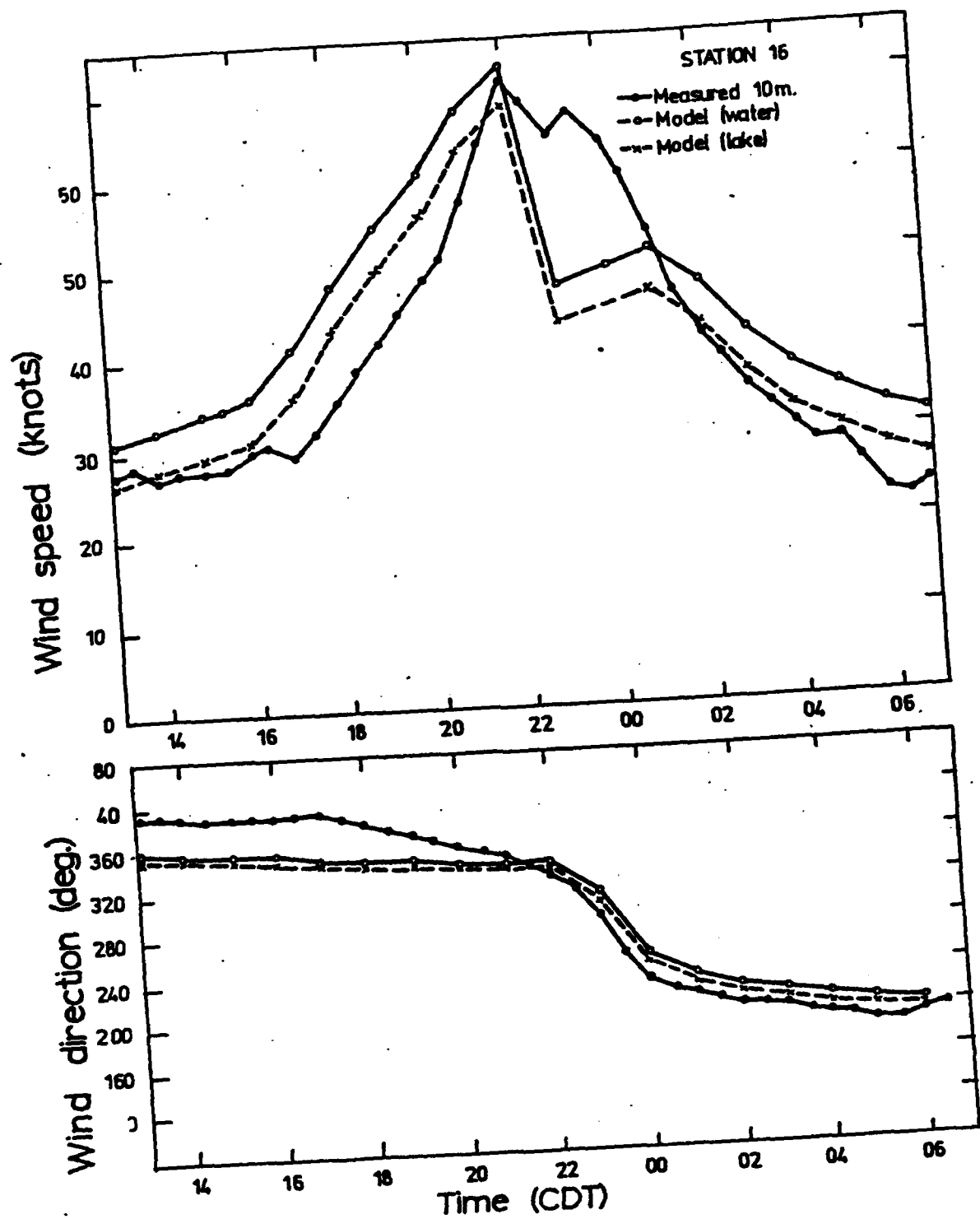


Figure 27. Comparison of measured and modelled wind speed and direction at station 15 in the 1949 Lake Okeechobee hurricane

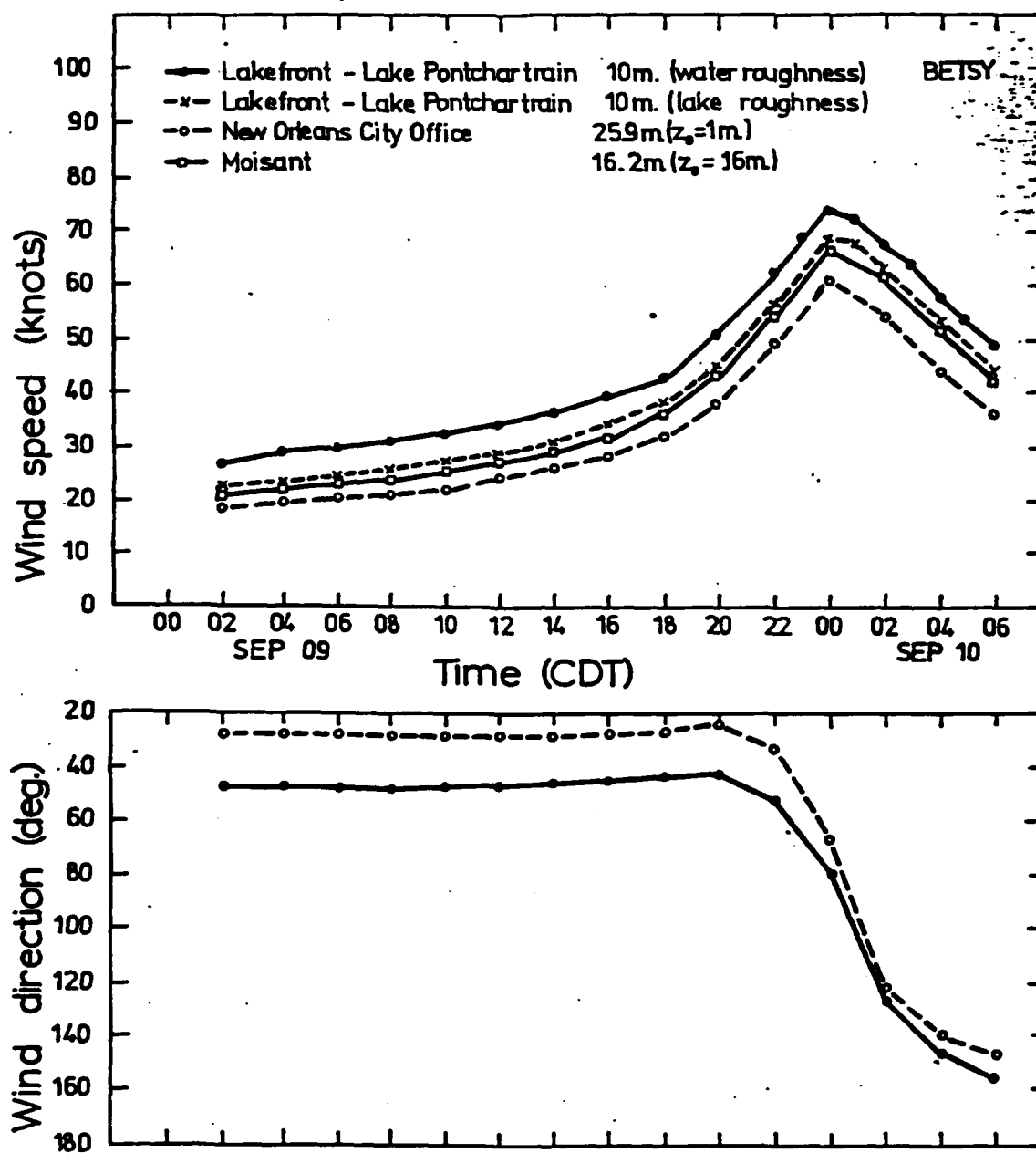


Figure 28. Modelled wind speed and direction for various terrain roughnesses in Hurricane Betsy

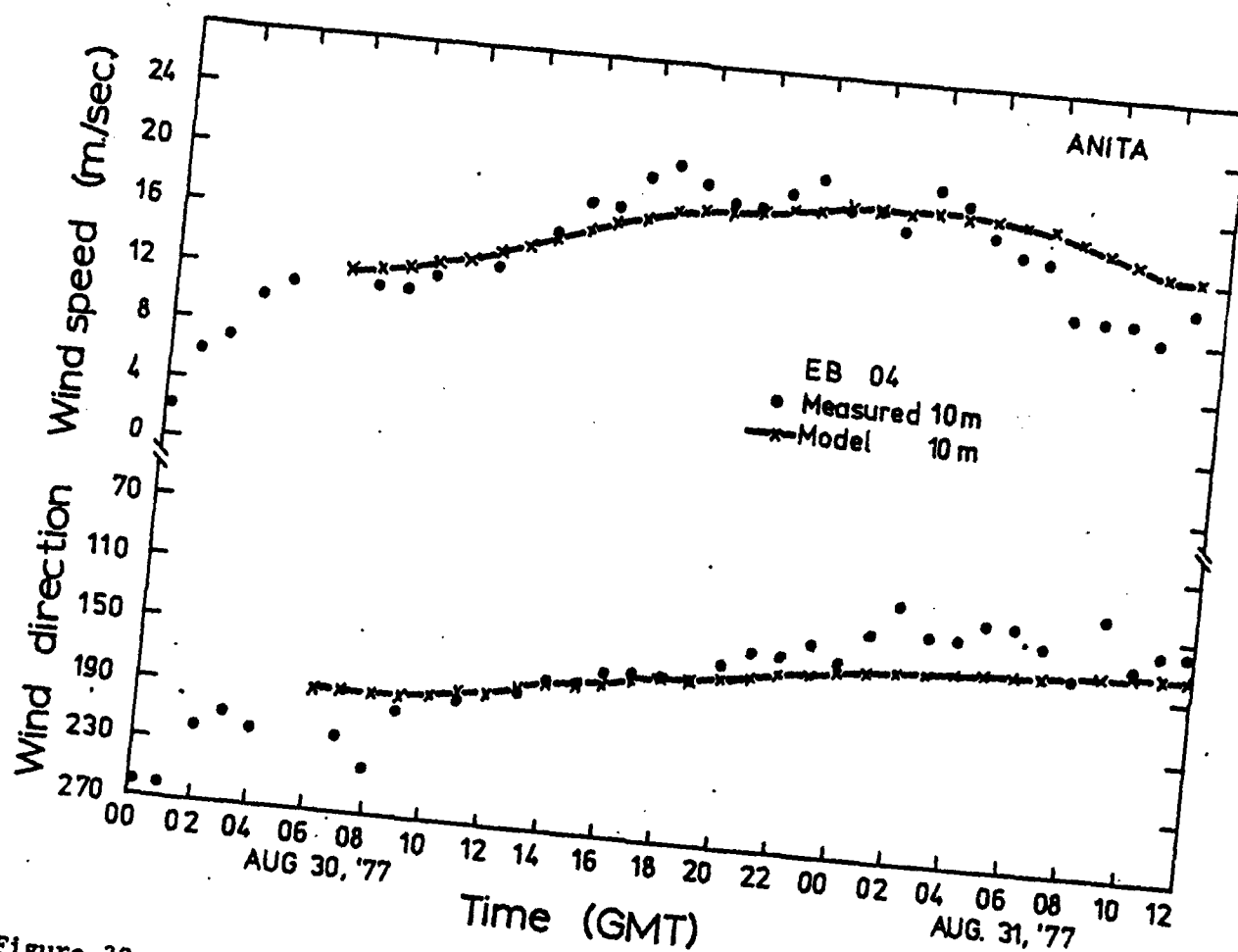


Figure 30. Comparison of measured and modelled wind speed and direction at buoy EB04 in Hurricane Anita

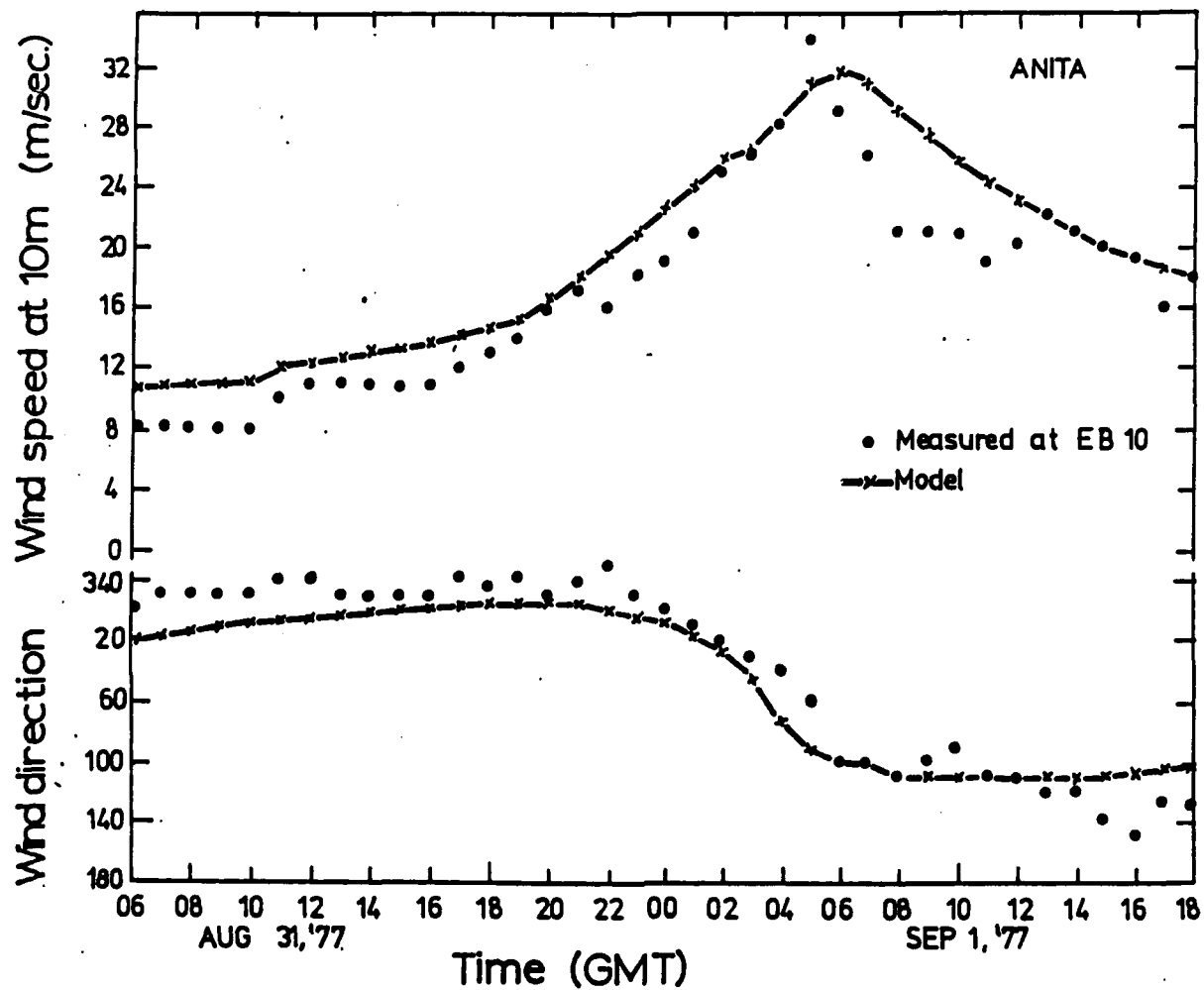


Figure 31. Comparison of measured and modelled wind speed and direction at buoy EB71 in Hurricane Anita

APPENDIX A: NAMELIST

1. Source. The material below is abridged from §6.4 of "Sperry Univac Series 1100, FORTRAN V Level 4 R1, programmer reference", edition of April 1979.

2. The nonexecutable NAMELIST statement and the associated forms of the formatted input/output statements provide a simplified means of transmitting an annotated list of data to and from peripheral units. The input/output statements take the form

```
      READ (unit, x)
      and
      WRITE (unit, x)
```

where *x* is a namelist name. The list of items in the namelist is used on input to specify those items which may have their values defined in the records to be read. Not all items of the namelist list need be used in the input records nor must the input fields be in the same order as the list items. On output, each list item of the designated namelist is formatted in a standard fashion for output in the order specified by the list.

3. Namelist Statement. The general form of the statement is

```
      NAMELIST /X/A,B,....,C/Y/D,E,....,F/Z/G,H,....,I
```

where *X*, *Y*, *Z*,.... are namelist names and *A*, *B*, *C*, *D*,.... are simple variables, subscripted variables, or array names. An array must be dimensioned before appearing in a namelist. The following rules apply to defining and using a namelist:

- a. A namelist name consists of from one to six alphanumeric characters, the first of which must be alphabetic.
- b. Within a NAMELIST statement, a namelist name is enclosed in slashes. The list of variables associated with a namelist name ends when a new namelist name enclosed in slashes is encountered or with the end of the NAMELIST statement.
- c. A namelist name may be defined only once in a routine by its appearance in a NAMELIST statement. In the routine in which it is defined, a namelist name may appear only in

input/output statements and in the defining NAMELIST statement.

- d. A namelist name must not be the same as any other name in the routine in which it appears.
- e. A variable name, array element name, or an array name may be assigned to one or more namelist names. Array names must have been previously declared.
- f. The subscript(s) of an array element must consist of constants.

4. Namelist Input. The READ (i,X) statement causes the records that contain the input data for the variables and arrays that belong to the namelist name X to be read from input unit i. For READ (i,X) , the first character in each data record to be read is always ignored. The second character of the first record of a group of data records to be read must be a \$ immediately followed by the namelist name and a blank. The remainder of the first record and following records may contain any combination of the legal data items which are separated by commas (a comma after the last data group is ignored). The last input record is terminated by a blank followed by \$END.

5. The forms the data items may take are:

- a. Variable Name= Constant. Variable name is a simple variable name.
- b. Subscripted Variable=Constant. The array element appears in the NAMELIST statement. The subscripts in the input record must be constants.
- c. Array Name=Set of Constants. The set is represented by constants separated by commas, or k*constant may represent k constants (k is an unsigned integer). The number of constants must be less than or equal to the number of elements in the array.

6. Constants used in the data items may take any of the following forms:

- a. Integer constants.
- b. Real constants. These are written with a decimal point, and, optionally, they are written with an exponent consisting of E , + , or - , or a combination of E and sign (for example, E+2, E2, +2).
- c. Hollerith constants. These are written as nHhhh....h where hh....h is a string of n alphanumeric characters, including blanks. Six characters can be stored in one

location. If less than six characters remain they are stored left-justified with the rest of the computer word filled out with blanks.

7. Hollerith constants may only be associated with integer or real variables. The data items that appear on the input records need not appear in the same order as the corresponding variable or array names in the namelist. All variable or array names of the namelist need not have a corresponding data item in the input records; if none appears, the contents of the variable or array are unchanged. Names that are equivalenced to these names may not be used in the input records unless they are part of the namelist. Blanks must not be embedded in a constant or a repeat constant field, but may be used freely elsewhere in a data record. The name of an array and the value of its first elements must appear on the same record. The last item on each record that contains data items must be a constant followed by a comma. The comma is optional in the record that contains or precedes the \$END sentinel.

8. Namelist Output. The WRITE (i,X) statement causes all names of variables and arrays (as well as their values) that belong to the namelist name X to be written on the output unit i. In the WRITE (i,X) statement, all variables and arrays, and their values belonging to the namelist name, are written out according to their types. The output data is written such that:

- a. The name of a variable and its value are written on one line.
- b. The name of an array is written, with the values of the elements of the array written in a convenient number of columns, in the order of the array in main storage, that is, with the left dimension [varying fastest].
- c. The data fields are large enough to contain all the significant digits.
- d. The output can be read by an input statement referencing the namelist name.

APPENDIX B: PROGRAM LISTING

```

C
C
SUBROUTINE AANGEL (I20)
  CONVERTS U,V TO SPEED(KN), DIRECTION.
  COMPUTES SPEED AT 20 MTRS ALTITUDE IF I20 NE 0.
  COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
  1 ,PX(21,21,5),FY(21,21,5),VTN(21,21,5),ANG(21,21,5)
  2 ,LW(21,21,5)
  COMMON
  $/C4/ CUR(100,2,2),UXV(100,2),TURN(100,2)
  $/C5/ FLAT,PTH,DTH(2),HH,ZOLAND,LS,VV(100),UX(3),UV(3),
  $ OUV(3),K35,K2,G,6A,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,FF
  REAL K35,K2
  DO 1000 NEST=1,5
  DO 1000 I=1,21
  DO 1000 J=1,21
  C COMPUTE VTN
  VTN(I,J,NEST)=SQRT(UN(I,J,NEST)**2+VN(I,J,NEST)**2)
  IF(VTN(I,J,NEST)) 860,840,860
  840 ANG(I,J,NEST)=0.0
  GO TO 1000
  860 AN=57.29578*ATAN2(VN(I,J,NEST),UN(I,J,NEST))
  ANG(I,J,NEST)=AMOD(270.-AN, 360.)
  C
  C
  REDUCE SPEED TO 20 MTRS IF I20 NE 0
  REDUCE SPEED TO KNOTS IF I20 EQ 0
  IF (I20 .NE. 0) GO TO 900
  VTN(I,J,NEST) = VTN(I,J,NEST)*.3600./1852.
  GO TO 1000
  900 SPP = 1.25*VTN(I,J,NEST)
  KPP = SPP
  SPP = SPP-KPP
  LS = LW(I,J,NEST)
  IF (KPP .NE. 0) GO TO 910
  UXX=VTN(I,J,NEST)*UXV(I,LS)
  TWIST = TURN(I,LS)
  GO TO 930

```

```

910 IF (KPP .GE. 100) GO TO 920
    UXX = VTN(I,J,NEST)*(1.-SPP)*UXV(KPP,LS)+SPP*UXV(KPP+1,LS))
    TWIST = (1.-SPP)*TURN(KPP,LS)+SPP*TURN(KPP+1,LS)
    GO TO 930
920 UXX = VTN(I,J,NEST)*UXV(100,LS)
    TWIST = TURN(100,LS)
930 220 = 19.5/20LAND
    IF (LS .EQ. 2) 220 = 19.5/(6A*UXX**2)
    VTN(I,J,NEST) = (3600./1852.)*AMIN1
    $ (UXX/K35*ALOG(220),VTN(I,J,NEST))
    ANG(I,J,NEST) = ANG(I,J,NEST)+57.29578*TWIST
    IF (ANG(I,J,NEST).LT. 0.) ANG(I,J,NEST) = ANG(I,J,NEST)+360.
1000 CONTINUE
    RETURN
    END

```

```

SUBROUTINE ABCC
COMMON
$ /C4/ COR(100,2,2),UXV(100,2),TURN(100,2)
$ /C5/ FLAT,PTH,OTH(2),HH,ZOLAND,LS,VV(100),UX(3),UV(3),
$   UVV(3),K35,K2,G,GA,DEN,VV2,HL,K123,Z0,ZLOG,AM,BH,CM,FF
REAL K35,K2
IF (LS.EQ. 1) GO TO 53
Z0 = GA*UX(K123)**2/HH
ZLOG = ALOG(Z0)
53 HL = -HH*DEN/(UX(K123)**2*PTH*(ZLOG+CM))
IF (HL+2.) 54,55,56
54 HLOG = ALOG(-HL)
AM = AMIN1(HLOG+1.5,-.875*ZLOG)
BM = 1.8*EXP(.2*HL)
CM = AMIN1(HLOG+3.7,-.875*ZLOG)
GO TO 60
55 AM = 2.1931472
BM = 1.2065761
CM = 4.3931472
GO TO 60

```

```

56 IF (HL-2.) 57,58,59
57 AM = 1.3865736-.4032868*HL
    BM = 1.953288+.37335598*HL
    CM = 2.5465736-HL+.9232868
    GO TO 60
58 AM = .58
    BM = 2.70
    CM = .7
    GO TO 60
59 YLOG = ZLOG+.4.7
    HL = .25*(YLOG+SQRT(YLOG**2+.8*.HH*DEN/(UX(K123)**2*PTH)))
    AM = AMAX1(2.5-.96*HL,-99.)
    BM = AMIN1(1.1+.8*HL,99.)
    CM = 4.7-2.*HL
60 UV(K123) = UX(K123)**2/K2*((ZLOG+AM)**2+BM**2)
    DUV(K123) = UV(K123)-VV2
    RETURN
    END

```

```

SUBROUTINE ABCCC
COMMON /C57/ PTH,DTH,HH,ZCOEFF(3,5),LAKE,VV(100),UX(3),UV(3),
$   DUV(3),K35,K2,6,6A,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,UXV(100,6),
$   TURN(100,6),COST(100),SINT(100)
REAL K2,K35
Z0 = GA*UX(K123)**2/HH
ZLOG = ALOG(Z0)
53  HL = -HH*DEN/(UX(K123)**2*PTH*(ZLOG+CM))
    IF (HL+2.) 54,55,56
54  HLOG = ALOG(-HL)
    AM = AMIN1(HLOG+1.5,-.875*ZLOG)
    BM = 1.8*EXP(.2*HL)
    CM = AMIN1(HLOG+3.7,-.875*ZLOG)
    GO TO 60
55  AM = 2.1931472
    BM = 1.2065761
    CM = 4.3931472
    GO TO 60
56  IF (HL-2.) 57,58,59
57  AM = 1.3665736-.4032868*HL
    BM = 1.953288+.37335598*HL
    CM = 2.5465736-HL+.9232868
    GO TO 60
58  AM = .58
    BM = 2.70
    CM = .7
    GO TO 60
59  YLOG = ZLOG+.4.7
    HL = .25*(YLOG+SORT(YLOG**2+.8*HH*DEN/(UX(K123)**2*PTH)))
    AM = AMAX1(2.5,-.96*HL,-99.)
    BM = AMIN1(1.1+.8*HL,99.)
    CM = 4.7-2.*HL
60  UV(K123) = UX(K123)**2/K2*((ZLOG+AM)**2+BM**2)
    DUV(K123) = UV(K123)-VV2
    RETURN
END

```

```

SUBROUTINE BLOWUO
C BLOWUP PRODUCES THE WIND FIELD FOR MOVING VORTEX IN THE PLANETARY
C BOUNDARY LAYER. ITS U(EASTWARD) AND V(NORTHWARD) COMPONENTS
C ARE IN ARRAYS UN,VN RESPECTIVELY UPON EXIT.
C SGW IS MAGNITUDE OF SURFACE GEOSTROPHIC WIND
C AN1 IS ANGLE BETWEEN SGW AND EAST, COUNTERCLOCKWISE FROM EAST
C ST12 IS DISTANCE IN KM FROM AXIS OF STORM TO HALF MAGNITUDE OF SGW
C (UG,VG) IS THE SFC GEOSTROPHIC WIND.
C CS IS SPEED OF STORM MOVEMENT.
COMMON/C1/NAME,NSNAP,D1(2),F,SGW,AN1,UC,VC,UG,VG,CS,NM,IB
,ST12
COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
1 ,PX(21,21,5),PY(21,21,5),VTN(21,21,5),ANG(21,21,5)
2 ,LV(21,21,5)
COMMON
$/C4/ CDR(100,2,2),UXV(100,2),TURN(100,2)
$/C5/ FLAT,PTH,OTH(2),HH,ZOLAND,LS,VV(100),UX(3),UV(3),
$ DUV(3),K35,K2,G,GA,DEN,VV2,HL,K123,Z0,ZLOG,AM,8M,CM,FF
REAL K35,K2
DIMENSION LEVEL(16)
REAL CDH2(2)
DATA LEVEL/1,5,1,2,1,3,1,2,1,4,1,2,1,3,1,2/
DEGG = AN1/57.29578
UG=SGW+CUS(DEGG)
VG=SGW+SIN(DEGG)
CALL SHORE
CALL PYTH
IF (IB.NE.0) CALL OUTOUT(0,NAME,4,HINIT,NSNAP)
SPP = 1.25*SGW
KPP = SPP
SPP = SPP-KPP
DO 1020 LS = 1,2
CDH2(LS) = ((1.-SPP)*UXV(KPP,LS)+SPP*UXV(KPP+1,LS))*2/HH)**2
CONTINUE
CS=SQRT(UC**2+VC**2)
DO 1026 I = 1,21
1020
1026

```

```

DO 1026 J = 1,21
IF (I .EQ. 1) GO TO 1025
IF (I .EQ. 21) GO TO 1025
IF (J .EQ. 1) GO TO 1025
IF (J .EQ. 21) GO TO 1025
GO TO 1026
1025 CONTINUE
LS = LW(I,J,5)
AA = CDH2(LS)*(PX(I,J,5)**2+PY(I,J,5)**2)
F2=F**2/2.0
SK=AA/(F2+SQR(F2**2+AA))
BK=SQR(SK)
V(I,J,5)=(F+PX(I,J,5))-BK*PY(I,J,5)/(F**2+SK)
U(I,J,5)=-PY(I,J,5)/F-V(I,J,5)*BK/F
V(I,J,5)=V(I,J,5)-VC
U(I,J,5)=U(I,J,5)-UC
1026 CONTINUE
DO 1028 I = 1,21
DO 1028 J = 1,21
UN(I,J,5)=U(I,J,5)
VN(I,J,5)=V(I,J,5)
1028 CONTINUE
DO 1030 NEST = 1,5
DO 1030 I = 1,21
DO 1030 J = 1,21
PX(I,J,NEST)=PX(I,J,NEST)-F*VC
1030 PY(I,J,NEST)=PY(I,J,NEST)+F*UC
C
DO 1430 K=1,NH
KCK = MOD(K,16)
CALL COMOUT (LEVEL(KCK+1))
1430 CONTINUE
CALL OUTFLO
C
C SOLUTION OF WIND FIELD ON COORDINATE SYSTEM MOVING
C WITH STORM IS NOW COMPLETE.

```

```

C      COMPUTE SOLUTION WITH RESPECT TO SEA SURFACE.
DO 1450 NEST=1,5
DO 1450 I=1,21
DO 1450 J=1,21
  UN(I,J,NEST)=UN(I,J,NEST)+UC
  VN(I,J,NEST)=VN(I,J,NEST)+VC
1450 CONTINUE
  CALL OUTPUT(1,NAME,4HSNAP,NSNAP)
  CALL OUTPUT(0,NAME,4HSNAP,NSNAP)
  RETURN
  END

```

```

SUBROUTINE BREEZE
  REAL LA0,LA1,L00,L01,LB,LL
  COMMON /C57/ PTH,OTH,HH,ZCOEFF(3,5),LAKE,VV(100),UX(3),UV(3),
$   DUV(3),K35,K2,G,6A,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,UXV(100,6),
$   TURN(100,6),COST(100),SINT(100)
  REAL K2,K35
  COMMON /D1/LA0,L00,ROT,LA1,L01,DX,STHT,LANSEA,V1,TH1,D,AL,UST
  COMMON /D2/ XX(21,21,10)
  EQUIVALENCE (U1,XY), (V1,XY(2)), (UXX,UST)      INPUT (RADIANS)
  LA0,L00 ARE LAT,LON OF EYE(PT0)
  LA1,L01 ARE LAT,LON OF POINT AT WHICH WIND IS WANTED(PT1)-INPUT(RAD)
  C      LONGITUDE IS POSITIVE WEST.
  C
  C   DX IS GRID SPACING OF INNERMOST NEST - INPUT(KILOMETERS)
  C   V1 IS WIND SPEED AT PT1,20 METERS - OUTPUT(KNOTS)
  C   D IS DISTANCE BETWEEN PT0 AND PT1 - OUTPUT(KM)
  C   ROT IS ANGLE FROM TRUE NORTH TO Y-AXIS OF NESTED RECTANGULAR
  C       GRID WIND FIELD (CLOCKWISE,DEGREES).
  C   TH1 IS DIRECTION TO WHICH WIND BLOWS, CLOCKWISE FROM SOUTH(DEG)
  C   AL IS BEARING OF POINT 1 FROM POINT 0, CLOCKWISE FROM NORTH(DEG)
  C   LANSEA IS TERRAIN CODE AT POINT 1
  C       1 IS OCEAN, 2 TO 6 ARE VARIOUS GROUNDS AND LAKES
  C
  C   DIMENSION XY(2)
  C   NAMELIST/DBG2/I,J,F1,F2,XY,SPP,LANSEA,UXX,TWIST,STHT,GA,K35
  C   HAV(X) = (SIN(.5*X))**2
  C   AHAV(X) = 2.*ASIN(SQRT(X))
  C   SQRU(X) = SQRT(ABS(X))
  C   LL = LA0+LA1
  C   LB = LA0-LA1
  C   R = AHAV(HAV(LB)+COS(LA0)+COS(LA1))*HAV(L00-L01))
  C   IF(R.EQ.0.) GO TO 16
  C   IF (R.LT.1E-4) AB = ATAN2((L00-L01)*COS(.5+LL),-LB)
  C   AB = AB*.5
  C   IF(R.GE.1E-4) AB = ATAN2(SQRU(COS(.5*(LL+R))+SIN(.5*(R+LB))),
1   SQRU(COS(.5*(LL-R))*SIN(.5*(R-LB))))
  C   IF (L01 .GT. L00) AB = -AB
  C   AL = 2.*57.29578*AB

```

```

10 IF (AL .LT. 0.) AL = AL+360.
    DE = (AL-ROT)/57.29578
    D = R*1.852+3437.7468
    AA = 10.0+DX
    IZ = 1
    XY(1) = D*SIN(DE)
    XY(2) = D*COS(DE)
    AB = AMAX1(ABS(XY(1)),ABS(XY(2)))
    IF (AB .LT. AA) GO TO 11
    AA = AA+AA
    IZ = IZ+1
    GO TO 10
11 IF (I7 .LE. 5) GO TO 12
    U1 = 0.
    V1 = 0.
    W1 = 0.
    TH1 = 0.
    RETURN
12 DO 13 IA = 1,2
13 XY(IA) = (AA+XY(IA))*10./AA
    I = XY(1)
    J = XY(2)
    F1 = XY(1)-I
    F2 = XY(2)-J
    G11 = (1.-F1)*(1.-F2)
    G12 = (1.-F1)*F2
    G21 = F1*(1.-F2)
    G22 = F1*F2
    DO 14 IA = 1,2
    IB = 5+IA+IZ-5
    XY(IA) = G11*XX(I+1,J+1,IB)+G12*XX(I+1,J+2,IB)+G21*
    *XX(I+2,J+1,IB)+G22*XX(I+2,J+2,IB)
    W1 = U1+V1+W1
    IF (W1.EQ.0.) GO TO 110
    W1 = SORT(W1)
14
15

```

```

C
900  REDUCE W1 TO STATION HEIGHT
      SPP = 1.25*W1
      KPP = SPP
      SPP = SPP-KPP
      IF (KPP .NE. 0) GO TO 910
      UX = W1*UXV(1,LANSEA)
      TWIST = TURN(1,LANSEA)
      GO TO 930
910  IF (KPP .GE. 100) GO TO 920
      UX = W1*((1.-SPP)*UXV(KPP,LANSEA)+SPP*UXV(KPP+1,LANSEA))
      TWIST = (1.-SPP)*TURN(KPP,LANSEA)+SPP*TURN(KPP+1,LANSEA)
      GO TO 930
920  UX = W1*UXV(100,LANSEA)
      TWIST = TURN(100,LANSEA)
930  IF (LANSEA .EQ. 1) Z0 = CA*UST**2
      IF (LANSEA .NE. 1) Z0 = ZCOEFF(1,LANSEA-1)/UST+
      $ ZCOEFF(2,LANSEA-1)*UST**2+ZCOEFF(3,LANSEA-1)
      Z20 = STHT/Z0
      WRITE(6,DBG2)
      W1 = (3600./1852.)*AMIN1
      $ (UX/K35*ALOG(Z20),W1)
      TH1 = (ATAN2(-U1,-V1)+TWIST)*57.29578+ROT
      IF (TH1 .LT. 0.) TH1 = TH1+360.
      RETURN
16   U1=XX(11,11,1)
      V1=XX(11,11,6)
      D=0.
      AL=0.
      GO TO 15
      END

```

```

C
C
C
C
SUBROUTINE BREEZE
*** THIS VERSION OF BREEZE USES TURNING FROM TERRAIN TYPE 6 ****
*** FOR TERRAIN TYPE 2 ****

REAL LA0,LA1,L00,L01,LB,LL
COMMON /C57/ PTH,DTM,HH,ZCOEFF(3,5),LAKE,VV(100),UX(3),UV(3),
$ DUV(3),K35,K2,G,GA,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,UXV(100,6),
$ TURN(100,6),COST(100),SINT(100)
REAL K2,K35
COMMON /D1/LA0,L00,ROT,LA1,L01,DX,STHT,LANSEA,V1,TH1,D,AL,UST
COMMON /D2/ XX(21,21,10)
EQUIVALENCE (U1,XY), (V1,XY(2)), (UX,UST)      INPUT (RADIANS)
LA0,L00 ARE LAT,LON OF EYE(PT0)
LA1,L01 ARE LAT,LON OF POINT AT WHICH WIND IS WANTED(PT1)-INPUT(RAD)
      LONGITUDE IS POSITIVE WEST.
OX IS GRID SPACING OF INNERMOST NEST - INPUT(KILOMETERS)
V1 IS WIND SPEED AT PT1,20 METERS - OUTPUT(KNOTS)
D IS DISTANCE BETWEEN PT0 AND PT1 - OUTPUT(KM)
ROT IS ANGLE FROM TRUE NORTH TO Y-AXIS OF NESTED RECTANGULAR
      GRID WIND FIELD (CLOCKWISE,DEGREES).
TH1 IS DIRECTION TO WHICH WIND BLOWS, CLOCKWISE FROM SOUTH(DEG)
AL IS BEARING OF POINT 1 FROM POINT 0, CLOCKWISE FROM NORTH(DEG)
LANSEA IS TERRAIN CODE AT POINT 1
      1 IS OCEAN, 2 TO 6 ARE VARIOUS GROUNDS AND LAKES
DIMENSION XY(2)
NAMELIST/DBG2/I,J,F1,F2,XY,SPP,LANSEA,UX,X,TWIST,STHT,GA,K35
HAY(X) = (SIN(.5*X))**2
AHAY(X) = 2.*ASIN(SQRT(X))
SURU(X) = SORT(ABS(X))
LL = LA0+LA1
LB = LA0-LA1
R = AHAY(HAY(LB)+COS(LA0)+COS(LA1))+HAY(LU0-L01))
IF(R.EQ.0.) GO TO 16
IF (R.LT.1E-4) AB = ATAN2((L00-L01)*COS(.5+LL),-LB)
AB = AB*.5

```

```

IF(R-GE.1E-4) AB = ATAN2(SQRU(COS(.5*(LL+R))*SIN(.5*(R+LB))),
1  SQRU(COS(.5*(LL-R))*SIN(.5*(R-LB)))
IF (L01 .GT. L00) AB = -AB
AL = 2.*57.29578*AB
IF (AL .LT. 0.) AL = AL+360.
DE = (AL-ROT)/57.29578
D = R+1.852+3437.7468
AA = 10.0*DX
IZ = 1
XY(1) = D*SIN(DE)
XY(2) = D*COS(DE)
AB = AMAX1(ABS(XY(1)),ABS(XY(2)))
10 IF (AB .LT. AA) GO TO 11
AA = AA+AB
IZ = IZ+1
GO TO 10
11 IF (IZ .LE. 5) GO TO 12
U1 = 0.
V1 = 0.
W1 = 0.
TH1 = 0.
110 RETURN
12 DO 13 IA = 1,2
13 XY(IA) = (AA+XY(IA))*10./AA
I = XY(1)
J = XY(2)
F1 = XY(1)-I
F2 = XY(2)-J

```

```

- G11 = (1.-F1)*(1.-F2)
G12 = (1.-F1)*F2
G21 = F1*(1.-F2)
G22 = F1*F2
DO 14 IA = 1,2
IB = 5+IA+IZ-5
14 XY(IA) = G11*XX(I+1,J+1,IB)+G12*XX(I+1,J+2,IB)+G21*
+XX(I+2,J+1,IB)+G22*XX(I+2,J+2,IB)
15 W1 = U1+U1+V1+V1
IF (W1.EQ.0.) GO TO 110
W1 = SORT(W1)
C REDUCE W1 TO STATION HEIGHT
900 SPP = 1.25*W1
KPP = SPP
SPP = SPP-KPP
LSSUB=LANSEA
IF (LSSUB.EQ.2) LSSUB=6
IF (KPP .NE. 0) GO TO 910
UXX = W1*UXV(1,LANSEA)
TWIST = TURN(1,LSSUB)
GO TO 930
910 IF (KPP .GE. 100) GO TO 920
UXX = W1*((1.-SPP)*UXV(KPP,LANSEA)+SPP*UXV(KPP+1,LANSEA))
TWIST = (1.-SPP)*TURN(KPP,LSSUB)+SPP*TURN(KPP+1,LSSUB)
GO TO 930
920 UXX = W1*UXV(100,LANSEA)
TWIST = TURN(100,LSSUB)
930 IF (LANSEA .EQ. 1) Z0 = GA*UST**2
IF (LANSEA .NE. 1) Z0 = ZCOEFF(1,LANSEA-1)/UST+
$ ZCOEFF(2,LANSEA-1)*UST**2+ZCOEFF(3,LANSEA-1)
Z20 = STHT/Z0

```

```

C      WRITE(6,UBG2)
      W1 = (3600./1852.)*AMIN1
      $ (UXX/K35*ALOG(Z20),W1)
      TH1 = (ATAN2(-U1,-V1)+TWIST)*57.29578+ROT
      IF (TH1 .LT. 0.) TH1 = TH1+360.
      RETURN
16     U1=XX(11,11,1)
      V1=XX(11,11,6)
      D=0.
      AL=0.
      GO TO 15
      END

```

```

SUBROUTINE CCROSS
COMMON
$ /C4/ CDR(100,2,2),UXV(100,2),TURF(100,2)
$ /C5/ FLAT,PTH,DTH(2),HH,ZOLAND,LS,VV(100),UX(3),UV(3),
$   DUV(3),K35,K2,G,GA,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,FF
REAL K35,K2
FF = AMAX1(ABS(FLAT),1.832E-6)
DO 10 IA = 1,100
  VV(IA) = .8*FLUAT(IA)
10 CONTINUE
DO 41 LS = 1,2
  DEN = G*K2*DTH(LS)
  DO 40 IA = 1,100
    IB = 101-IA
    VV2 = VV(IB)*.2
    IF (IA.NE. 1) GO TO 20
    CM = 2.55
    K123 = 1
    UX(1) = 2.74
    IF (LS.EQ. 1) UX(1) = 3.38
    Z0 = ZOLAND/HH
    ZLOG = ALOG(Z0)
    CALL ABCC
    K123 = 2
    UX(2) = UX(1)*80./SQRT(UV(1))
    GO TO 30
    UX(1) = UX(3)
    UV(1) = UV(3)
    DUV(1) = UV(1)-VV2
    K123 = 2
    UX(2) = UX(1)*VV(IB)/VV(IB+1)
    CALL ABCC
    KSTOP = 0
    K123 = 3
  
```

```

31      IF (DUV(1).EQ. DUV(2)) GO TO 32
        UX(3) = AMAX1(.5*AMIN1(UX(1),UX(2)),
          AMIN1(2.*AMAX1(UX(1),UX(2)),
            (UX(1)+DUV(2)-UX(2)+DUV(1))/(DUV(2)-DUV(1))))
        CALL ABCC
        IF (KSTOP .NE. 0) GO TO 32
        IF (ABS(DUV(3)).LT. .1E-4*VV2) KSTOP = 1
        UX(1) = UX(2)
        UX(2) = UX(3)
        DUV(1) = DUV(2)
        DUV(2) = DUV(3)
        GO TO 31
32      AB = SQRT((ZLOG+AM)**2+BM**2)
        UXV(IB,LS) = K35/AB
        AB = UXV(IB,LS)**2/AB
        CDR(IB,LS,1) = (ZLOG+AM)*AB
        CDR(IB,LS,2) = BM*AB
        TURN(IB,LS) = ATAN(BM/(ZLOG+AM))
        CONTINUE
40      CONTINUE
41      RETURN
      END

```

```

SUBROUTINE COMOUT (LEVEL)
COMMON/C1/DM1(2),DX,DT,F,DM2(2),UC,VC,DM3(5)
,ST12
COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
1 ,PX(21,21,5),PY(21,21,5),VTH(21,21,5),ANG(21,21,5)
2 ,LV(21,21,5)
COMMON
$/C4/ CDR(100,2,2),UXV(100,2),TURN(100,2)
$/C5/ FLAT,PTH,DTH(2),HH,ZOLAND,LS,VV(100),UX(3),UV(3),
$ OUV(3),K35,K2,G,GA,DEN,VV2,HL,K123,Z0,ZLOG,AH,BM,CM,FF
DIMENSION HKL(21,21),DRAG(2)
DATA E1,E2/0.5,0.5/
DATA VONK/0.4/
C SQQ IS APPROXIMATION TO SORT OF SUM OF SQUARES
SQQ(A,B) = (ABS(A)+ABS(B))/2.51 + (ABS(A+H)+ABS(A-B))*0.7071/2.51
DO 800 NC = 1,LEVEL
NEST = LEVEL-NC+1
DO 720 I = 1,21
DO 720 J = 1,21
U(I,J,NEST) = UN(I,J,NEST)
V(I,J,NEST) = VN(I,J,NEST)
CONTINUE
720 IF (NEST.EQ.LEVEL) GO TO 721
IF (NEST.NE.5) CALL OUTBY2(NEST)
GO TO 722
721 CALL OUTBY1(NEST)
722 CONTINUE
DXL = 2.0*(NEST-1)*DX+1000.0
DXL2=DXL**2
DTL=2.0*(NEST-1)*DT
FTL=F*DTL
FTL1=FTL**2+1.0
FCL=2.0*VONK**2*(DXL/2.0)**2
C INNER BOUNDARY
IF (NEST.EQ.1) GO TO 730
DO 724 J=1,10

```

```

724 U(7,J+6,NEST)=UN(3,2+J+1,NEST-1)
    V(7,J+6,NEST)=VN(3,2+J+1,NEST-1)
    V(15,J+6,NEST)=VN(19,2+J+1,NEST-1)
    U(15,J+6,NEST)=UH(19,2+J+1,NEST-1)
    CONTINUE
    DO 726 I=1,10
    U(1+6,7,NEST)=UN(2+1+1,3,NEST-1)
    V(1+6,7,NEST)=VN(2+1+1,3,NEST-1)
    U(1+6,15,NEST)=UN(2+1+1,19,NEST-1)
    V(1+6,15,NEST)=VN(2+1+1,19,NEST-1)
726 CONTINUE
    C COMPUTATION OF INTERIOR POINT
730 DO 734 I=1,20
    DO 734 J=1,20
    IF (NEST.EQ. 1) GO TO 733
    IF (I.LE. 6 .OR. I.GE. 15) GO TO 733
    IF (J.LE. 6 .OR. J.GE. 15) GO TO 733
    HKL(I,J)=0.0
    GO TO 734
733 D1=0.5*(U(I+1,J,NEST)-U(I,J,NEST)+U(I+1,J+1,NEST)-U(I,J+1,NEST)
    1 -V(I,J+1,NEST)+V(I,J,NEST)-V(I+1,J+1,NEST)+V(I+1,J,NEST))/DXL
    D2=0.5*(V(I+1,J,NEST)-V(I,J,NEST)+V(I+1,J+1,NEST)-V(I,J+1,NEST)
    1 +U(I,J+1,NEST)-U(I,J,NEST)+U(I+1,J+1,NEST)-U(I+1,J,NEST))/DXL
    HKL(I,J) = FCL*SQ(D1,D2)
734 CONTINUE
    DO 775 I=2,20
    DO 775 J=2,20
    IF (NEST.EQ. 1) GO TO 736
    IF (I.LE. 6 .OR. I.GE. 16) GO TO 736
    IF (J.LE. 6 .OR. J.GE. 16) GO TO 736
    UN(I,J,NEST)=U(I,J,NEST)
    VN(I,J,NEST)=V(I,J,NEST)
    GO TO 775
736 U1=U(I,J,NEST)+UC
    V1=V(I,J,NEST)+VC

```

```

C DRAG(1) IS TANGENTIAL DRAG CORRECTION TERM
C DRAG(2) IS NORMAL DRAG CORRECTION TERM
  LS=LW(I,J,NEST)
  SPP=SQ3(U1,V1)
  SPP1 = AMAX1(1.,AMIN1(99.99,1.25*SPP))
  KPP=SPP1
  SPP1=SPP1-KPP
  SPH = SPP/HH
  DO 737 IA = 1,2
    DRAG(IA) = SPH*(CDR(KPP,LS,IA)+
      $ SPP1*(CDR(KPP+1,LS,IA)-CDR(KPP,LS,IA)))
737  CONTINUE
    IF(NEST .NE. 5) GO TO 741
    IF(I .NE. 2 .AND. J .NE. 20) GO TO 741
    IF(I-2) 738,738,740
738  IF(U(I,J,NEST)) 739,739,741
739  UKX=0.0
    VKX=0.0
    GO TO 742
740  IF(U(I,J,NEST)) 741,739,739
741  UKX=0.5*((HKL(I,J-1)+HKL(I,J))+(U(I+1,J,NEST)-U(I,J,NEST)))
1    -((HKL(I-1,J-1)+HKL(I-1,J))+(U(I,J,NEST)-U(I-1,J,NEST)))/DXL2
    VKX=0.5*((HKL(I,J-1)+HKL(I,J))+(V(I+1,J,NEST)-V(I,J,NEST)))
1    -((HKL(I-1,J-1)+HKL(I-1,J))+(V(I,J,NEST)-V(I-1,J,NEST)))/DXL2
    IF(NEST .NE. 5) GO TO 746
742  IF(J .NE. 2 .AND. J .NE. 20) GO TO 746
    IF(J-2) 743,743,745
743  IF(V(I,J,NEST)) 744,744,746
744  UKY=0.0
    VKY=0.0
    GO TO 747
745  IF(V(I,J,NEST)) 746,744,744
746  UKY=0.5*((HKL(I-1,J)+HKL(I,J))+(U(I,J+1,NEST)-U(I,J,NEST)))
1    -((HKL(I-1,J-1)+HKL(I,J-1))+(U(I,J,NEST)-U(I,J-1,NEST)))/DXL2
    VKY=0.5*((HKL(I-1,J)+HKL(I,J))+(V(I,J+1,NEST)-V(I,J,NEST)))
1    -((HKL(I-1,J-1)+HKL(I,J-1))+(V(I,J,NEST)-V(I,J-1,NEST)))/DXL2

```

```

747 IF(U(I,J,NEST)) 748,750,750
748 UX=-U(I,J,NEST)*(U(I,J,NEST)-U(I+1,J,NEST))/DXL
VX=-U(I,J,NEST)*(V(I,J,NEST)-V(I+1,J,NEST))/DXL
GO TO 752
750 UX= U(I,J,NEST)*(U(I,J,NEST)-U(I-1,J,NEST))/DXL
VX= U(I,J,NEST)*(V(I,J,NEST)-V(I-1,J,NEST))/DXL
752 IF(V(I,J,NEST)) 754,756,756
754 UY=-V(I,J,NEST)*(U(I,J,NEST)-U(I,J+1,NEST))/DXL
VY=-V(I,J,NEST)*(V(I,J,NEST)-V(I,J+1,NEST))/DXL
GO TO 758
756 UY= V(I,J,NEST)*(U(I,J,NEST)-U(I,J-1,NEST))/DXL
VY= V(I,J,NEST)*(V(I,J,NEST)-V(I,J-1,NEST))/DXL
758 UR=0.5*(U(I,J,NEST)+V(I,J,NEST))
VR=0.5*(-U(I,J,NEST)+V(I,J,NEST))
IF(UR) 760,762,762
760 UX1=-UR*(U(I,J,NEST)-U(I+1,J+1,NEST))/DXL
VX1=-UR*(V(I,J,NEST)-V(I+1,J+1,NEST))/DXL
GO TO 764
762 UX1= UR*(U(I,J,NEST)-U(I-1,J-1,NEST))/DXL
VX1= UR*(V(I,J,NEST)-V(I-1,J-1,NEST))/DXL
764 IF(VR) 766,768,768
766 UY1=-VR*(U(I,J,NEST)-U(I-1,J+1,NEST))/DXL
VY1=-VR*(V(I,J,NEST)-V(I-1,J+1,NEST))/DXL
GO TO 770
768 UY1= VR*(U(I,J,NEST)-U(I+1,J-1,NEST))/DXL
VY1= VR*(V(I,J,NEST)-V(I+1,J-1,NEST))/DXL
770 UXY=E1*(UX+UY)+E2*(UX1+UY1)
VXY=E1*(VX+VY)+E2*(VX1+VY1)

```

```

      B1 = U(I,J,NEST)+DTL*
      $ (UKX+UKY-PX(I,J,NEST)-UXY+U1*DRAG(1)+V1*DRAG(2))
      B2 = V(I,J,NEST)+DTL*
      $ (VKX+VKY-PY(I,J,NEST)-VXY+V1*DRAG(1)-U1*DRAG(2))
      UN(I,J,NEST)=(B1+FTL*B2)/FTL1
      VN(I,J,NEST)=(B2-FTL*B1)/FTL1
      775 CONTINUE
      800 CONTINUE
      RETURN
      END

```

SUBROUTINE GRAD
 GRAD COMPUTES PRESSURE GRADIENT
 COMPLEX CD,CR,CT
 COMMON/C1/DH1(2),DX,DH2(4),UC,VC,DH3(4),IB
 ,ST12
 COMMON/C2/JA(15),AB(21,21,15),AC(21,7,21)
 DIMENSION AD(21,4),AP(3,2),AT(2),BA(15),BC(4,2),BP(2,2)
 EQUIVALENCE (CR,AP(2,1)),(CD,AP(2,2)),(CT,AT),(BC,BA(8))
 IB IS SWITCH VARIABLE. IB = 0 TO SUPPRESS PRINTING.
 ITRACK IS INDICATOR FOR CODING OF DIREC
 EYELAT IS NORTH LATITUDE OF EYE IN DEGREES
 (SOUTH LATITUDE MUST HAVE MINUS SIGN)
 EYLONG IS EAST LONGITUDE OF EYE IN DEGREES
 (WEST LONGITUDE MUST HAVE MINUS SIGN)
 DIREC IS DIRECTION OF TRACK OF HURRICANE, CLOCKWISE FROM NORTH
 ITRACK = 0, DIREC IN DEGREES
 ITRACK = 1, DIREC IN POINTS OF 11.25 DEG
 SPEED IS FORWARD SPEED OF HURRICANE IN KNOTS
 IQUAD IS INDICATOR FOR QUADRANTS OF PRESSURE FIELD
 IQUAD = 0, CIRCULARLY SYMMETRIC PRESSURE FIELD
 IQUAD = 1, FIRST QUADRANT IS RIGHT FRONT
 IQUAD = 2, FIRST QUADRANT IS FORWARD
 QUADRANTS FOLLOW CLOCKWISE FROM FIRST
 LYPRES IS PRESSURE AT EYE IN MILLIBARS
 RADIUS(1,2,3,4) ARE R IN FOUR QUADRANTS IN UNITS OF 1.0 NM
 (1852 METERS)
 PFAR(1,2,3,4) ARE FAR FIELD PRESSURE IN FOUR QUADRANTS,
 IN MILLIBARS
 IF IQUAD = 0, ENTER RADIUS(1) AND PFAR(1) ONLY
 AB(I+11,J+11,K+1) IS DP/DX (EAST) IN MB/KM AT 5*I+2**K KM EAST OF EYE
 AND 5*J+2**K KM SOUTH OF EYE
 AB(I+11,J+11,K+6) IS DP/DY (NORTH) IN MB/KM AT SAME POINT
 AB(I+11,J+11,K+11) IS DP/DR (OUTWARD) IN MB/KM AT SAME POINT
 AC(I+11,J+11) IS COS OF ANGLE OF POINT I,J
 (SAME FOR ALL GRID NESTS)

```

C      AC(I+11,2,J+11) IS SIN OF ANGLE OF POINT I,J
C      (SAME FOR ALL GRID NESTS)
C      AC(I+11,3...7,J+11) IS RADIUS OF POINT I,J IN NEST 1...5
C      RESPECTIVELY (METERS)

      REAL RADIUS(4),PFAR(4)
      EQUIVALENCE (ITRACK,JA),(EYELAT,JA(2)),(LYLONG,JA(3)),
$      (DIREC,JA(4)),(SPEED,JA(5)),(IQUAD,JA(6)),(EYPRES,JA(7)),
$      (RADIUS,JA(8)),(PFAR,JA(12))
      DATA LU/6/
      DATA DEG / .017453293/
      DATA S45 / .70710678/
      COMPUTE GRID ANGLES AND DISTANCES (FUNCTION OF DX ONLY)
      DO 10 IG = 1,21
      AD(IG,1) = DX*FLOAT(IG-11)
      DO 12 IC = 1,21
      DO 12 ID = 1,21
      AE = AD(IC,1)*2+AD(ID,1)*2
      IF (AE.LE.0) GO TO 12
      AC(IC,3,ID) = SORT(AE)
      AC(IC,1,ID) = AD(IC,1)/AC(IC,3,ID)
      AC(IC,2,ID) = -AD(ID,1)/AC(IC,3,ID)
      DO 11 IE = 4,7
      AC(IC,IE,ID) = AC(IC,IE-1,10)+AC(IC,IE-1,ID)
11      CONTINUE
12      HA(4) = DIREC*DEG
      IF (JA(1).NE.0) BA(4) = BA(4)+11.25
      BA(5) = SPEED*(1852./3600.)
      IF (JA(6).EQ.0) GO TO 280
      DU 21 IC = 1,4
      BA(IC+7) = RADIUS(IC)+1.852
      BA(IC+11) = PFAR(IC)-EYPRES
      CONTINUE
21      DO 25 IC=1,2
24      AP(1,IC) = .25*(BC(1,IC)+BC(2,IC)+BC(3,IC)+BC(4,IC))
25      IF (JA(6).EQ.2) GO TO 27

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```

26 DO 26 IC = 1,2
   AP(2,IC) = .5*S45*(BC(1,IC)+BC(2,IC)-BC(3,IC)-BC(4,IC))
   AP(3,IC) = .5*S45*(BC(1,IC)-BC(2,IC)-BC(3,IC)+BC(4,IC))
   GO TO 29

27 DO 28 IC = 1,2
   AP(2,IC) = .5*(EC(2,IC)-BC(4,IC))
   AP(3,IC) = .5*(BC(1,IC)-BC(3,IC))
   CONTINUE

28 GO TO 29
   CONTINUE

29 AP(1,1) = RADIUS(1)*1.852
   AP(1,2) = PFAR(1)-EYPRES
   CONTINUE
   AT(1) = COS(BA(4))
   AT(2) = -SIN(BA(4))
   CR = CR*CT
   CD = CD*CT
   UC = -AT(2)*BA(5)
   VC = AT(1)*BA(5)

31 DO 40 IE = 1,5
   DO 38 ID = 1,21
   DO 35 IC = 1,21
   IF (JA(6).EQ. 0) GO TO 340
   DU 32 IH = 1,2
   BP(1,IH) = AP(1,IH)+AP(2,IH)*AC(IC,1,ID)+AP(3,IH)*AC(IC,2,ID)
   BP(2,IH) = -AP(2,IH)*AC(IC,2,ID)+AP(3,IH)*AC(IC,1,ID)
   IF (AC(IC,3,ID).GT. 0) GO TO 33
   AD(IC,1) = 0.
   AD(IC,2) = 0.
   GO TO 34
   AE = EXP(-BP(1,1)/AC(IC,IE+2,ID))
   AF = AE*BP(1,2)
   C   COMPUTE RADIAL PRESSURE GRADIENT
   AD(IC,1) = -AF*BP(1,1)/AC(IC,IE+2,ID)**2
   AD(IC,2) = (AE*BP(2,2)-AF/AC(IC,IE+2,ID)*BP(2,1))/AC(IC,IE+2,ID)
   C   TANGENTIAL PRESSURE GRADIENT

```

```

34  AD(IC,3) = AD(IC,1)*AC(IC,1,ID)-AD(IC,2)*AC(IC,2,ID)
    AD(IC,4) = AD(IC,1)*AC(IC,2,ID)+AD(IC,2)*AC(IC,1,ID)
    GO TO 341
340  AD(IC,2) = 0.
    C CIRCULARLY SYMMETRIC PRESSURE FIELD: ZERO TANGENTIAL GRADIENT
    C
    AD(IC,1) = EXP(-AP(1,1)/AC(IC,IE+2,ID))*AP(1,2)*AP(1,1)/
    AAC(IC,IE+2,ID)**2
    AD(IC,3) = AD(IC,1)*AC(IC,1,ID)
    AD(IC,4) = AD(IC,1)*AC(IC,2,ID)
341  CONTINUE
    AB(IC,ID,IE+10) = AD(IC,1)
    AB(IC,ID,IE) = AD(IC,3)
35  AB(IC,ID,IE+5) = AD(IC,4)
    IF (IB.EQ. 0) GO TO 38
    C IF NO PROGRAM CHANGES, NORTH IS PRINTED AT TOP
    C OF PAGE, WEST AT LEFT, ETC.
    WRITE (LU,36) AD
    FORMAT (4(1X,1P21F6.2/))
36  CONTINUE
38  IF (IB.EQ. 0) GO TO 40
    WRITE (LU,39)
    FORMAT (////)
39  CONTINUE
40  RETURN
    END

```



```

C****
PARAMETER MAXI=62,MAXJ=31,IGRDHT=100

COMMON /C57/ PTH,DTH,HH,ZCOEFF(3,5),LAKE,VV(100),UX(3),UV(3),
1 DUV(3),K35,K2,GGA,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,UXV(100,6),
2 TURN(100,6),COST(100),SINT(100)
REAL K2,K35

INTEGER LLAKE(100)
COMMON /D1/LA0,LO0,ROT,LA1,LO1,DX,STHT,LANSEA,W1,TH1,D,AL,UST
COMMON /D2/ XX(21,21,10)
COMMON/D3/NSNAP1(100),NSNAP2(100),PCT(100),
1 IPI(100),NHT,INTVN,INTVI
DIMENSION NAD(100),NAM(100),NOD(100),NOM(100),IROT(100)
DIMENSION MAD(100),MAH(100),MMOD(100),MOM(100),YLA(100),YLO(100)
DIMENSION JSEQ(100),KDATE(100),KTIME(100)
DIMENSION WIND(2,MAXI,MAXJ)

C****
DIMENSION ZLA(MAXJ), ZLO(MAXI), ZANG(MAXI,MAXJ)
DIMENSION LSTAB(MAXI,MAXJ)

C****
DIMENSION XY(21,21,10)
DIMENSION STAHT(100),DTHI(2),KSTA(100)
DIMENSION JA(15)
EQUIVALENCE (ITRACK,JA),(FVELAT,JA(2)),(LYLONG,JA(3)),
1 (DIREC,JA(4)),(SPEED,JA(5)),(IQUAD,JA(6)),(EYPRES,JA(7)),
2 (RADIUS,JA(8)),(PFAR,JA(12))
EQUIVALENCE (XY,WIND)

C
DATA CON /57.29578/
DATA LR,LP,LSNAP/5,6,13/
DATA LTEMP/10/
DATA LTROUT/20/
DATA KSNAP1,KSNAP2/2,0/

C
NAMELIST/NAME4/NBASE,ISTART,IZONE,ICNVRT,NPRT
NAMELIST/NAME5/LAKE,ZCOEFF

```

```

NAMELIST/NAMEP/DTH,HH,LAKE,6,ZCOEFF,GARR,PTH,K35
GRIDHT=FLOAT(IGRIDHT)/10.
IMAX=MAXI
JMAX=MAXJ
DO 5 J=1,MAXJ
DO 5 I=1,MAXI
LSTAB(I,J)=0
ZANG(I,J)=0.
DTH=-2.
HHI=650.
LAKE=0
G=9.806
GARR=.035
PTH=300.
K35=.35
DO 10 J=1,5
DO 10 I=1,3
ZCOEFF(I,J)=0.
REVIND LSNAP
REVIND LTEMP
HEAD (LR,NAME4)
WRITE (LP,NAME4)
PRINT 100, NBASE, ISTART, IZONE
READ (LSNAP) XX,NAME,DX,JA,SGW,ANI,SI12,DTHI,HH,GARR,PTH,K35
READ (LR,NAME5)
IF (ICNVRT.NE.0) CALL RDGRID(ZLA,ZLO,LSTAB,MAXI,MAXJ)
CTH=DTHI(2)
WRITE (LP,NAME P)
K2=K35**2
GA=GARR/G
OT=10.0*OX
CALL UXXV
CALL UPDOWN
IF (NBASE.NE.NAME) STOP 515
NHR=0

```

4

5

10

```

C      READ HINDCAST LOCATIONS INPUT CARDS
C
C      15
C      IF (NBR.EQ.100) STOP 516
C      READ (LR,165,ERR=145,END=20) MAD(NBR+1),HAM(NBR+1),MMOD(NBR+1),MOM(
1(NBR+1),LLAKE(NBR+1),STAHT(NBR+1),KSTA(NBR+1)
NBR=NBR+1
WRITE(LP,170) MAD(NBR),HAM(NBR),MMOD(NBR),MOM(NBR),
1 LLAKE(NBR),STAHT(NBR),KSTA(NBR)
XL=IABS(MAD(NBR))
YLA(NBR)=(XL+FLOAT(HAM(NBR)))/60.0)/CON
IF (MAD(NBR).LT.0)YLA(NBR)=-YLA(NBR)
XL=IABS(MMOD(NBR))
YLO(NBR)=(XL+FLOAT(MOM(NBR)))/60.0)/CUN
IF (MMOD(NBR).LT.0)YLO(NBR)=-YLO(NBR)
GO TO 15
CONTINUE
20  IF (NBR.NE.0) WRITE (LP,175)
C      READ HOOKLY INPUT CARDS .
C
C      NHT=0
C      25  READ (LR,180,ERR=145,END=30) NAD(NHT+1),NAM(NHT+1),NOD(NHT+1),NOM(
1NHT+1),NSNAP1(NHT+1),NSNAP2(NHT+1),PCT(NHT+1),IROT(NHT+1),
2 IPI(NHT+1)
NHT=NHT+1
IF (NHT.LT.100) GO TO 25
STOP 517
CONTINUE
30  WRITE (LP,185)
KY=ISTART/10**6+1900
KH=MOD((ISTART/10**4),100)
KD=MOD((ISTART/100),100)
KTIME(1)=MOD(ISTART,100)
KJD=JULIAN(KM,KD,KY)

```



```

55 READ (LSNAP) XY,NAMEI
60 CONTINUE
CONTINUE
IF (PCT(KHR).EQ.0.) GO TO 70
KSNAP1=0
IF (PCT(KHK).LT.0..OR.PCT(KHR).GT.1.) STOP ***
DO 65 K=1,10
DO 65 J=1,21
DO 65 I=1,21
XX(I,J,K)=(1.-PCT(KHR))*XX(I,J,K)+PCT(KHR)*XY(I,J,K)
CONTINUE
CONTINUE
CONTINUE

IF (KHR.EQ.1) GO TO 75
IF (JSEQ(KHR).EQ.JSEQ(KHR-1)) GO TO 80
WRITE (LTEKP) XX,JSEQ(KHR)
CONTINUE
IF (NBR.EQ.0) GO TO 106

COMPUTE WIND FOR EACH HINDCAST LOCATION AT THIS TIME STEP

DO 105 K=1,NBR
WRITE (LP,185)
LA1=YLA(K)
LO1=YLO(K)
STHT=STAHT(K)
LANSEA=LLAKE(K)

REWIND LTEMP

DO 100 KHR=1,NHT
IF (KHR.EQ.1) GO TO 85
IF (JSEQ(KHR).EQ.JSEQ(KHR-1)) GO TO 90
READ (LTEMP,ERR=146) XX,KSELQ

```



```

1065      READ (LTEMP,ERR=146) XX,KSEQ
107       CONTINUE
      DO 111 J=1,MAXJ
C****
      LA1=ZLA(J)
C****
      DO 110 I=1,MAXI
C****
      LO1=ZLO(I)
C****
      LANSEA=LSTAB(I,J)
      CALL BREEZE
      WIND(1,I,J)=V1
      WIND(2,I,J)=TH1+ZANG(I,J)
110      CONTINUE
111      CONTINUE
      WRITE (LTROUT) NBASE,KHR,ISTART,IZONE,IMAX,JMAX,GRIDHT,NAD(KHR),
1      NAM(KHR),NOD(KHR),NOM(KHR),WIND
      IF (IPI(KHR).NE.0) GO TO 112
      IF (NPRT.EQ.0) GO TO 113
      IF (MOD((KHR-1),NPRT).NE.0) GO TO 113
112      CALL PRLAKE (NBASE,KHR,ISTART,IZONE,WIND,LSTAB,MAXI,MAXJ)
113      CONTINUE
      END FILE LTROUT
C
135      WRITE (LP,205)
      STOP 999
145      STOP 5
146      STOP 146
C
160      FORMAT (4X,A4,4X,1B,A3)
165      FORMAT (5I4,F6.1,1X,13)
170      FORMAT(1X,2(I4,1X,J2),I3,F6.1,13)
175      FORMAT (//)
180      FORMAT(6I4,F8.4,2I4)
185      FORMAT (1H1)

```

```

190  FORMAT (1H1,///,T20,'STORM HISTORY 1ST HOUR IS ',I8,I8,A3,/,/,I1
195  1X,I4,6I4,F8.4,3I4,I8,J2),
      FORMAT (1X,A6,J6,J2,' W1=',F6.2,' TH1=',F5.1,' D=',F6.1,' AL=',F5
1.1,' UST=',F6.2,' STA',I3,'=,I3,I3,J2,I4,I1X,J2,
2.0  ' EYE=',I3,I1X,J2,I4,I1X,J2,' TERR=',I1,
3.0  ' HT=',F5.1,I4,I2)
200  FORMAT (//)
205  FORMAT (1H1,' END OF HIST/MAIN')
      END

```

```

C
C
C
COMPILER (XN=1), (EQUIV=CHN)
SUBROUTINE INVJO (J,M,D,Y)
  REVERSE OF FUNCTION 'JULIAN'.
  COMPUTES INVERSE JULIAN DATE J FROM
  MONTH(M), DAY(D), AND YEAR(Y) INPUT.
  INTEGER J,M,D,Y,TJ,TH,TD,TY,MTD
  TJ=J-1721119
  TY=(4+TJ-1)/146097
  TJ=4+TJ-1-146097*TY
  TD=TJ/4
  MTD=4*TD+3
  TJ=MTD/1461
  TD=MTD-1461*TJ
  TD=(TD+4)/4
  MTD=5*TD-3
  TH=MTD/153
  TD=MTD-153*TH
  D=(TD+5)/5
  Y=100*TY+TJ
  IF (TH.GE.10) GO TO 2
1 M=TH+3
  RETURN
2 M=TH-9
  Y=Y+1
  RETURN
END

```



```

SUBROUTINE OUTBY1(NEST)
C  OUTER BOUNDARY ( NOT AT THE SAME TIME LEVEL)
COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
1  ,PX(21,21,5),PY(21,21,5),VTN(21,21,5),ANG(21,21,5)
2  ,LW(21,21,5)
UN(1,1,NEST)=0.5*(UN(6,6,NEST+1)+U(6,6,NEST+1))
VN(1,1,NEST)=0.5*(VN(6,6,NEST+1)+V(6,6,NEST+1))
DO 780 J=1,10
UN(1,2+J+1,NEST)=0.5*(UN(6,J+6,NEST+1) +U(6,J+6,NEST+1))
VN(1,2+J+1,NEST)=0.5*(VN(6,J+6,NEST+1) +V(6,J+6,NEST+1))
UN(21,2+J+1,NEST)=0.5*(UN(16,J+6,NEST+1)+U(16,J+6,NEST+1))
VN(21,2+J+1,NEST)=0.5*(VN(16,J+6,NEST+1)+V(16,J+6,NEST+1))
UN(1,2+J,NEST)=0.250*(UN(6,J+5,NEST+1)+UN(6,J+6,NEST+1)
1  + U(6,J+5,NEST+1)+U(6,J+6,NEST+1))
VN(1,2+J,NEST)=0.250*(VN(6,J+5,NEST+1)+VN(6,J+6,NEST+1)
1  + V(6,J+5,NEST+1)+V(6,J+6,NEST+1))
UN(21,2+J,NEST)=0.250*(UN(16,J+5,NEST+1)+UN(16,J+6,NEST+1)
1  + U(16,J+5,NEST+1)+U(16,J+6,NEST+1))
VN(21,2+J,NEST)=0.250*(VN(16,J+5,NEST+1)+VN(16,J+6,NEST+1)
1  + V(16,J+5,NEST+1)+V(16,J+6,NEST+1))
780  CONTINUE
DO 790 I=1,10
UN(2,1+I,1,NEST)=0.5*(UN(1+6,6,NEST+1)+U(1+6,6,NEST+1))
VN(2,1+I,1,NEST)=0.5*(VN(1+6,6,NEST+1)+V(1+6,6,NEST+1))
UN(2,1+I,21,NEST)=0.5*(VN(1+6,16,NEST+1)+V(1+6,16,NEST+1))
UN(2,1+I,21,NEST)=0.5*(UN(1+6,16,NEST+1)+U(1+6,16,NEST+1))
UN(2,1,1,NEST)=0.250*(UN(1+5,6,NEST+1)+UN(1+6,6,NEST+1)
1  + U(1+5,6,NEST+1)+U(1+6,6,NEST+1))
VN(2,1,1,NEST)=0.250*(VN(1+5,6,NEST+1)+VN(1+6,6,NEST+1)
1  + V(1+5,6,NEST+1)+V(1+6,6,NEST+1))
UN(2,1,21,NEST)=0.250*(UN(1+5,16,NEST+1)+UN(1+6,16,NEST+1)
1  + U(1+5,16,NEST+1)+U(1+6,16,NEST+1))
VN(2,1,21,NEST)=0.250*(VN(1+5,16,NEST+1)+VN(1+6,16,NEST+1)
1  + V(1+5,16,NEST+1)+V(1+6,16,NEST+1))
790  CONTINUE
RETURN
END

```

```

C
SUBROUTINE OUTBY2(NEST)
  OUTER BOUNDARY (AT SAME TIME LEVEL)
  COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
  1 ,PX(21,21,5),PY(21,21,5),VTN(21,21,5),ANG(21,21,5)
  2 ,LW(21,21,5)
  UN(1,1,NEST)=UN(6,6,NEST+1)
  VN(1,1,NEST)=VN(6,6,NEST+1)
  DO 820 J=1,10
    UN(1,2,J+1,NEST)=UN(6,J+6,NEST+1)
    VN(1,2,J+1,NEST)=VN(6,J+6,NEST+1)
    UN(21,2,J+1,NEST)=VN(16,J+6,NEST+1)
    UN(21,2,J+1,NEST)=UN(16,J+6,NEST+1)
    UN(1,2,J,NEST)=0.5*(UN(6,J+5,NEST+1)+UN(6,J+6,NEST+1))
    VN(1,2,J,NEST)=0.5*(VN(6,J+5,NEST+1)+VN(6,J+6,NEST+1))
    VN(21,2,J,NEST)=0.5*(VN(16,J+5,NEST+1)+VN(16,J+6,NEST+1))
    UN(21,2,J,NEST)=0.5*(UN(16,J+5,NEST+1)+UN(16,J+6,NEST+1))
  CONTINUE
P20 DO 830 I=1,10
    UN(2,I+1,1,NEST)=UN(1+6,6,NEST+1)
    VN(2,I+1,1,NEST)=VN(1+6,6,NEST+1)
    UN(2,I+1,21,NEST)=VN(1+6,16,NEST+1)
    UN(2,I+1,21,NEST)=UN(1+6,16,NEST+1)
    UN(2,I+1,NEST)=0.5*(UN(1+5,6,NEST+1)+UN(1+6,6,NEST+1))
    VN(2,I+1,NEST)=0.5*(VN(1+5,6,NEST+1)+VN(1+6,6,NEST+1))
    VN(2,I+1,21,NEST)=0.5*(VN(1+5,16,NEST+1)+VN(1+6,16,NEST+1))
    UN(2,I+1,21,NEST)=0.5*(UN(1+5,16,NEST+1)+UN(1+6,16,NEST+1))
  CONTINUE
R30 CONTINUE
  RETURN
  END

```

```

SUBROUTINE OUTFLO
COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
1  ,PX(21,21,5),PY(21,21,5),VTN(21,21,5),ANG(21,21,5)
2  ,LW(21,21,5)
DATA C08,SI6/.99026807,.1391731/
DO 10 IA = 1,2205
  XX = UN(IA,1,1)*C08+VN(IA,1,1)*SI6
  VN(IA,1,1) = VN(IA,1,1)+C08-UN(IA,1,1)*SI6
  UN(IA,1,1) = XX
10 CONTINUE
RETURN
END

```

```

SUBROUTINE JUTOUT(I20,NAME,IDENT,NSEQ)
COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
1  ,PX(21,21,5),PY(21,21,5),VTN(21,21,5),ANG(21,21,5)
2  ,LW(21,21,5)
DATA LP/6/
WRITE (6,10)
FORMAT (1H1)
IF (IDENT.EQ.4)INIT) GO TO 190
DO 80 NEST = 1,4
DO 80 I=1,10
DO 80 J=1,10
UN(I+6,J+6,NEST+1)=UN(2+I+1,2+J+1,NEST)
VN(I+6,J+6,NEST+1)=VN(2+I+1,2+J+1,NEST)
CONTINUE
CALL AANGEL (I20)
CALL TVEL(VTN,ANG,NAME,IDENT,NSEQ,4,I20)
CALL TVEL(VTN,ANG,NAME,IDENT,NSEQ,3,I20)
CALL TVEL(VTN,ANG,NAME,IDENT,NSEQ,1,I20)
RETURN
END

```

10

80
190

```

SUBROUTINE PRLAKE(NBASE,KHR,ISTART,IZONE,WIND,LSTAB,MAXI,MAXJ)
COMMON /LGRID/ ILAT(31),ILONG(62)
DIMENSION WIND(2,MAXI,MAXJ),LSTAB(MAXI,MAXJ)
DIMENSION ILN(3),LLN(3),KODES(6)
DIMENSION LIST(24)
DATA ILN/1,20,39/
DATA LLN/24,43,62/
DATA KODES/3H 3H**3H==3H---3H++3H$$$/
DEFINE KODESP(N)=KODES(N)
DO 60 NPLAT=1,2
LLATSQ=(2-NPLAT)*14+1
ILATSQ=LLATSQ+16
DO 55 NPLONG=1,3
J1=ILN(NPLONG)
J2=LLN(NPLONG)
PRINT 20,NBASE,KHR,ISTART,IZONE,(ILONG(J),J=J1,J2)
FORMAT(1H1,' STORM ',A4,
1 ' LAKE PONT WINDS AT HCUR', I3,' 1ST HOUR IS',
2 I10,A3,/,5X,24I5,/)
DO 30 L=LLATSQ,ILATSQ
LAT=ILATSQ+LLATSQ-L
KOUNT=0
DO 22 I=J1,J2
KOUNT=KOUNT+1
LIST(KOUNT)=KODESP(LSTAB(I,LAT))
CONTINUE
PRINT 25,ILAT(LAT),(WIND(1,J,LAT),J=J1,J2),ILAT(LAT),
1 ILAT(LAT),(WIND(2,K,LAT),K=J1,J2),ILAT(LAT),LIST
FORMAT(1X,14,24F5.1,I5,/,1X,14,24F5.0,I5,/,7X,24(A3,2X))
CONTINUE
CONTINUE
CONTINUE
CONTINUE
END

```

```

C
C
C
SUBROUTINE PXYM
  PXYM CALLS SUBROUTINE GRAD TO GET PRESSURE GRADIENT,
  THEN REARRANGES THE PRESSURE GRADIENT, THEN PRODUCES
  INITIAL GRADIENT WIND FIELD.
  COMMON /C1/ Z1(2),DX,DT,F,SGW,AN1,Z2(2),UG,VG,Z3(3),ST12
  COMMON /C2/JA(15),BA(21,21,15),BC(21,7,21)
  COMMON /C3/ U(21,21,5),V(21,21,5),UN(21,21,5),VN(21,21,5)
  1 ,PX(21,21,5),FY(21,21,5),VTN(21,21,5),ANG(21,21,5)
  2 ,LW(21,21,5)
  DO 50 VEST = 1,5
  GO TO (10,30,30,30,30),NEST
  CALL GRAD
  AN2 = AN1*3.14159265/180.
  IF (ST12 .LE. 0) GO TO 30
  DX2 = .5*DX/ST12
  CO2 = COS(AN2)*DX2
  SI2 = SIN(AN2)*DX2
  DO 31 I = 1,21
  DO 31 J = 1,21
  MJ=22-J
  PX(I,J,NEST) = BA(I,MJ,NEST)*(1E-4/1.15E-3)
  PY(I,J,NEST) = BA(I,MJ,NEST+5)*(1E-4/1.15E-3)
  AG = BA(I,MJ,NEST+10)*(1E-4/1.15E-3)
  AH=BC(I,NEST+2,MJ)*F*500.
  AI=AG+BC(I,NEST+2,MJ)*1000.
  IF (AI.NE.0.) AI = AI/(AI+SORT(AH*AH+AI))
  U(I,J,NEST) = -AI*BC(I,2,MJ)
  V(I,J,NEST) = AI*BC(I,1,MJ)
  UN(I,J,NEST) = U(I,J,NEST)
  VN(I,J,NEST) = V(I,J,NEST)
  SGW NON-ZERO FOR STEERING FLOW.
  IF (SGW.EQ.0.) GO TO 50
  AG = F*UG
  AH = F*VG

```

	IF (ST12 .GT. 0) GO TO 34
	DO 33 I = 1,21
	DO 33 J = 1,21
33	PX(I,J,NEST) = PY(I,J,NEST)+AH
	PY(I,J,NEST) = PY(I,J,NEST)-AG
	GO TO 50
34	C02 = C02+C02
	SI2 = SI2+SI2
	DO 36 I = 1,21
	AI = (I-11)*SI2
	DO 35 J = 1,21
	AJ = (J-11)*C02
	FADE = -.69314718*(AJ-AI)**2
	FADE = EXP(FADE)
	IF (FADE .LE. 0.) GO TO 35
	PX(I,J,NEST) = PX(I,J,NEST)+AH*FADE
	PY(I,J,NEST) = PY(I,J,NEST)-AG*FADE
35	CONTINUE
36	CONTINUE
50	CONTINUE
99	RETURN
	END

```

SUBROUTINE KUGRID (ZLA,ZLO,LSTAB,MAXI,MAXJ)
COMMON /LGRID/ ILAT(31),ILONG(62)
DIMENSION LSTAB(MAXI,MAXJ)
DIMENSION ZLA(MAXJ),ZLO(MAXI)
DO 25 J=1,4
  I1=(J-1)*15+1
  I2=I1+14
  READ 15,(ILONG(I),I=I1,I2),KSEQ
  FORMAT (16I5)
  IF(KSEQ.EQ.0) GO TO 25
  PRINT 20,KSEQ,J,(ILONG(I),I=I1,I2)
  FORMAT(/,' GRID INPUT ERROR',16I5)
  STOP 21
CONTINUE
READ 30,ILONG(61),ILONG(62),KSEQ
FORMAT(2I5,65X,I5)
IF(KSEQ.EQ.5) GO TO 35
PRINT 20,KSEQ,ILONG(61),ILONG(62)
STOP 21
READ 15,(ILAT(I),I=1,15),KSEQ
IF(KSEQ.NE.1) GO TO 40
READ 15,(ILAT(I),I=16,30),KSEQ
IF(KSEQ.NE.2) GO TO 40
READ 37,ILAT(31),KSEQ
FORMAT(15,70X,I5)
IF(KSEQ.EQ.3) GO TO 45
PRINT 20,ILAT,KSEQ
STOP 23
CONTINUE
DO 35 J=1,MAXJ
  L=IABS(ILAT(J))/100
  M=IABS(MOD(ILAT(J),100))
  ZLA(J)=(FLOAT(L)+FLOAT(M)/60.)*.0174532
  IF(ILAT(J).LT.0) ZLA(J)=-ZLA(J)
  READ 50,(LSTAB(I,J),I=1,62),KSEQ
  FORMAT(10X,62I1,6X,I2)

```

```

51      IF (KSEQ.EU.J) GO TO 55
        PRINT 51,J,KSEQ,(LSTAB(I,J),I=1,62)
        FORMAT(' LS INPUT ERROR',2I4,2X,62I1)
        STOP 51
55      CONTINUE
        DO 60 I=1,MAXI
          L=IABS(I LONG(I))/100
          M=IABS(MOD(I LONG(I),100))
          ZLO(I)=(FLOAT(L)+FLOAT(M)/60.)*.0174532
          IF (I LONG(I).LT.0) ZLO(I)=-ZLO(I)
60      CONTINUE
        END

```

```

SUBROUTINE SHORE
COMMON /C3/ U(21,21,5),V(21,21,5),UH(21,21,5),VN(21,21,5)
1  ,PX(21,21,5),PY(21,21,5),VTN(21,21,5),ANG(21,21,5)
2  ,LW(21,21,5)
DO 20 I=1,2205
  LW(I)=2
RETURN
END

```

20


```

C
REAL K35,K2
DATA LR,LP,LSNAP,LSHORE/5,6,13,14/
DATA PTH/300./
DATA HH/650./
DATA ZOLAND/.08/
DATA K35/.35/
DATA G/9.805/
DATA GARR/.0144/
DATA DTH/0.-2./

C
NAMELIST/NAME1/IR,NZ
NAMELIST/NAME2/DTH,HH,ZOLAND,GARR,PTH,K35
NAMELIST/NAME3/SGW,AN1,NAME,
$ EYELAT,EYLONG,DIREC,SPEED,EYPRES,RADIUS,PFAR,
$ NH,DX,ST12,ITRACK,IQUAD

C
REVIND LSNAP
READ (LR,NAME1)
WRITE (LP,NAME1)
FORMAT (2I5)
READ (LR,NAME2)
WRITE (LP,NAME2)
K2=K35**2
GA = GARR/G

C
DO 20 NSNAP= 1,NZ
WRITE (LP,15)
NM = 800
DX = 5.
ST12 = 0.
ITRACK = 0
IQUAD = 0
READ (LR,NAME3)
WRITE (LP,NAME3)
DT = 10.0*DX

```



```

C      SUBROUTINE TVEL(VTN,ANG,NBASE,IDENT,KSEQ,LV,I20)
C      IF IN ARRAYS VTN,ANG 1ST DIMENSION INCREASES EASTWARD AND
C      2ND DIMENSION INCREASES NORTHWARD, SUBROUTINE TVEL PRINTS
C      WEST AT TOP OF PAGE,NORTH AT RIGHT OF PAGE, ETC.
C      NEST LV IS PRINTED AS INNER NEST, LV+1 AS OUTER NEST.
      DIMENSION VTN(21,21,5),ANG(21,21,5)
      DIMENSION KREDUC(2)/AHNOT ,IH /
      DATA LU/6/
      WRITE (LU,100)
      FORMAT(1111)
      CVP=LV+1
      I20P=I20+1
      WRITE (LU,200) NBASE,IDENT,KSEQ,LVP,KREDUC(I20P)
      FORMAT(1H0,20X,A4,5X,A4,1X,I4, ' LEVEL',13,5X,A4,'REDUCED')
1150   WRITE (LU,I200) (J, J=1,12)
1200   FORMAT(1H0,11X,12(I2,UX))
      DO 1210 I=1,5
1210   WRITE (LU,I220) (I,(VTN(I,J,LVP),J=1,12),(ANG(I,J,LVP),J=1,12))
1220   FORMAT(1H0,6X,12,12(1PF5.0,5X)/9X,12(0PF5.0,5X),/1H0,/)
1240   DO 1248 I=1,11
      IL=I+5
      IO=2+I-1
      IE=2+I
      IF (I-11) 1242,1246,1246
1242   WRITE (LU,1244) IL,(VTN(IL,J,LVP),J=1,5),(VTN(IO,N,LV),N=1,13)
      1 , (ANG(IL,J,LVP),J=1,5),(ANG(IO,N,LV),N=1,13)
      2 , (VTN(IE,N,LV),N=1,13),(ANG(IE,N,LV),N=1,13)
1244   FORMAT(1H0,6X,12,5(1PF5.0,5X),13(1PF5.0)/9X,5(0PF5.0,5X),
      1 13(0PF5.0)/1H0,58X,13(1PF5.0)/59X,13(0PF5.0))
      GO TO 1248
1246   WRITE (LU,1247) IL,(VTN(IL,J,LVP),J=1,5),(VTN(IO,N,LV),N=1,13)
      1 , (ANG(IL,J,LVP),J=1,5),(ANG(IO,N,LV),N=1,13)
1247   FORMAT(1H0,6X,12,5(1PF5.0,5X),13(1PF5.0)/9X,5(0PF5.0,5X),
      1 13(0PF5.0)/1H0,/)
1248   CONTINUE

```

```

1300 DO 1300 I=17,21
      WRITE (LU,1220) (I,(VTN(I,J,LVP),J=1,12),(ANG(I,J,LVP),J=1,12))
      WRITE (LU,1330)
      FORMAT (1H1,/1H0,15X)
1330 WRITE (LU,1340) (J,J=13,21)
      FORMAT(1H0,16X,9(I2,8X))
1340 DO 1345 I=1,5
      WRITE (LU,1350) ((VTN(I,J,LVP),J=13,21),I,(ANG(I,J,LVP),J=13,21))
1345 FORMAT(1H0,13X,9(1PF5.0,5X),I2/14X,9(0PF5.0,5X),/1H0,/)
1350 DO 1378 I=1,11
      IL=I+5
      IO=2*I-1
      IE=2*I
      IF(I-11) 1372,1376,1376
1372 WRITE (LU,1374) (VTN(IO,N,LV),N=14,21),(VTN(IL,J,LVP),J=17,21),IL,
      1 (ANG(IO,N,LV),N=14,21), (ANG(IL,J,LVP),J=17,21),
      2 (VTN(IE,N,LV),N=14,21),(ANG(IE,N,LV),N=14,21)
1374 FORMAT(1H0,8X,8(1PF5.0),5X,5(1PF5.0,5X),I2/9X,8(0PF5.0),5X,
      1 5(0PF5.0,5X)/1H0,8X, 8(1PF5.0)/9X, 8(0PF5.0))
      GO TO 1378
1376 WRITE (LU,1377) (VTN(IO,N,LV),N=14,21),(VTN(IL,J,LVP),J=17,21),IL,
      1 (ANG(IO,N,LV),N=14,21), (ANG(IL,J,LVP),J=17,21)
1377 FORMAT(1H0,8X,8(1PF5.0),5X,5(1PF5.0,5X),I2/9X,8(0PF5.0),5X,
      1 5(0PF5.0,5X)/1H0,/)
1378 CONTINUE
      DO 1400 I=17,21
1400 WRITE (LU,1350) ((VTN(I,J,LVP),J=13,21),I,(ANG(I,J,LVP),J=13,21))
      RETURN
      END

```

```

SUBROUTINE UPDOWN
COMMON /C57/ PTH,DTI,HH,ZCOEFF(3,5),LAKE,VV(100),UX(3),UV(3),
$   DUV(3),K35,K2,G,GA,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,UXV(100,6),
$   TURN(100,6),COST(100),SINT(100)
REAL K2,K35
REAL VV2(100),TOL(100),TARN(100)
IF (LAKE .EQ. 0) RETURN
BM = 1.95*K35
BM2 = BM**2
HLOG = 1.39-ALOG(HH)
DO 61 IA = 1,100
  UM = VV(IA)*COST(IA)
  VM = VV(IA)*SINT(IA)
  VPLUS = -VV(IA)*UXV(IA,1)
  VTOP = VM+VPLUS
  VV2(IA) = UM**2+VTOP**2
  TOL(IA) = 1E-4*VV2(IA)
  TARN(IA) = UM*VPLUS/(UM**2+VM*VTOP)
CONTINUE
DO 70 INCH = 1,LAKE
  AZ = ZCOEFF(1,INCH)
  BZ = ZCOEFF(2,INCH)
  CZ = ZCOEFF(3,INCH)
  UX(1) = 1.
  IF (AZ*BZ .NE. 0.) UX(1) = CGRT(.5*AZ/BZ)
  ZLOG = HLOG+ALOG(AZ/UX(1)+BZ*UX(1)**2+CZ)
  DO 69 IA = 1,100
    UX(1) = K35*SQRT(VV2(IA)/(ZLOG**2+BM2))
    ZLOG = HLOG+ALOG(AZ/UX(1)+BZ*UX(1)**2+CZ)
    UV(1) = UX(1)**2/K2*(ZLOG**2+BM2)
    DUV(1) = UV(1)-VV2(IA)
    UX(2) = K35*SQRT(VV2(IA)/(ZLOG**2+BM2))
    UV(2) = UX(2)**2/K2*(ZLOG**2+BM2)
    DUV(2) = UV(2)-VV2(IA)
  KSTOP = 0

```

61

```

62      IF (DUV(1).EQ. DUV(2)) GO TO 63
        UX(3) = (UX(1)*DUV(2)-UX(2)*DUV(1))/(DUV(2)-DUV(1))
        ZLOG = HLOG+ALOG(AZ/UX(3)+BZ*UX(3)**2+CZ)
        UV(3) = UX(3)**2/K2*(ZLOG**2+BM2)
        DUV(3) = UV(3)-VV2(IA)
        IF (KSTOP.NE. 0) GO TO 63
        IF (ABS(DUV(3)).LT. TOL) KSTOP = 1
        UX(1) = UX(2)
        UX(2) = UX(3)
        DUV(1) = DUV(2)
        DUV(2) = DUV(3)
        GO TO 62
63      UXV(IA,INCH+1) = K35*SQR(T(VV2(IA)/(ZLOG**2+BM2)))/VV(IA)
        TURN(IA,INCH+1) = (BM-ZLOG*TARN(IA))/(ZLOG+BM*TARN(IA))
69      CONTINUE
70      RETURN
      END

```

```

SUBROUTINE UXXV
COMMON /C57/ PTH,DTH,HH,ZCOEFF(3,5),LAKE,VV(100),UX(3),UV(3),
$ DUV(3),K35,K2,G,GA,DEN,VV2,HL,K123,Z0,ZLOG,AM,BM,CM,UXV(100,6),
$ TURN(100,6),COST(100),SINT(100)
REAL K2,K35
DATA A125/1.25/
DO 10 IA = 1,100
  VV(IA) = FLOAT(IA)/A125
10 CONTINUE
  DEN = G*K2*DTH
  DO 40 IA = 1,100
    IB = 101-IA
    VV2 = VV(IB)**2
    TOL = 1E-4*VV2
    IF (IA.NE. 1) GO TO 20
    CM = 2.55
    K123 = 1
    UX(1) = 2.74
    CALL ABCCC
    K123 = 2
    UX(2) = UX(1)*80./SQRT(UV(1))
    GO TO 30
    UX(1) = UX(3)
    UV(1) = UV(3)
    DUV(1) = UV(1)-VV2
    K123 = 2
    UX(2) = UX(1)+VV(IB)/VV(IB+1)
    CALL ABCCC
    KSTOP = 0
    K123 = 3
    IF (DUV(1).EQ. DUV(2)) GO TO 32
    UX(3) = AMAX1(.5*AMINI(UX(1),UX(2)),
$ AMJN1(2.*AMAX1(UX(1),UX(2)),
$ (UX(1)+DUV(2)-UX(2)*DUV(1))/(DUV(2)-DUV(1))))

```

```

CALL ARCCC
IF (KSTOP .NE. 0) GO TO 32
IF (ABS(DUV(3)).LT. TOL) KSTOP = 1
UX(1) = UX(2)
UX(2) = UX(3)
DUV(1) = DUV(2)
DUV(2) = DUV(3)
GO TO 31
AB = SQRT((ZLOG+AM)**2+BM**2)
UXV(IB,1) = K35/AB
TURN(IB,1) = ATAN(BM/(ZLOG+AM))
COST(IH) = -(ZLOG+AM)/AB
SINT(IB) = BM/AB
CONTINUE
RETURN
END

```

32

40

**APPENDIX C: PROGRAM HIST LISTING
OF TEST STORM (BETSY) INPUT
AND SAMPLE ANNOTATED OUTPUT**

[illegible]

CC-CORP-M11-LARI-PORTGK 10

1	9119	9084	9357	9366	9327	9316	9304	9252	9241	9229	9210	9209	9201	9155	9150	1
2	9166	9143	9140	9137	9134	9131	9127	9121	9114	9106	9086	9104	9031	9021	9013	2
3	9066	8955	8953	8947	8943	8939	8935	8931	8927	8923	8920	8916	8912	8909	8905	3
4	8981	8956	8852	8847	8842	8837	8832	8826	8821	8815	8810	8805	8801	8757	8752	4
5	8744	8719														5
6	8756	8646	8616	8517	8537	8497	8456	8403	8309	8210	8116	8022	7927	7932	7936	6
7	8268	8242	8256	8259	8259	8259	8259	8259	8259	8259	8259	8259	8259	8259	8259	7
8	8245															8
9	8245															9
10	8245															10
11	8245															11
12	8245															12
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43	8245															43
44	8245															44
45	8245															45

SPRT CUPECH-BEISYDATA

STURN HICELAY		1ST HUUR IS		65P99991 CDT						
1	20	24	20	1	0	0000	-74	1	1	65090921
2	20	24	21	1	0	0000	-74	0	1	65090922
3	20	24	21	1	0	0000	-74	0	1	65090923
4	20	24	21	1	0	0000	-74	0	1	65090924
5	20	24	21	1	0	0000	-74	0	1	65090925
6	20	24	21	1	0	0000	-74	0	1	65090926
7	20	24	21	1	0	0000	-74	0	1	65090927
8	20	24	21	1	0	0000	-74	0	1	65090928
9	20	24	21	1	0	0000	-74	0	1	65090929
10	20	24	21	1	0	0000	-74	0	1	65090930
11	20	24	21	1	0	0000	-74	0	1	65090931
12	20	24	21	1	0	0000	-74	0	1	65090932
13	20	24	21	1	0	0000	-74	0	1	65090933
14	20	24	21	1	0	0000	-74	0	1	65090934
15	20	24	21	1	0	0000	-74	0	1	65090935
16	20	24	21	1	0	0000	-74	0	1	65090936
17	20	24	21	1	0	0000	-74	0	1	65090937
18	20	24	21	1	0	0000	-74	0	1	65090938
19	20	24	21	1	0	0000	-74	0	1	65090939
20	20	24	21	1	0	0000	-74	0	1	65090940
21	20	24	21	1	0	0000	-74	0	1	65090941
22	20	24	21	1	0	0000	-74	0	1	65090942
23	20	24	21	1	0	0000	-74	0	1	65090943
24	20	24	21	1	0	0000	-74	0	1	65090944
25	20	24	21	1	0	0000	-74	0	1	65090945
26	20	24	21	1	0	0000	-74	0	1	65090946
27	20	24	21	1	0	0000	-74	0	1	65090947
28	20	24	21	1	0	0000	-74	0	1	65090948
29	20	24	21	1	0	0000	-74	0	1	65090949
30	20	24	21	1	0	0000	-74	0	1	65090950

Sample listings of time history of
surface wind field at individual stations

65B1	Storm identification
65091001	Year, month, day, hour
W1	Wind speed in knots
TH1	Wind direction (meteorological) in degrees
D	Distance of station from eye of hurricane (km)
AL	Bearing of station from eye (degrees)
UST	Friction velocity (cm/sec)
STA	Station number, latitude (deg, min) longitude (deg, min)
EYE	Eye latitude and longitude (deg, min)
TERR	Terrain roughness category
H	Anemometer height at station

6501	65090901	W1	21-01	TH1	00.4	00	670.3	AL333.0	US10	15.27	STA	10	29	59	90	15	EVE	25	54	TEAR3	M12	16.2	1	1
6501	65090902	W1	22-30	TH1	00.1	00	650.0	AL334.5	US10	16.09	STA	10	29	59	90	15	EVE	25	58	TEAR3	M12	16.2	2	1
6501	65090903	W1	22-07	TH1	30.4	00	670.1	AL335.0	US10	16.24	STA	10	29	59	90	15	EVE	26	03	TEAR3	M12	16.2	3	1
6501	65090904	W1	23-37	TH1	00.1	00	680.1	AL336.4	US10	70.10	STA	10	29	59	90	15	EVE	26	07	TEAR3	M12	16.2	4	1
6501	65090905	W1	23-37	TH1	00.2	00	670.2	AL337.0	US10	70.11	STA	10	29	59	90	15	EVE	26	12	TEAR3	M12	16.2	5	1
6501	65090906	W1	24-02	TH1	00.3	00	650.3	AL338.1	US10	70.24	STA	10	29	59	90	15	EVE	26	17	TEAR3	M12	16.2	6	1
6501	65090907	W1	20-06	TH1	00.5	00	650.5	AL339.2	US10	70.11	STA	10	29	59	90	15	EVE	26	22	TEAR3	M12	16.2	7	1
6501	65090908	W1	20-18	TH1	00.2	00	650.2	AL340.1	US10	70.33	STA	10	29	59	90	15	EVE	26	30	TEAR3	M12	16.2	8	1
6501	65090909	W1	20-45	TH1	30.8	00	670.8	AL341.0	US10	70.32	STA	10	29	59	90	15	EVE	26	38	TEAR3	M12	16.2	9	1
6501	65090910	W1	21-17	TH1	30.3	00	650.3	AL342.2	US10	81.09	STA	10	29	59	90	15	EVE	26	46	TEAR3	M12	16.2	10	1
6501	65090911	W1	26-04	TH1	30.4	00	670.4	AL343.7	US10	81.10	STA	10	29	59	90	15	EVE	26	54	TEAR3	M12	16.2	11	1
6501	65090912	W1	29-03	TH1	30.5	00	670.5	AL344.0	US10	81.11	STA	10	29	59	90	15	EVE	27	02	TEAR3	M12	16.2	12	1
6501	65090913	W1	30-06	TH1	30.5	00	670.5	AL345.1	US10	90.26	STA	10	29	59	90	15	EVE	27	10	TEAR3	M12	16.2	13	1
6501	65090914	W1	31-27	TH1	30.0	00	670.0	AL346.6	US10	90.79	STA	10	29	59	90	15	EVE	27	21	TEAR3	M12	16.2	14	1
6501	65090915	W1	32-71	TH1	30.5	00	670.5	AL347.2	US10	90.09	STA	10	29	59	90	15	EVE	27	32	TEAR3	M12	16.2	15	1
6501	65090916	W1	30-21	TH1	37.0	00	670.7	AL348.9	US10	100.61	STA	10	29	59	90	15	EVE	27	43	TEAR3	M12	16.2	16	1
6501	65090917	W1	26-67	TH1	36.6	00	670.6	AL349.2	US10	100.11	STA	10	29	59	90	15	EVE	27	53	TEAR3	M12	16.2	17	1
6501	65090918	W1	30-65	TH1	36.7	00	670.7	AL350.7	US10	110.07	STA	10	29	59	90	15	EVE	28	07	TEAR3	M12	16.2	18	1
6501	65090919	W1	31-20	TH1	30.5	00	670.5	AL351.0	US10	120.80	STA	10	29	59	90	15	EVE	28	31	TEAR3	M12	16.2	19	1
6501	65090920	W1	45-92	TH1	30.2	00	670.2	AL352.5	US10	137.72	STA	10	29	59	90	15	EVE	28	42	TEAR3	M12	16.2	20	1
6501	65090921	W1	51-60	TH1	30.7	00	670.7	AL353.4	US10	150.75	STA	10	29	59	90	15	EVE	28	55	TEAR3	M12	16.2	21	1
6501	65090922	W1	50-91	TH1	41.2	00	670.2	AL354.1	US10	170.66	STA	10	29	59	90	15	EVE	29	09	TEAR3	M12	16.2	22	1
6501	65090923	W1	71-72	TH1	40.1	00	670.1	AL355.1	US10	200.17	STA	10	29	59	90	15	EVE	29	23	TEAR3	M12	16.2	23	1
6501	65090924	W1	75-50	TH1	40.0	00	670.0	AL356.0	US10	220.66	STA	10	29	59	90	15	EVE	29	37	TEAR3	M12	16.2	24	1
6501	65090925	W1	72-04	TH1	101.6	00	670.6	AL357.0	US10	237.37	STA	10	29	59	90	15	EVE	29	47	TEAR3	M12	16.2	25	1
6501	65090926	W1	67-06	TH1	127.1	00	670.1	AL358.1	US10	282.97	STA	10	29	59	90	15	EVE	29	56	TEAR3	M12	16.2	26	1
6501	65090927	W1	62-00	TH1	143.2	00	670.4	AL359.0	US10	300.32	STA	10	29	59	90	15	EVE	30	05	TEAR3	M12	16.2	27	1
6501	65090928	W1	67-06	TH1	152.4	00	670.6	AL360.1	US10	370.53	STA	10	29	59	90	15	EVE	30	15	TEAR3	M12	16.2	28	1
6501	65090929	W1	72-66	TH1	157.2	00	670.2	AL361.5	US10	457.91	STA	10	29	59	90	15	EVE	30	25	TEAR3	M12	16.2	29	1
6501	65090930	W1	47-02	TH1	159.0	00	670.0	AL362.4	US10	502.22	STA	10	29	59	90	15	EVE	30	35	TEAR3	M12	16.2	30	1

6501	65090001	W12	23.07	TH12	39.0	D2	646.4	AL313.4	US12	67.17	S1A	22	29	50	90	01	EVL2	25	54	45	10	TEAR23	M12	21.3	1	1	
6501	65090002	W12	23.09	TH12	39.0	D2	622.1	AL316.7	US12	68.03	S1A	22	29	50	90	01	EVL2	25	50	65	26	TEAR23	M12	21.3	2	1	
6501	65090003	W12	29.02	TH12	38.4	D2	596.4	AL315.4	US12	70.62	S1A	22	29	50	90	01	EVL2	26	03	65	47	TEAR23	M12	21.3	3	1	
6501	65090004	W12	25.11	TH12	36.7	D2	573.3	AL317.0	US12	72.13	S1A	22	29	50	90	01	EVL2	26	07	85	58	TEAR23	M12	21.3	4	1	
6501	65090005	W12	25.11	TH12	36.2	D2	568.3	AL318.3	US12	73.92	S1A	22	29	50	90	01	EVL2	26	12	16	14	TEAR23	M12	21.3	5	1	
6501	65090006	W12	16.07	TH12	38.9	D2	513.5	AL319.7	US12	75.93	S1A	22	29	50	90	01	EVL2	26	17	46	30	TEAR23	M12	21.3	6	1	
6501	65090007	W12	27.14	TH12	39.1	D2	500.5	AL321.0	US12	78.06	S1A	22	29	50	90	01	EVL2	26	22	44	45	TEAR23	M12	21.3	7	1	
6501	65090008	W12	27.19	TH12	38.6	D2	475.4	AL321.6	US12	80.27	S1A	22	29	50	90	01	EVL2	26	30	46	28	TEAR23	M12	21.3	8	1	
6501	65090009	W12	26.12	TH12	38.4	D2	450.9	AL322.7	US12	82.45	S1A	22	29	50	90	01	EVL2	26	38	87	11	TEAR23	M12	21.3	9	1	
6501	65090010	W12	25.03	TH12	38.2	D2	426.2	AL323.7	US12	85.09	S1A	22	29	50	90	01	EVL2	26	46	87	24	TEAR23	M12	21.3	10	1	
6501	65090011	W12	28.75	TH12	38.3	D2	401.1	AL324.4	US12	87.32	S1A	22	29	50	90	01	EVL2	26	54	87	27	TEAR23	M12	21.3	11	1	
6501	65090012	W12	31.16	TH12	37.4	D2	377.2	AL326.1	US12	91.49	S1A	22	29	50	90	01	EVL2	27	02	87	50	TEAR23	M12	21.3	12	1	
6501	65090013	W12	33.20	TH12	36.1	D2	353.1	AL327.5	US12	95.23	S1A	22	29	50	90	01	EVL2	27	10	88	13	TEAR23	M12	21.3	13	1	
6501	65090014	W12	34.16	TH12	35.2	D2	326.2	AL328.2	US12	99.01	S1A	22	29	50	90	01	EVL2	27	21	88	14	TEAR23	M12	21.3	14	1	
6501	65090015	W12	36.01	TH12	34.7	D2	299.4	AL329.0	US12	100.44	S1A	22	29	50	90	01	EVL2	27	32	88	25	TEAR23	M12	21.3	15	1	
6501	65090016	W12	36.22	TH12	34.2	D2	272.7	AL329.9	US12	100.71	S1A	22	29	50	90	01	EVL2	27	43	88	36	TEAR23	M12	21.3	16	1	
6501	65090017	W12	36.27	TH12	33.4	D2	245.3	AL330.6	US12	106.35	S1A	22	29	50	90	01	EVL2	27	55	88	41	TEAR23	M12	21.3	17	1	
6501	65090018	W12	42.11	TH12	35.7	D2	217.4	AL331.4	US12	123.64	S1A	22	29	50	90	01	EVL2	28	07	88	46	TEAR23	M12	21.3	18	1	
6501	65090019	W12	47.11	TH12	35.2	D2	187.0	AL332.1	US12	135.31	S1A	22	29	50	90	01	EVL2	28	20	89	46	TEAR23	M12	21.3	19	1	
6501	65090020	W12	57.51	TH12	36.4	D2	159.3	AL336.4	US12	151.90	S1A	22	29	50	90	01	EVL2	28	31	89	42	TEAR23	M12	21.3	20	1	
6501	65090021	W12	59.65	TH12	40.9	D2	131.2	AL343.7	US12	177.11	S1A	22	29	50	90	01	EVL2	28	42	89	28	TEAR23	M12	21.3	21	1	
6501	65090022	W12	60.20	TH12	45.9	D2	102.5	AL353.7	US12	195.73	S1A	22	29	50	90	01	EVL2	28	55	89	24	TEAR23	M12	21.3	22	1	
6501	65090023	W12	76.41	TH12	44.4	D2	76.4	AL3	5.4	US12	215.52	S1A	22	29	50	90	01	EVL2	29	09	90	01	TEAR23	M12	21.3	23	1
6501	65091001	W12	75.31	TH12	51.7	D2	59.5	AL3	32.7	US12	228.66	S1A	22	29	50	90	01	EVL2	29	23	90	21	TEAR23	M12	21.3	24	1
6501	65091002	W12	73.30	TH12	45.6	D2	56.3	AL3	65.3	US12	210.47	S1A	22	29	50	90	01	EVL2	29	37	90	34	TEAR23	M12	21.3	25	1
6501	65091003	W12	41.67	TH12	41.9	D2	70.9	AL3	85.3	US12	195.32	S1A	22	29	50	90	01	EVL2	29	47	90	45	TEAR23	M12	21.3	26	1
6501	65091004	W12	56.68	TH12	45.4	D2	106.4	AL304.9	US12	170.05	S1A	22	29	50	90	01	EVL2	29	56	90	53	TEAR23	M12	21.3	27	1	
6501	65091005	W12	56.52	TH12	41.2	D2	126.7	AL310.2	US12	171.91	S1A	22	29	50	90	01	EVL2	30	05	91	02	TEAR23	M12	21.3	28	1	
6501	65091006	W12	45.77	TH12	46.0	D2	137.0	AL314.1	US12	131.25	S1A	22	29	50	90	01	EVL2	30	16	91	15	TEAR23	M12	21.3	29	1	
6501	65091007	W12	45.77	TH12	46.0	D2	137.0	AL314.1	US12	131.25	S1A	22	29	50	90	01	EVL2	30	23	91	22	TEAR23	M12	21.3	30	1	

6501	65090901	W1	17.78	TH1	26.8	D1	442.2	AL313.7	US1120.43	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	1
6501	65090902	W1	18.20	TH1	26.2	D1	437.9	AL313.6	US1120.57	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	2
6501	65090903	W1	18.47	TH1	26.2	D1	432.4	AL313.6	US1121.71	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	3
6501	65090904	W1	19.09	TH1	26.5	D1	508.9	AL317.0	US1121.24	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	4
6501	65090905	W1	19.45	TH1	26.6	D1	564.1	AL318.4	US1121.61	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	5
6501	65090906	W1	20.09	TH1	26.7	D1	539.7	AL319.6	US1121.72	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	6
6501	65090907	W1	20.52	TH1	26.9	D1	516.6	AL320.9	US1122.44	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	7
6501	65090908	W1	21.19	TH1	26.7	D1	491.6	AL321.6	US1123.56	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	8
6501	65090909	W1	21.67	TH1	26.2	D1	466.4	AL322.5	US1123.72	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	9
6501	65090910	W1	22.29	TH1	27.9	D1	441.9	AL323.4	US1123.75	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	10
6501	65090911	W1	23.65	TH1	26.0	D1	417.2	AL324.5	US1123.74	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	11
6501	65090912	W1	23.71	TH1	26.1	D1	532.9	AL325.7	US1123.34	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	12
6501	65090913	W1	24.27	TH1	26.3	D1	506.1	AL327.0	US1123.62	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	13
6501	65090914	W1	25.81	TH1	27.8	D1	393.7	AL327.6	US1123.55	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	14
6501	65090915	W1	27.01	TH1	27.3	D1	314.1	AL328.2	US1123.10	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	15
6501	65090916	W1	28.31	TH1	26.8	D1	268.1	AL329.1	US1123.55	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	16
6501	65090917	W1	29.04	TH1	25.9	D1	268.1	AL329.7	US1123.24	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	17
6501	65090918	W1	31.71	TH1	25.0	D1	233.1	AL330.3	US1123.07	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	18
6501	65090919	W1	34.06	TH1	24.0	D1	204.1	AL330.9	US1123.94	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	19
6501	65090920	W1	36.50	TH1	24.5	D1	174.1	AL331.5	US1123.61	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	20
6501	65090921	W1	43.36	TH1	27.8	D1	145.4	AL334.0	US1123.92	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	21
6501	65090922	W1	49.54	TH1	33.7	D1	115.1	AL340.6	US1123.41	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	22
6501	65090923	W1	50.52	TH1	44.4	D1	67.1	AL3	US1123.31	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	23
6501	65090924	W1	61.45	TH1	66.3	D1	64.1	AL3	US1123.79	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	24
6501	65090925	W1	67.09	TH1	101.0	D1	59.6	AL3	US1123.41	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	25
6501	65090926	W1	53.69	TH1	122.3	D1	61.7	AL3	US1123.46	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	26
6501	65090927	W1	49.52	TH1	130.6	D1	75.4	AL3	US1123.49	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	27
6501	65090928	W1	49.52	TH1	131.7	D1	72.5	AL3	US1123.76	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	28
6501	65090929	W1	49.99	TH1	145.5	D1	112.4	AL307.0	US1123.35	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	29
6501	65090930	W1	26.97	TH1	147.0	D1	133.1	AL311.0	US1123.02	STA	42	29	56	90	00	EVE	29	56	100006	W1	25.9	30

6501	65095901	11	26.06	TH12	46.0	DE	662.0	AL3315.0	US12	51.27	51A	50	02	90	02	EVE	25	54	15	14	TER02	M12	10.1	1	
6501	65095915	11	26.01	TH12	48.2	DE	638.2	AL3316.1	US12	52.00	51A	50	02	90	02	EVE	25	58	05	16	TER02	M12	10.1	2	
6501	65095902	11	27.03	TH12	47.7	DE	613.5	AL3317.2	US12	53.70	51A	50	02	90	02	EVE	26	03	05	42	TER02	M12	10.1	3	
6501	65095904	11	27.09	TH12	48.0	DE	598.1	AL3318.4	US12	54.09	51A	50	02	90	02	EVE	26	07	05	50	TER02	M12	10.1	4	
6501	65095905	11	28.02	TH12	46.1	DE	565.7	AL3319.7	US12	54.17	51A	12	31	02	90	02	EVE	26	12	40	10	TER02	M12	10.1	5
6501	65095906	11	28.05	TH12	48.1	DE	541.0	AL3321.1	US12	57.64	51A	50	02	90	02	EVE	26	17	06	26	TER02	M12	10.1	6	
6501	65095917	11	29.07	TH12	48.1	DE	519.1	AL3322.5	US12	55.17	51A	50	02	90	02	EVE	26	22	16	42	TER02	M12	10.1	7	
6501	65095918	11	30.23	TH12	47.7	DE	494.3	AL3323.3	US12	60.85	51A	50	02	90	02	EVE	26	30	06	50	TER02	M12	10.1	8	
6501	65095909	11	30.25	TH12	47.3	DE	469.5	AL3324.2	US12	62.77	51A	50	02	90	02	EVE	26	38	07	11	TER02	M12	10.1	9	
6501	65095910	11	31.72	TH12	46.9	DE	445.0	AL3325.3	US12	64.79	51A	50	02	90	02	EVE	26	46	07	24	TER02	M12	10.1	10	
6501	65095911	11	32.57	TH12	46.4	DE	420.7	AL3326.4	US12	67.05	51A	50	02	90	02	EVE	26	54	17	27	TER02	M12	10.1	11	
6501	65095912	11	33.09	TH12	47.0	DE	396.1	AL3327.7	US12	69.52	51A	50	02	90	02	EVE	27	02	07	56	TER02	M12	10.1	12	
6501	65095913	11	34.57	TH12	47.1	DE	372.7	AL3329.2	US12	72.43	51A	50	02	90	02	EVE	27	10	00	03	TER02	M12	10.1	13	
6501	65095914	11	35.73	TH12	46.6	DE	345.9	AL3330.0	US12	78.07	51A	50	02	90	02	EVE	27	21	00	14	TER02	M12	10.1	14	
6501	65095915	11	37.09	TH12	46.1	DE	319.3	AL3330.8	US12	79.93	51A	50	02	90	02	EVE	27	32	00	25	TER02	M12	10.1	15	
6501	65095916	11	38.19	TH12	45.5	DE	292.8	AL3331.9	US12	83.93	51A	50	02	90	02	EVE	27	43	00	36	TER02	M12	10.1	16	
6501	65095917	11	40.57	TH12	44.6	DE	265.5	AL3332.7	US12	89.17	51A	50	02	90	02	EVE	27	55	00	46	TER02	M12	10.1	17	
6501	65095918	11	42.85	TH12	43.6	DE	238.2	AL3333.6	US12	95.30	51A	50	02	90	02	EVE	28	07	00	56	TER02	M12	10.1	18	
6501	65095919	11	45.61	TH12	41.9	DE	209.5	AL3334.4	US12	102.09	51A	50	02	90	02	EVE	28	20	00	66	TER02	M12	10.1	19	
6501	65095920	11	48.21	TH12	40.2	DE	180.5	AL3335.2	US12	110.93	51A	50	02	90	02	EVE	28	31	00	76	TER02	M12	10.1	20	
6501	65095921	11	50.19	TH12	38.0	DE	153.1	AL3335.4	US12	118.35	51A	50	02	90	02	EVE	28	42	00	86	TER02	M12	10.1	21	
6501	65095922	11	51.26	TH12	37.1	DE	124.4	AL3336.1	US12	126.72	51A	50	02	90	02	EVE	28	55	00	96	TER02	M12	10.1	22	
6501	65095923	11	53.17	TH12	35.5	DE	98.0	AL3337.0	US12	135.50	51A	50	02	90	02	EVE	29	09	00	106	TER02	M12	10.1	23	
6501	65095924	11	55.14	TH12	34.6	DE	76.4	AL3337.9	US12	144.50	51A	50	02	90	02	EVE	29	23	00	116	TER02	M12	10.1	24	
6501	65095925	11	57.07	TH12	32.7	DE	54.0	AL3338.8	US12	153.60	51A	50	02	90	02	EVE	29	37	00	126	TER02	M12	10.1	25	
6501	65095926	11	59.02	TH12	30.2	DE	32.0	AL3339.7	US12	162.60	51A	50	02	90	02	EVE	29	47	00	136	TER02	M12	10.1	26	
6501	65095927	11	61.07	TH12	27.6	DE	10.0	AL3340.6	US12	171.60	51A	50	02	90	02	EVE	29	56	00	146	TER02	M12	10.1	27	
6501	65095928	11	63.09	TH12	25.2	DE	05.7	AL3341.5	US12	180.60	51A	50	02	90	02	EVE	30	05	00	156	TER02	M12	10.1	28	
6501	65095929	11	65.14	TH12	22.7	DE	01.0	AL3342.4	US12	189.60	51A	50	02	90	02	EVE	30	14	00	166	TER02	M12	10.1	29	
6501	65095930	11	67.19	TH12	20.3	DE	00.0	AL3343.3	US12	198.60	51A	50	02	90	02	EVE	30	23	00	176	TER02	M12	10.1	30	
6501	65095931	11	69.24	TH12	17.9	DE	00.0	AL3344.2	US12	207.60	51A	50	02	90	02	EVE	30	32	00	186	TER02	M12	10.1	31	
6501	65095932	11	71.29	TH12	15.5	DE	00.0	AL3345.1	US12	216.60	51A	50	02	90	02	EVE	30	41	00	196	TER02	M12	10.1	32	
6501	65095933	11	73.34	TH12	13.1	DE	00.0	AL3346.0	US12	225.60	51A	50	02	90	02	EVE	30	50	00	206	TER02	M12	10.1	33	
6501	65095934	11	75.39	TH12	10.7	DE	00.0	AL3346.9	US12	234.60	51A	50	02	90	02	EVE	30	59	00	216	TER02	M12	10.1	34	
6501	65095935	11	77.44	TH12	8.3	DE	00.0	AL3347.8	US12	243.60	51A	50	02	90	02	EVE	31	08	00	226	TER02	M12	10.1	35	
6501	65095936	11	79.49	TH12	5.9	DE	00.0	AL3348.7	US12	252.60	51A	50	02	90	02	EVE	31	17	00	236	TER02	M12	10.1	36	
6501	65095937	11	81.54	TH12	3.5	DE	00.0	AL3349.6	US12	261.60	51A	50	02	90	02	EVE	31	26	00	246	TER02	M12	10.1	37	
6501	65095938	11	83.59	TH12	1.1	DE	00.0	AL3350.5	US12	270.60	51A	50	02	90	02	EVE	31	35	00	256	TER02	M12	10.1	38	
6501	65095939	11	85.64	TH12	0.0	DE	00.0	AL3351.4	US12	279.60	51A	50	02	90	02	EVE	31	44	00	266	TER02	M12	10.1	39	
6501	65095940	11	87.69	TH12	0.0	DE	00.0	AL3352.3	US12	288.60	51A	50	02	90	02	EVE	31	53	00	276	TER02	M12	10.1	40	
6501	65095941	11	89.74	TH12	0.0	DE	00.0	AL3353.2	US12	297.60	51A	50	02	90	02	EVE	31	62	00	286	TER02	M12	10.1	41	
6501	65095942	11	91.79	TH12	0.0	DE	00.0	AL3354.1	US12	306.60	51A	50	02	90	02	EVE	31	71	00	296	TER02	M12	10.1	42	
6501	65095943	11	93.84	TH12	0.0	DE	00.0	AL3355.0	US12	315.60	51A	50	02	90	02	EVE	31	80	00	306	TER02	M12	10.1	43	
6501	65095944	11	95.89	TH12	0.0	DE	00.0	AL3355.9	US12	324.60	51A	50	02	90	02	EVE	31	89	00	316	TER02	M12	10.1	44	
6501	65095945	11	97.94	TH12	0.0	DE	00.0	AL3356.8	US12	333.60	51A	50	02	90	02	EVE	31	98	00	326	TER02	M12	10.1	45	
6501	65095946	11	99.99	TH12	0.0	DE	00.0	AL3357.7	US12	342.60	51A	50	02	90	02	EVE	31	107	00	336	TER02	M12	10.1	46	
6501	65095947	11	102.04	TH12	0.0	DE	00.0	AL3358.6	US12	351.60	51A	50	02	90	02	EVE	31	116	00	346	TER02	M12	10.1	47	
6501	65095948	11	104.09	TH12	0.0	DE	00.0	AL3359.5	US12	360.60	51A	50	02	90	02	EVE	31	125	00	356	TER02	M12	10.1	48	
6501	65095949	11	106.14	TH12	0.0	DE	00.0	AL3360.4	US12	369.60	51A	50	02	90	02	EVE	31	134	00	366	TER02	M12	10.1	49	
6501	65095950	11	108.19	TH12	0.0	DE	00.0	AL3361.3	US12	378.60	51A	50	02	90	02	EVE	31	143	00	376	TER02	M12	10.1	50	
6501	65095951	11	110.24	TH12	0.0	DE	00.0	AL3362.2	US12	387.60	51A	50	02	90	02	EVE	31	152	00	386	TER02	M12	10.1	51	
6501	65095952	11	112.29	TH12	0.0	DE	00.0	AL3363.1	US12	396.60	51A	50	02	90	02	EVE	31	161	00	396	TER02	M12	10.1	52	
6501	65095953	11	114.34	TH12	0.0	DE	00.0	AL3364.0	US12	405.60	51A	50	02	90	02	EVE	31	170	00	406	TER02	M12	10.1	53	
6501	65095954	11	116.39	TH12	0.0	DE	00.0	AL3364.9	US12	414.60	51A	50	02	90	02	EVE	31	179	00	416	TER02	M12	10.1	54	
6501	65095955	11	118.44	TH12	0.0	DE	00.0	AL3365.8	US12	423.60	51A	50	02	90	02	EVE	31	188	00	426	TER02	M12	10.1	55	
6501	65095956	11	120.49	TH12	0.0	DE	00.0	AL3366.7	US12	432.60	51A	50	02	90	02	EVE	31	197	00	436	TER02	M12	10.1	56	
6501	65095957	11	122.54	TH12	0.0	DE	00.0	AL3367.6	US12	441.60	51A	50	02	90	02	EVE	31	206	00	446	TER02	M12	10.1	57	
6501	65095958	11	124.59	TH12	0.0	DE	00.0	AL3368.5	US12	450.60	51A	50	02	90	02	EVE	31	215	00	456	TER02	M12	10.1	58	
6501	65095959	11	126.64	TH12	0.0	DE	00.0	AL3369.4	US12	459.60	51A	50	02	90	02	EVE	31	224	00	466	TER02	M12	10.1	59	
6501	65095960	11	12																						

65089501	W	20.22	THU	05.00	D	62.2	AL=315.0	US1=	00.42	STA	6	30	02	90	02	LVE	25	2.4	P2	10	THU=2	M12	10.1	1
65089502	W	20.07	THU	04.10	D	63.0	AL=316.1	US1=	00.06	STA	6	30	02	90	02	LVE	25	2.0	P2	26	THU=2	M12	10.1	1
65089503	W	20.01	THU	04.15	D	63.5	AL=317.2	US1=	00.04	STA	6	30	02	90	02	LVE	26	0.3	P2	42	THU=2	M12	10.1	1
65089504	W	20.05	THU	04.10	D	64.0	AL=318.4	US1=	00.00	STA	6	30	02	90	02	LVE	26	0.7	P2	54	THU=2	M12	10.1	1
65089505	W	20.02	THU	04.13	D	64.5	AL=319.7	US1=	00.04	STA	6	30	02	90	02	LVE	26	1.2	P2	10	THU=2	M12	10.1	1
65089506	W	20.23	THU	04.13	D	64.7	AL=321.1	US1=	00.04	STA	6	30	02	90	02	LVE	26	1.4	P2	30	THU=2	M12	10.1	1
65089507	W	20.42	THU	04.16	D	65.0	AL=322.5	US1=	00.00	STA	6	30	02	90	02	LVE	26	2.2	P2	44	THU=2	M12	10.1	1
65089508	W	20.38	THU	04.23	D	64.8	AL=323.5	US1=	00.00	STA	6	30	02	90	02	LVE	26	3.0	P2	58	THU=2	M12	10.1	1
65089509	W	20.22	THU	04.23	D	64.5	AL=324.5	US1=	00.00	STA	6	30	02	90	02	LVE	26	2.0	P2	11	THU=2	M12	10.1	1
65089510	W	20.01	THU	04.10	D	64.0	AL=325.3	US1=	00.19	STA	6	30	02	90	02	LVE	26	4.6	P2	24	THU=2	M12	10.1	1
65089511	W	20.47	THU	04.11	D	64.0	AL=326.4	US1=	00.12	STA	6	30	02	90	02	LVE	26	4.0	P2	37	THU=2	M12	10.1	1
65089512	W	20.10	THU	04.23	D	64.0	AL=327.7	US1=	00.06	STA	6	30	02	90	02	LVE	27	0.2	P2	47	THU=2	M12	10.1	1
65089513	W	20.40	THU	04.26	D	64.7	AL=329.2	US1=	00.05	STA	6	30	02	90	02	LVE	27	1.0	P2	03	THU=2	M12	10.1	1
65089514	W	20.09	THU	04.23	D	64.9	AL=330.0	US1=	00.00	STA	6	30	02	90	02	LVE	27	2.1	P2	10	THU=2	M12	10.1	1
65089515	W	20.46	THU	04.26	D	65.2	AL=330.8	US1=	00.19	STA	6	30	02	90	02	LVE	27	3.2	P2	25	THU=2	M12	10.1	1
65089516	W	20.04	THU	04.27	D	65.1	AL=331.9	US1=	00.17	STA	6	30	02	90	02	LVE	27	4.3	P2	36	THU=2	M12	10.1	1
65089517	W	20.1	THU	04.16	D	65.3	AL=332.7	US1=	00.05	STA	6	30	02	90	02	LVE	27	5.3	P2	48	THU=2	M12	10.1	1
65089518	W	20.15	THU	04.24	D	65.3	AL=333.6	US1=	00.10	STA	6	30	02	90	02	LVE	28	0.7	P2	06	THU=2	M12	10.1	1
65089519	W	20.10	THU	04.24	D	65.2	AL=333.6	US1=	00.19	STA	6	30	02	90	02	LVE	28	2.0	P2	19	THU=2	M12	10.1	1
65089520	W	20.46	THU	04.25	D	65.5	AL=335.2	US1=	00.31	STA	6	30	02	90	02	LVE	28	3.1	P2	32	THU=2	M12	10.1	1
65089521	W	20.41	THU	04.08	D	65.3	AL=335.4	US1=	00.28															

Sample listing of surface wind speed direction on Wes grid:

. Six pages of output are required to list the wind field at one time level. Grid points are identified on each page by latitude (deg, min), left side margin, and longitude (deg, min), top margin. At each grid point location are printed the wind speed at 10 meter height in knots (top), the wind direction in degrees (middle) and the terrain classification code of the grid points (bottom). The sample listing shown is for the 24th hour of the test Betsy simulation, for the rectangular grid system provided by WES.

STORM 6511 LAKE PORT WINDS AT HOUR 24 1ST HOUR 18 65190901001

	9420	9406	9352	9346	9327	9316	9304	9252	9241	9229	9218	9209	9201	9155	9150	9146	9143	9140	9137	9134	9131	9127	9121	9114		
3045	15.9	16.0	17.0	18.7	19.7	20.6	21.7	22.0	22.5	22.9	23.3	24.0	24.7	25.0	25.3	26.6	27.7	28.0	27.9	31.0	31.9	32.3	32.8	33.4	34.2	34.5
3047	15.9	17.1	16.1	15.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	16.1	
3039	15.5	16.4	17.6	18.7	19.1	20.7	21.8	23.3	24.2	25.6	26.9	28.0	27.1	30.0	30.6	31.2	31.7	32.1	32.6	33.1	33.9	34.2	35.3	35.8	36.2	36.9
3039	15.5	16.4	17.6	18.7	19.1	20.7	21.8	23.3	24.2	25.6	26.9	28.0	27.1	30.0	30.6	31.2	31.7	32.1	32.6	33.1	33.9	34.2	35.3	35.8	36.2	36.9
3039	15.5	16.4	17.6	18.7	19.1	20.7	21.8	23.3	24.2	25.6	26.9	28.0	27.1	30.0	30.6	31.2	31.7	32.1	32.6	33.1	33.9	34.2	35.3	35.8	36.2	36.9
3033	19.6	19.7	22.0	23.1	24.5	25.7	27.1	28.7	30.1	31.9	33.6	35.0	36.4	37.6	38.6	39.3	39.9	40.5	41.2	41.9	42.5	43.3	44.6	45.1	45.3	
3033	19.6	19.7	22.0	23.1	24.5	25.7	27.1	28.7	30.1	31.9	33.6	35.0	36.4	37.6	38.6	39.3	39.9	40.5	41.2	41.9	42.5	43.3	44.6	45.1	45.3	
3026	19.5	19.7	21.9	23.1	24.1	25.6	27.2	28.4	30.4	32.2	34.0	35.6	37.1	38.3	39.3	40.2	40.9	41.5	42.2	42.9	43.6	44.6	45.9	47.6	48.6	
3026	19.5	19.7	21.9	23.1	24.1	25.6	27.2	28.4	30.4	32.2	34.0	35.6	37.1	38.3	39.3	40.2	40.9	41.5	42.2	42.9	43.6	44.6	45.9	47.6	48.6	
3021	19.5	20.6	21.9	23.1	24.5	25.8	27.2	28.4	30.4	32.2	34.0	35.6	37.1	38.3	39.3	40.2	40.9	41.5	42.2	42.9	43.6	44.6	45.9	47.6	48.6	
3021	19.5	20.6	21.9	23.1	24.5	25.8	27.2	28.4	30.4	32.2	34.0	35.6	37.1	38.3	39.3	40.2	40.9	41.5	42.2	42.9	43.6	44.6	45.9	47.6	48.6	
3016	19.4	20.6	21.9	23.1	24.5	25.8	27.3	29.1	30.6	32.6	34.3	36.3	38.6	39.3	40.3	41.4	42.1	42.0	43.6	44.0	45.1	46.1	47.0	48.1	49.2	
3016	19.4	20.6	21.9	23.1	24.5	25.8	27.3	29.1	30.6	32.6	34.3	36.3	38.6	39.3	40.3	41.4	42.1	42.0	43.6	44.0	45.1	46.1	47.0	48.1	49.2	
3013	19.3	20.5	21.0	23.1	24.5	25.0	27.3	29.0	30.7	32.7	34.7	36.5	38.2	39.6	40.0	41.7	42.4	42.3	44.0	44.0	45.6	46.0	47.6	48.3	49.3	
3013	19.3	20.5	21.0	23.1	24.5	25.0	27.3	29.0	30.7	32.7	34.7	36.5	38.2	39.6	40.0	41.7	42.4	42.3	44.0	44.0	45.6	46.0	47.6	48.3	49.3	
3013	19.3	20.5	21.0	23.1	24.5	25.0	27.3	29.0	30.7	32.7	34.7	36.5	38.2	39.6	40.0	41.7	42.4	42.3	44.0	44.0	45.6	46.0	47.6	48.3	49.3	
3010	19.3	20.5	21.0	23.1	24.5	25.0	27.3	29.0	30.7	32.7	34.7	36.5	38.2	39.6	40.0	41.7	42.4	42.3	44.0	44.0	45.6	46.0	47.6	48.3	49.3	
3010	19.3	20.5	21.0	23.1	24.5	25.0	27.3	29.0	30.7	32.7	34.7	36.5	38.2	39.6	40.0	41.7	42.4	42.3	44.0	44.0	45.6	46.0	47.6	48.3	49.3	
3006	19.3	20.5	21.0	23.1	24.5	25.0	27.3	29.0	30.7	32.7	34.7	36.5	38.2	39.6	40.0	41.7	42.4	42.3	44.0	44.0	45.6	46.0	47.6	48.3	49.3	
3006	19.3	20.5	21.0	23.1	24.5	25.0	27.3	29.0	30.7	32.7	34.7	36.5	38.2	39.6	40.0	41.7	42.4	42.3	44.0	44.0	45.6	46.0	47.6	48.3	49.3	
3003	19.2	20.0	21.7	23.0	24.4	25.7	27.1	28.3	29.1	30.9	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0	44.0	45.0	46.0	
3003	19.2	20.0	21.7	23.0	24.4	25.7	27.1	28.3	29.1	30.9	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0	44.0	45.0	46.0	
3003	19.2	20.0	21.7	23.0	24.4	25.7	27.1	28.3	29.1	30.9	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0	44.0	45.0	46.0	
3003	19.2	20.0	21.7	23.0	24.4	25.7	27.1	28.3	29.1	30.9	32.0	33.0	34.0	35.0	36.0	37.0	38.0	39.0	40.0	41.0	42.0	43.0	44.0	45.0	46.0	
2999	19.1	20.3	21.6	22.9	24.3	25.7	27.3	29.1	30.9	33.1	35.3	37.5	39.1	40.6	41.9	42.9	44.0	44.7	47.4	48.2	49.1	50.3	51.7	52.9	53.9	
2999	19.1	20.3	21.6	22.9	24.3	25.7	27.3	29.1	30.9	33.1	35.3	37.5	39.1	40.6	41.9	42.9	44.0	44.7	47.4	48.2	49.1	50.3	51.7	52.9	53.9	
2999	19.1	20.3	21.6	22.9	24.3	25.7	27.3	29.1	30.9	33.1	35.3	37.5	39.1	40.6	41.9	42.9	44.0	44.7	47.4	48.2	49.1	50.3	51.7	52.9	53.9	
2994	19.0	20.2	21.7	23.0	24.2	25.6	27.0	28.3	29.1	30.9	32.1	33.1	34.2	35.1	36.1	37.1	38.1	39.1	40.1	41.1	42.1	43.1	44.1	45.1	46.1	
2994	19.0	20.2	21.7	23.0	24.2	25.6	27.0	28.3	29.1	30.9	32.1	33.1	34.2	35.1	36.1	37.1	38.1	39.1	40.1	41.1	42.1	43.1	44.1	45.1	46.1	
2994	19.0	20.2	21.7	23.0	24.2	25.6	27.0	28.3	29.1	30.9	32.1	33.1	34.2	35.1	36.1	37.1	38.1	39.1	40.1	41.1	42.1	43.1	44.1	45.1	46.1	
2990	18.9	20.1	21.5	22.7	24.2	25.6	27.2	28.1	30.9	33.2	35.4	37.4	39.4	40.9	42.3	43.5	44.3	45.2	46.1	47.1	48.1	49.1	50.1	51.1	52.1	
2990	18.9	20.1	21.5	22.7	24.2	25.6	27.2	28.1	30.9	33.2	35.4	37.4	39.4	40.9	42.3	43.5	44.3	45.2	46.1	47.1	48.1	49.1	50.1	51.1	52.1	
2990	18.9	20.1	21.5	22.7	24.2	25.6	27.2	28.1	30.9	33.2	35.4	37.4	39.4	40.9	42.3	43.5	44.3	45.2	46.1	47.1	48.1	49.1	50.1	51.1	52.1	
2945	16.7	16.0	21.3	28.0	36.1	31.5	31.2	29.0	30.9	34.7	35.0	39.1	41.1	42.0	43.5	44.4	45.4	46.3	47.3	48.3	49.3	50.3	51.3	52.3	53.3	
2945	16.7	16.0	21.3	28.0	36.1	31.5	31.2	29.0	30.9	34.7	35.0	39.1	41.1	42.0	43.5	44.4	45.4	46.3	47.3	48.3	49.3	50.3	51.3	52.3	53.3	
2945	16.7	16.0	21.3	28.0	36.1	31.5	31.2	29.0	30.9	34.7	35.0	39.1	41.1	42.0	43.5	44.4	45.4	46.3	47.3	48.3	49.3	50.3	51.3	52.3	53.3	
2940	18.0	15.0	27.7	24.0	30.0	31.4	33.1	35.1	36.1	33.0	35.3	37.4	41.1	42.7	44.1	45.3	46.2	47.2	48.2	49.2	50.2	51.2	52.2	53.2	54.2	
2940	18.0	15.0	27.7	24.0	30.0	31.4	33.1	35.1	36.1	33.0	35.3	37.4	41.1	42.7	44.1	45.3	46.2	47.2	48.2	49.2	50.2	51.2	52.2	53.2	54.2	
2940	18.0	15.0	27.7	24.0	30.0	31.4	33.1	35.1	36.1	33.0	35.3	37.4	41.1	42.7	44.1	45.3	46.2	47.2	48.2	49.2	50.2	51.2	52.2	53.2	54.2	
2936	16.5	25.7	27.0	28.3	29.6	31.2	32.9	35.0	36.9	33.0	35.2	37.4	39.4	40.9	42.3	43.5	44.3	45.2	46.1	47.1	48.1	49.1	50.1	51.1	52.1	
2936	16.5	25.7	27.0	28.3	29.6	31.2	32.9	35.0	36.9	33.0	35.2	37.4	39.4	40.9	42.3	43.5	44.3	45.2	46.1	47.1	48.1	49.1	50.1	51.1	52.1	
2936	16.5	25.7	27.0	28.3	29.6	31.2	32.9	35.0	36.9	33.0	35.2	37.4	39.4	40.9	42.3	43.5	44.3	45.2	46.1	47.1	48.1	49.1	50.1	51.1	52.1	

	9150	9131	9117	9121	9110	9106	9056	9004	9021	9013	9006	8959	8953	8947	8943	8939	8935	8931	8927	8923	8920	8916	8912
3005	31.3	32.4	33.4	34.4	35.3	36.4	37.7	39.1	40.7	42.9	45.9	49.9	54.9	60.7	67.5	75.4	84.2	95.0	107.5	121.5	137.0	154.0	172.5
3006	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1	30.1	31.1	32.1	33.1	34.1	35.1	36.1	37.1	38.1	39.1	40.1	41.1	42.1	43.1
3007	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1	24.1	25.1	26.1	27.1	28.1	29.1	30.1	31.1	32.1	33.1
3008	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3009	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3010	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3011	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3012	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3013	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3014	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3015	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3016	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3017	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3018	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3019	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3020	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3021	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3022	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3023	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3024	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3025	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3026	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3027	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3028	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3029	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3030	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3031	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3032	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3033	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3034	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3035	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3036	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3037	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3038	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3039	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3040	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3041	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3042	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3043	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3044	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3045	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3046	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3047	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3048	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3049	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3050	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3051	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3052	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3053	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3054	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3055	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3056	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3057	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3058	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3059	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3060	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3061	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1	13.1	14.1	15.1	16.1	17.1	18.1	19.1	20.1	21.1	22.1	23.1
3062	1.1	2.1	3.1	4.1	5.1	6.1	7.1	8.1	9.1	10.1	11.1	12.1</											

STUMP (511) LARI FORT LINES AT HOUR 24 1ST HOUR IS 6:50PM (10:00)

	8927	8923	8920	8916	8912	8909	8905	8901	8897	8893	8889	8885	8881	8877	8873	8869	8865	8861	8857	8853	8849	8845	8841	8837	8833	8829	8825	8821	8817	8813	8809	8805	8801	8797	8793	8789	8785	8781	8777	8773	8769	8765	8761	8757	8753	8749	8745	8741	8737	8733	8729	8725	8721	8717	8713	8709	8705	8701	8697	8693	8689	8685	8681	8677	8673	8669	8665	8661	8657	8653	8649	8645	8641	8637	8633	8629	8625	8621	8617	8613	8609	8605	8601	8597	8593	8589	8585	8581	8577	8573	8569	8565	8561	8557	8553	8549	8545	8541	8537	8533	8529	8525	8521	8517	8513	8509	8505	8501	8497	8493	8489	8485	8481	8477	8473	8469	8465	8461	8457	8453	8449	8445	8441	8437	8433	8429	8425	8421	8417	8413	8409	8405	8401	8397	8393	8389	8385	8381	8377	8373	8369	8365	8361	8357	8353	8349	8345	8341	8337	8333	8329	8325	8321	8317	8313	8309	8305	8301	8297	8293	8289	8285	8281	8277	8273	8269	8265	8261	8257	8253	8249	8245	8241	8237	8233	8229	8225	8221	8217	8213	8209	8205	8201	8197	8193	8189	8185	8181	8177	8173	8169	8165	8161	8157	8153	8149	8145	8141	8137	8133	8129	8125	8121	8117	8113	8109	8105	8101	8097	8093	8089	8085	8081	8077	8073	8069	8065	8061	8057	8053	8049	8045	8041	8037	8033	8029	8025	8021	8017	8013	8009	8005	8001	7997	7993	7989	7985	7981	7977	7973	7969	7965	7961	7957	7953	7949	7945	7941	7937	7933	7929	7925	7921	7917	7913	7909	7905	7901	7897	7893	7889	7885	7881	7877	7873	7869	7865	7861	7857	7853	7849	7845	7841	7837	7833	7829	7825	7821	7817	7813	7809	7805	7801	7797	7793	7789	7785	7781	7777	7773	7769	7765	7761	7757	7753	7749	7745	7741	7737	7733	7729	7725	7721	7717	7713	7709	7705	7701	7697	7693	7689	7685	7681	7677	7673	7669	7665	7661	7657	7653	7649	7645	7641	7637	7633	7629	7625	7621	7617	7613	7609	7605	7601	7597	7593	7589	7585	7581	7577	7573	7569	7565	7561	7557	7553	7549	7545	7541	7537	7533	7529	7525	7521	7517	7513	7509	7505	7501	7497	7493	7489	7485	7481	7477	7473	7469	7465	7461	7457	7453	7449	7445	7441	7437	7433	7429	7425	7421	7417	7413	7409	7405	7401	7397	7393	7389	7385	7381	7377	7373	7369	7365	7361	7357	7353	7349	7345	7341	7337	7333	7329	7325	7321	7317	7313	7309	7305	7301	7297	7293	7289	7285	7281	7277	7273	7269	7265	7261	7257	7253	7249	7245	7241	7237	7233	7229	7225	7221	7217	7213	7209	7205	7201	7197	7193	7189	7185	7181	7177	7173	7169	7165	7161	7157	7153	7149	7145	7141	7137	7133	7129	7125	7121	7117	7113	7109	7105	7101	7097	7093	7089	7085	7081	7077	7073	7069	7065	7061	7057	7053	7049	7045	7041	7037	7033	7029	7025	7021	7017	7013	7009	7005	7001	6997	6993	6989	6985	6981	6977	6973	6969	6965	6961	6957	6953	6949	6945	6941	6937	6933	6929	6925	6921	6917	6913	6909	6905	6901	6897	6893	6889	6885	6881	6877	6873	6869	6865	6861	6857	6853	6849	6845	6841	6837	6833	6829	6825	6821	6817	6813	6809	6805	6801	6797	6793	6789	6785	6781	6777	6773	6769	6765	6761	6757	6753	6749	6745	6741	6737	6733	6729	6725	6721	6717	6713	6709	6705	6701	6697	6693	6689	6685	6681	6677	6673	6669	6665	6661	6657	6653	6649	6645	6641	6637	6633	6629	6625	6621	6617	6613	6609	6605	6601	6597	6593	6589	6585	6581	6577	6573	6569	6565	6561	6557	6553	6549	6545	6541	6537	6533	6529	6525	6521	6517	6513	6509	6505	6501	6497	6493	6489	6485	6481	6477	6473	6469	6465	6461	6457	6453	6449	6445	6441	6437	6433	6429	6425	6421	6417	6413	6409	6405	6401	6397	6393	6389	6385	6381	6377	6373	6369	6365	6361	6357	6353	6349	6345	6341	6337	6333	6329	6325	6321	6317	6313	6309	6305	6301	6297	6293	6289	6285	6281	6277	6273	6269	6265	6261	6257	6253	6249	6245	6241	6237	6233	6229	6225	6221	6217	6213	6209	6205	6201	6197	6193	6189	6185	6181	6177	6173	6169	6165	6161	6157	6153	6149	6145	6141	6137	6133	6129	6125	6121	6117	6113	6109	6105	6101	6097	6093	6089	6085	6081	6077	6073	6069	6065	6061	6057	6053	6049	6045	6041	6037	6033	6029	6025	6021	6017	6013	6009	6005	6001	5997	5993	5989	5985	5981	5977	5973	5969	5965	5961	5957	5953	5949	5945	5941	5937	5933	5929	5925	5921	5917	5913	5909	5905	5901	5897	5893	5889	5885	5881	5877	5873	5869	5865	5861	5857	5853	5849	5845	5841	5837	5833	5829	5825	5821	5817	5813	5809	5805	5801	5797	5793	5789	5785	5781	5777	5773	5769	5765	5761	5757	5753	5749	5745	5741	5737	5733	5729	5725	5721	5717	5713	5709	5705	5701	5697	5693	5689	5685	5681	5677	5673	5669	5665	5661	5657	5653	5649	5645	5641	5637	5633	5629	5625	5621	5617	5613	5609	5605	5601	5597	5593	5589	5585	5581	5577	5573	5569	5565	5561	5557	5553	5549	5545	5541	5537	5533	5529	5525	5521	5517	5513	5509	5505	5501	5497	5493	5489	5485	5481	5477	5473	5469	5465	5461	5457	5453	5449	5445	5441	5437	5433	5429	5425	5421	5417	5413	5409	5405	5401	5397	5393	5389	5385	5381	5377	5373	5369	5365	5361	5357	5353	5349	5345	5341	5337	5333	5329	5325	5321	5317	5313	5309	5305	5301	5297	5293	5289	5285	5281	5277	5273	5269	5265	5261	5257	5253	5249	5245	5241	5237	5233	5229	5225	5221	5217	5213	5209	5205	5201	5197	5193	5189	5185	5181	5177	5173	5169	5165	5161	5157	5153	5149	5145	5141	5137	5133	5129	5125	5121	5117	5113	5109	5105	5101	5097	5093	5089	5085	5081	5077	5073	5069	5065	5061	5057	5053	5049	5045	5041	5037	5033	5029	5025	5021	5017	5013	5009	5005	5001	4997	4993	4989	4985	4981	4977	4973	4969	4965	4961	4957	4953	4949	4945	4941	4937	4933	4929	4925	4921	4917	4913	4909	4905	4901	4897	4893	4889	4885	4881	4877	4873	4869	4865	4861	4857	4853	4849	4845	4841	4837	4833	4829	4825	4821	4817	4813	4809	4805	4801	4797	4793	4789	4785	4781	4777	4773	4769	4765	4761	4757	4753	4749	4745	4741	4737	4733	4729	4725	4721	4717	4713	4709	4705	4701	4697	4693	4689	4685	4681	4677	4673	4669	4665	4661	4657	4653	4649	4645	4641	4637	4633	4629	4625	4621	4617	4613	4609	4605	4601	4597	4593	4589	4585	4581	4577	4573	4569	4565	4561	4557	4553	4549	4545	4541	4537	4533	4529	4525	4521	4517	4513	4509	4505	4501	4497	4493	4489	4485	4481	4477	4473	4469	4465	4461	4457	4453	4449	4445	4441	4437	4433	4429	4425	4421	4417	4413	4409	4405	4401	4397	4393	4389	4385	4381	4377	4373	4369	4365	4361	4357	4353	4349	4345	4341	4337	4333	4329	4325	4321	4317	4313	4309	4305	4301	4297	4293	4289	4285	4281	4277	4273	4269	4265	4261	4257	4253	4249	4245	4241	4237	4233	4229	4225	4221	4217	4213	4209	4205	4201	4197	4193	4189	4185	4181	4177	4173	4169	4165	4161	4157	4153	4149	4145	4141	4137	4133	4129	4125	4121	4117	4113	4109	4105	4101	4097	4093	4089	4085	4081	4077	4073	4069	4065	4061	4057	4053	4049	4045	4041	4037	4033	4029	4025	4021	4017	4013	4009	4005	4001	3997	3993	3989	3985	3981	3977	3973	3969	3965	3961	3957	3953	3949	3945	3941	3937	3933	3929	3925	3921	3917	3913	3909	3905	3901	3897	3893	3889	3885	3881	3877	3873	3869	3865	3861	3857	3853	3849	3845	3841	3837	3833	3829	3825	3821	3817	3813	3809	3805	3801	3797	3793	3789	3785	3781	3777	3773	3769	3765	3761	3757	3753	3749	3745	3741	3737	3733	3729	3725	3721	3717	3713	3709	3705	3701	3697	3693	3689	3685	3681	3677	3673	3669	3665	3661	3657	3653	3649	3645	3641	3637	3633	3629	3625	3621	3617	3613	3609	3605	3601	3597	3593	3589	3585	3581	3577	3573	3569	3565	3561	3557	3553	3549	3545	3541	3537	3533	3529	3525	3521	3517	3513	3509	3505	3501	3497	3493	3489	3485	3481	3477
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STORM 6581 LARL POINT WINDS AT 1000 24 151 HOUR IS 65090901C01

9026	9406	9352	9300	9327	9316	9304	9252	9201	9229	9218	9209	9155	9150	9146	9143	9140	9137	9134	9131	9127	9121	9110
2905	10.7	20.0	21.3	20.4	30.1	31.2	33.2	29.0	30.9	30.7	35.0	41.1	42.0	42.5	44.4	45.0	46.3	47.3	48.3	49.0	50.1	50.5
2906	7.	4.	2.	7.	5.	3.	1.	35.0	35.5	35.0	35.2	35.3	35.3	35.3	35.1	35.0	35.0	35.0	35.0	35.0	35.0	35.0
2907	16.4	19.0	27.2	20.4	30.0	31.4	33.1	35.1	35.0	35.3	37.0	42.7	44.1	45.3	46.2	47.2	48.5	49.0	50.1	50.5	50.5	50.5
2908	1.	3.	6.	6.	3.	1.	35.9	35.0	35.0	35.0	35.0	35.0	35.0	35.1	35.1	35.2	35.1	35.2	35.3	35.3	35.3	35.3
2909	10.5	22.7	27.0	20.5	20.1	31.2	32.9	35.0	35.0	35.2	37.0	42.7	44.1	45.3	46.2	47.2	48.5	49.0	50.1	50.5	50.5	50.5
2910	4.	10.	7.	9.	2.	36.0	35.7	35.0	35.0	35.0	35.0	35.0	35.0	35.1	35.1	35.2	35.1	35.2	35.3	35.3	35.3	35.3
2911	20.3	21.5	20.5	20.0	29.7	31.1	32.0	34.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1	35.1
2912	12.	9.	6.	3.	0.	35.0	35.0	35.1	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
2927	20.1	25.4	26.7	20.0	29.4	30.9	32.6	34.1	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
2927	11.	7.	4.	2.	35.0	35.0	35.2	35.0	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5	34.5
2922	23.9	25.2	26.5	27.0	29.2	30.7	32.3	34.1	35.7	41.0	43.2	45.1	46.7	48.1	49.3	50.1	51.1	52.0	53.1	54.2	55.2	56.2
2922	5.	6.	3.	36.0	35.7	35.5	35.2	35.0	34.6	34.0	34.5	34.7	34.7	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1	34.1
2918	23.7	25.0	26.3	27.6	29.1	30.5	32.1	33.5	35.0	40.0	42.0	44.0	46.5	47.7	48.9	49.7	50.7	51.7	52.7	53.7	54.7	55.7
2918	6.	5.	1.	35.5	35.0	35.3	35.0	34.6	34.7	34.2	34.1	34.0	33.9	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8	33.8
2919	23.6	24.5	26.1	27.4	28.5	30.2	31.9	33.7	35.7	40.5	42.5	44.5	46.0	47.3	48.5	49.4	50.3	51.2	52.1	53.0	54.0	55.0
2919	7.	4.	6.	35.7	35.0	35.1	34.9	34.0	34.2	34.0	33.9	33.6	33.7	33.6	33.5	33.5	33.5	33.5	33.5	33.5	33.5	33.5
2909	24.6	25.9	27.2	28.6	29.0	31.6	33.5	35.2	37.7	40.1	42.2	44.0	45.5	46.9	48.0	48.7	49.3	50.4	51.5	52.3	53.6	54.7
2909	1.	3.	35.5	35.6	35.0	34.7	34.0	34.2	34.0	33.0	33.3	33.3	33.3	33.2	33.2	33.1	33.1	33.1	33.1	33.1	33.1	33.1
2903	23.1	24.3	25.6	26.9	28.3	29.6	31.3	33.0	34.7	37.1	39.5	41.5	43.4	44.9	46.0	47.1	48.3	49.6	50.4	51.2	52.3	53.3
2903	6.	0.	35.7	35.0	35.6	34.6	34.5	34.2	33.5	33.7	33.4	33.2	33.1	33.0	32.9	32.7	32.7	32.6	32.6	32.5	32.5	32.5
2056	23.7	23.9	25.3	26.4	27.8	29.2	30.7	32.4	34.2	36.0	38.7	40.7	42.5	43.9	45.1	46.1	47.3	48.5	49.0	50.2	51.3	52.3
2056	7.	35.5	35.0	34.8	34.5	34.2	33.5	33.6	33.3	33.0	32.7	32.5	32.4	32.3	32.2	32.1	32.0	31.9	31.9	31.9	31.9	31.9
2007	22.2	23.5	24.7	25.9	27.1	28.4	30.0	31.7	33.5	35.3	37.0	38.7	40.4	42.1	43.5	44.5	45.7	46.9	47.9	48.7	49.1	49.1
2007	0.	35.6	35.2	34.9	34.5	34.2	33.5	33.6	33.3	33.0	32.7	32.5	32.4	32.3	32.2	32.1	32.0	31.9	31.9	31.9	31.9	31.9
2037	21.6	22.0	24.1	25.3	26.6	27.7	29.3	30.9	32.3	34.2	36.0	37.0	38.5	40.0	41.0	42.0	43.0	44.0	45.0	46.0	47.0	48.0
2037	35.6	35.4	34.9	34.0	34.2	33.9	33.5	33.1	32.8	32.5	32.1	31.7	31.3	31.1	31.0	30.9	30.8	30.7	30.6	30.5	30.5	30.5
2027	20.0	21.1	23.0	24.5	25.9	27.1	28.4	29.9	31.3	33.1	34.7	36.0	37.6	39.0	40.5	41.1	41.7	42.3	43.0	43.5	44.1	44.1
2027	35.5	35.1	34.7	34.3	33.9	33.6	33.2	32.8	32.4	32.0	31.7	31.4	31.1	30.7	30.6	30.5	30.4	30.3	30.2	30.1	30.1	30.1
2016	20.0	21.3	22.6	23.7	25.0	26.1	27.4	28.9	30.2	31.6	33.3	34.7	36.0	37.6	39.0	40.5	41.1	41.7	42.3	43.0	43.5	44.1
2016	35.5	34.0	34.0	33.6	33.2	32.6	32.4	32.0	31.6	31.2	30.9	30.6	30.2	30.0	29.9	29.9	29.8	29.7	29.6	29.5	29.5	29.5
2000	19.0	20.3	21.6	22.7	23.9	25.1	26.3	27.5	28.8	30.3	31.6	33.0	34.6	35.9	36.5	36.9	37.3	37.7	38.2	38.7	39.2	39.2
2000	35.0	34.5	34.1	33.7	33.2	32.9	32.5	32.0	31.6	31.2	30.8	30.4	30.0	29.6	29.5	29.5	29.5	29.5	29.5	29.5	29.5	29.5
2750	10.1	19.2	20.4	21.5	22.4	23.7	24.9	26.2	27.5	28.8	30.3	31.6	33.0	34.6	35.9	36.5	36.9	37.3	37.7	38.2	38.7	39.2
2750	34.7	34.7	33.7	33.5	32.0	32.5	32.6	31.6	31.5	30.7	30.3	29.5	29.0	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9	28.9

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9136	9131	9127	9121	9114	9106	9094	9031	9013	9006	8955	8933	8947	8943	8939	8935	8931	8927	8923	8920	8916	8912
22905	47.3	46.3	45.1	44.1	42.9	42.4	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22906	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22907	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22908	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22909	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22910	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22911	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22912	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22913	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22914	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22915	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22916	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22917	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22918	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22919	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22920	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22921	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	39.7
22922	35.6	35.7	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9	35.9
22923	47.5	46.5	45.5	44.5	43.5	43.1	46.9	46.2	46.7	45.2	46.8	47.6	46.9	45.5	44.9	43.7	42.6	42.0	41.0	40.2	3

