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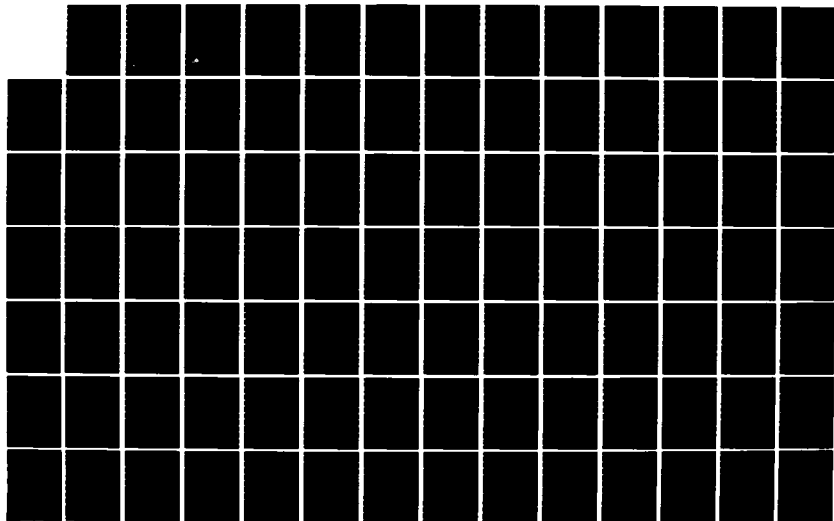
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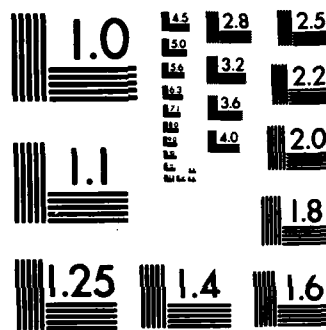
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FINAL REPORT 83-1155

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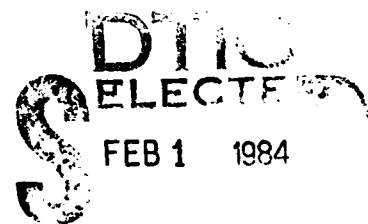
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Prepared Under:

Contract No. N00014-82-C-2306

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This final technical report documents the research efforts in the numerical simulations of tropical weather systems carried out under the auspices of ONR Contract N00014-82-C-2306, for the Atmospheric Physics Branch, Space Science Division, of the Naval Research Laboratory (NRL).

Our research efforts mainly concentrate in two major study areas: the interactions between two tropical cyclones and the construction of an axisymmetric ocean model. The research in both of these areas has been completed and reported in two articles. A paper entitled "A Numerical Study of the Interactions Between Two Tropical Cyclones" was accepted by the Monthly Weather Review and is to be published in the 1983 September issue. The draft of a second article on the ocean model has been completed. Both articles are included as Appendices in this final report. We have also attached a listing of the computer code of the ocean model, which is also stored in and accessible from the TI-ASC of NRL. Here, a brief summary of the study result will be given.

The interactions between atmospheric vortex pairs are simulated and studied with a nondivergent barotropic model and a three-dimensional tropical cyclone model (NRL/SAI mesoscale model). Numerical experiments with nondivergent barotropic vortex pairs show that the relative movements of the vortices are sensitive to the separation distance



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and the characteristics of the swirling wind of the vortex. No observed mutual attraction is found in any of the nondivergent, barotropic vortex pairs tested.

Results from the 3D NRL/SAI tropical cyclone model show that on a constant- f plane with no mean wind, the movements of the two interacting tropical cyclones consist of a mutual cyclonic rotation, attraction, and eventual merging, in agreement with Fujiwhara's description. The displacement of one interacting storm in the mutual rotation is proportional to the combined strength of the binary system, but inversely proportional to the size of the storm and to the square of the separation distance. The rate of merging is related to the development of a mean secondary circulation on the radial-vertical plane, and is quite independent of the strength of the two tropical cyclones.

The latitudinal variation of the Coriolis parameter adds a northwest beta drift to the trajectories. Depending on their relative strength and location, the beta drift can either speed up the merging process or separate the two interacting tropical cyclones.

The axisymmetric ocean model consists of primitive equations for the conservation of momenta in three spatial dimensions and the buoyancy. A Boussinesq assumption is made so that the background stratification is kept constant, the horizontal and vertical diffusion is of the Fickian type.

A leapfrog temporal integration is employed. The grid is fully staggered as Arakawa C type. The system is non-hydrostatic, the resultant elliptic equation for the pressure is solved by a stablized error vector propagation technique. The basic equations, the finite differencing form, and boundary conditions are discussed in detail in the attached Appendix.

APPENDIX I
A NUMERICAL STUDY OF THE INTERACTIONS BETWEEN
TWO TROPICAL CYCLONES

A Numerical Study of the Interactions Between
Two Tropical Cyclones

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June 1983

ABSTRACT

↙ The interactions between atmospheric vortex pairs are simulated and studied with a nondivergent barotropic model and a three-dimensional tropical cyclone model.

Numerical experiments with nondivergent barotropic vortex pairs show that the relative movements of the vortices are sensitive to the separation distance and the characteristics of the swirling wind of the vortex. No mutual attraction is found in any of the nondivergent, barotropic vortex pairs tested.

Results from the 3D tropical cyclone model show that on a constant- f plane with no mean wind, the movements of the two interacting tropical cyclones consist of a mutual cyclonic rotation, attraction, and eventual merging, in agreement with Fujiwhara's description. The displacement of one interacting storm in the mutual rotation is proportional to the combined strength of the binary system, but inversely proportional to the size of the storm and to the square of the separation distance. The rate of merging is related to the development of a mean secondary circulation on the radial-vertical plane, and is quite independent of the strength of the two tropical cyclones.

The latitudinal variation of the Coriolis parameter adds a northwest beta drift to the trajectories. Depending on their relative strength and location, the beta drift either speeds up the merging process or separates the two interacting tropical cyclones.

1. INTRODUCTION

When two tropical cyclones are present simultaneously in the same region, it is often observed that they rotate around each other with decreasing separation between them in the absence of large scale wind flow (Fig. 1). The phenomenon was made well-known by Fujiwhara (1921), and is therefore referred to as the Fujiwhara effect. By laboratory experiment and geophysical observation, Fujiwhara (1923, 1931) demonstrated that the relative motion of two counterclockwise vortices was a counterclockwise rotation. Haurwitz (1951) examined several tropical cyclone pairs by introducing the concept of center of mass around which the two tropical cyclones rotate about each other. By approximating the circulation around a tropical cyclone with that of a Rankine vortex, Haurwitz (1951) derived a relationship between the rotation rate and the sum of the total mass circulation of the two tropical cyclones. Many discrepancies were found when he applied the relationship to observations. Haurwitz attributed the discrepancies to the influence of large scale flow and lack of data, which led to deficiency in analyses.

Hoover (1961) studied binary tropical cyclones in both the Atlantic and Western Pacific Oceans. He found that the interaction between tropical cyclone pairs in the Western Pacific Ocean agrees with Fujiwhara's description while those pairs in the Atlantic Ocean rotated in an anticyclonic sense. He suggested that the different large scale atmospheric flow patterns in the two basins may have caused the binary systems to behave differently. The influence of the large scale flow was also noted by Liu and Wang (1966). They found that two interacting tropical cyclones in the Western Pacific are not always attracted to each other when there are strong shears in the environmental

flow. Recently, Dong and Neumann (1982)¹ found that storm pairs exhibiting behavior most in accordance with Fujiwhara's description were located in the Intertropical Convergence Zone where horizontal shears in large scale flow are negligible. They suggest that the effects of environmental flows be filtered before the real Fujiwhara effects can be determined. But to define and remove the large scale flows from observational data is difficult to accomplish.

Over the 35 year period 1946-1981, storm pairs known to have interactions averaged 1.5 annually in Western North Pacific and 0.33 annually in the Atlantic (Dong and Neumann, 1982). The presence of binary interacting has been noted to have contributed to forecast errors of tropical cyclone tracks (Brand, 1970; Jarrell et. al.; 1978; Neumann, 1982). Forecasting as well as analyzing a single tropical cyclone is often hindered by the paucity of observational data in the tropical cyclone basin (Neumann, 1982); the presence of two storms in close proximity can further compound the difficulties.

The purpose of our study is to investigate the interactions between two tropical cyclones by numerical simulations. Because the spatial resolutions of the models are better than the current observational network, and because numerical models can be controlled to produce "clean" results void of undesirable factors, analyzing realistic numerical simulations can sometimes result in a better isolation and understanding of the phenomenon than can be achieved from an observational approach. In this paper we will first determine the role of vorticity advection between the two vortices. For this purpose, a nondivergent, barotropic model is introduced to test two types of vortex pairs with different

¹Dong, K. and C. J. Neumann, 1982: On the relative motion of binary tropical cyclones. Regional Scientific Conference on Tropical Meteorology, Tsukuba Ibaraki, Japan, Oct. 1982.

swirling winds. These barotropic tests will be presented in Section 2. In Section 3, three-dimensional simulations of the interactions between two diabatically driven tropical cyclones on a constant- f plane and with variable f will be discussed. Our findings will be summarized in Section 4.

2. INTERACTIONS BETWEEN NONDIVERGENT, BAROTROPIC VORTEX PAIRS

In this section, we investigate the interactions between nondivergent barotropic vortex pairs. Through the interactions of such vortex pairs, we can determine the contribution of horizontal advection of vorticity, because in such a system advection is the only mechanism for interaction. A description of the nondivergent, barotropic model will be presented first, and the experimental design and the results will then be discussed.

a. Nondivergent Barotropic Model

The simple non-divergent, barotropic model can be described as

$$\frac{\partial}{\partial t} \nabla^2 \psi = -\underline{v}_\psi \cdot (\nabla^2 \psi + f), \text{ and} \quad (1)$$

$$\underline{v}_\psi = \hat{k} \times \nabla \psi \quad (2)$$

where f is the Coriolis parameter, ψ is the stream function, $\underline{v}_\psi$ is the nondivergent wind, and $\hat{k}$ is a vertically pointing unit vector. The boundary conditions for (1) and (2) are Neumann, i.e., $\nabla^2 \psi = 0$ at boundaries. The model has 51×51 grid points with a uniform horizontal resolution of 50 km. The relevant elliptic equation

$$\nabla^2 \psi = \zeta \quad (3)$$

where the relative vorticity is defined by

$$\zeta = \hat{k} \cdot \nabla \times \underline{v}_\psi \quad (4)$$

is solved by a stabilized error vector propagation method (Madala, 1978).

b. Experimental Design

The major application of the nondivergent barotropic model is to determine the effects of separation distance and the radial distribution of tangential winds on the interaction of the two vortices. Two kinds of wind distributions were tested. The first kind (type A) of vortex is defined by its cyclonic swirl wind v_o as function of radius r from the vortex center

$$v_o = \begin{cases} Ar (1 - \sin \frac{\pi r}{r_o}), & 0 \leq r \leq r_o \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

where constant $A = 4 \times 10^{-4} \text{ s}^{-1}$ and $r_o = 400 \text{ km}$. Equation (5) yields a maximum swirl of $\sim 26 \text{ m s}^{-1}$ at $r = 150 \text{ km}$ and a maximum vorticity $\zeta \approx 7.2 \times 10^{-4} \text{ s}^{-1}$ at $r = 0$. We note that there is a cutoff of v_o at r_o .

The second kind of vortex (type B) is defined as

$$v_o = Br \exp(-\frac{r^2}{r_e^2}) \quad (6)$$

where the e-folding distance r_e is 150 km. By letting the constant $B = 3.6 \times 10^{-4} \text{ s}^{-1}$, (6) yields a vortex with similar strength as that described by (5) with maximum swirl of $\sim 29 \text{ m s}^{-1}$ and a maximum $\zeta \approx 7 \times 10^{-4} \text{ s}^{-1}$. Type B vortex differs from Type A in that there is no cutoff of swirl. Fig. 2 compares the radial distributions of relative vorticities described by (5) and (6).

Four initial separation distances (300, 400, 600, and 1000 km) have been tested for each type of vortex pairs. All intergrations with the barotropic model are performed with constant $f = 4.37 \times 10^{-5} \text{ s}^{-1}$.

c. Results

Fig. 3 shows the trajectories of storm pairs having two types of swirl wind at four separation distances. It is very clear from Fig. 3 that the smaller the separation distance the faster the mutual transport. For instance, at a separation distance of 1000 km, neither type A vortex pair (with swirl cutoff at $r = 300 \text{ km}$) nor type B vortex pair can induce mutual motion. But at a separation distance of 400 km, they move at a speed of $\sim 400 \text{ km day}^{-1}$.

It is also evident that the mutually-induced motions of type A and type B vortices are very different, in spite of the values of constants for A and B which were chosen to give vortices of similar strength. Furthermore, the trajectories of type A vortex pairs are more anticyclonic. This may be a result of the fact that type B vortices have positive vorticities at $r \leq 200 \text{ km}$ whereas the vorticities of type A vortices change sign at $r = 150 \text{ km}$ (Fig. 2). Only vortex pairs at small separation distances rotate in a cyclonic fashion because they interact with positive shears. The motion of vortices in our model can only be caused by the advection of vorticity, the shear in one vortex can very much determine the movement of the other. These results indicate that the mutual motion of two interacting nondivergent, barotropic vortex pair are quite sensitive to the characteristics of the swirl winds.

In all the experiments illustrated in Fig. 3 the storm pairs drift apart, there is no mutual attraction as observed in some interacting typhoons. This suggests that the observed mutual attraction in typhoon pairs may be due to

the divergence and/or convergence that is not included in the barotropic model. Indeed, complicated diabatic processes in tropical cyclone such as long wave radiation, surface boundary layer effects and moist convection generate convergent flow in lower troposphere and divergent flow in upper troposphere. The irrotational component of the vortex circulation may be responsible for the occurrence of the observed cyclonic rotation and mutual attraction.

3. INTERACTIONS BETWEEN TROPICAL CYCLONE PAIRS

We have seen that nondivergent pairs do not cause a mutual motion similar to the description of Fujiwhara. The observed Fujiwhara effects may be due to dynamics that can only be resolved by a more complete model. To see that, we will simulate the interactions between two diabatically driven tropical cyclones with a three-dimensional model.

a. Three-dimensional Tropical Cyclone Model

The baroclinic model is identical to the one in Chang and Madala (1980) and Chang (1982), except for parameterization of the latent heating. The governing equations are in surface-pressure-weighted flux form for conservation of momentum, temperature and water vapor. The normalized pressure $\sigma = p/p_s$ is the vertical coordinate, where p_s is the surface pressure. The system is assumed hydrostatic. The bulk boundary layer parameterization is based on a generalized similarity theory (Chang, 1981). The model has 51×51 horizontal grid points with seven sigma layers in the vertical. The horizontal resolution is $\frac{1}{2}^\circ$ in both the latitudinal and longitudinal directions. The east-west boundaries are cyclic. The boundary conditions at the north and south boundaries are such that the second derivatives of thermodynamic variables

normal to the boundaries vanish. In addition, diffusion coefficients are increased near the north and south boundaries to damp numerical noise there.

Kuo's parameterization was used in Chang and Madala (1980) and Chang (1982), but a prescribed heating is applied in this model as done by Anthes (1971) in a axisymmetric model. The heating rate here is defined as

$$\dot{Q}(r, \sigma) = \begin{cases} \dot{Q}_0 \cos\left(\frac{\pi r}{2R}\right) \sin[\pi(\sigma - 0.1)], & \text{for } r \leq R, 0.1 \leq \sigma \leq 0.9 \\ 0, & \text{otherwise} \end{cases} \quad (7)$$

where r is the distance between a grid point and the low pressure center, and $R = 300$ km is the limit of the heating function. Two values of $\dot{Q}_0$, 100 K day^{-1} and 200 K day^{-1} , have been used in various numerical experiments to define the weak and strong tropical cyclones, respectively. The vertical and horizontal distributions of the heating pattern described in (7) are illustrated in Figs. 4 and 5. The vertical heating distribution is similar to that of the differences between temperatures in convective clouds (T_c) and the environment (T) in a mean hurricane season sounding for the Gulf of Mexico as computed by a one-dimensional cloud model (Anthes, 1977, Fig 4a). The horizontal heating distribution agrees with the mean rainfall rate inferred from satellite observation in a typhoon (Adler and Rogers, 1977), except for the observed smooth fall-off at $r \geq 300$ km. No effort is attempted to simulate the eye because of the model horizontal resolution.

The heating prescribed by (7) nevertheless generates realistic circulations for tropical cyclones. Figure 6 shows the radial distribution of the quasi-steady wind speeds at the sixth ($\bar{\sigma} = 0.85$) and seventh ($\bar{\sigma} = 0.965$) model layers after 24 h of heating with $\dot{Q}_0 = 200 \text{ K day}^{-1}$. The wind speeds have a peak at $r = 1^\circ$ and decrease gradually outward without discontinuity

at $r = R = 300$ km.

We note however that by using the prescribed heating in (7) the effects of the interaction between the two cyclones on the scale of the cumulus convection cannot be adequately simulated. In reality the momentum field in each storm, which affects the cumulus convection, can be modified by the proximity of another storm. A change in the cumulus convection in each storm may alter the storm's intensities, which can in turn affect the interaction between the two tropical cyclones. But these feedbacks may be secondary and are only important when the separation of the two storms is small. As a preliminary study, the more economical, prescribed heating is used to investigate the first order effects in the interaction.

b. Experimental Design

The tropical cyclone pairs in all numerical experiments (Table 1) with the 3D model are dynamically initialized by a 24h stationary heating at two locations, i.e., by applying (7) at two fixed grid points for 24h. Dong and Neumann (1982) found that in real cases when the separation distances are less than 11 degree of latitude, cyclonic rotation predominates. Therefore, the two fixed grid points for the stationary heating are set ten degree longitude apart in all experiments to ensure the occurrence of interaction. After the dynamic initialization period, the heating patterns are allowed to follow the low pressure centers. In Exps. 1-3 we simulate the Fujiwhara effects in zero large scale winds on a constant- f plane for strong-strong (Exp. 1) weak-weak (Exp. 2) and strong-weak (Exp. 3) storm pairs. Exp. 1 and 3 are repeated in Exp. 5 and 6 on a real variation of f . There is only one single tropical cyclone in Exp. 4 to help isolate the effect of the beta-drift. Unlike on a

Table 1: List of three-dimensional Numerical Experiments

Exp.	$\dot{Q}$ (K day ⁻¹)		f (s ⁻¹)	Characteristic
	Storm A	Storm B		
1	200	200	4.37×10^{-5}	strong-strong interaction
2	100	100	"	weak-weak interaction
3	100	100	"	weak-strong interaction
4	200	-	variable f	beta drift
5	200	200	"	strong-strong interaction
6	100	200	"	weak-strong interaction
7	200	100	"	strong-weak interaction

constant- f plane where geophysical orientation is not meaningful, the interactions with real f for a weak (west)-strong (east) pair and strong (west)-weak (east) pair are quite different, as we shall see later, thus Exp. 7 is conducted to study the latter situation.

c. Results on a Constant- f Plane

Fig. 7 shows the surface pressure field at 24, 48, 72, and 96h for Exp. 1. The southward displacement of storm A (west) and the northward displacement of storm B (east) at 24h indicate that their interaction has already caused the two storms to begin to rotate cyclonically in spite of the stationary heating. The merging of the two storms progresses with the merging of the outer isobars as observed (Fig. 1). By 96h, only the 996 mb isobars show two separate low pressure centers. The pressure at the center point of the model decreases by 10 mb while the approaching of the two initial low pressure centers between 24-96h can only account for a pressure decrease of 2 mb. This indicates that the mutual rotation and merging involve dynamics more complicated than merely advective processes.

Exp. 1-3 are integrated with a constant f . Therefore the orientation has little meaning and the results are independent of the absolute initial positions of the storms. Fig. 8 shows the trajectories of the storm centers in Exp. 1, in which two strong model tropical cyclones are of the same strength. The trajectories show that the two storms rotate about each other in a cyclonic fashion before the coalescence at 102h. The two trajectories are symmetric about the center of mass, which coincides with the center of the model domain. Superimposed on the symmetric rotation is a convergence of the two tropical cyclones. The distance between the two storms decreases from ~ 1024 km at 24h to ~ 612 km at 96h. The symmetry remains until 102h when the two heating

patterns overlap and one single large area of low pressure is formed.

Exp. 2 is identical to Exp. 1 except that the heating rate is reduced by one half. The cyclonic trajectories (Fig. 9) are still remarkably symmetric about the center of mass. Because of the weaker heating, two identifiable centers still exist at 120h when they are only ~ 100 km apart. We note again that at small separation distances feedbacks between cumulus convection and the storm pair's interaction have been masked by the prescribed heating in our model.

The speeds at which the two tropical cyclones in Exp. 1 and 2 rotate around and approach each other are shown in Fig. 10. The tangential velocity of the cyclonic rotation in Exp. 1 increases from $\sim 3 \text{ m s}^{-1}$ at 24-36h to well over 6 m s^{-1} after 72h as the separation between the two tropical cyclones becomes small. The rotation speeds in Exp. 2 are about 1 m s^{-1} slower than those in Exp. 1. However, the rate of convergence seems quite independent of the combined strength as indicated by the radial velocities in Fig. 10. The faster rotations between stronger pairs are evident observationally at small separation distances (Dong and Neumann, 1982). At larger separation distances, this relationship is not clear because the observational data contains environmental influences.

Fig. 11 shows the trajectories of the two storm center in Exp. 3, in which the maximum heating rate in storm A is only half that of storm B. We see that the two storms still rotate about each other cyclonically and that they still move toward each other. However, the trajectories are asymmetric and the weaker storm A moves much faster than the stronger storm B in a way similar to that of a binary celestial system in which the two bodies have different masses. The "mass" of a vortex is perhaps best expressed as the product of its mean

angular velocity and the square of an effective radius $\bar{\omega}R^2$. We will discuss this further later. This type of interaction between storms of different intensities has been observed between Typhoons Flossie and Grace in 1950 (Liu and Wang, 1966). Instead of being stationary, the center of rotation moved within a small area defined by the lines connecting the two storm centers at different times as in Fig. 10.

Results in Exps. 1-3 demonstrate that on an f-plane with no large scale wind, interactions between two tropical cyclones cause the two storms to rotate cyclonically, to attract each other and to coalesce eventually.

In order to examine the momentum fields associated with the interaction we transform the model 500 mb wind fields in Exp. 1 onto a polar grid with respect to the center of the model domain. We now define the azimuthal mean velocity as

$$\bar{\mathbf{v}} = (\bar{v}_r, \bar{v}_\theta, \bar{v}_z) = \frac{1}{2\pi} \int_0^{2\pi} (v_r, v_\theta, v_z) d\theta \quad (8)$$

where v_r , v_θ , v_z are radial, tangential and vertical velocities on the polar grid, and θ is the azimuthal angle. Fig. 12 shows the mean vertical (upper), tangential (middle), and radial (lower) velocities for Exp. 1 at 24, 48, 72, and 96h. It is interesting that the mean momentum fields relative to the center of domain shown here are similar to those in weak but intensifying tropical disturbances (Hawkins and Rubsam, 1968). For example, at 24h there is a maximum mean tangential velocity of $\sim 4 \text{ m s}^{-1}$ at $r \sim 600 \text{ km}$ and a minimum of $\sim -2 \text{ m s}^{-1}$ at $r \sim 400 \text{ km}$, reflecting the cyclonic wind fields about the two storm centers. The maximum tangential velocity gradually increases to $\sim 16 \text{ m s}^{-1}$ and moves toward the center to a radius $\sim 350 \text{ km}$ at 96h. The maximum inflow also

develops from 2 m s^{-1} at $r \sim 600 \text{ km}$ at 24h to $\sim 4 \text{ m s}^{-1}$ at $r \sim 350 \text{ km}$ at 96h. The evolution of the mean vertical velocity includes the increasing magnitude and contracting radii of maximum upward motion. The development of the mean circulation is accompanied with the pressure decrease of 10 mb at the domain midpoint from 24-96h, as discussed before.

The development of the azimuthal mean circulation can also be illustrated by comparing the kinetic energy (KE) of the mean velocity (KEM) and the KE of the eddy velocity (KEE), where

$$\text{KEM} = \iint_0^{1000 \text{ km}} (\bar{v}_r, \bar{v}_\theta) \cdot (\bar{v}_r, \bar{v}_\theta) r dr d\theta \quad (9)$$

$$\text{KEE} = \iint_0^{1000 \text{ km}} (v'_r, v'_\theta) \cdot (v'_r, v'_\theta) r dr d\theta \quad (10)$$

$$\text{and } (v'_r, v'_\theta) = (v_r, v_\theta) - (\bar{v}_r, \bar{v}_\theta) \quad (11)$$

As shown by Fig. 13, the KEE, which can mostly be attributed to the circulations around the two centers, reaches a quasi-steady state after 36h. Meanwhile the KEM, representing the strength of the mean circulation as depicted in Fig. 10 around the center of rotation, steadily increases until the coalescence of the two tropical cyclones. The ratio KEE/KEM decreases from ~ 3 at 24h to less than 1 at 96h.

These analyses suggest that a mean circulation relative to the center of rotation develops due to the interaction of two tropical cyclones. This mean

circulation includes tangential, radial and vertical components resembling those associated with tropical cyclones. It is therefore not surprising that the trajectories of the two interacting storms are similar to the trajectories in the hurricane boundary layer (e.g. Anthes 1982, Fig. 4.6). Compared with the nondivergent, barotropic experiments in Section 2, it seems that the diabatic heating in two storms plays a crucial role for the merging of the two storms.

In additional numerical experiments, the surface friction was suppressed to test the frictional effects in the interaction. Results from these experiments were nearly identical to those presented for Exps. 1-3. We also halved the coefficients for the internal dissipation. For the same given heating rates, the interactions are nearly the same except for faster rotation rates, because the model cyclones were stronger with less internal friction. Therefore, neither surface nor internal friction seem to be critical processes in the interactions.

d. Relation of Mutual Rotation Rate to Bulk Parameters of the System

The results presented so far indicate generally that the rate of the mutual cyclonic rotation depends on the strength of the binary system and the separation distance of the two interacting storms. Perhaps by relating some extent parameters through laws governing solid body rotation, a simple description of the numerical results is attainable.

We now consider the rotation of the binary storms is similar to that of a dumbbell. The equation of motion for rotation states that the torque τ acting on the binary system is equal to the product of the rotational inertia of the system I and the angular acceleration $\dot{\omega}$ with respect to the axis of rotation, i.e.

$$\tau = I\dot{\omega} \quad (12)$$

If we let R be an effective radius of the storm and H be the scale height, the

mass of one storm can be approximated by $\rho_0 \pi R^2 H$. Because the radius of the mutual rotation is about $L/2$, the rotational inertia

$$I \propto \rho_0 (\bar{R}_A^2 + \bar{R}_B^2) H L^2 \quad (13)$$

where ρ_0 is a reference density and subscript A and B are pertinent for storms A and B, respectively.

The torque is equal to the cross product of a force and radius of rotation. The force involved in the interaction can be approximated by the advection, then it can be scaled by $\rho_0 \bar{V}^2 / L$, where $\bar{V}$ is the velocity of the mean circulation defined by (8). Because the mean circulation depends on the combined strength of the two interacting cyclones, therefore $\bar{V} \propto \bar{v}_A + \bar{v}_B$, where $\bar{v}_A$ and $\bar{v}_B$ are the mean wind speed within the effective radius $\bar{R}_A$ and $\bar{R}_B$, respectively. Thus, the torque is proportional to

$$\tau \propto L H \rho_0 (\bar{R}_A^2 + \bar{R}_B^2) (\bar{v}_A + \bar{v}_B)^2 L^{-1} \quad (14)$$

We note that the torque contains the dimension of the kinetic energy of the two storms, which is ultimately related to the applied heating $\dot{Q}$ in our model. Substituting (13) and (14) into (12) and dropping the over-bars, we get

$$(\bar{v}_A + \bar{v}_B)^2 \propto \dot{\omega} L^2 \sim f \omega L^2 \quad (15)$$

In above, f^{-1} is selected as the time scale, so that $\dot{\omega} \sim \omega / T \sim f \omega$. For our purposes of examining numerical results of a limited domain model away from the equator where f remain nearly a constant, the selection of f^{-1} as a time scale is justifiable.

$$\omega \propto \frac{(v_A + v_B)}{fL^2} \quad (16)$$

Relationship (16) states simply that the rate of the mutual rotation is proportional to the combined kinetic energy of the two interacting tropical cyclone and inversely proportional to the square of the separation distance. In addition, the displacement of one storm should be inversely proportional to its size, because the radius of rotation is inversely proportional to the mass $\pi \rho_0 R^2 H$.

In applying (16) to the numerical results, the mean wind speed within the radius of the gale force wind (17 m s^{-1}) is used as v_A and v_B . Excluding data when the separation distance is smaller than the sum of two radii of the gale force, rotation rates of binary system at every 6h were compared with $(v_A + v_B)^2 / fL^2$ for Exps 1,2 and 3 (Fig. 14). It is clear the (16) is a good description of the results Exp. 1-3. The rotation rates ω and quantities $(v_A + v_B)^2 / fL^2$ have a correlation coefficient of 0.81. Therefore, our numerical results can to some extent be represented by surprisingly simple relationship (16).

It should be noted, however, that (16) is arrived through several simplifying assumptions. These include approximating the mutual rotation of two vortex in the atmosphere by using solid body mechanics and excluding the merging from consideration. While (16) yields good correlation, it is only an approximation of the rotation component of the interaction.

e. The Effects of Variation of the Coriolis Parameter

Exps. 4-7 were carried out with variable Coriolis parameter, which can produce northwestward drifts of tropical cyclones in the northern hemisphere (Adem, 1956; Anthes and Hoke, 1975; Madala and Piacsek, 1975). The velocity of the drift depends on the latitude and the cyclone's circulation. To examine the free drift of a single tropical cyclone in our model, we carried out Exp. 4. As shown by trajectory C in Fig. 15, the model tropical cyclone has an initial northward movement, but changes toward the northwest after 36h, similar to the results of Anthes and Hoke (1975). The 0-72h mean drift velocity is 1.18 m s^{-1}

toward the west and 1.37 m s^{-1} toward the north. The center at 72h is $\sim 6^\circ$ to the west and $\sim 6.5^\circ$ to the north of the initial position.

The latitudinal variation of the Coriolis parameter has a pronounced effect on the trajectories of the two interacting tropical cyclones. The trajectories of the two tropical cyclones with equal strength in Exp. 5 are shown in Fig. 15. The two storms merge much faster than Exp. 1 due to the faster northwest drift of the storm located to the south. At 87h only one large low pressure center is identifiable, while in Exp. 1, two low pressure centers still existed at 96h (Fig. 7). Instead of rotating around the + point in Fig. 8 as in Exp. 1, storm A moves toward the southeast then quickly turns toward the northeast, while storm B rapidly moves northwestward and rotates cyclonically with respect to storm A. The two storms eventually merge into one at 87h, with storm B having traveled a much larger distance from its initial position than storm A. The relative trajectories of A and B with respect to trajectory C (Exp. 4) are computed. The resultant relative trajectories (not shown) are nearly the same as those in Exp. 1 (Fig. 3), indicating that the trajectories A and B in Fig. 15 is nearly a linear combination of the trajectories in Fig. 3 and the beta drift.

Exp. 6 is to be compared with Exp. 3, where storm A is weaker than storm B. The trajectories of the storm centers in Exp. 6 (Fig. 16) again appear very different from those in Exp. 3. The stronger storm B shows more noticeable northwest drift than in Exp. 3. The weaker storm A rotates cyclonically toward the southeast at a much reduced rate and with a smaller radius, apparently due to the counteracting beta drift.

Most interesting is Exp. 7, in which storm A is stronger than storm B. From 24 to 72h, the weaker storm B moves cyclonically relative to storm A.

In the meantime storm A moves slowly toward the southwest nearly perpendicular to and away from storm B. The trajectories take a strange turn after 72h because the two storms now are close to the boundaries and start to influence each other through the east-west boundaries because of the cyclic boundary conditions there.

The distinctively different behavior between Exps. 5-7 can be explained by examining schematically the vectors of forces upon each storm. We let the northwest drift be proportional to the storm's intensity and size (Rossby, 1948; Adem, 1956) and the force due to the interaction be proportional to the combined strength of the binary system but inversely proportional to the strength of individual storm as discussed in Section 3c. Figure 17 shows the vectors and the resultant directions of movements for storm A at 24h of Exps. 5-7. In Exp. 5 both the beta drift and interaction (both the rotation and convergence are counted for) are strong, the movement of the storm is mostly due south as evident in Fig. 15. In Exp. 6, the beta drift is weaker but the interaction is the strongest, the movement is nearly along the vector of the interaction. In Exp. 7, the beta effect is strong while the interaction is weak, results in a slow movement of the storm away from storm B.

4. SUMMARY

The interactions between two mesoscale cyclonic vortices in the absence of large scale winds have been investigated with a nondivergent, barotropic model and a three-dimensional model. Model results indicate that the interactions between a nondivergent barotropic vortex pair are very different from those observed between a tropical cyclone pair, and that our three-dimensional simulations agree with the observed Fujiwhara phenomenon.

Two types of vortex pairs with various initial separation distances have been tested with the nondivergent, barotropic model. No mutual attraction is found in any of the cases tested. The curvature of the mutually induced rotation depends on the radial profile of swirl winds (or vorticities) of each vortex, the speed of mutually induced motion is a function of separation — the closer the two vortices, the faster they move. This is quite understandable, because in such a nondivergent barotropic model the two vortices can only interact by advection. These numerical experiments suggest that the observed Fujiwhara phenomenon is caused by a more complex mechanism than just vorticity advection.

Our simulations with a three-dimensional model reproduce observed Fujiwhara effects. The trajectories of simulated strong-strong, weak-weak, and weak-strong tropical cyclone pairs on a constant- f plane all consist of cyclonic rotations and mutual attractions. The rotation rate between two strong tropical cyclones is generally faster than that between a weak pair. The rate of convergence of a weak pair is not slower than that between a strong pair.

Additional analyses show that as the tropical cyclone pair start to interact, there forms a mean circulation about the center of mass of the two storms as the pressure there decreases more than can be expected by simple advective merging. The development of the mean circulation, consisting of a cyclonic tangential flow and a inward radial flow, resembles the circulation in weak but intensifying tropical disturbances. The kinetic energy of this mean circulation grows by a factor of four in 72h in one experiment, while the kinetic energy of the circulations associated with individual tropical cyclone remains relatively unchanged. It suggests that the development of a mean circulation on the vertical-radial plane relative to the center of mass of the interacting storm pairs is crucial in generating the cyclonic mutual rotation and merging.

A simple analysis points out that the displacement of one tropical cyclone interacting with another is proportional to the combined strength of the

vortex pair and inversely proportional to its own size and to the square of the separation distance. Our model results fit this description well except for cases when interacting storms become highly asymmetric about their own centers.

The latitudinal variation of the Coriolis parameter (beta effect) has a large influence on the trajectories of the interacting storm pairs. The beta effect causes a northwest shift and a faster merging of the two tropical cyclones of equal strength. The trajectories of two interacting tropical cyclones of equal strength have a northwest drift superposed on the symmetrical trajectories found on the constant-f plane. Observation studies showed that typhoon pairs sometimes drifted away from each other if there were strong shears in large scale flow (Liu and Wang, 1966; Dong and Neumann, 1982). This study indicated that differential beta drifts can also cause the two interacting tropical cyclones of different strength to diverge when the one initially located to the west is stronger.

These findings should not be accepted without caution because of several limitations of the numerical model. The model domain is perhaps too small for two tropical cyclones. In addition, the horizontal resolution of $\frac{1}{2}^\circ$ is only marginal for resolving realistically the smaller scale dynamics near the center. Being a uniform grid model, without decreasing the horizontal resolution, the model domain cannot be expanded due to limited computing resources. The cyclic boundary conditions created problems (as evident in Exp. 7) when two storms may have interacted with each other through the east-west boundaries. Perhaps the most serious limitation of our simulation is the heating prescribed a priori in the three-dimensional simulations, which may have masked the interactions between two adjacent tropical cyclones on the scale of cumulus convections. However, the development of the mean circulation about the center of mass of the two tropical

cyclones occurs at very early stage of the interaction when the separation is still large. This suggests that the detailed characteristics of cumulus convection in individual storm may not be important in setting up the cyclic rotation and mutual attraction. The use of the prescribed heating was justifiable except at small separations where the divergent-convergent pattern in each storm may be modified due to the proximity of another one.

In future research, a parameterized convective heating should be utilized to investigate the abovementioned secondary effect of the cumulus convection. In addition, the parameterized heating may react to large scale winds in a nonlinear fashion. Therefore, the nonlinear effects of the large scale winds on the interactions of two tropical cyclones also ought to be studied. The question of what is the maximum separation distance for storm pair to interact is also left for future studies when numerical models of tropical cyclone cover a larger domain are constructed.

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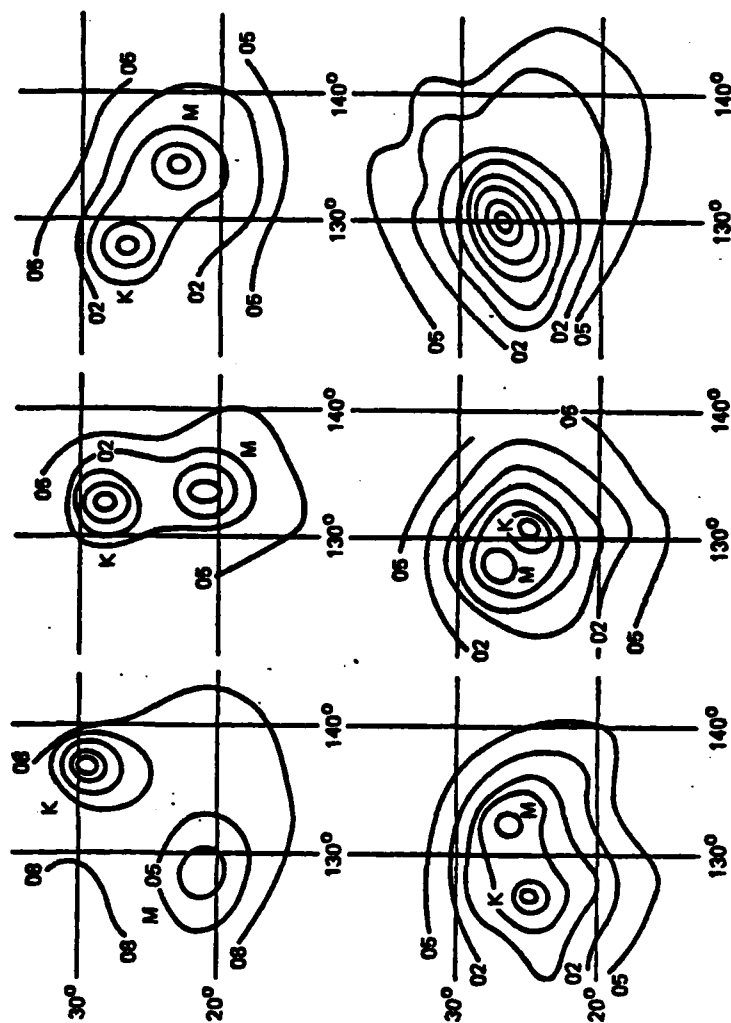
FIGURES

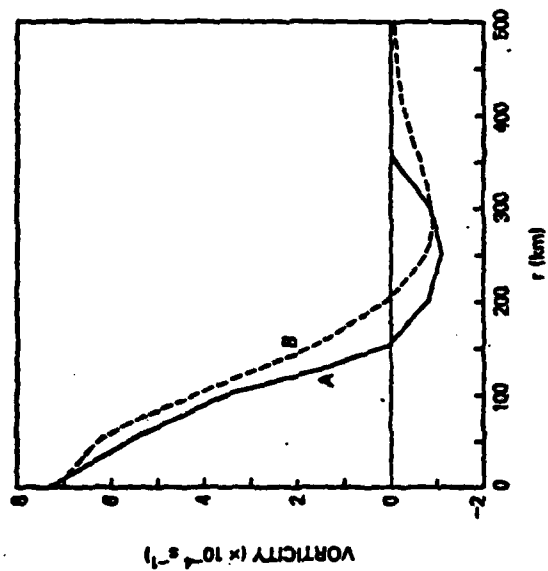
- Figure 1: Surface isobaric analyses at 0000Z on Sept. 15-20, 1964 showing the rotation and merging of typhoons Kathy (K) and Marie (M). Isobars are plotted every 3 mb. (From Liu and Wang, 1966).
- Figure 2: The radial distribution of relative vorticity for type A (solid) and type B vortex (dashed).
- Figure 3: The trajectories of type A (solid lines) and type B (dashed lines) vortices at separation distances of 300, 400, 600, and 1000 km. The cross is the center of the domain. Time interval between two adjacent dots is 12h. Squares denote the initial vortex centers.
- Figure 4: The vertical distribution of heating used in the model plotted on an arbitrary scale (solid), as compared with $(T_c - T)$ for mean hurricane sounding produced by a one-dimensional cloud model (Anthes, 1977, Fig. 4).
- Figure 5: The horizontal distribution of heating used in the model plotted on an arbitrary scale (solid), as compared with the observed radial distribution of rainfall rate in a typhoon (Adler and Rodgers, 1977, Fig. 5).
- Figure 6: The radial distribution of the quasi-steady wind speeds in model layer six ($\bar{\sigma} = 0.85$) and seven ($\bar{\sigma} = 0.963$) generated by the stationary prescribed heating.
- Figure 7: The surface pressure field at 24, 48, 72, 84, and 96h. Contour intervals are 4 mb, the outmost closed isobars are 1008 mb. Longitudes are arbitrarily set.
- Figure 8: The trajectories of storm centers in Exp. 1. Numbers on the curve denote times in hour.
- Figure 9: As in Figure 8, except for Exp. 2.
- Figure 10: The tangential and radial speeds of the two interacting tropical cyclones relative to their centers of mass in Exps. 1 and 2.
- Figure 11: As in Fig. 8, except for Exp. 3.
- Figure 12: The azimuthal mean radial (v_r), tangential (v_θ), and vertical velocity (w) of the wind fields relatives to the center of mass in Exp. 1 at 24, 48, 72 and 96h.
- Figure 13: The development of the kinetic energy of the "mean" flow (solid) relative to the center of mass and the kinetic energy of the "eddy" associated with the two storm centers (dashed) in Exp. 1.
- Figure 14: The rotational rates ω compared with $(v_A + v_B)^2 / fL^2$.

Figure 15: The trajectories of the free drifting storm in Exp. 4 (Curve C) and of the two interacting storms in Exp. 5 (Curves a and B).

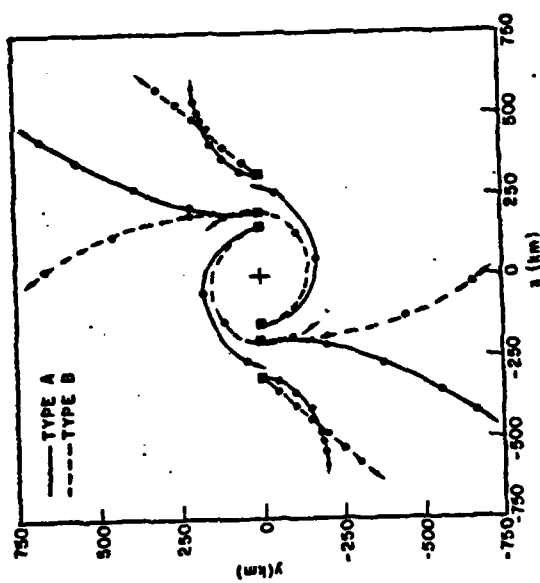
Figure 16: As in Fig. 15 except for Exps. 6 (solid lines with dots) and 7 (solid lines with squares).

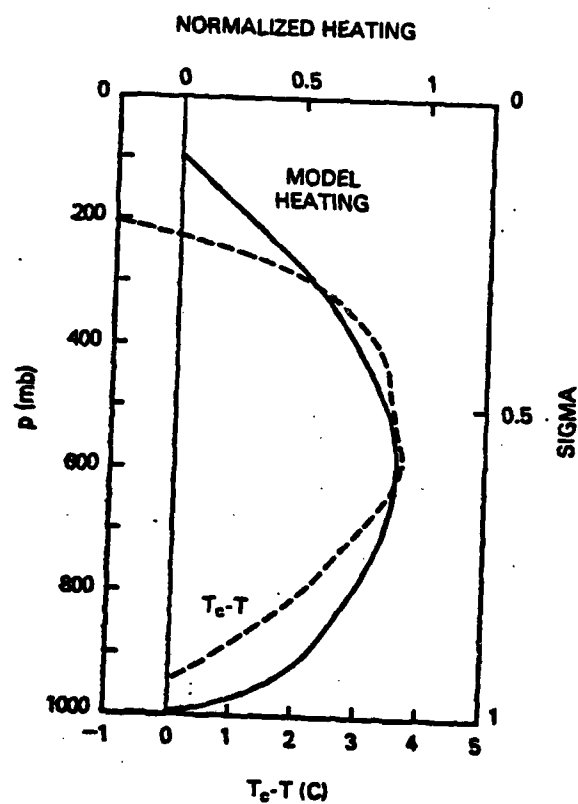
Figure 17: Vectors showing schematically the force of interaction (I), beta drift (D), and the resultant movement (M) for tropical cyclones A at 24h of Exps. 5, 6, and 7.

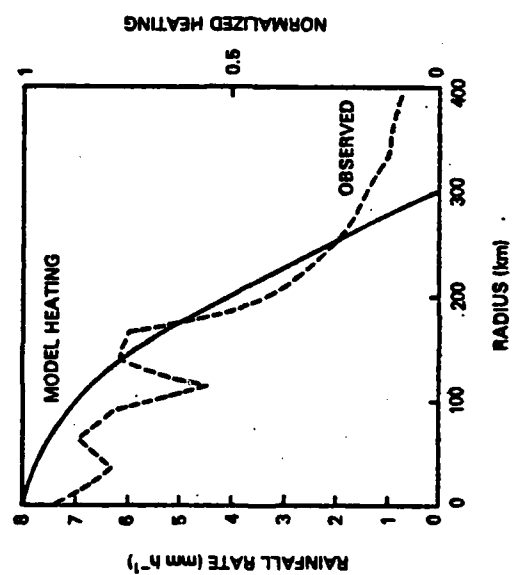


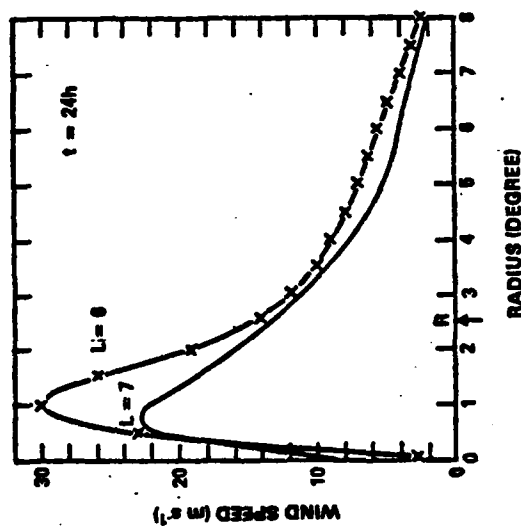


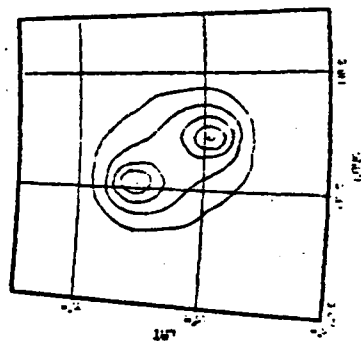
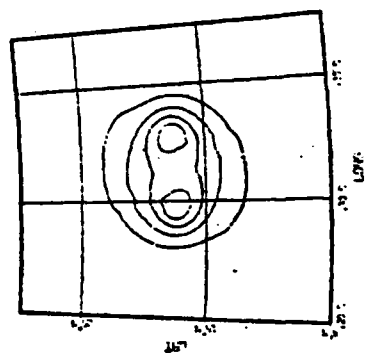
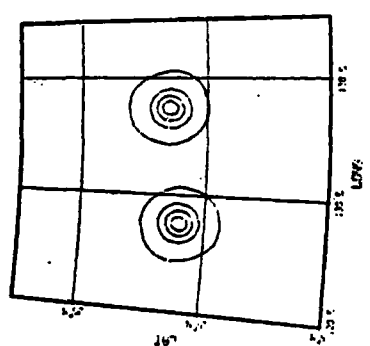
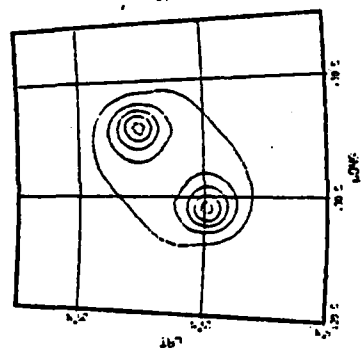
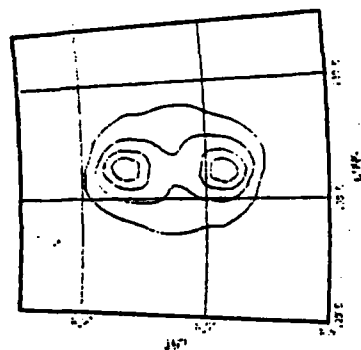
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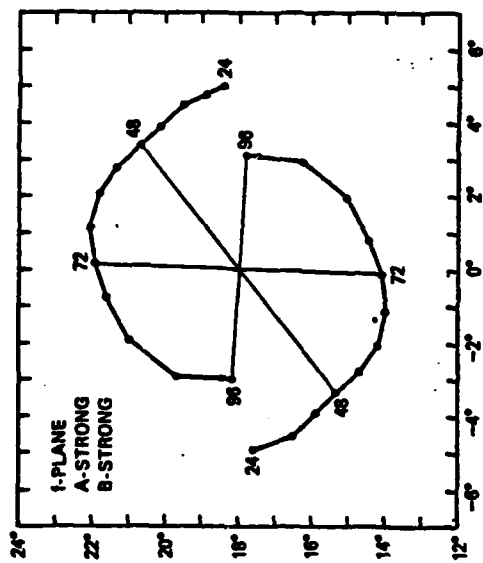


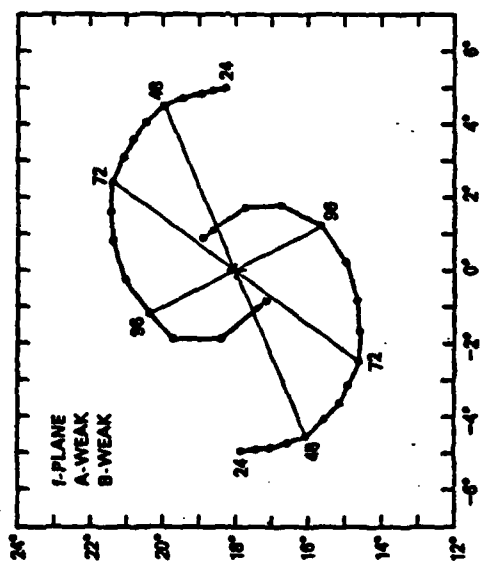


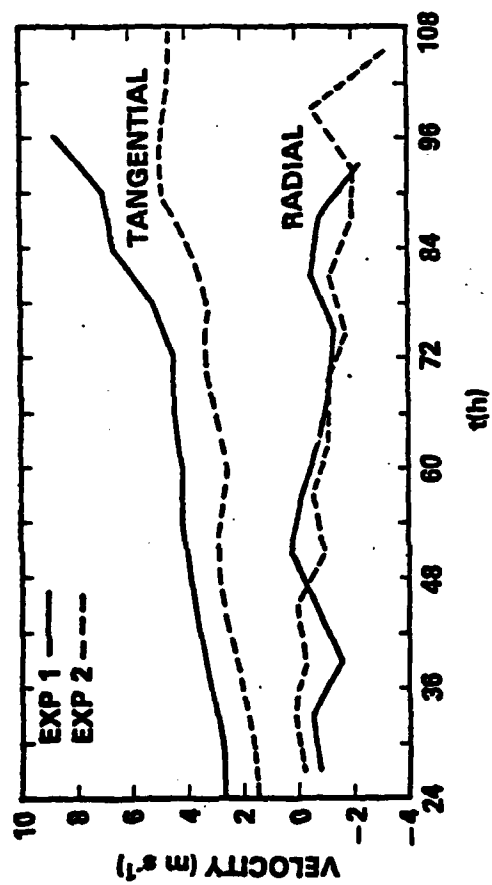


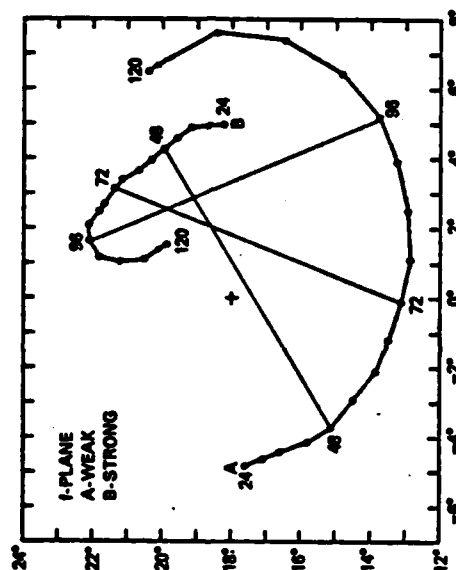




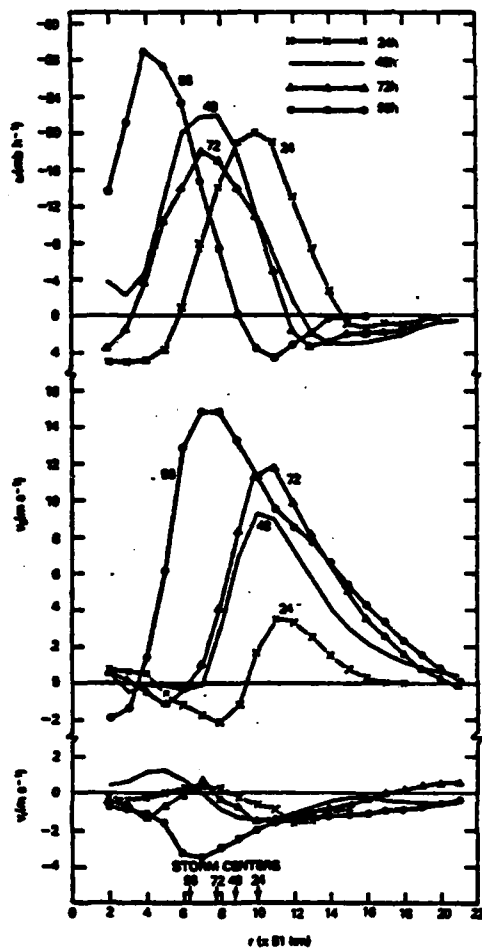


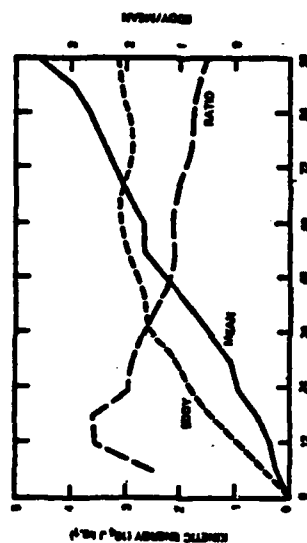


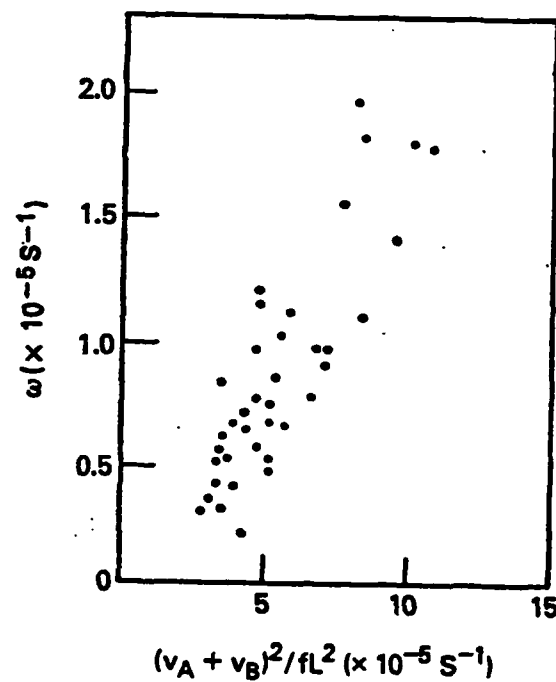




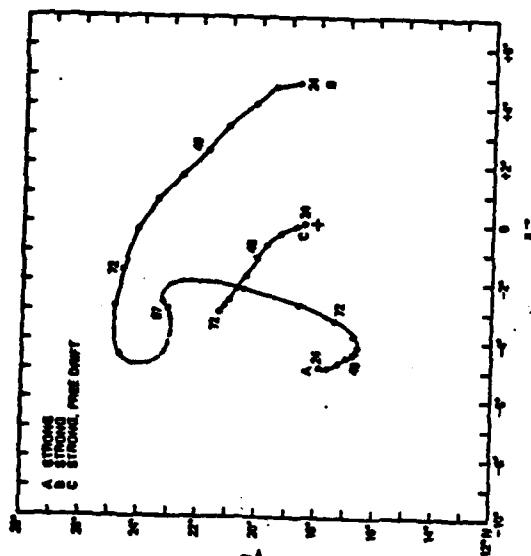
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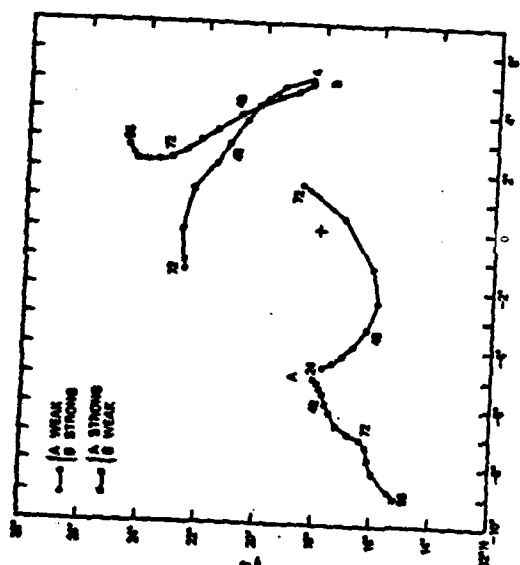


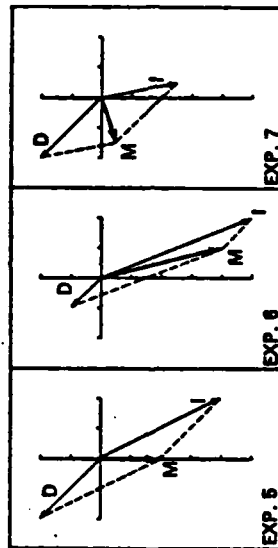




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APPENDIX II

AN AXISYMMETRIC MODEL FOR A NON-HYDROSTATIC
BOUSSINESQ OCEAN

AN AXISYMMETRIC MODEL FOR A NON-HYDROSTATIC
BOUSSINESQ OCEAN

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AN AXISYMMETRIC, NUMERICAL MODEL FOR A NON-HYDROSTATIC BOUSSINESQ OCEAN

1. GOVERNING EQUATIONS

The governing equations of the axisymmetric, non-hydrostatic, Boussinesq ocean model are

$$\begin{aligned} \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial r} + w \frac{\partial u}{\partial z} = \frac{v^2}{r} + fv - \frac{1}{\rho_0} \frac{\partial p}{\partial r} + K_H \left(\nabla^2 u - \frac{u}{r^2} \right) \\ + K_z \frac{\partial^2 u}{\partial z^2} \end{aligned} \quad (1-1)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial r} + w \frac{\partial v}{\partial z} = - \frac{uv}{r} - fu + K_H \left(\nabla^2 v - \frac{v}{r^2} \right) + K_z \frac{\partial^2 v}{\partial z^2} \quad (1-2)$$

$$\frac{\partial w}{\partial t} + u \frac{\partial w}{\partial r} + w \frac{\partial w}{\partial z} = -b - \frac{1}{\rho_0} \frac{\partial p}{\partial z} + K_H \nabla^2 w + K_z \frac{\partial^2 w}{\partial z^2} \quad (1-3)$$

$$\frac{\partial b}{\partial t} + u \frac{\partial b}{\partial r} + w \frac{\partial b}{\partial z} = N_z^2 w + K_H \nabla^2 b + K_z \frac{\partial^2 b}{\partial z^2} \quad (1-4)$$

where $\nabla^2 \equiv \frac{\partial^2}{\partial r^2} + \frac{1}{r} \frac{\partial}{\partial r}$, other symbols are listed in Appendix A.

Above, the density anomaly b is defined according to

$$b = \frac{\rho - \rho_r(z)}{\rho_0} g, \quad (1-5)$$

where $\rho_r(z)$ is a reference density and is a function of depth only. Brunt-Väisälä frequency N_z is defined as

$$N_z = \sqrt{\left(\frac{-g}{\rho_0} \frac{\partial \rho_r}{\partial z} \right)} \quad (1-6)$$

The continuity equation is that of the incompressible fluid,

$$\frac{1}{r} \frac{\partial ur}{\partial r} + \frac{\partial w}{\partial z} = 0 \quad (1-7)$$

2. THE MODEL GRID

It is determined that a fully staggered grid is most expedient for storage economy for a given spatial resolution. As shown in Fig. 1, the radial (u) and the tangential (v) velocities are defined at cross points, vertical velocities (w) are defined at open circle points, and the pressures (p) and density anomalies (b) are defined at blackened dot points. This grid system has the following advantages:

- a) it saves storage for a given spatial resolution
- b) it is very economical in terms of number of computational operations for the finite difference (FD) equations of (1-1) to (1-4).
- c) it is very easy to specify the boundary conditions,
- d) the pressure diagnostic equation, of the elliptic type, can be reduced to the standard form, and
- e) there is no spatial separation of solutions on the grid.

In order to consistently index the grid points, we let index pair (ij) represent the i -th point in the r -direction and j -th point in the z -direction. In addition, m is the maximum number of points in the r -direction, and n , the maximum number of points in the z -direction. Therefore there are $m \times (n-1)$ points for radial and tangential velocities, $(m-1) \times n$ points for vertical velocities, and $(m-1) \times (n-1)$ points for mass distribution (b and p).

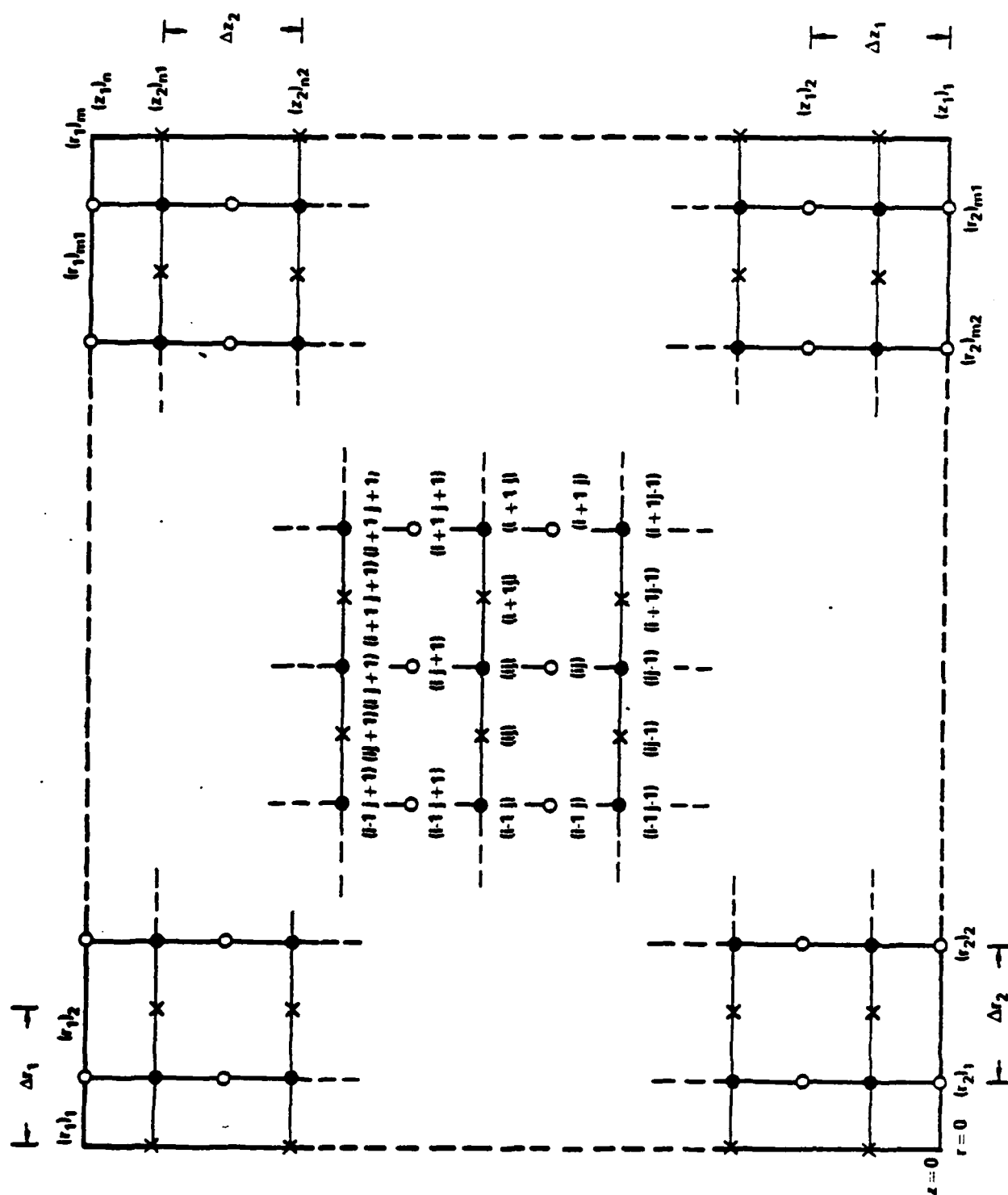


Fig. 1 The fully staggered grid system of the ocean model.

3. THE FINITE DIFFERENCE EQUATIONS

The leapfrog, or centered-in-time, integration scheme for the inviscid terms and the forward-in-time integration scheme for the viscous terms are used. The scheme is described as

$$\begin{pmatrix} u^{t+\Delta t} \\ v^{t+\Delta t} \\ w^{t+\Delta t} \\ b^{t+\Delta t} \end{pmatrix} = \begin{pmatrix} u^{t-\Delta t} \\ v^{t-\Delta t} \\ w^{t-\Delta t} \\ b^{t-\Delta t} \end{pmatrix} + 2\Delta t \begin{pmatrix} \frac{\partial u}{\partial t}^t \\ \frac{\partial v}{\partial t}^t \\ \frac{\partial w}{\partial t}^t \\ \frac{\partial b}{\partial t}^t \end{pmatrix} \quad (3-1)$$

A second order, or centered-in-space, scheme is applied to derive the tendencies in (3-1) according to (1-1) ~ (1-4).

(a) The Equation of Motion in r-direction

$$\frac{\partial u_{ij}^t}{\partial t} = H_{ij}^t - \frac{1}{\rho_0} \frac{1}{(\Delta r_2)_i} (p_{ij} - p_{i-ij}) \quad (3-2)$$

where

$$\begin{aligned}
H_{ij}^t = & -0.25 \left[\frac{1}{(\Delta r_1)_{i-1}} (u_{ij}^t + u_{i-1j}^t) (u_{ij}^t - u_{i-1j}^t) \right. \\
& + \frac{1}{(\Delta r_1)_i} (u_{i+1j}^t + u_{ij}^t) (u_{i+1j}^t - u_{ij}^t) \\
& + \frac{1}{(\Delta z_2)_j} (w_{i-1j}^t + w_{ij}^t) (u_{ij}^t - u_{ij-1}^t) \\
& \left. + \frac{1}{(\Delta z_2)_{j+1}} (w_{ij+1}^t + w_{i-1j+1}^t) (u_{ij+1}^t - u_{ij}^t) \right] \\
& + v_{ij}^t \left[\frac{v_{ij}^t}{(r_1)_i} + f \right] \\
& + K_H \left\{ \frac{1}{(\Delta r_2)_i} \left[\frac{1}{(\Delta r_1)_i} (u_{i+1j}^{t-\Delta t} - u_{ij}^{t-\Delta t}) \right. \right. \\
& \quad \left. \left. - \frac{1}{(\Delta r_1)_{i-1}} (u_{ij}^{t-\Delta t} - u_{i-1j}^{t-\Delta t}) \right] \right. \\
& + 0.5 \left[\frac{1}{(r_2)_i (\Delta r_1)_i} (u_{i+1j}^{t-\Delta t} - u_{ij}^{t-\Delta t}) \right. \\
& \quad \left. + \frac{1}{(r_2)_{i-1} (\Delta r_1)_{i-1}} (u_{ij}^{t-\Delta t} - u_{i-1j}^{t-\Delta t}) \right] \\
& \left. - \frac{u_{ij}^{t-\Delta t}}{(r_1)_i} \right\} + \frac{K_z}{(\Delta z_1)_j} \left[\frac{1}{(\Delta z_2)_{j-1}} (u_{ij-1}^{t-\Delta t} - u_{ij}^{t-\Delta t}) \right. \\
& \quad \left. - \frac{1}{(\Delta z_2)_j} (u_{ij}^{t-\Delta t} - u_{ij-1}^{t-\Delta t}) \right]
\end{aligned}$$

3-5

(b)

The Equation of Motion in s-direction

$$\begin{aligned}
\frac{\partial v_{ij}^t}{\partial t} = & -0.25 \left[\frac{1}{(\Delta r_1)_{i-1}} (u_{ij}^t + u_{i-1j}^t) (v_{ij}^t - v_{i-1j}^t) \right. \\
& + \frac{1}{(\Delta r_1)_i} (u_{i+1j}^t + u_{ij}^t) (v_{i+1j}^t - v_{ij}^t) \\
& + \frac{1}{(\Delta z_2)_j} (w_{i-1j}^t + w_{ij}^t) (v_{ij}^t - v_{i-1j}^t) \\
& \left. + \frac{1}{(\Delta z_2)_{j+1}} (w_{ij+1}^t + w_{i-1j+1}^t) (v_{ij+1}^t - v_{ij}^t) \right] \\
& - u_{ij}^t \left[\frac{v_{ij}^t}{(r_1)_i} + f \right] \\
& + \frac{K_H}{(\Delta r_2)_i} \left\{ \left[\frac{1}{(\Delta r_1)_i} (v_{i+1j}^{t-\Delta t} - v_{ij}^{t-\Delta t}) \right. \right. \\
& \quad \left. \left. - \frac{1}{(\Delta r_1)_{i-1}} (v_{ij}^{t-\Delta t} - v_{i-1j}^{t-\Delta t}) \right] \right. \\
& + 0.5 \left[\frac{1}{(r_2)_i (\Delta r_1)_i} (v_{i+1j}^{t-\Delta t} - v_{ij}^{t-\Delta t}) \right. \\
& \quad \left. + \frac{1}{(r_2)_{i-1} (\Delta r_1)_{i-1}} (v_{ij}^{t-\Delta t} - v_{i-1j}^{t-\Delta t}) \right] \\
& \left. - \frac{v_{ij}^{t-\Delta t}}{(r_1)_i^2} - \frac{K_E}{(\Delta z_1)_j} \left[\frac{1}{(\Delta z_2)_{j-1}} (v_{ij-1}^{t-\Delta t} - v_{ij}^{t-\Delta t}) \right. \right. \\
& \quad \left. \left. - \frac{1}{(\Delta z_2)_j} (v_{ij}^{t-\Delta t} - v_{i-1j-1}^{t-\Delta t}) \right] \right\}
\end{aligned}$$

(5-4)

(c) The Equation of Motion in z-direction

$$\frac{\partial w_{ij}^t}{\partial t} = G_{ij}^t - \frac{1}{c_0(\Delta z_2)_j} (p_{ij} - p_{ij-1}) \quad (3-5)$$

where

$$\begin{aligned} G_{ij}^t = & -0.25 \left[\frac{1}{(\Delta r_2)_i} (u_{ij}^t + u_{ij-1}^t) (w_{ij}^t - w_{i-1j}^t) \right. \\ & + \frac{1}{(\Delta r_2)_{i+1}} (u_{i+1j}^t + u_{i+1j-1}^t) (w_{i+1j}^t - w_{ij}^t) \\ & + \frac{1}{(\Delta z_1)_{j-1}} (w_{ij-1}^t + w_{ij}^t) (w_{ij}^t - w_{ij-1}^t) \\ & \left. + \frac{1}{(\Delta z_1)_j} (w_{ij+1}^t + w_{ij}^t) (w_{ij+1}^t - w_{ij}^t) \right] \\ & - 0.5 (b_{ij}^t + b_{ij-1}^t) \\ & + K_H \left\{ \frac{1}{(\Delta r_1)_i} \left[\frac{1}{(\Delta r_2)_{i+1}} (w_{i+1j}^{t-\Delta t} - w_{ij}^{t-\Delta t}) \right. \right. \\ & \quad \left. \left. - \frac{1}{(\Delta r_2)_i} (w_{ij}^{t-\Delta t} - w_{i-1j}^{t-\Delta t}) \right] \right. \\ & + 0.5 \left[\frac{1}{(r_1)_{i+1} (\Delta r_2)_{i+1}} (w_{i+1j}^{t-\Delta t} - w_{ij}^{t-\Delta t}) \right. \\ & \quad \left. \left. + \frac{1}{(r_1)_i (\Delta r_2)_i} (w_{ij}^{t-\Delta t} - w_{i-1j}^{t-\Delta t}) \right] \right\} \end{aligned}$$

$$+ \frac{K_z}{(\Delta z_2)_j} \left[\frac{1}{(\Delta z_1)_j} (w_{ij+1}^{t-\Delta t} - w_{ij}^{t-\Delta t}) - \frac{1}{(\Delta z_1)_{j-1}} (w_{ij}^{t-\Delta t} - w_{ij-1}^{t-\Delta t}) \right] \quad (5-6)$$

(d) The Thermodynamic Equation

$$\frac{\partial b_{ij}^t}{\partial t} = -0.5 \left[\frac{u_{ij}^t}{(\Delta r_2)_i} (b_{ij}^t - b_{i-1j}^t) + \frac{u_{i+1j}^t}{(\Delta r_2)_{i+1}} (b_{i+1j}^t - b_{ij}^t) \right.$$

$$+ \frac{w_{ij}^t}{(\Delta z_2)_j} (b_{ij}^t - b_{ij-1}^t) + \frac{w_{ij+1}^t}{(\Delta z_2)_{j+1}} (b_{ij+1}^t - b_{ij}^t) \left. \right]$$

$$+ 0.5 (w_{ij+1}^t + w_{ij}^t) N_z^2$$

$$+ K_H \left\{ \frac{1}{(\Delta r_1)_i} \left[\frac{1}{(\Delta r_2)_{i+1}} (b_{i+1j}^{t-\Delta t} - b_{ij}^{t-\Delta t}) \right. \right.$$

$$\left. \left. - \frac{1}{(\Delta r_2)_i} (b_{ij}^{t-\Delta t} - b_{i-1j}^{t-\Delta t}) \right] \right.$$

$$+ 0.5 \left[\frac{1}{(r_1)_{i+1} (\Delta r_2)_{i+1}} (b_{i+1j}^{t-\Delta t} - b_{ij}^{t-\Delta t}) \right.$$

$$\left. + \frac{1}{(r_1)_i (\Delta r_2)_i} (b_{ij}^{t-\Delta t} - b_{i-1j}^{t-\Delta t}) \right] \left. \right\}$$

$$+ \frac{K_z}{(\Delta z_1)_j} \left[\frac{1}{(\Delta z_2)_{j+1}} (b_{ij+1}^{t-\Delta t} - b_{ij}^{t-\Delta t}) \right.$$

$$\left. - \frac{1}{(\Delta z_2)_j} (b_{ij}^{t-\Delta t} - b_{ij-1}^{t-\Delta t}) \right]$$

(5-7)

4. DERIVATION OF THE DIAGNOSTIC EQUATION FOR PRESSURE

The nonhydrostatic pressure at time t is needed to compute the pressure gradient forces in (3-2) and (3-5). To "recover" the pressure from the motion fields, we make use of the continuity equation by differentiating (1-7) with time we get

$$\frac{1}{r} \frac{\partial}{\partial r} r \frac{\partial u}{\partial t} + \frac{\partial}{\partial z} \frac{\partial w}{\partial t} = 0 ,$$

which can be written in finite difference form for a mass point ij as

$$\begin{aligned} & \frac{1}{\frac{1}{2}[(r_1)_i + (r_1)_{i+1}](\Delta r_1)_i} \left[(r_1)_{i+1} \frac{\partial u_{i+1j}^t}{\partial t} - (r_1)_i \frac{\partial u_{ij}^t}{\partial t} \right] \\ & + \frac{1}{(\Delta z_1)_j} \left[\frac{\partial w_{ij+1}^t}{\partial t} - \frac{\partial w_{ij}^t}{\partial t} \right] = 0 \end{aligned} \quad (4-1)$$

$$\text{Let } c_i = (r_1)_{i+1} / \left\{ \frac{1}{2} [(r_1)_i + (r_1)_{i+1}] (\Delta r_1)_i \right\}, \quad (4-2)$$

$$\text{and } a_i = (r_1)_i / \left\{ \frac{1}{2} [(r_1)_i + (r_1)_{i+1}] (\Delta r_1)_i \right\}$$

Substituting (3-2), (3-5) and (4-2) into (4-1), we have

$$\begin{aligned}
c_i H_{i+1j}^t &= \frac{1}{\rho_0} \frac{c_i}{(\Delta r_2)_{i+1}} (p_{i+1j} - p_{ij}) - a_i H_{ij}^t \\
&+ \frac{1}{\rho_0} \frac{a_i}{(\Delta r_2)_i} (p_{ij} - p_{i-1j}) + \frac{1}{(\Delta z_1)_j} G_{ij-1}^t - \frac{1}{(\Delta z_1)_j} G_{ij}^t \\
&- \frac{1}{\rho_0 (\Delta z_1)_j (\Delta z_2)_{j+1}} (p_{ij+1} - p_{ij}) \\
&+ \frac{1}{\rho_0 (\Delta z_1)_j (\Delta z_2)_j} (p_{ij} - p_{ij-1}) = 0
\end{aligned}$$

After some rearrangements, we get

$$\begin{aligned}
&= \frac{c_i}{(\Delta r_2)_{i+1}} p_{i+1j} - \frac{a_i}{(\Delta r_2)_i} p_{i-1j} \\
&- \frac{1}{(\Delta z_1)_j (\Delta z_2)_j} p_{ij-1} - \frac{1}{(\Delta z_1)_j (\Delta z_2)_{j+1}} p_{ij+1} \\
&+ \left[\frac{c_i}{(\Delta r_2)_{i+1}} + \frac{a_i}{(\Delta r_2)_i} + \frac{1}{(\Delta z_1)_j (\Delta z_2)_{j+1}} + \frac{1}{(\Delta z_1)_j (\Delta z_2)_j} \right] p_{ij} \\
&= \rho_0 \left[-c_i H_{i+1j}^t + a_i H_{ij}^t - \frac{1}{(\Delta z_1)_j} G_{ij+1}^t + \frac{1}{(\Delta z_1)_j} G_{ij}^t \right] \quad (4-5)
\end{aligned}$$

Now let $-F_{ij} = \text{RHS of (4-5)},$

$$CX_i = \frac{c_i}{(\Delta r_2)_{i+1}} = (r_1)_{i+1} \left\{ \frac{1}{\Delta r_1} [(r_1)_i - (r_1)_{i+1}] \right. \\ \left. (\Delta r_1)_i (\Delta r_2)_{i+1} \right\} ,$$

$$AX_i = \frac{a_i}{(\Delta r_2)_i} = (r_1)_i \left\{ \frac{1}{\Delta r_1} [(r_1)_i - (r_1)_{i-1}] \right. \\ \left. (\Delta r_1)_i (\Delta r_2)_i \right\} ,$$

$$CZ_j = 1/[(\Delta z_1)_j (\Delta z_2)_{j+1}] ,$$

$$AZ_j = 1/[(\Delta z_1)_j (\Delta z_2)_j] , \text{ and}$$

$$BB_{ij} = - CX_i - AX_i - CZ_j - AZ_j \quad (4-4)$$

We obtain the standard form of an elliptic equation in FD form

$$AX_i P_{i-1j} + AZ_j P_{ij-1} + BB_{ij} P_{ij} + CX_i P_{i+1j} + CZ_j P_{ij+1} = F_{ij} \quad (4-5)$$

Equation (4-5) can be solved numerically by the SEVP solver (Madala, 1978), providing the boundary conditions are properly posed.

The conditions for the four boundaries are determined according to the following assumptions:

(a) At $(r_1)_i = (r_1)_1 = 0$, the natural condition for the cylindrical coordinates calls for $u = v = 0 = \partial u / \partial t = \partial v / \partial t$, the gradient balance requires that $(\partial P / \partial r)_{r=0} = 0$. Therefore an extra column of P is needed

$$P_{0j} = P_{1j}$$

4-6

(b) At $(r_1)_i = (r_1)_m$, assuming both the horizontal divergence and the vorticity are continuous, i.e., $\frac{\partial}{\partial r} \frac{1}{r} \frac{\partial u r}{\partial r} = 0$ and $\frac{\partial}{\partial r} \frac{1}{r} \frac{\partial v r}{\partial r} = 0$. These lead to

$$u_{mj} = b_a u_{m1j} + b_b [(r_1)_{m1} u_{m1j} - (r_1)_{m2} u_{m2j}] \quad (4-7)$$

$$v_{mj} = b_a v_{m1j} + b_b [(r_1)_{m1} v_{m1j} - (r_1)_{m2} v_{m2j}]$$

where $b_a = (r_1)_{m1}/(r_1)_m$, and

$$b_b = [(r_1)_{m1} + (r_1)_m] (\Delta r_1)_{m1} / \{ (\Delta r_1)_{m2} [(r_1)_{m1} + (r_1)_{m2}] \}$$

Note that if b_b is set equal to zero, (4-7) describes a non-divergent and zero-vorticity boundary condition at $r = (r_1)_m$. Once v_{mj} is determined, a gradient balance at $r = (r_1)_m$ requires

$$\rho_o v_{mj} \left[\frac{v_{mj}}{(r_1)_m} + f \right] = \frac{1}{(\Delta r_2)_m} (p_{mj} - p_{m-1j})$$

or

$$p_{mj} = p_{m-1j} + \rho_o (\Delta r_2)_m v_{mj} \left[\frac{v_{mj}}{(r_1)_m} + f \right] \quad (4-8)$$

where a column of dummy points p_{mj} has been introduced for computational purposes. The second part of the RHS of (4-8) is thus the forcing function at $(r_1)_m$ for the elliptic equation (4-5).

(c) At the bottom, $w_{i1} = \frac{\partial}{\partial t} w_{i1} = 0$. Substituting these into the continuity equation (4-1), we get

$$\frac{1}{\frac{1}{2} (r_1)_i + (r_1)_{i+1} (\Delta r_1)_i} \left[(r_1)_{i+1} \frac{\partial u_{i+1}^t}{\partial t} - (r_1)_i \frac{\partial u_{i1}^t}{\partial t} \right] + \frac{1}{(\Delta z_1)_1} \frac{\partial w_{i2}^t}{\partial t} = 0. \quad (4-9)$$

Following the same deduction between (4-1) and (4-5), we get an expression similar to (4-5) with the second term on the LHS and G_{i1} in the RHS absent. Thus, P_{i1} can be obtained by the same SEVP solver by setting $C_{i1} = 0$ and $G_{i1} = 0$.

(d) At top $w_{in} = \partial/\partial t w_{in} = 0$. Following the same line of reasoning as in (c), we obtain P_{in} by solving (4-5) with $C_{in} P_{in+1} = 0$ and $G_{in} = 0$.

In summary, the elliptic pressure diagnostic equation (4-4) is to be solved with the following boundary conditions

- 1) At $r = 0$ $P_{0j} = P_{1j}$ i.e., (4-6)
- 2) At $r = (r_1)_m$ $P_{mj} = P_{m-1j} + \text{function}(v_{mj})$ (4-8)
- 3) At $z = 0$ $A_{i1} = 0$ and $G_{i1} = 0$
- 4) At $z = (z_1)_n$ $C_{in} = 0$ and $G_{in} = 0$

LIST OF SYMBOLS

AX_i	an array of constants, varying only in r-direction, defined by (4-4), used in (4-5)
AZ_j	an array of constants, varying only in z-direction defined by (4-4), used in (4-5)
a_i	an array of constants related to r_1 and Δr_1 used in (4-2)
BB_{ij}	an array of constants, used in (4-5)
b	density anomalies, defined in (1-5), cm s^{-2}
CX_i	an array of constants, varying only in r-direction, defined by (4-4), used in (4-5)
CZ_j	an array of constants, varying only in z-direction, defined by (4-4), used in (4-5)
c_i	an array of constants, related to r_1 and Δr_1 , used in (4-5)
f	Coriolis parameter, s^{-1}
g	gravitational acceleration, cm s^{-2}
i	an index, denoting i-th point in r-direction
j	an index, denoting j-th point in z-direction
K_H	horizontal diffusion coefficient, $\text{cm}^2 \text{s}^{-1}$
K_z	vertical diffusion coefficient, $\text{cm}^2 \text{s}^{-1}$
LHS	left hand side
m	the maximum number of grid points in r-direction, upper bound of i

m_1	$m-1$
m_2	$m-2$
N_z	Brunt-Väisälä frequency, s^{-1}
n	the maximum number of grid points in z -direction, upper bound of j
n_1	$n-1$
n_2	$n-2$
p	pressure, dyne cm^{-2}
RHS	right hand side
r	radius, cm
r_1	radii of momentum points, cm
r_2	radii of mass points, cm
Δr_1	distance between two horizontally adjacent momentum points, cm
Δr_2	distance between two horizontally adjacent mass points, cm
SEVP	<u>s</u> tabilized <u>e</u> rror <u>v</u> ector <u>p</u> ropagation
t	time, s
Δt	time interval, s
u	radial velocity, $cm\ s^{-1}$
v	tangential velocity, $cm\ s^{-1}$
w	vertical velocity, $cm\ s^{-1}$
z	height from ocean bottom, cm
z_1	heights of circle points, cm
z_2	heights of cross and dot points, cm

Δz_1 distance between two vertically adjacent circle points, cm
 Δz_2 distance between two vertically adjacent cross or dot points
 ρ density, g cm^{-3}
 ρ_0 a constant density, 1 g cm^{-3}
 ρ_r a reference density, varying only in z -direction, g cm^{-3}

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Discussions with Dr. R. V. Madala on the SEVP solver and the skillful typing of Mrs. Doris Beechum and Mrs. Judy Staudinger are greatly appreciated.

REFERENCE

Madala, R. V., 1978: An Efficient Direct Solver for Separable and Non-Separable Elliptic Equations. Month Weather Review, 106, 1735-1741.

APPENDIX A — FORTRAN CODE FOR THE NON-HYDROSTATIC MODEL

A listing of FORTRAN code of the ocean model. The major functions of the main program and subroutines are as follows:

OCEAN	main program, calls all subroutines, manages job flow, controls input/output.
INIT	sets up independent variables, defines constants
START	defines initial conditions
{ PUTOUT	gets various fields ready for output
{ MAP	prints
ADVECT	computes all inviscous terms, except for the pressure gradient forces
DIFF	computes horizontal and vertical diffusions
PRESS	solves the pressure diagnostic equations and computes the pressure gradient forces, appears only in the non-hydrostatic version
MATINV	inverts matrices
BSM1	} Used in SEVP method
BSM2	
BSM3	
FRWRD	matches forward
BOUNDV	sets outer boundary conditions for momentum
CHECK	checks if the time step is linearly stable.

APPENDIX B — FORTRAN CODE FOR THE HYDROSTATIC MODEL

The hydrostatic version of the model can be obtained by simplifying the non-hydrostatic version. In the hydrostatic version, the equation of motion in z -direction (1-5) is reduced to the hydrostatic equation

$$-\frac{1}{\rho_0} \frac{\partial p}{\partial z} = b \quad (B-1)$$

Instead of solving the elliptic equation (4-5), the pressure p is thus obtainable by vertically integrating (B-1). The vertical velocity w can also be computed by vertically integrating the continuity equation (1-7).

The FD forms of (B-1) and (1-7) are, respectively,

$$p_{ij} = p_{ij-1} - 0.5 \rho_0 (\Delta z_r)_j (B_{ij}^t + B_{ij-1}^t) \quad (B-2)$$

$$w_{ij} = w_{ij} + \frac{[(r_1)_{i+1} u_{i+1,j-1}^t - (r_1)_i u_{ij-1}^t] (\Delta z_1)_i}{0.5 (\Delta r_1)_i [(r_1)_{i+1} + (r_1)_i]} \quad (B-3)$$

<<SPLIT OCEAN0,SOLRC0,PRINT,SEG

```

10 PROGRAM OCEAN                                0001000
20 PARAMETER M=21,N=21                          0002000
30 PARAMETER N1=M+1,N2=M+2,N1N=N1,N2N=N2        0003000
40 PARAMETER N1N2=N1+N1N+N1N2                  0004000
50 DIMENSION DATA1(NC),DATA2(NC),DATA3(NC)      0005000
60 COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M,N1),B1(M,N1),VR2(M,N1), 0006000
70 1 VT2(M,N1),VZ2(M,N1),B2(M,N1),VR3(M,N1),VT3(M,N1), 0007000
80 2 VZ3(M,N1),B3(M,N1),P(M,N1)                 0008000
90 EQUIVALENCE (DATA1,VR1),(DATA2,VR2),(DATA3,VR3) 0009000
10 DATA DATA1/ND=0.,DATA2/ND=0.,DATA3/ND=0./    0010000
11 COMMON/TMR/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N) 0011000
12 COMMON/THR/RHR,M=PR(N1),BV2(N),ALPHA,BNDA,BNDB,COR1,G,MK(M),ZK(N) 0012000
13 COMMON/FOR/DELT,XTIME,ITIME,ISTEP,ISMC,ITAPE,TBV 0013000
14 CALL INDUMP                                    0014000
15 100 FORMAT(IJ)                                  0015000
16 READ(5,100)ITIME                               0016000
17 READ(5,100)ITER                                 0017000
18 READ(5,100)INIT                                 0018000
19 READ(5,100)ISMC                                 0019000
20 ISTEP=0                                         0020000
21 READ(5,100)ITAPE                                0021000
22 CALL INIT                                       0022000
23 IF(ITIME.EQ.0)GO TO 10                         0023000
24 C 0024000
25 C CONTINUED INTEGRATION FROM A HISTORY TAPE 0025000
26 C 0026000
27 READ(1)ITIME,DATA1,DATA2,P                    0027000
28 GO TO 20                                         0028000
29 10 CALL START                                    0029000
30 20 XTIME=ITIME+3600.                             0030000
31 C 0031000
32 C PRINT OUT INITIAL FIELDS                     0032000
33 C 0033000
34 CALL PUTOUT                                     0034000
35 IF(ITER.EQ.0)STOP                               0035000
36 DO 90 ISTEP=1,ITER                             0036000
37 C 0037000
38 C COMPUTE ALL INVISCID TERMS                   0038000
39 C 0039000
40 CALL ADVECT                                    0040000
41 C 0041000
42 C COMPUTE VISCOUS TERMS                       0042000
43 C 0043000
44 CALL DIFF                                       0044000
45 C 0045000
46 C AND ACC PRESSURE GRADIENT FORCES TO TENDENCIES 0046000
47 C DIAGNOSE (RECOVER) THE PRESSURE FIELD       0047000
48 C 0048000
49 CALL PRESS                                     0049000
50 C 0050000
51 C MARCHING IN TIME                             0051000
52 C FIRST TIME STEP IS FORWARD IF START IS CALLED 0052000
53 C 0053000
54 IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=0.5*DELT    0054000
55 CALL FHRD                                        0055000
56 IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=2.*DELT      0056000
57 C 0057000
58 C DEFINE BOUNDARY VALUES FOR VELOCITY        0058000
59 C 0059000
60 CALL BRUNDV                                     0060000
61 C 0061000
62 C CHECK IF DELT IS STABLE                     0062000
63 C 0063000
64 CALL CHECK                                       0064000
65 XTIME=XTIME+DELT                                0065000
66 ITIME=XTIME/3600.                               0066000
67 C 0067000
68 C PRINT OUT RESULTS EVERY INLT STEPS          0068000
69 C 0069000
70 IF(MOD(ISTEP,10LT).EQ.0)CALL PUTOUT            0070000
71 C 0071000
72 C WRITE HISTORY TAPE EVERY ITAPE STEPS        0072000
73 C 0073000
74 IF(MOD(ISTEP,ITAPE).EQ.0)WRITE(2)ITIME,DATA1,DATA2,P 0074000
75 90 CONTINUE                                     0075000
76 STOP                                           0076000
77 END                                             0077000

```

*** MEMBER INIT

```

1* SUBROUTINE INIT                                0001000
2* PARAMETER M=21,N=21                            0002000
3* PARAMETER M1=M-1,N1=N-1,N1N=1,N1NN=2          0003000
4* COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M,N1),R1(M1,N1),VR2(M,N1), 0004000
5* 1 VT2(M,N1),VZ2(M,N1),R2(M1,N1),VR3(M,N1),VT3(M,N1), 0005000
6* 2 VZ3(M,N1),R3(M1,N1),R(M1,N1)                0006000
7* COMMON/TWO/R1(M),R2(M1),OR1(M1),OR2(M1),Z1(N),Z2(N1),CZ1(N1),DZ2(N) 0007000
8* COMMON/THREE/RHO,HPR(N1),RV2(N),ALPHA,BNOA,BNOR,CORI,G,HX(N),ZK(N) 0008000
9* COMMON/FOUR/DELTA,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV 0009000
10* PARAMETER MP=M+1,NPN=N+1                      0010000
11* PARAMETER NBLK=2,NBLK1=NBLK-1                 0011000
12* PARAMETER MP1=MP-1,MP2=MP-2,NP1=NP-1,NP2=NP-2 0012000
13* REAL*8 RCON,RINV,RINV1,RTILDA                 0013000
14* COMMON/EV/RINV(MP2,NP2,NBLK),RINV1(MP2,MP2,NBLK1),RCON(MP,3), 0014000
15* 1 RTILDA(MP2),F(MP,NP),NBSIZ2(NBLK),IS(NBLK),SLMF(NBLK), 0015000
16* 2 IE(NBLK),F11(MP),F14(MP),F21(MP),F24(MP),AX(MP),AY(MP), 0016000
17* 3 RB(MP,NP),CX(MP),CY(MP)                    0017000
18* C                                              0018000
19* C INITIALIZE ALL DEPENDENT VARIABLES AND CONSTANTS 0019000
20* C                                              0020000
21* C                                              0021000
22* C ALPHA IS THE NONDIMENSIONAL SMOOTHING COEF. 0022000
23* C FOR TIME SMOOTHING IN SUBROUTINE FROD      0023000
24* C                                              0024000
25* C DELTA=0.00,                                0025000
26* C ALPHA=0.10,                                0026000
27* C G=0.80,                                    0027000
28* C LAT=30,                                    0028000
29* C COR1=2.*7.2722E-5*SIN(LAT*3.14159/180.) 0029000
30* C                                              0030000
31* C DEFINE RADII AT GRID POINTS AND ALL GRID INTERVALS 0031000
32* C                                              0032000
33* C DO 10 I=1,M1                                0033000
34* 10 R1(I)=20.E5                                0034000
35* C R1(I)=0.0,                                  0035000
36* C DO 20 I=2,M                                0036000
37* 20 R1(I)=R1(I-1)+0.1*(I-1)                    0037000
38* C DO 30 I=1,M1                                0038000
39* 30 R2(I)=0.5*(R1(I)+R1(I+1))                  0039000
40* OR2(I)=2.*(R2(I)-R1(I))                      0040000
41* OR2(M)=2.*(R1(M)-R2(M))                      0041000
42* C DO 40 I=2,M1                                0042000
43* 40 OR2(I)=OR2(I)-R2(I-1)                      0043000
44* C MAX=MAX(MAG(R1))                            0044000
45* C ORMAX=OR1(MAX)                             0045000
46* C                                              0046000
47* C DEFINE ALL NZ'S                             0047000
48* C                                              0048000
49* C DO 100 J=1,N                                0049000
50* 100 Z1(J)=(J-1)*200.E2                        0050000
51* C Z1(J)=0.0,                                  0051000
52* 110 Z2(J)=Z1(J+1)-Z1(J)                      0052000
53* C Z2(1)=2.*(0.5*(Z1(1)+Z1(2)))               0053000
54* Z2(1)=0.5*Z2(1)                              0054000
55* C DO 120 J=2,N1                                0055000
56* 120 Z2(J)=0.5*(Z2(J)+CZ1(J+1))               0056000
57* Z2(J)=Z2(J)-1)*Z2(J)                         0057000
58* C Z2(N)=2.*(Z1(N)-Z1(N-1)+0.5*Z1(N))          0058000
59* C MAX=MAX(MAG(Z2))                            0059000
60* C Z2MAX=Z2(MAX)                              0060000
61* C                                              0061000
62* C DEFINE CONSTANTS FOR SEVD SOLVER          0062000
63* C                                              0063000
64* C AX(I)=0.0,                                  0064000
65* C CX(MP)=0.0,                                 0065000
66* C AY(I)=0.0,                                  0066000
67* C CY(MP)=0.0,                                 0067000
68* C DO 50 I=1,M1                                0068000
69* 50 AX(I+1)=R1(I)/(0.5*(R1(I)+R1(I+1))+CR1(I)+OR2(I)) 0069000
70* CX(I+1)=R1(I+1)/(0.5*(R1(I)+R1(I+1))+CR1(I)+OR2(I+1)) 0070000
71* C DO 60 J=1,N1                                0071000
72* 60 AY(J+1)=R1(I)/(Z2(J)+CZ2(J))              0072000
73* CY(J+1)=R1(I)/(Z2(J)+CZ2(J+1))              0073000
74* C DO 70 J=1,NP                                0074000
75* 70 RB(J)=CX(I)-AX(I)-CY(J)-AY(J)             0075000
76* C NBSIZ2(NBLK)=NBLK1                         0076000
77* C NBSIZ2(NBLK)=NBLK1                         0077000
78* C NBSIZ2(NBLK)=NBLK1                         0078000
79* 40 NBSIZ2(NBLK)=NBSIZ2(NBLK+1)=NBSIZ2(NBLK1) 0079000
80* NBSIZ2(NBLK)=NBSIZ2(NBLK+1)=NBSIZ2(NBLK1)

```

*** MEMBER INIT

81	C		0000000
82	C		0001000
83	C	A AND B ARE CONSTANT USED IN SUBROUTINE DEL-DV	0002000
84	C	FOR CONSTANT DIV. AND VERT. CONDITIONS	0003000
85	C		0004000
86	C	ENDC=M1(M1)/R1(M)	0005000
87	C	ENDR=(R1(M1)*R1(M))*DR1(M1)/((R1(M1)+R1(M2))*R1(M)*DR1(M2))	0006000
88	C	ENDDB=0.	0007000
89	C		0008000
90	C	DEFINE DENSITY RELATED CONSTANTS	0009000
91	C		0010000
92	C	DP=130 J=1,N	0011000
93	C	130 BV2(J)=1,E=6	0012000
94	C	TBV=0.	0013000
95	C	DP=135 J=1,N	0014000
96	C	135 TBV=MAX1(TBV,BV2(J))	0015000
97	C	TBV=1./SQRT(TBV)	0016000
98	C		0017000
99	C	DEFINE HORIZONTAL AND VERTICAL DIFFUSION COEFFICIENTS	0018000
100	C		0019000
101	C	CDEFH=0.002*DR1(1)*2/DELT	0100000
102	C	CDEFZ=0.001*DZ1(1)*2/DELT	0101000
103	C	DP=140 I=1,M1	0102000
104	C	140 HK(I)=CDEFH*(1.+5.*EXP(-FLOAT(M1-I)/7.))	0103000
105	C	DP=150 J=1,N1	0104000
106	C	150 ZK(J)=CDEFZ*(1.+5.*(EXP(-FLOAT(J-1)/5.)*EXP(-FLOAT(M1-J)/5.)))	0105000
107	C	RETURN	0106000
108	C	END	0107000
			0108000

*** MEMBER START

```

10 SUBROUTINE START                                0001000
20 PARAMETER M=21,N=21                            0002000
30 PARAMETER M1=M-1,N1=N-1,N2=N-2                0003000
40 COMMON/ONE/VR1(M,N1),VT1(M,N1),VZ1(M1,N),P1(M1,N1),VR2(M,N1),  0004000
50 1 VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1),          0005000
60 2 VZ3(M,N1),B3(M1,N1),P(M1,N1)                  0006000
70 COMMON/TWO/P1(M),B2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),CZ1(N1),DZ2(N) 0007000
80 COMMON/THREE/RHO,RHO1(N1),RV2(N),ALPHA,BNCA,BNDB,CSRI,G,PK(M),ZX(N) 0008000
90 PARAMETER N0=2*M+M1+M1+N+M1+N1                0009000
100 DIMENSION DATA1(N0),DATA2(N0)                0010000
110 EQUIVALENCE (DATA1,VR1),(DATA2,VR2)           0011000
120 C                                               0012000
130 C INITIALIZE MASS FIELDS FOR A THEORETICAL RING 0013000
140 C                                               0014000
150 C I1=1                                           0015000
160 C I2=13                                          0016000
170 C I2=I2+1                                        0017000
180 C I22=M1                                         0018000
190 C RMAG=0.0002                                    0019000
200 C DO 10 I=I1,I2                                0020000
210 10 B1(I,M1)=RMAG*CRS(FLOAT(I-I1)/P,=3.14159)*G/RM9          0021000
220 C DO 30 I=I21,I22                               0022000
230 30 B1(I,M1)=B1(I2,M1)*EXP(-FLOAT(I-I21+1)/4.)              0023000
240 C DO 40 J=1,N2                                   0024000
250 FACT=EXP(FLOAT(J-M1)/5.)                          0025000
260 C DO 40 J=1,M1                                   0026000
270 40 B1(I,J)=B1(I,M1)*FACT                          0027000
280 C                                               0028000
290 C PRESSURE IS OBTAINED HYDROSTATICALLY FROM BUOYANCY 0029000
300 C                                               0030000
310 C DO 50 I=1,M1                                   0031000
320 50 P(I,1)=0.5*RM9*DZ2(I)+B1(I,1)                  0032000
330 C DO 60 J=2,M1                                   0033000
340 C DO 60 I=1,M1                                   0034000
350 60 P(I,J)=P(I,J-1)+0.5*RM9*DZ2(J)*(B1(I,J)+B1(I,J-1))      0035000
360 C                                               0036000
370 C TANGENTIAL VELOCITY IS IN GRADIENT BALANCE WITH MASS 0037000
380 C                                               0038000
390 C DO 70 J=1,M1                                   0039000
400 C DO 70 I=2,M1                                   0040000
410 PGF=(P(I,J)-P(I-1,J))/(RM9*CR2(I))                0041000
420 RAD=(0.5*CRRI+M1(I))*2+R1(I)+PGF                  0042000
430 JJ=J                                                0043000
440 II=I                                                0044000
450 IF(MAG,LT,0.)GO TO 100                            0045000
460 70 VT1(I,J)=0.5*CRRI+R1(I)+SQRT(RAD)              0046000
470 C                                               0047000
480 C SET DATA2=DATA1 FOR LEAPFROG                0048000
490 C                                               0049000
500 C DO 90 I=1,N0                                   0050000
510 90 DATA2(I)=DATA1(I)                              0051000
520 CALL BOUNDV                                       0052000
530 C DO 90 I=1,N0                                   0053000
540 90 DATA1(I)=DATA2(I)                              0054000
550 RETURN                                             0055000
560 100 PRINT 110,II,JJ,PGF,RAD                      0056000
570 110 FORMAT(' RADICAL IN SUBROUTINE START IS NEGATIVE AT (I,J)=',2IS, 0057000
580 1' PGF, RAD ',1P2E12,3)                          0058000
590 STOP                                              0059000
600 END                                              0060000

```

*** MEMBER BOUNDV

```

1* SUBROUTINE BOUNDV                                0001000
2* PARAMETER M1=1,M2=1                                0002000
3* PARAMETER N1=1,N2=2,N1=N1,N2=N2                    0003000
4* COMMON/BOUNDV/VR1(M,N1),VT1(M,N1),VZ1(M,N1),R1(M,N1),VR2(M,N1),  0004000
5* VT2(M,N1),VZ2(M,N1),R2(M,N1),VR3(M,N1),VT3(M,N1),  0005000
6* VZ3(M,N1),R3(M,N1),P(M,N1)  0006000
7* COMMON/TWR/PI(M),F2(M1),DP1(M1),DP2(M1),Z1(N),Z2(N1),DZ1(N1),DZ2(N)  0007000
8* COMMON/TWR/RMA,LCR(N1),BV2(N),ALPHA,ENDA,BNDB,COR1,G,M(M),ZK(N)  0008000
9* C  0009000
10* C LATERAL BOUNDARY FOR TANGENTIAL AND RADIAL VELOCITIES  0010000
11* C ASSUMING CONTINUOUS VORTICITY AND DIVERGENCE  0011000
12* C  0012000
13* DO 10 J=1,N1  0013000
14* VR2(M,J)=BNDA*VR2(M1,J)+BNDB*(R1(M1)*VR2(M1,J)-R1(M2)*VR2(M2,J))  0014000
15* 10 VT2(M,J)=BNDA*VT2(M1,J)+BNDB*(R1(M1)*VT2(M1,J)-R1(M2)*VT2(M2,J))  0015000
16* RETURN  0016000
17* END  0017000

```

*** MEMBER DIFF

```

1*      SUBROUTINE DIFF                                0001000
2*      C                                              0002000
3*      C      COMPLETE THE DIFFUSION TERMS          0003000
4*      C                                              0004000
5*      C      PARAMETER M=21,N=21                    0005000
6*      C      PARAMETER M1=M+1,M2=M+2,N1=N+1,N2=N+2  0006000
7*      C      COMMON/PHI/VR1(M,N1),VT1(M,N1),VZ1(M,N1),B1(M1,N1),VR2(M,N1),  0007000
8*      C      VT2(M,N1),VZ2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),  0008000
9*      C      VZ3(M,N1),B3(M1,N1),P(M1,N1)          0009000
10*     C      COMMON/TMR/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),CZ1(N1),CZ2(N)  0010000
11*     C      COMMON/TMR/RMR,RMR(M1),BVR2(N),ALPHA,BNDA,BNDB,COR1,G,PX(M),ZK(N)  0011000
12*     C      DIMENSION VR(M,N1),VT(M,N1),VZ(M,N1),B(M1,N1)  0012000
13*     C      EQUIVALENCE (VR,VR1),(VT,VT1),(VZ,VZ1),(B,B1)  0013000
14*     C                                              0014000
15*     C      HORIZONTAL DIFFUSION OF RADIAL VELOCITY  0015000
16*     C      C                                              0016000
17*     C      DO 10 J=1,N1                            0017000
18*     C      DO 10 I=2,M1                            0018000
19*     C      10 VR3(I,J)=VR3(I,J)+HK(I)*((VR(I+1,J)-VR(I,J))/DR1(I)  0019000
20*     C      1  *(VR(I,J)-VR(I-1,J))/DR1(I-1))/DR2(I)+VR(I,J)/(R1(I)+R1(I))  0020000
21*     C      2  +0.5*((VR(I+1,J)-VR(I,J))/DR1(I)+R2(I))  0021000
22*     C      3  *(VR(I,J)-VR(I-1,J))/(DR1(I-1)+R2(I-1)))  0022000
23*     C      C                                              0023000
24*     C      HORIZONTAL DIFFUSION OF TANGENTIAL VELOCITY  0024000
25*     C      C                                              0025000
26*     C      DO 20 J=1,N1                            0026000
27*     C      DO 20 I=2,M1                            0027000
28*     C      20 VT3(I,J)=VT3(I,J)+HK(I)*((VT(I+1,J)-VT(I,J))/DR1(I)  0028000
29*     C      1  *(VT(I,J)-VT(I-1,J))/DR1(I-1))/DR2(I)+VT(I,J)/(R1(I)+R1(I))  0029000
30*     C      2  +0.5*((VT(I+1,J)-VT(I,J))/DR1(I)+R2(I))  0030000
31*     C      3  *(VT(I,J)-VT(I-1,J))/(DR1(I-1)+R2(I-1)))  0031000
32*     C      C                                              0032000
33*     C      HORIZONTAL DIFFUSION OF VERTICAL VELOCITY  0033000
34*     C      C                                              0034000
35*     C      DO 30 J=2,M1                            0035000
36*     C      DO 30 I=2,M2                            0036000
37*     C      30 VZ3(I,J)=VZ3(I,J)+HK(I)*((VZ(I+1,J)-VZ(I,J))/DR2(I+1)  0037000
38*     C      1  *(VZ(I,J)-VZ(I-1,J))/DR2(I))/DR1(I)  0038000
39*     C      2  +0.5*((VZ(I+1,J)-VZ(I,J))/DR2(I)+R1(I+1))  0039000
40*     C      3  *(VZ(I,J)-VZ(I-1,J))/(DR2(I)+R1(I)))  0040000
41*     C      DO 40 J=2,M1                            0041000
42*     C      40 VZ3(I,J)=VZ3(I,J)+HK(I)*((VZ(2,J)-VZ(1,J))/(DR2(1)+DR1(1))  0042000
43*     C      1  +0.5*(VZ(2,J)-VZ(1,J))/(DR2(2)+R1(2)))  0043000
44*     C      DO 50 J=2,M1                            0044000
45*     C      50 VZ3(M1,J)=VZ3(M1,J)+HK(M1)*((VZ(M1,J)+VZ(M2,J))/(DR2(M1)+DR1(M1))  0045000
46*     C      1  *(VZ(M1,J)+VZ(M2,J))/(DR2(M1)+R1(M1)))  0046000
47*     C      C                                              0047000
48*     C      HORIZONTAL DIFFUSION OF B              0048000
49*     C      C                                              0049000
50*     C      DO 60 J=1,N1                            0050000
51*     C      DO 60 I=2,M2                            0051000
52*     C      60 B3(I,J)=B3(I,J)+HK(I)*((B(I+1,J)-B(I,J))/DR2(I+1)  0052000
53*     C      1  *(B(I,J)-B(I-1,J))/DR2(I))/DR1(I)  0053000
54*     C      2  +0.5*((B(I+1,J)-B(I,J))/DR2(I)+R1(I+1))  0054000
55*     C      3  *(B(I,J)-B(I-1,J))/(DR2(I)+R1(I)))  0055000
56*     C      DO 70 J=1,N1                            0056000
57*     C      70 B3(1,J)=B3(1,J)+HK(1)*((B(2,J)-B(1,J))/(DR2(2)+DR1(1))  0057000
58*     C      1  +0.5*(B(2,J)-B(1,J))/(DR2(2)+R1(2)))  0058000
59*     C      DO 80 J=1,N1                            0059000
60*     C      80 B3(M1,J)=B3(M1,J)+HK(M1)*((B(M1,J)+B(M2,J))/(DR2(M1)+DR1(M1))  0060000
61*     C      1  *(B(M1,J)+B(M2,J))/(DR2(M1)+R1(M1)))  0061000
62*     C      C                                              0062000
63*     C      VERTICAL DIFFUSION OF RADIAL VELOCITY  0063000
64*     C      C                                              0064000
65*     C      DO 90 J=2,M2                            0065000
66*     C      DO 90 I=2,M1                            0066000
67*     C      90 VR3(I,J)=VR3(I,J)+ZK(J)*((VR(I,J+1)-VR(I,J))/CZ2(J+1)  0067000
68*     C      1  *(VR(I,J)-VR(I,J-1))/CZ2(J))/CZ1(J)  0068000
69*     C      DO 100 I=2,M1                            0069000
70*     C      100 VR3(I,1)=VR3(I,1)+ZK(1)*(VR(I,2)-VR(I,1))/CZ2(2)+CZ1(1))  0070000
71*     C      DO 110 I=2,M1                            0071000
72*     C      110 VR3(I,M1)=VR3(I,M1)+ZK(1)*(VR(I,M1)+VR(I,M2))/CZ2(M1)+CZ1(M1))  0072000
73*     C      C                                              0073000
74*     C      VERTICAL DIFFUSION OF TANGENTIAL VELOCITY  0074000
75*     C      C                                              0075000

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*** MEMBER DIFF

```

76*      DP 120 J=2,N2                      0076000
77*      DP 120 I=2,M1                      0077000
78*      120 VT3(I,J)=VT3(I,J)+ZK(J)*((VT(I,J+1)-VT(I,J))/DZ2(J+1)  0078000
79*      1      -(VT(I,J)-VT(I,J-1))/DZ2(J))/DZ1(J)          0079000
80*      DP 130 I=2,M1                      0080000
81*      130 VT3(I,1)=VT3(I,1)+ZK(1)*((VT(I,2)-VT(I,1))/DZ2(2)+DZ1(1))  0081000
82*      DP 140 I=2,M1                      0082000
83*      140 VT3(I,N1)=VT3(I,N1)+ZK(N1)*((VT(I,N1)-VT(I,N2))/DZ2(N1)+DZ1(N1))  0083000
84*                                          0084000
85* C                                          0085000
86* C          VERTICAL DIFFUSION OF VERTICAL VELOCITY          0086000
87* C                                          0087000
88*      DP 150 J=2,N1                      0088000
89*      DP 150 I=1,M1                      0089000
90*      150 VZ3(I,J)=VZ3(I,J)+ZK(J)*((VZ(I,J+1)-VZ(I,J))/DZ1(J)  0090000
91*      1      -(VZ(I,J)-VZ(I,J-1))/DZ1(J-1))/DZ2(J)          0091000
92* C                                          0092000
93* C          VERTICAL DIFFUSION OF B          0093000
94* C                                          0094000
95*      DP 160 J=2,N2                      0095000
96*      DP 160 I=1,M1                      0096000
97*      160 B3(I,J)=B3(I,J)+ZK(J)*((B(I,J+1)-B(I,J))/DZ2(J+1)  0097000
98*      1      -(B(I,J)-B(I,J-1))/DZ2(J))/DZ1(J)          0098000
99*      DP 170 I=1,M1                      0099000
100*      170 B3(I,1)=B3(I,1)+ZK(1)*((B(I,2)-B(I,1))/DZ2(2)+DZ1(1))  0100000
101*      DP 180 I=1,M1                      0101000
102*      180 B3(I,N1)=B3(I,N1)+ZK(N1)*((B(I,N1)-B(I,N2))/DZ2(N1)+DZ1(N1))  0102000
103*      RETURN          0103000
104*      END          0104000

```

*** MEMBER FORWARD

```

1*      SUBROUTINE FFWFL                                0001000
2*      PARAMETER M=21,N=21                                0002000
3*      PARAMETER M1=1,M2=2,N1=1,N2=2                    0003000
4*      PARAMETER N0=2,M=N1+M1+N+M1+N1                    0004000
5*      COMMON/ONE/DATA1(N0),DATA2(N0),DATA3(N0),P(M1,N1) 0005000
6*      COMMON/TWO/RHO,LHCR(N1),BV2(N),ALPHA,CNDA,BNDB,CSP1,G,M(M),ZK(N) 0006000
7*      COMMON/THREE/DELTA,XTIME,ITIME,ISTEP,ISMC,ITAPE,TBV 0007000
8*      C                                                    0008000
9*      C      REPLACE DATA3 WITH THE NEW VALUES          0009000
10*     C                                                    0010000
11*     C      DO 10 I=1,N0                                0011000
12*     C      10 DATA3(I)=DATA1(I)+2.*DELTA*DATA3(I)      0012000
13*     C                                                    0013000
14*     C      TIME SMOOTHING                                0014000
15*     C                                                    0015000
16*     C      IF(MOD(ISTEP,ISMC).NE.0)GO TO 30             0016000
17*     C      DO 20 I=1,N0                                0017000
18*     C      20 DATA2(I)=DATA2(I)+(DATA1(I)+DATA3(I)-2.*DATA2(I))*ALPHA 0018000
19*     C      30 CONTINUE                                   0019000
20*     C                                                    0020000
21*     C      FORWARD MARCHING                             0021000
22*     C                                                    0022000
23*     C      DO 40 I=1,N0                                0023000
24*     C      40 DATA1(I)=DATA2(I)                        0024000
25*     C      DO 50 I=1,N0                                0025000
26*     C      50 DATA2(I)=DATA3(I)                        0026000
27*     C                                                    0027000
28*     C      ZERO OUT DATA3 FOR NEXT STEP                0028000
29*     C                                                    0029000
30*     C      DO 60 I=1,N0                                0030000
31*     C      60 DATA3(I)=0.                                0031000
32*     C      RETURN                                         0032000
33*     C      END                                           0033000

```

*** MEMBER CHECK

```

1*      SUBROUTINE CHECK                                0001000
2*      PARAMETER MB21,NB21                             0002000
3*      PARAMETER M1B=M1,P2B=M2,N1B=N1,N2B=N2           0003000
4*      COMMON/CNE/VR1(M,N1),VT1(M,N1),VZ1(M1,N),R1(M1,N1),VR2(M,N1), 0004000
5*      1 VT2(M,N1),VZ2(M1,N),R2(M1,N1),VR3(M,N1),VT3(M,N1), 0005000
6*      2 VZ3(M1,N),R3(M1,N1),P(M1,N1)                 0006000
7*      COMMON/TM/R1(M),M2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),CZ1(N1),CZ2(N) 0007000
8*      COMMON/PCR/DELT,XTIME,ITIME,ISTEP,ISMN,ITAPE,TBV 0008000
9*      DIMENSION WORK1(M),WORK2(N)                     0009000
10*     DO 10 J=1,M1                                     0010000
11*     DO 20 I=1,M                                       0011000
12*     20 WORK1(I)=DR2(I)/APAX1(1.,VR2(I,J))            0012000
13*     MIN=MIN(MAG(WORK1))+1                             0013000
14*     DT=WORK1(MIN)*0.9                                 0014000
15*     DT=AMINI(DT,DELT)                                0015000
16*     10 CONTINUE                                     0016000
17*     DO 40 I=1,M1                                     0017000
18*     DO 30 J=1,N                                       0018000
19*     30 WORK2(J)=VZ2(J)/APAX1(1.,VZ2(I,J))            0019000
20*     MIN=MIN(MAG(WORK2))+1                             0020000
21*     DT=WORK2(MIN)*0.9                                 0021000
22*     DT=AMINI(DT,DELT)                                0022000
23*     40 CONTINUE                                     0023000
24*     DT=AMINI(DT,TRV)                                  0024000
25*     IF (DT.GE,DELT)RETURN                             0025000
26*     DELT=0.75*DELT                                   0026000
27*     PRINT 100,DELT                                    0027000
28*     100 FORMAT(//////,'*****DELT IS CHANGED TO',1PE11.2,' *****') 0028000
29*     RETURN                                           0029000
30*     END                                              0030000

```

*** MEMBER ZILCH

```
1*      SUBROUTINE ZILCH(A,N)
2*      DIMENSION A(N)
3*      DO 10 I=1,N
4*      10 A(I)=0.
5*      RETURN
6*      END
```

```
0001000
0002000
0003000
0004000
0005000
0006000
```

*** MEMBER ADVECT

```

1*      SUBROUTINE ADVECT                                0001000
2*      C                                                0002000
3*      C      COMPLETE THE ADVECTIVE TERMS              0003000
4*      C                                                0004000
5*      C      PARAMETER M21,M22                        0005000
6*      C      PARAMETER M1M=1,M2M=2,M1M=1,M2M=2        0006000
7*      C      COMMON/ONE,VR1(M,N1),VT1(M,N1),VZ1(M,N1),B1(M1,N1),VR2(M,N1), 0007000
8*      C      VT2(M,N1),VZ2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1), 0008000
9*      C      VZ3(M,N1),B3(M1,N1),P(M1,N1)              0009000
10*     C      COMMON/TWO,R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N) 0010000
11*     C      COMMON/THREE,RHR,MHR(N1),BV2(N),ALPHA,BNDA,BNDB,COR1,C,PK(M1),ZK(N) 0011000
12*     C      DIMENSION VR(M,N1),VT(M,N1),VZ(M1,N),B(M1,N1) 0012000
13*     C      EQUIVALENCE (VR,VR2),(VT,VT2),(VZ,VZ2),(B,B2) 0013000
14*     C                                                0014000
15*     C      HORIZONTAL ADVECTION FOR RADIAL VELOCITY  0015000
16*     C                                                0016000
17*     C      DO 10 J=1,N1                                0017000
18*     C      DO 10 I=2,M1                                0018000
19*     C      10 VR3(I,J)=0.25*((VR(I,J)+VR(I-1,J))*(VR(I,J)-VR(I-1,J)),CR1(I-1) 0019000
20*     C      1      *(VR(I+1,J)+VR(I,J))*(VR(I+1,J)-VR(I,J))/DR1(I)) 0020000
21*     C      2      +VR3(I,J)                            0021000
22*     C      HORIZONTAL ADVECTION FOR TANGENTIAL VELOCITY 0022000
23*     C      C      DO 20 J=1,N1                            0023000
24*     C      C      DO 20 I=2,M1                            0024000
25*     C      C      20 VT3(I,J)=0.25*((VR(I,J)+VR(I-1,J))*(VT(I,J)-VT(I-1,J)),CP1(I-1) 0025000
26*     C      C      1      *(VR(I+1,J)+VR(I,J))*(VT(I+1,J)-VT(I,J))/DR1(I)) 0026000
27*     C      C      2      +VT3(I,J)                            0027000
28*     C      C      1      *(VR(I+1,J)+VR(I,J))*(VT(I+1,J)-VT(I,J))/DR1(I)) 0028000
29*     C      C      2      +VT3(I,J)                            0029000
30*     C      HORIZONTAL ADVECTION FOR VERTICAL VELOCITY 0030000
31*     C      C      DO 30 J=2,N1                            0031000
32*     C      C      DO 30 I=2,M2                            0032000
33*     C      C      30 VZ3(I,J)=0.25*((VR(I,J)+VR(I-1,J))*(VZ(I,J)-VZ(I-1,J)),CR2(I) 0033000
34*     C      C      1      *(VR(I+1,J)+VR(I-1,J))*(VZ(I+1,J)-VZ(I,J))/DR2(I+1)) 0034000
35*     C      C      2      +VZ3(I,J)                            0035000
36*     C      C      DO 40 J=2,N1                            0036000
37*     C      C      40 VZ3(I,J)=0.25*((VR(2,J)+VR(2,J-1))*(VZ(2,J)-VZ(1,J))/DR2(2) 0037000
38*     C      C      1      +VZ3(I,J)                            0038000
39*     C      C      DO 50 J=2,N1                            0039000
40*     C      C      50 VZ3(M1,J)=0.25*((VR(M1,J)+VR(M1,J-1))*(VZ(M1,J)-VZ(M2,J))/DR2(M1) 0040000
41*     C      C      1      +VZ3(M1,J)                            0041000
42*     C      C      50 VZ3(M1,J)=0.25*((VR(M1,J)+VR(M1,J-1))*(VZ(M1,J)-VZ(M2,J))/DR2(M1) 0042000
43*     C      C      1      +VZ3(M1,J)                            0043000
44*     C      HORIZONTAL ADVECTION FOR BUOYANCY          0044000
45*     C      C      DO 60 J=1,N1                            0045000
46*     C      C      DO 60 I=2,M2                            0046000
47*     C      C      60 B3(I,J)=B3(I,J)+0.5*((VR(I,J)+B(I,J)-B(I-1,J))/DR2(I) 0047000
48*     C      C      1      *(VR(I+1,J)+B(I+1,J)-B(I,J))/DR2(I+1)) 0048000
49*     C      C      DO 70 J=1,N1                            0049000
50*     C      C      70 B3(I,J)=B3(I,J)+0.5*((VR(2,J)+B(2,J)-B(1,J))/DR2(2) 0050000
51*     C      C      DO 80 J=1,N1                            0051000
52*     C      C      80 B3(M1,J)=B3(M1,J)+0.5*((VR(M1,J)+B(M1,J)-B(M2,J))/DR2(M1) 0052000
53*     C      C      80 B3(M1,J)=B3(M1,J)+0.5*((VR(M1,J)+B(M1,J)-B(M2,J))/DR2(M1) 0053000
54*     C      C      80 B3(M1,J)=B3(M1,J)+0.5*((VR(M1,J)+B(M1,J)-B(M2,J))/DR2(M1) 0054000
55*     C      C      80 B3(M1,J)=B3(M1,J)+0.5*((VR(M1,J)+B(M1,J)-B(M2,J))/DR2(M1) 0055000
56*     C      C      VERTICAL ADVECTION FOR RADIAL VELOCITY 0056000
57*     C      C      DO 90 J=2,N2                            0057000
58*     C      C      DO 90 I=2,M1                            0058000
59*     C      C      90 VR3(I,J)=VR3(I,J)+0.25*((VZ(I-1,J)+VZ(I,J))*(VR(I,J)-VR(I-1,J)) 0059000
60*     C      C      1      /DZ2(I)+VZ(I,J+1)+VZ(I-1,J+1))*(VR(I,J+1)-VR(I,J)) 0060000
61*     C      C      2      /DZ2(I+1))                            0061000
62*     C      C      DO 95 I=2,M1                            0062000
63*     C      C      95 VR3(I,1)=VR3(I,1)+0.25*((VZ(I,2)+VZ(I-1,2))*(VR(I,2)-VR(I,1)) 0063000
64*     C      C      1      /DZ2(2))                            0064000
65*     C      C      DO 96 I=2,M1                            0065000
66*     C      C      96 VR3(I,N1)=VR3(I,N1)+0.25*((VZ(I-1,N1)+VZ(I,N1))*(VR(I,N1)-VR(I,N2)) 0066000
67*     C      C      1      /DZ2(N1))                            0067000
68*     C      C      96 VR3(I,N1)=VR3(I,N1)+0.25*((VZ(I-1,N1)+VZ(I,N1))*(VR(I,N1)-VR(I,N2)) 0068000
69*     C      C      1      /DZ2(N1))                            0069000
70*     C      VERTICAL ADVECTION FOR TANGENTIAL VELOCITY 0070000
71*     C      C      96 VR3(I,N1)=VR3(I,N1)+0.25*((VZ(I-1,N1)+VZ(I,N1))*(VR(I,N1)-VR(I,N2)) 0071000

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*** MEMBER ADVECT

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72*      DO 100 J=2,N2
73*      DO 100 I=2,M1
74*      100 VT3(I,J)=VT3(I,J)+0.25*((VZ(I-1,J)+VZ(I,J))*(VT(I,J)-VT(I,J-1))
75*      1      /DZ2(J)+(VZ(I,J+1)+VZ(I-1,J+1))*(VT(I,J+1)-VT(I,J))
76*      2      /DZ2(J+1))
77*      DO 100 I=2,M1
78*      100 VT3(I,1)=VT3(I,1)+0.25*(VZ(I,2)+VZ(I-1,2))*(VT(I,2)-VT(I,1))
79*      1      /DZ2(2)
80*      DO 100 I=2,M1
81*      100 VT3(I,M1)=VT3(I,M1)+0.25*(VZ(I,M1)+VZ(I-1,M1))*(VT(I,M1)-VT(I,M2))
82*      1      /DZ2(M1)
83*      C
84*      C          VERTICAL ADVECTION FOR VERTICAL VELOCITY
85*      C
86*      DO 140 J=2,N1
87*      DO 140 I=1,M1
88*      140 VZ3(I,J)=VZ3(I,J)+0.25*((VZ(I,J-1)+VZ(I,J))*(VZ(I,J)-VZ(I,J-1))
89*      1      /DZ1(J-1)+(VZ(I,J+1)+VZ(I,J))*(VZ(I,J+1)-VZ(I,J))
90*      2      /DZ1(J))
91*      C
92*      C          VERTICAL ADVECTION FOR B
93*      C
94*      DO 150 J=2,N2
95*      DO 150 I=1,M1
96*      150 B3(I,J)=B3(I,J)+0.5*(VZ(I,J)*(B(I,J)-B(I,J-1))/DZ2(J)
97*      1      +VZ(I,J+1)*(B(I,J+1)-B(I,J))/DZ2(J+1))
98*      DO 160 I=1,M1
99*      160 B3(I,1)=B3(I,1)+0.5*VZ(I,2)*(B2(I,2)-B2(I,1))/DZ2(2)
100*      DO 170 I=1,M1
101*      170 B3(I,M1)=B3(I,M1)+0.5*VZ(I,M1)*(B(I,M1)-B(I,M2))/DZ2(M1)
102*      C
103*      C          INERTIA TERMS FOR HORIZONTAL MOMENTUM
104*      C
105*      DO 110 J=1,N1
106*      DO 110 I=2,M1
107*      VR3(I,J)=VR3(I,J)+VT(I,J)*(VT(I,J)/R1(I)+COR1)
108*      110 VT3(I,J)=VT3(I,J)+VR(I,J)*(VT(I,J)/R1(I)+COR1)
109*      C
110*      C          BLOYANCY TERM FOR VERTICAL ACCELERATION
111*      C
112*      DO 120 J=2,N1
113*      DO 120 I=1,M1
114*      120 VZ3(I,J)=VZ3(I,J)+0.5*(P(I,J)+B(I,J-1))
115*      C
116*      C          STRATIFICATION TERM
117*      C
118*      DO 130 J=1,N1
119*      DO 130 I=1,M1
120*      130 P3(I,J)=P3(I,J)+0.5*(VZ(I,J)+BV2(J)+VZ(I,J+1)+BV2(J+1))
121*      RETURN
122*      END

```

*** MEMBER ADVECT ADDED TO SOURCE -- 122 RECORDS

*** MEMBER PLTOLY

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10 SUBROUTINE PUTOLT
11 PARAMETER M=21,N=21
12 PARAMETER M1=4,N1=2,M2=2,N2=4,N3=1,N4=2,M5=2
13 COMMON/ONE/VR1(N,N1),VT1(N,N1),VZ1(N1,N),B1(M1,N1),VR2(N,N1),
14 VT2(N,N1),VZ2(N1,N),B2(M1,N1),VR3(N,N1),VT3(N,N1),
15 VZ3(N1,N),B3(N1,N1),P(M1,N1)
16 COMMON/TWO/P1(M),R2(N1),DR1(M1),DR2(N),Z1(N),Z2(N1),CZ1(N1),CZ2(N)
17 COMMON/THREE/RMN,FMER(N1),BV2(N),ALPHA,BNDA,BNDP,COR1,C,MK(N),ZK(N)
18 COMMON/FOUR/DELTA,XTIME,ITIME,ISTEP,ISMC,ITAPE,TBV
19
20 THIS SUBROUTINE PRINT OUT FIELDS FOR A QUICK LOOK
21
22 DIMENSION IDUM(N,N)
23
24 700 FORMAT(////,' LACIAL VELOCITY (CM/S) AT T=,I6,' M')
25 705 FORMAT(////,' TANGENTIAL VELOCITY (CM/S) AT T=,I6,' M')
26 710 FORMAT(////,' VERTICAL VELOCITY (CM/S) AT T=,I6,' M')
27 715 FORMAT(////,' ELEVANCY FIELD (.001) AT T=,I6,' M')
28 725 FORMAT(////,' PRESSURE (*10 DYNE/CM**2) AT TIME=,I6,' M')
29 730 FORMAT(1M,////,'***** OUTPUT AT TIME =,I6,' M *****')
30
31 1 DAY
32 DAY=ITIME/86400,+.0001
33 PRINT 720,ITIME,DAY,ISTEP
34 DO 10 J=1,N1
35 DO 10 I=1,M
36 10 IDUM(I,J)=VR2(I,J)
37 PRINT 700,ITIME
38 CALL MAP(IDUM,R1,Z2,M,N1)
39 DO 20 J=1,N1
40 DO 20 I=1,M
41 20 IDUM(I,J)=VT2(I,J)
42 PRINT 705,ITIME
43 CALL MAP(IDUM,R1,Z2,M,N1)
44 DO 30 J=1,N
45 DO 30 I=1,M1
46 30 IDUM(I,J)=VZ2(I,J)
47 PRINT 710,ITIME
48 CALL MAP(IDUM,R2,Z1,N1,N)
49 DO 40 J=1,N1
50 DO 40 I=1,M1
51 40 IDUM(I,J)=R2(I,J)*1.E3
52 PRINT 715,ITIME
53 CALL MAP(IDUM,R2,Z2,M1,N1)
54 DO 50 J=1,N1
55 DO 50 I=1,M1
56 50 IDUM(I,J)=P(I,J)*1.E=1
57 PRINT 725,ITIME
58 CALL MAP(IDUM,R2,Z2,M1,N1)
59 RETURN
60 END

```

*** RETURN MAP

1*	SUBROUTINE MAP(A,M,Z,MM,NN)	0001000
2*	PARAMETER M21,M22	0002000
3*	DIMENSION R(M),Z(NN)	0003000
4*	INTEGER A (M,M),IR(M),IZ(N)	0004000
5*	70 FORMAT(1H5,7X,25IS)	0005000
6*	80 FORMAT(1H5,10,3X,25IS)	0006000
7*	MP=100(25,MM)	0007000
8*	DO 10 I=1,MP	0008000
9*	10 IR(I)=R(I)*1.E-5+0.1	0009000
10*	DO 20 J=1,NN	0010000
11*	20 IZ(J)=Z(J)*1.E-5+0.1	0011000
12*	PRINT 70	0012000
13*	PRINT 70,(IR(I),1=1,MP)	0013000
14*	PRINT 70	0014000
15*	DO 30 JJ=1,NN	0015000
16*	JJNN=1+JJ	0016000
17*	30 PRINT 80,IZ(J),(A(I,J),1=1,MP)	0017000
18*	RETURN	0018000
19*	END	0019000

*** MENEM PRESS

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14 SUBROUTINE PRESS                                0001000
15 C                                                0002000
16 C THIS SUBROUTINE SETS UP FORCING FUNCTIONS AND BOUNDARY 0003000
17 C CONDITIONS FOR THE PRESSURE DIAGNOSTIC EQUATIONS FOR 50004000
18 C                                                0005000
19 C PARAMETER M21,N21                                0006000
20 C PARAMETER M12M=1,M22M=2,N12M=1,N22M=2          0007000
21 C PARAMETER NBLK2,NBLK1,NBLK=1                    0008000
22 C REAL*8 RCP,RINV,RINV1,RTILDA,DUMMY1             0009000
23 C COMMON/FILE/VR1(M,N1),VT1(M,N1),VZ1(M,N),B1(M1,N1),VR2(M,N1), 0010000
24 C VT2(M,N1),VZ2(M1,N),B2(M1,N1),VR3(M,N1),VT3(M,N1), 0011000
25 C VZ3(M1,N),B3(M1,N1),P(M1,N1)                   0012000
26 C COMMON/TAP/R1(M),R2(M1),CR1(M1),CR2(M),Z1(N),Z2(N1),CZ1(N1),CZ2(N) 0013000
27 C COMMON/TAP/R1(M),R2(M1),CR1(M1),CR2(M),Z1(N),Z2(N1),CZ1(N1),CZ2(N) 0014000
28 C CR1(M1),CR2(M1),CR3(M1),CR4(M1),CR5(M1),CR6(M1),CR7(M1),CR8(M1), 0015000
29 C CR9(M1),CR10(M1),CR11(M1),CR12(M1),CR13(M1),CR14(M1),CR15(M1), 0016000
30 C CR16(M1),CR17(M1),CR18(M1),CR19(M1),CR20(M1),CR21(M1),CR22(M1), 0017000
31 C CR23(M1),CR24(M1),CR25(M1),CR26(M1),CR27(M1),CR28(M1),CR29(M1), 0018000
32 C CR30(M1),CR31(M1),CR32(M1),CR33(M1),CR34(M1),CR35(M1),CR36(M1), 0019000
33 C CR37(M1),CR38(M1),CR39(M1),CR40(M1),CR41(M1),CR42(M1),CR43(M1), 0020000
34 C CR44(M1),CR45(M1),CR46(M1),CR47(M1),CR48(M1),CR49(M1),CR50(M1), 0021000
35 C CR51(M1),CR52(M1),CR53(M1),CR54(M1),CR55(M1),CR56(M1),CR57(M1), 0022000
36 C CR58(M1),CR59(M1),CR60(M1),CR61(M1),CR62(M1),CR63(M1),CR64(M1), 0023000
37 C CR65(M1),CR66(M1),CR67(M1),CR68(M1),CR69(M1),CR70(M1),CR71(M1), 0024000
38 C CR72(M1),CR73(M1),CR74(M1),CR75(M1),CR76(M1),CR77(M1),CR78(M1), 0025000
39 C CR79(M1),CR80(M1),CR81(M1),CR82(M1),CR83(M1),CR84(M1),CR85(M1), 0026000
40 C CR86(M1),CR87(M1),CR88(M1),CR89(M1),CR90(M1),CR91(M1),CR92(M1), 0027000
41 C CR93(M1),CR94(M1),CR95(M1),CR96(M1),CR97(M1),CR98(M1),CR99(M1), 0028000
42 C CR100(M1),CR101(M1),CR102(M1),CR103(M1),CR104(M1),CR105(M1), 0029000
43 C CR106(M1),CR107(M1),CR108(M1),CR109(M1),CR110(M1),CR111(M1), 0030000
44 C CR112(M1),CR113(M1),CR114(M1),CR115(M1),CR116(M1),CR117(M1), 0031000
45 C CR118(M1),CR119(M1),CR120(M1),CR121(M1),CR122(M1),CR123(M1), 0032000
46 C CR124(M1),CR125(M1),CR126(M1),CR127(M1),CR128(M1),CR129(M1), 0033000
47 C CR130(M1),CR131(M1),CR132(M1),CR133(M1),CR134(M1),CR135(M1), 0034000
48 C CR136(M1),CR137(M1),CR138(M1),CR139(M1),CR140(M1),CR141(M1), 0035000
49 C CR142(M1),CR143(M1),CR144(M1),CR145(M1),CR146(M1),CR147(M1), 0036000
50 C CR148(M1),CR149(M1),CR150(M1),CR151(M1),CR152(M1),CR153(M1), 0037000
51 C CR154(M1),CR155(M1),CR156(M1),CR157(M1),CR158(M1),CR159(M1), 0038000
52 C CR160(M1),CR161(M1),CR162(M1),CR163(M1),CR164(M1),CR165(M1), 0039000
53 C CR166(M1),CR167(M1),CR168(M1),CR169(M1),CR170(M1),CR171(M1), 0040000
54 C CR172(M1),CR173(M1),CR174(M1),CR175(M1),CR176(M1),CR177(M1), 0041000
55 C CR178(M1),CR179(M1),CR180(M1),CR181(M1),CR182(M1),CR183(M1), 0042000
56 C CR184(M1),CR185(M1),CR186(M1),CR187(M1),CR188(M1),CR189(M1), 0043000
57 C CR190(M1),CR191(M1),CR192(M1),CR193(M1),CR194(M1),CR195(M1), 0044000
58 C CR196(M1),CR197(M1),CR198(M1),CR199(M1),CR200(M1),CR201(M1), 0045000
59 C CR202(M1),CR203(M1),CR204(M1),CR205(M1),CR206(M1),CR207(M1), 0046000
60 C CR208(M1),CR209(M1),CR210(M1),CR211(M1),CR212(M1),CR213(M1), 0047000
61 C CR214(M1),CR215(M1),CR216(M1),CR217(M1),CR218(M1),CR219(M1), 0048000
62 C CR220(M1),CR221(M1),CR222(M1),CR223(M1),CR224(M1),CR225(M1), 0049000
63 C CR226(M1),CR227(M1),CR228(M1),CR229(M1),CR230(M1),CR231(M1), 0050000
64 C CR232(M1),CR233(M1),CR234(M1),CR235(M1),CR236(M1),CR237(M1), 0051000
65 C CR238(M1),CR239(M1),CR240(M1),CR241(M1),CR242(M1),CR243(M1), 0052000
66 C CR244(M1),CR245(M1),CR246(M1),CR247(M1),CR248(M1),CR249(M1), 0053000
67 C CR250(M1),CR251(M1),CR252(M1),CR253(M1),CR254(M1),CR255(M1), 0054000
68 C CR256(M1),CR257(M1),CR258(M1),CR259(M1),CR260(M1),CR261(M1), 0055000
69 C CR262(M1),CR263(M1),CR264(M1),CR265(M1),CR266(M1),CR267(M1), 0056000
70 C CR268(M1),CR269(M1),CR270(M1),CR271(M1),CR272(M1),CR273(M1), 0057000
71 C CR274(M1),CR275(M1),CR276(M1),CR277(M1),CR278(M1),CR279(M1), 0058000
72 C CR280(M1),CR281(M1),CR282(M1),CR283(M1),CR284(M1),CR285(M1), 0059000
73 C CR286(M1),CR287(M1),CR288(M1),CR289(M1),CR290(M1),CR291(M1), 0060000
74 C CR292(M1),CR293(M1),CR294(M1),CR295(M1),CR296(M1),CR297(M1), 0061000
75 C CR298(M1),CR299(M1),CR300(M1),CR301(M1),CR302(M1),CR303(M1), 0062000
76 C CR304(M1),CR305(M1),CR306(M1),CR307(M1),CR308(M1),CR309(M1), 0063000
77 C CR310(M1),CR311(M1),CR312(M1),CR313(M1),CR314(M1),CR315(M1), 0064000
78 C CR316(M1),CR317(M1),CR318(M1),CR319(M1),CR320(M1),CR321(M1), 0065000
79 C CR322(M1),CR323(M1),CR324(M1),CR325(M1),CR326(M1),CR327(M1), 0066000
80 C CR328(M1),CR329(M1),CR330(M1),CR331(M1),CR332(M1),CR333(M1), 0067000
81 C CR334(M1),CR335(M1),CR336(M1),CR337(M1),CR338(M1),CR339(M1), 0068000
82 C CR340(M1),CR341(M1),CR342(M1),CR343(M1),CR344(M1),CR345(M1), 0069000
83 C CR346(M1),CR347(M1),CR348(M1),CR349(M1),CR350(M1),CR351(M1), 0070000
84 C CR352(M1),CR353(M1),CR354(M1),CR355(M1),CR356(M1),CR357(M1), 0071000
85 C CR358(M1),CR359(M1),CR360(M1),CR361(M1),CR362(M1),CR363(M1), 0072000
86 C CR364(M1),CR365(M1),CR366(M1),CR367(M1),CR368(M1),CR369(M1), 0073000
87 C CR370(M1),CR371(M1),CR372(M1),CR373(M1),CR374(M1),CR375(M1), 0074000
88 C CR376(M1),CR377(M1),CR378(M1),CR379(M1),CR380(M1),CR381(M1), 0075000
89 C CR382(M1),CR383(M1),CR384(M1),CR385(M1),CR386(M1),CR387(M1), 0076000
90 C CR388(M1),CR389(M1),CR390(M1),CR391(M1),CR392(M1),CR393(M1), 0077000
91 C CR394(M1),CR395(M1),CR396(M1),CR397(M1),CR398(M1),CR399(M1), 0078000
92 C CR400(M1),CR401(M1),CR402(M1),CR403(M1),CR404(M1),CR405(M1), 0079000
93 C CR406(M1),CR407(M1),CR408(M1),CR409(M1),CR410(M1),CR411(M1), 0080000
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95 C CR418(M1),CR419(M1),CR420(M1),CR421(M1),CR422(M1),CR423(M1), 0082000
96 C CR424(M1),CR425(M1),CR426(M1),CR427(M1),CR428(M1),CR429(M1), 0083000
97 C CR430(M1),CR431(M1),CR432(M1),CR433(M1),CR434(M1),CR435(M1), 0084000
98 C CR436(M1),CR437(M1),CR438(M1),CR439(M1),CR440(M1),CR441(M1), 0085000
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187 C CR970(M1),CR971(M1),CR972(M1),CR973(M1),CR974(M1),CR975(M1), 0174000
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192 C CR1000(M1),CR1001(M1),CR1002(M1),CR1003(M1),CR1004(M1),CR1005(M1), 0179000
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194 C CR1012(M1),CR1013(M1),CR1014(M1),CR1015(M1),CR1016(M1),CR1017(M1), 0181000
195 C CR1018(M1),CR1019(M1),CR1020(M1),CR1021(M1),CR1022(M1),CR1023(M1), 0182000
196 C CR1024(M1),CR1025(M1),CR1026(M1),CR1027(M1),CR1028(M1),CR1029(M1), 0183000
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205 C CR1078(M1),CR1079(M1),CR1080(M1),CR1081(M1),CR1082(M1),CR1083(M1), 0192000
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207 C CR1090(M1),CR1091(M1),CR1092(M1),CR1093(M1),CR1094(M1),CR1095(M1), 0194000
208 C CR1096(M1),CR1097(M1),CR1098(M1),CR1099(M1),CR1100(M1),CR1101(M1), 0195000
209 C CR1102(M1),CR1103(M1),CR1104(M1),CR1105(M1),CR1106(M1),CR1107(M1), 0196000
210 C CR1108(M1),CR1109(M1),CR1110(M1),CR1111(M1),CR1112(M1),CR1113(M1), 0197000
211 C CR1114(M1),CR1115(M1),CR1116(M1),CR1117(M1),CR1118(M1),CR1119(M1), 0198000
212 C CR1120(M1),CR1121(M1),CR1122(M1),CR1123(M1),CR1124(M1),CR1125(M1), 0199000
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215 C CR1138(M1),CR1139(M1),CR1140(M1),CR1141(M1),CR1142(M1),CR1143(M1), 0202000
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218 C CR1156(M1),CR1157(M1),CR1158(M1),CR1159(M1),CR1160(M1),CR1161(M1), 0205000
219 C CR1162(M1),CR1163(M1),CR1164(M1),CR1165(M1),CR1166(M1),CR1167(M1), 0206000
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221 C CR1174(M1),CR1175(M1),CR1176(M1),CR1177(M1),CR1178(M1),CR1179(M1), 0208000
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225 C CR1198(M1),CR1199(M1),CR1200(M1),CR1201(M1),CR1202(M1),CR1203(M1), 0212000
226 C CR1204(M1),CR1205(M1),CR1206(M1),CR1207(M1),CR1208(M1),CR1209(M1), 0213000
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229 C CR1222(M1),CR1223(M1),CR1224(M1),CR1225(M1),CR1226(M1),CR1227(M1), 0216000
230 C CR1228(M1),CR1229(M1),CR1230(M1),CR1231(M1),CR1232(M1),CR1233(M1), 0217000
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232 C CR1240(M1),CR1241(M1),CR1242(M1),CR1243(M1),CR1244(M1),CR1245(M1), 0219000
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234 C CR1252(M1),CR1253(M1),CR1254(M1),CR1255(M1),CR1256(M1),CR1257(M1), 0221000
235 C CR1258(M1),CR1259(M1),CR1260(M1),CR1261(M1),CR1262(M1),CR1263(M1), 0222000
236 C CR1264(M1),CR1265(M1),CR1266(M1),CR1267(M1),CR1268(M1),CR1269(M1), 0223000
237 C CR1270(M1),CR1271(M1),CR1272(M1),CR1273(M1),CR1274(M1),CR1275(M1), 0224000
238 C CR1276(M1),CR1277(M1),CR1278(M1),CR
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*** WHEN PRESS

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52*      IF(NCALL,GT,1)GO TO 30
53*      DO 20 J=1,NP2
54*      DO 20 I=1,NP2
55*      20 X(I+1,J+1)=P(I,J)
56*      30 CONTINUE
57*      CALL ZILCH(F11,MP)
58*      CALL ZILCH(F14,MP)
59*      CALL ZILCH(F21,MP)
60*      C
61*      C
62*      C      DEFINE THE FORCING AT BOUNDARY SO THAT THERE
63*      C      IS GRADIENT BALANCE AT OUTER BOUNDARY
64*      C
65*      DO 605 J=2,MP1
66*      F2M(J)=RHRM*DR2(M)+VT2(M,J+1)*(VT2(M,J+1)/R1(M)+CORI)
67*      605 CONTINUE
68*      A1=1
69*      A1N=1
70*      A2=1
71*      A2N=1
72*      DO 104 J=2,MP1
73*      MP(2,J)=RH(2,J)+AX(2)*A21
74*      F(2,J)=F(2,J)+AX(2)*F21(J)+A21
75*      X(1,J)=X(1,0+A21)*X(1,J)
76*      RH(MP=1,J)=RH(MP=1,J)+CX(MP=1)*A2M
77*      F(MP=1,J)=F(MP=1,J)+CX(MP=1)*F2M(J)+A2M
78*      X(MP,J)=X(1,0+A2M)*X(MP,J)
79*      101 CONTINUE
80*      DO 102 I=2,MP1
81*      RH(I,2)=RH(I,2)+AY(2)*A11
82*      F(I,2)=F(I,2)+AY(2)*F11(I)+A11
83*      X(I,1)=X(1,0+A11)*X(I,1)
84*      RH(I,MP=1)=RH(I,MP=1)+CY(MP=1)*A1N
85*      F(I,MP=1)=F(I,MP=1)+CY(MP=1)*F1N(I)+A1N
86*      X(I,MP)=X(1,0+A11)*X(I,MP)
87*      102 CONTINUE
88*      IF(NCALL,EQ,1)CALL HSP1
89*      ERRH=1,E=3
90*      CALL HSP2(X,ERRH,A11,A1N,A21,A2M)
91*      C
92*      C
93*      C      DEFINE THE DIAGNOSED PRESSURE
94*      C
95*      DO 110 J=1,MP1
96*      DO 110 I=1,MP1
97*      110 P(I,J)=X(I+1,J+1)
98*      115 CONTINUE
99*      C
100*      C
101*      C      AIC PRESSURE GRADIENT FORCES TO VR3 AND VZ3
102*      C
103*      DO 120 J=1,MP1
104*      DO 120 I=2,MP1
105*      120 VR3(I,J)=VR3(I,J)+(P(I,J)-P(I-1,J))/(RH0+DR2(I))
106*      DO 130 J=2,MP1
107*      DO 130 I=1,MP1
108*      130 VZ3(I,J)=VZ3(I,J)+(P(I,J)-P(I,J+1))/(RH0+DR2(J))
109*      RETURN
110*      END

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*** MENUEEN BSM1

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10  SIGNATURE BSM1                                0001000
20  PARAMETER MB21,NB21                            0002000
30  PARAMETER M1MB1,P2MB2,N1MB1,P2NB2            0003000
40  PARAMETER MPMB1,APMB1                          0004000
50  PARAMETER MP1MB1,MP2MB2,MP1BMB1,AP2BMB2      0005000
60  PARAMETER NBLKMB2,NBLK1,NBLK=1                0006000
70  REAL*8 RCOR,RINV,RINV1,RTILDA,DUMMY1          0007000
80  COMMON/TEMP/R1(N),R2(N1),DR1(N1),DR2(N),Z1(N),Z2(N1),DZ1(N1),DZ2(N) 0008000
90  COMMON/EVP/RINV(MP2,MP2,NBLK),RINV1(MP2,MP2,NBLK1),RCOR(MP,3), 0009000
100 1 RTILDA(MP2),F(MP,NP),NBSIZ2(NBLK),IS(NBLK),SLPF(NBLK), 0010000
110 2 IE(NBLK),F11(MP),F1N(MP),F21(NP),F2N(MP),AX(MP),AY(MP), 0011000
120 3 RB(MP,AP),CX(MP),CY(MP)                      0012000
130 DIMENSION DUMMY1(MP2,MP2)                    0013000
140 EQUIVALENCE (DUMMY1,RINV(1,1,NBLK))          0014000
150 IE(1)=NBSIZ2(1)+2                             0015000
160 DO 90 NMB2,NBLK                                0016000
170 IE(NB)=IE(NB-1)+NBSIZ2(NB)+1                 0017000
180 90 CONTINUE                                     0018000
190 DO 95 NMB1,NBLK1                              0019000
200 IS(NB+1)=IE(NB)=1                             0020000
210 95 CONTINUE                                     0021000
220 IS(1)=1                                         0022000
230 DO 115 I=1,MP2                                0023000
240 DR 110 J=1,3                                    0024000
250 CR 110 I=1,MP                                  0025000
260 RCOR(I,J)=0.0                                  0026000
270 110 CONTINUE                                   0027000
280 RCOR(I+1,2)=1.0                                0028000
290 NMB=IE(1)=1                                    0029000
300 DR 130 J=2,NMB                                  0030000
310 DO 135 I=2,MP1                                 0031000
320 RCOR(I,3)=(-AX(I)+RCOR(I=1,2)+AY(J)+RCOR(I,1)+RB(I,J)). 0032000
330 IRCOR(I,2)=CX(I)+RCOR(I+1,2))/CY(J1)          0033000
340 135 CONTINUE                                   0034000
350 DO 140 I=1,MP                                  0035000
360 RCOR(I,1)=RCOR(I,2)                            0036000
370 RCOR(I,2)=RCOR(I,3)                            0037000
380 140 CONTINUE                                   0038000
390 130 CONTINUE                                   0039000
400 DO 145 I=1,MP2                                0040000
410 RINV(I,1,1)=RCOR(I+1,1)                        0041000
420 DUMMY1(I,1)=RCOR(I+1,2)                        0042000
430 145 CONTINUE                                   0043000
440 115 CONTINUE                                   0044000
450 CALL MATINV(DUMMY1)                            0045000
460 DO 160 I=1,MP2                                0046000
470 DO 160 J=1,MP2                                0047000
480 RINV1(I,J,1)=0.0                                0048000
490 DO 161 K=1,MP2                                0049000
500 RINV1(I,J,1)=RINV1(I,J,1)+DUMMY1(I,K)*RINV(K,J,1) 0050000
510 161 CONTINUE                                   0051000
520 160 CONTINUE                                   0052000
530 DO 170 I=1,MP2                                0053000
540 DO 170 J=1,MP2                                0054000
550 RINV(I,J,1)=DUMMY1(I,J)                        0055000
560 170 CONTINUE                                   0056000
570 DO 205 NMB2,NBLK1                              0057000
580 DO 215 I=1,MP2                                0058000
590 DO 210 J=1,3                                    0059000
600 DO 210 I=1,MP                                  0060000
610 RCOR(I,J)=0.0                                  0061000
620 210 CONTINUE                                   0062000
630 DO 220 I=1,MP2                                0063000
640 RCOR(I+1,1)=RINV1(I,1,NB-1)                   0064000
650 220 CONTINUE                                   0065000
660 RCOR(I+1,2)=1.0                                0066000
670 IE=IE(NB-1)                                     0067000
680 IE2=IE(NB)=1                                    0068000
690 IF(NB.LT.NBLK) GO TO 232                       0069000
700 IE2=IE2+1                                       0070000
710 232 CONTINUE                                   0071000
720 DO 230 J=IE1,IE2                                0072000
730 DO 235 I=2,MP1                                 0073000
740 RCOR(I,3)=(-AX(I)+RCOR(I=1,2)+AY(J)+RCOR(I,1)+RB(I,J)). 0074000
750 IRCOR(I,2)=CX(I)+RCOR(I+1,2))/CY(J1)          0075000
760 235 CONTINUE                                   0076000
770 DO 240 I=1,MP                                  0077000

```

*** MEMOEN USP1

78*	RCOR(I,1)=RCOR(I,2)	0077000
79*	RCOR(I,2)=RCOR(I,3)	0078000
80*	210 CONTINUE	0079000
81*	241 CONTINUE	0080000
82*	230 CONTINUE	0081000
83*	IF(NB.EG,NBLK) GO TO 246	0082000
84*	DO 245 I=1,MP2	0083000
85*	RINV(I,I,NB)=R(R(I+1,1))	0084000
86*	245 CONTINUE	0085000
87*	DO 247 I=1,MP2	0086000
88*	DUMMY1(I,I)=RCOR(I+1,2)	0087000
89*	247 CONTINUE	0088000
90*	GO TO 249	0089000
91*	246 CONTINUE	0090000
92*	DO 248 I=2,MP1	0091000
93*	DUMMY1(I,I)=MAX(I)=RCOR(I=1,2)+AY(NP=1)=RCOR(I,1)+	0092000
94*	19H(I,NP=1)=RCOR(I,2)+CX(I)=RCOR(I+1,2)	0093000
95*	248 CONTINUE	0094000
96*	249 CONTINUE	0095000
97*	215 CONTINUE	0096000
98*	CALL MATINV(DUMMY1)	0097000
99*	IF(NB.EG,NBLK) GO TO 275	0098000
100*	DO 260 J=1,MP2	0099000
101*	DO 261 I=1,MP2	0100000
102*	RINV(I,J,NB)=0	0101000
103*	DO 261 K=1,MP2	0102000
104*	RINV(I,J,NB)=RINV(I,J,NB)+DUMMY1(I,K)*RINV(K,J,NB)	0103000
105*	261 CONTINUE	0104000
106*	260 CONTINUE	0105000
107*	DO 270 J=1,MP2	0106000
108*	DO 270 I=1,MP2	0107000
109*	RINV(I,J,NB)=DUMMY1(I,J)	0108000
110*	270 CONTINUE	0109000
111*	275 CONTINUE	0110000
112*	295 CONTINUE	0111000
113*	RETURN	0112000
114*	END	0113000
		0114000

*** MEMBER MATINV

```

10 SUBROUTINE MATINV(B)
20 PARAMETER M=21
30 PARAMETER MP=4,
40 REAL*8 R(MP,MP)
50 REAL*8 P1(MP),P2(MP)
60 MP=MP-1
70 DO 110 I=1,MP1
80 B(I)=1.0/B(I,I)
90 B(I,I)=1.0
100 DO 112 J=1,MP
110 B(I,J)=B(I,J)*B1(I)
112 CONTINUE
120 J=1
130 DO 120 I=1,MP1,MP
140 DO 125 I=1,MP
150 B(I,I)=B(I,I)
160 CONTINUE
170 DO 125 I=1,MP
180 B(I,I)=0.0
190 CONTINUE
200 DO 127 J=1,MP
210 B2(J)=B(I,J)
220 CONTINUE
230 DO 135 I=1,MP1,MP
240 DO 135 J=1,MP
250 B(I,J)=B(I,J)-P1(I)*B2(J)
260 CONTINUE
270 CONTINUE
280 B1(I)=1.0/4(MP,MP)
290 B(MP,MP)=1.0
300 DO 140 J=1,MP
310 B(MP,J)=B(MP,J)*B1(I)
320 CONTINUE
330 DO 150 I=2,MP
340 DO 155 I=2,MP1
350 B(I,I)=B(I,I)
360 CONTINUE
370 J=1
380 DO 150 I=2,MP1,MP
390 B(I,I)=B(I,I)
400 CONTINUE
410 DO 157 J=1,MP
420 B2(J)=B(I,J)
430 CONTINUE
440 J=1
450 DO 160 I=2,MP1,MP
460 DO 160 J=1,MP
470 B(I,J)=B(I,J)-B1(I)*B2(J)
480 CONTINUE
490 CONTINUE
500 RETURN
510 END

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*** MEMOEN 05=2

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1* SUPRRTIME 49M2(X,FHWRD,A11,A1N,A21,A2M) 0001000
2* PARAMETER M=21,N=21 0002000
3* PARAMETER NBLK=2,NBL=1+4NBLK=1 0003000
4* PARAMETER MP=1+1,NP=1+1 0004000
5* PARAMETER MP1=1,MP2=2,NP1=1,NP2=2 0005000
6* REAL*8 RCR,RINV,RILDA 0006000
7* COMMON/EVP/RINV(MP2,MP2,NBLK),RINV1(MP2,MP2,NBLK),RCR(MP,3), 0007000
8* 1 RTILDA(MP2),F(MP,NP),NPSIZ2(NBLK),IS(NBLK),SUMF(NBLK), 0008000
9* 2 IE(NBLK),F11(MP),FIN(MP),F21(MP),F2M(MP),AX(MP1,AY(MP), 0009000
10* 3 RRC(MP,AP),CX(MP),CY(MP) 0010000
11* DIMENSION X(MP,NP) 0011000
12* DO 90 NR=1,NBLK 0012000
13* SUMF(NR)=0.0 0013000
14* 90 CONTINUE 0014000
15* DO 95 NR=1,NBLK 0015000
16* DO 95 I=2,MP1 0016000
17* SUMF(NR)=SUMF(NR)+ABS(F(I,IE(NR))-1)) 0017000
18* 95 CONTINUE 0018000
19* DO 96 NR=1,NBLK 0019000
20* IF(SUMF(NR).GT.(.C) GO TO 96 0020000
21* SUMF(NR)=1.0 0021000
22* 96 CONTINUE 0022000
23* NSTART=1 0023000
24* DO 199 I1=1,5 0024000
25* DO 200 NR=NSTART,NBLK 0025000
26* ISP1=IS(NR)+1 0026000
27* IEM2=IE(NR)+2 0027000
28* DO 205 J=ISP1,IEM2 0028000
29* DO 205 I=2,MP1 0029000
30* X(I,J+1)=(F(I,J)-AX(I)*X(I-1,J)-AY(J)*X(I,J-1)-BB(I,J)+ 0030000
31* IX(I,J)-CX(I)*X(I+1,J))/CY(J) 0031000
32* 205 CONTINUE 0032000
33* IF(NR.EQ.NBLK) GO TO 200 0033000
34* DO 522 I1=1,17 0034000
35* J1=IE(NR)+1 0035000
36* DO 215 I=2,MP1 0036000
37* RTILDA(I+1)*X(I,J1+1)=(F(I,J1)-AX(I)*X(I-1,J1)-AY(J1)* 0037000
38* IX(I,J1+1)-BR(I,J1)+X(I,J1)-CX(I)*X(I+1,J1))/CY(J1) 0038000
39* 215 CONTINUE 0039000
40* A2=0.0 0040000
41* DO 216 I=1,MP2 0041000
42* A2=A2+DABS(RTILDA(I)) 0042000
43* 216 CONTINUE 0043000
44* A3=A2/SUMF(NR) 0044000
45* IF(A3.LE.0.1) GO TO 230 0045000
46* DO 217 J=1,3 0046000
47* DO 217 I=1,MP 0047000
48* RCRH(I,J)=0.0 0048000
49* 217 CONTINUE 0049000
50* DO 223 J=1,MP2 0050000
51* RCRH(J+1,2)=0.0 0051000
52* DO 223 J1=1,MP2 0052000
53* RCRH(J+1,2)=RCR(J+1,2)+RTILDA(J1)*RINV(J1,J,NB) 0053000
54* 223 CONTINUE 0054000
55* IF(NB.EQ.1) GO TO 251 0055000
56* DO 225 J=2,MP1 0056000
57* RCRH(J,1)=0.0 0057000
58* DO 225 K=2,MP1 0058000
59* RCRH(J,1)=RCRH(J,1)+RCR(K,2)*RINV1(K=1,J=1,NP=1) 0059000
60* 225 CONTINUE 0060000
61* DO 226 I=2,MP1 0061000
62* X(I,IS(NB))*X(I,IS(NB))+RCR(I,1) 0062000
63* 226 CONTINUE 0063000
64* 251 CONTINUE 0064000
65* CALL BSM3(X,IS(NB),IE(NB)) 0065000
66* 522 CONTINUE 0066000
67* 230 CONTINUE 0067000
68* J1=IE(NB)+1 0068000
69* DO 220 I=2,MP1 0069000
70* X(I,J1+1)=(F(I,J1)-AX(I)*X(I-1,J1)-AY(J1)*X(I,J1+1)- 0070000
71* IBG(I,J1)+X(I,J1)-CX(I)*X(I+1,J1))/CY(J1) 0071000
72* 220 CONTINUE 0072000
73* 501 CONTINUE 0073000
74* 200 CONTINUE 0074000
75* DO 300 NR=1,NBLK 0075000
76* NP=NBLK+NB1+1 0076000
77* ISP1=IS(NB)+1 0077000

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*** MEMBER 09#2

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78*      IEM2=IE(NR)=2
79*      J=IEM2
80*      IF(NB.EQ.NBLK) GO TO 302
81*      DO 305 I=2,MP1
82*      X(I,J+1)=(F(I,J)-AX(I)*X(I=1,J)-AY(J)*X(I,J=1)-BB(I,J)+
83*      1X(I,J)-CX(I)*X(I+1,J))/CV(J)
84*      305 CONTINUE
85*      502 CONTINUE
86*      DO 552 I=1,10
87*      IF(NB.EQ.NBLK) GO TO 317
88*      J=IE(NB)=1
89*      DO 315 I=2,MP1
90*      RTILDA(I=1)=X(I,J+1)=(F(I,J)-AX(I)*X(I=1,J)-AY(J)*
91*      1X(I,J)-BB(I,J)+CX(I)*X(I+1,J))/CV(J)
92*      315 CONTINUE
93*      GO TO 318
94*      317 CONTINUE
95*      DO 319 I=2,MP1
96*      RTILDA(I=1)=F(I,NP=1)=(AX(I)*X(I=1,NP=1)+AY(NP=1)*X(I,NP=2)+
97*      1BB(I,NP=1)+CX(I)*X(I+1,NP=1))
98*      319 CONTINUE
99*      318 CONTINUE
100*      A2=0.0
101*      DO 316 I=1,MP2
102*      A2=A2+DABS(RTILDA(I))
103*      316 CONTINUE
104*      A3=A2/SUMF(NB)
105*      IF(A3.LE.ERROR) GO TO 300
106*      DO 320 J=1,3
107*      DO 320 I=1,MP
108*      RCR(I,J)=0.0
109*      320 CONTINUE
110*      DO 324 J=1,MP2
111*      RCR(J+1,2)=0.0
112*      DO 324 J=1,MP2
113*      RCR(J+1,2)=RCR(J+1,2)+RTILDA(J)*RINV(J,J,NB)
114*      324 CONTINUE
115*      IF(NB.EQ.1) GO TO 551
116*      DO 325 J=2,MP1
117*      RCR(J,1)=0.0
118*      DO 325 K=2,MP1
119*      RCR(J,1)=RCR(J,1)+RCR(K,2)*RINV(K=1,J=1,NP=1)
120*      325 CONTINUE
121*      DO 326 I=2,MP1
122*      X(I,IS(NB))=X(I,IS(NB))+RCR(I,1)
123*      326 CONTINUE
124*      551 CONTINUE
125*      CALL USM3(X,IS(NB),IE(NR))
126*      552 CONTINUE
127*      300 CONTINUE
128*      J=IE(1)
129*      DO 330 I=2,MP1
130*      RTILDA(I=1)=X(I,J+1)=(F(I,J)-AX(I)*X(I=1,J)-AY(J)*
131*      1X(I,J)-BB(I,J)+CX(I)*X(I+1,J))/CV(J)
132*      330 CONTINUE
133*      A2=0.0
134*      DO 332 I=1,MP2
135*      A2=A2+DABS(RTILDA(I))
136*      332 CONTINUE
137*      A3=A2/SUMF(1)
138*      IF(A3.LE.ERROR) GO TO 201
139*      NSTART=2
140*      199 CONTINUE
141*      201 CONTINUE
142*      DO 350 J=2,MP1
143*      X(1,J)=(1.0-A2)*X(1,J)+A2*(X(2,J)+F21(J))
144*      X(MP,J)=(1.0-A2)*X(MP,J)+A2*(X(MP=1,J)+F21(J))
145*      350 CONTINUE
146*      DO 366 I=2,MP1
147*      X(I,1)=(1.0-A1)*X(I,1)+A1*(X(I,2)+F11(I))
148*      X(I,NP)=(1.0-A1)*X(I,NP)+A1*(X(I,NP=1)+F11(I))
149*      366 CONTINUE
150*      DO 371 J=2,MP1
151*      RR(2,J)=RR(2,1)+AX(2)*A21
152*      F(2,J)=F(2,1)+AX(2)+F21(J)+A21
153*      RR(MP=1,J)=RR(MP=1,J)+CX(MP=1)*A21

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AD-A137 421

TROPICAL WEATHER SYSTEM AND OCEAN MODELING(U) SCIENCE
APPLICATIONS INC MCLEAN VA 5 CHANG 1983 SAI-83-1155
N00014-82-C-2306

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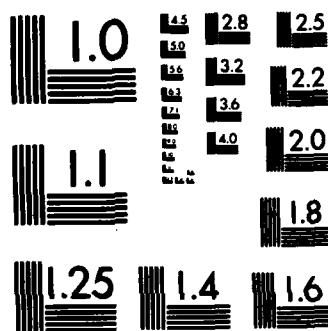
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

*** MEMBER US*2

```
154*      F(NP=1,J)=F(NP=1,J)+C1(NP=1)*F2*(J)*A2H
155* 371 CONTINUE
156*      D1 372 IN2,NP1
157*      BB(I,2)=BB(I,2)+AV(2)*A11
158*      F(I,2)=F(I,2)+AV(2)*F1(I)*A11
159*      BB(I,NP=1)=BB(I,NP=1)+CY(NP=1)*A1N
160*      F(I,NP=1)=F(I,NP=1)+CY(NP=1)*F1N(I)*A1N
161* 372 CONTINUE
162*      RETURN
163*      END
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*** MEMBER 08M3

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100 SUBROUTINE 08M3(X,ISS,IEE)
101   PARAMETER NS21=1,NS21
102   PARAMETER NSLK=2,NSLK=1
103   PARAMETER MP=1,MP=1
104   PARAMETER MP1=1,MP2=2,MP3=1,MP4=2
105   REAL*8 RCON,RINV,RINVA,RTILDA
106   DIMENSION X(MP,MP)
107   COMMON/EVP/RINV(MP2,MP2,NSLK),RINVA(MP2,MP2,NSLK),RCON(MP,3),
108   1   RTILDA(MP2),F(MP,MP),WSSIZ2(NSLK),IS(NSLK),S(MP(NSLK)),
109   2   IE(NSLK),F11(MP),FIN(MP),F21(MP),F2H(MP),AX(MP),AY(MP),
110   3   SB(MP,MP),CX(MP),CY(MP)
111   DO 135 I=2,MP1
112     X(I,ISS+1)=X(I,ISS+1)+RCON(I,2)
113   135 CONTINUE
114   ISPI=ISS+1
115   IEM2=IEE-2
116   DO 140 J=ISPI,IEM2
117     DO 145 I=2,MP1
118       RCON(I,3)=(-AX(I))+RCON(I=1,2)+AY(J)+RCON(I,1)+SB(I,J)+
119       140 RCON(I,2)+CX(I)+RCON(I+1,2))/CY(J)
120   145 CONTINUE
121   DO 150 I=2,MP1
122     X(I,J+1)=X(I,J+1)+RCON(I,3)
123   150 CONTINUE
124   RCON(I,1)+RCON(I,2)
125   RCON(I,2)+RCON(I,3)
126   150 CONTINUE
127   140 CONTINUE
128   RETURN
129   END

```

C48PLIT OCEAN1,SOURCE,PRINT,SEG

```

10 PROGRAM OCEAN
20 PARAMETER M21=1,M22=1
30 PARAMETER M10=1,M20=2,M10M=1,M20M=2
40 PARAMETER N0020=M21+M22
50 DIMENSION DATA1(NC),DATA2(NC),DATA3(NC)
60 COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),
70 1 VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),
80 2 B3(M1,N1),P(M1,N1),VZ(M1,N)
90 EQUIVALENCE (DATA1,VR1),(DATA2,VR2),(DATA3,VR3)
100 DATA DATA1/N000,/,DATA2/N000,/,DATA3/N000,/
110 COMMON/TWO/R1(M),P2(M1),DR1(M),DR2(M),Z1(N),Z2(N),DZ2(N)
120 COMMON/THREE/RHO,RHOB(N1),SV2(N),ALPHA,BNDA,BNDB,COR1,G,M(N),ZK(N)
130 COMMON/FOUR/DELT,XTIME,itime,ISTEP,ISNO,ITAPE,TSV
140 CALL INDDUMP
150 100 FORMAT(I6)
160 READ(5,100)ITIME
170 READ(5,100)ITER
180 READ(5,100)ISUT
190 READ(5,100)ISNO
200 ISTEP=0
210 READ(5,100)ITAPE
220 CALL INIT
230 IF(ITIME.EQ.0)GO TO 10
240 C
250 C CONTINUED INTEGRATION FROM A HISTORY TAPE
260 C
270 READ(1)ITIME,DATA1,DATA2,P
280 GO TO 30
290 10 CALL START
300 20 XTIME=ITIME+3000.
310 C
320 C PRINT OUT INITIAL FIELDS
330 C
340 CALL PUTOUT
350 IF(ITER.EQ.0)STOP
360 DO 90 ISTEP=1,ITER
370 C
380 C COMPUTE HYDROSTATIC PRESSURE AND DIAGNOSE VERTICAL VELOCITY
390 C
400 CALL UP
410 C
420 C COMPUTE ALL INVISCID TERMS
430 C
440 CALL ADVECT
450 C
460 C COMPUTE VISCOUS TERMS
470 C
480 CALL DIFF
490 C
500 C MARCHING IN TIME
510 C FIRST TIME STEP IS FORWARD IF START IS CALLED
520 C
530 IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=0.5*DELT
540 CALL PRHND
550 IF(ISTEP.EQ.1.AND.ITIME.EQ.0)DELT=2.0*DELT
560 C
570 C DEFINE BOUNDARY VALUES FOR VELOCITY
580 C
590 CALL BOUNDV
600 C
610 C CHECK IF DELT IS STABLE
620 C
630 CALL CHECK
640 XTIME=XTIME+DELT
650 ITIME=XTIME/3000.
660 C
670 C PRINT OUT RESULTS EVERY ISUT STEPS
680 C
690 IF(MOD(ISTEP,ISUT).EQ.0)CALL PUTOUT
700 C
710 C WRITE HISTORY TAPE EVERY ITAPE STEPS
720 C
730 IF(MOD(ISTEP,ITAPE).EQ.0)WRITE(2)ITIME,DATA1,DATA2,P
740 90 CONTINUE
750 STOP
760 END

```

*** MEMBER INIT

```

10 SUBROUTINE INIT
11 PARAMETER M=21,N=21
12 PARAMETER N1=M+1,N2=M+2,N1M=M+1,N2M=M+2
13 COMMON/ONE/VR1(M,N1),VT1(M,N1),E1(M1,N1),VR2(M,N1),
14 1 VT2(M,N1),E2(M1,N1),VR3(M,N1),VT3(M,N1),
15 2 E3(M1,N1),P(M1,N1),VZ(M1,N)
16 COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N)
17 COMMON/THREE/RHO,MH0,MHR(N1),MV2(N),ALPHA,BNDA,BNDB,COR1,G,MK(N),ZK(N)
18 COMMON/FOUR/DELT,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV
19
20 C INITIALIZE ALL DEPENDENT VARIABLES AND CONSTANTS
21 C
22 C ALPHA IS THE NONDIMENSIONAL SMOOTHING COEF.
23 C FOR TIME SMOOTHING IN SUBROUTINE FNRD
24 C
25 C DELT=0.00,
26 C ALPHA=0.10
27 C G=0.00,
28 C LAT=30
29 C COR1=2.*7.2722E-5*SIN(LAT*3.14159/180.)
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*** MEMBER START

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10 SUBROUTINE START                                0001000
20 PARAMETER M21,M22                                0002000
30 PARAMETER M10M=1,M20M=2,M10N=1,M20N=2          0003000
40 COMMON/ONE/VR1(M,N1),VT1(M,N1),P1(M1,N1),VR2(M,N1), 0004000
50 1 VT2(M,N1),P2(M1,N1),VR3(M,N1),VT3(M,N1),      0005000
60 2 P3(M1,N1),P(M1,N1),VZ(M1,N)                   0006000
70 COMMON/TWO/R1(M),R2(M1),OR1(M1),OR2(M),Z1(N),Z2(N1),CZ1(N1),DZ2(N) 0007000
80 COMMON/THREE/RHO,RH0,PH0R(N1),BV2(N),ALPHA,BNDA,BNDB,COR1,G,MK(M),ZK(N) 0008000
90 PARAMETER N002=M+1+M1+N1                         0009000
100 DIMENSION DATA1(NC),DATA2(NC)                 0010000
110 EQUIVALENCE (DATA1,VR1),(DATA2,VR2)            0011000
120 C                                                0012000
130 C          INITIALIZE MASS FIELDS FOR A THEORETICAL RING 0013000
140 C                                                0014000
150 I1=1                                             0015000
160 I2=13                                           0016000
170 I21=I2+1                                         0017000
180 I22=M1                                           0018000
190 NPA00=0002                                       0019000
200 DO 10 I=I1,I2                                   0020000
210 10 O1(I,N1)=DMAG=COS(PI*AT(I-I1)/8.+3.14159)/G/RH0 0021000
220 DO 30 I=I21,I22                                  0022000
230 30 O1(I,N1)=O1(I2,N1)*EXP(-PI*AT(I-I21+1)/4.) 0023000
240 DO 40 J=1,N2                                     0024000
250 FACT=EXP(PI*AT(J-A1)/2.)                        0025000
260 DO 40 I=1,M1                                     0026000
270 40 O1(I,J)=O1(I,N1)*FACT                       0027000
280 C                                                0028000
290 C          PRESSURE IS OBTAINED HYDROSTATICALLY FROM BUOYANCY 0029000
300 C                                                0030000
310 DO 50 I=1,M1                                     0031000
320 50 P(I,1)=0.5*RH0*DZ2(1)+O1(I,1)               0032000
330 DO 60 J=2,M1                                     0033000
340 DO 60 I=1,M1                                     0034000
350 60 P(I,J)=P(I,J-1)+0.5*RH0*DZ2(J)+(O1(I,J)+O1(I,J-1)) 0035000
360 C                                                0036000
370 C          TANGENTIAL VELOCITY IS AT GRADIENT BALANCE 0037000
380 C                                                0038000
390 DO 70 J=1,M1                                     0039000
400 DO 70 I=2,M1                                     0040000
410 PGP(P(I,J)-P(I-1,J))/(RH0*OR2(I))              0041000
420 RAD0=(0.5*COR1*O1(I))+2*O1(I)*PGP              0042000
430 JJ=J                                             0043000
440 II=I                                             0044000
450 IF (RAD,LT,0.) GO TO 100                        0045000
460 70 VT1(I,J)=0.5*COR1*O1(I)+SQRT(RAD0)           0046000
470 C                                                0047000
480 C          SET DATA2=DATA1 FOR LEAPFROG 0048000
490 C                                                0049000
500 DO 80 I=1,N0                                     0050000
510 80 DATA2(I)=DATA1(I)                           0051000
520 CALL UNLNDV                                       0052000
530 DO 90 I=1,N0                                     0053000
540 90 DATA1(I)=DATA2(I)                           0054000
550 RETURN                                           0055000
560 100 PRINT 110,II,JJ,PGP,RAD                    0056000
570 110 FORMAT(' RADICAL IN SUBROUTINE START IS NEGATIVE AT (I,J)=',2I5, 0057000
580 1' PGP, RAD 0',1P2E12.3)                       0058000
590 STOP                                             0059000
600 END                                              0060000

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*** MEMBER UP

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10 SUBROUTINE UP                                0001000
20 PARAMETER M1=1,M2=1                        0002000
30 PARAMETER M1M=1,M2M=2,M1M=1,M2M=2        0003000
40 COMMON/ONE/VR1(M,M1),VT1(M,M1),B1(M1,M1),VR2(M,M1), 0004000
50 1 VT2(M,M1),B2(M1,M1),VR3(M,M1),VT3(M,M1), 0005000
60 2 B3(M1,M1),P(M1,M1),VZ(M1,M1)           0006000
70 COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(M),Z2(M1),DZ1(M1),DZ2(M) 0007000
80 COMMON/THREE/RHO,RHOC(M1),BV2(M),ALPHA,BNDA,BNDB,COR1,C,MK(M),ZK(M) 0008000
90 PARAMETER M1M=1,M2M=2                    0009000
100 DATA VZ/MIN=0./                        0010000
110 C                                         0011000
120 C PRESSURE IS OBTAINED HYDROSTATICALLY FROM 0 0012000
130 C                                         0013000
140 C DO 10 I=1,M1                            0014000
150 10 P(I,1)=0.5*RHO*B22(I)+B2(I,1)         0015000
160 10 DO 20 J=2,M1                           0016000
170 20 P(I,J)=P(I,J-1)+0.5*RHO*B22(J)+(B2(I,J)+B2(I,J-1)) 0017000
180 C                                         0018000
190 C DIAGNOSE VERTICAL VELOCITY BY CONTINUITY EQUATION 0019000
200 C                                         0020000
210 C DO 30 J=2,M1                            0021000
220 30 DO 30 I=1,M1                          0022000
230 30 VZ(I,J)=VZ(I,J-1)+DZ1(J)*(R1(I+1)+VR2(I+1,J-1)-R1(I)+VR2(I,J-1)) 0023000
240 1 / (DR1(I)+0.5*(R1(I+1)+R1(I)))         0024000
250 RETURN                                    0025000
260 END                                        0026000
270                                         0027000

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*** MEMBER BOUNDV

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1*      SUBROUTINE BOUNDV                                0001000
2*      PARAMETER N021,N021                                0002000
3*      PARAMETER N10M=1,N20M=2,N10N=1,N20N=2            0003000
4*      COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1), 0004000
5*      1 VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),        0005000
6*      2 B3(M1,N1),P(M1,N1),VZ(M1,N1)                   0006000
7*      COMMON/TWO/R1(M),R2(M1),DR1(M1),DR2(M),Z1(M),Z2(M1),DZ1(M1),DZ2(M) 0007000
8*      COMMON/THREE/R00,B00R(N1),B02(N),ALPHA,B0DA,B0DB,CORI,G,MU(M),ZK(N) 0008000
9*      C                                                    0009000
10*     C LATERAL BOUNDARY FOR TANGENTIAL AND RADIAL VELOCITIES 0010000
11*     C ASSUMING CONTINUOUS VORTICITY AND DIVERGENCE      0011000
12*     C                                                    0012000
13*     DO 10 J=1,N1                                         0013000
14*     VR2(M,J)=B0DA*VR2(M1,J)+B0DB*(R1(M1)*VR2(M1,J)-R1(M2)*VR2(M2,J)) 0014000
15*     10 VT2(M,J)=B0DA*VT2(M1,J)+B0DB*(R1(M1)*VT2(M1,J)-R1(M2)*VT2(M2,J)) 0015000
16*     RETURN                                              0016000
17*     END                                                  0017000

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*** MEMBER DIFF

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10      SUBROUTINE DIFF                                0001000
20      C                                              0002000
30      C      COMPLETE THE DIFFUSION TERMS          0003000
40      C                                              0004000
50      PARAMETER M21=M21, M22=M22, M23=M23, M24=M24, M25=M25, M26=M26, M27=M27, M28=M28, M29=M29, M30=M30, M31=M31, M32=M32, M33=M33, M34=M34, M35=M35, M36=M36, M37=M37, M38=M38, M39=M39, M40=M40, M41=M41, M42=M42, M43=M43, M44=M44, M45=M45, M46=M46, M47=M47, M48=M48, M49=M49, M50=M50, M51=M51, M52=M52, M53=M53, M54=M54, M55=M55, M56=M56, M57=M57, M58=M58, M59=M59, M60=M60, M61=M61, M62=M62, M63=M63, M64=M64, M65=M65, M66=M66, M67=M67, M68=M68, M69=M69, M70=M70, M71=M71, M72=M72, M73=M73, M74=M74, M75=M75, M76=M76, M77=M77, M78=M78, M79=M79, M80=M80, M81=M81, M82=M82, M83=M83, M84=M84, M85=M85, M86=M86, M87=M87, M88=M88, M89=M89, M90=M90, M91=M91, M92=M92, M93=M93, M94=M94, M95=M95, M96=M96, M97=M97, M98=M98, M99=M99, M100=M100, M101=M101, M102=M102, M103=M103, M104=M104, M105=M105, M106=M106, M107=M107, M108=M108, M109=M109, M110=M110, M111=M111, M112=M112, M113=M113, M114=M114, M115=M115, M116=M116, M117=M117, M118=M118, M119=M119, M120=M120, M121=M121, M122=M122, M123=M123, M124=M124, M125=M125, M126=M126, M127=M127, M128=M128, M129=M129, M130=M130, M131=M131, M132=M132, M133=M133, M134=M134, M135=M135, M136=M136, M137=M137, M138=M138, M139=M139, M140=M140, M141=M141, M142=M142, M143=M143, M144=M144, M145=M145, M146=M146, M147=M147, M148=M148, M149=M149, M150=M150, M151=M151, M152=M152, M153=M153, M154=M154, M155=M155, M156=M156, M157=M157, M158=M158, M159=M159, M160=M160, M161=M161, M162=M162, M163=M163, M164=M164, M165=M165, M166=M166, M167=M167, M168=M168, M169=M169, M170=M170, M171=M171, M172=M172, M173=M173, M174=M174, M175=M175, M176=M176, M177=M177, M178=M178, M179=M179, M180=M180, M181=M181, M182=M182, M183=M183, M184=M184, M185=M185, M186=M186, M187=M187, M188=M188, M189=M189, M190=M190, M191=M191, M192=M192, M193=M193, M194=M194, M195=M195, M196=M196, M197=M197, M198=M198, M199=M199, M200=M200, M201=M201, M202=M202, M203=M203, M204=M204, M205=M205, M206=M206, M207=M207, M208=M208, M209=M209, M210=M210, M211=M211, M212=M212, M213=M213, M214=M214, 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*** MEMBER DIFF

70	C		0070000
71	C	VERTICAL DIFFUSION OF B	0071000
72	C		0072000
73		DO 100 J=2,N2	0073000
74		DO 100 I=1,M1	0074000
75	100	B3(I,J)=B3(I,J)+ZK(J)*((B1(I,J+1)-B(I,J))/DZ2(J+1)	0075000
76	1	-(B(I,J)-B(I,J-1))/DZ2(J))/DZ1(J)	0076000
77		DO 170 I=1,M1	0077000
78	170	B3(I,1)=B3(I,1)+ZK(1)*(B(I,2)-B(I,1))/(DZ2(2)+DZ1(1))	0078000
79		DO 180 I=1,M1	0079000
80	180	B3(I,N1)=B3(I,N1)+ZK(N1)*(-B(I,N1)+B(I,N2))/(DZ2(N1)+DZ1(N1))	0080000
81		RETURN	0081000
82		END	0082000

*** MEMBER FWRD

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10      SUBROUTINE FWRD                                0001000
20      PARAMETER M21,M21                                0002000
30      PARAMETER M1M=1,P2M=2,M1M=1,M2M=2              0003000
40      PARAMETER ND=2,M21+P1+M1                        0004000
50      COMMON/ONE/ DATA1(ND),DATA2(ND),DATA3(ND),P(M1,M1),V2(M1,N) 0005000
60      COMMON/THR/RMS,RMSR(M1),BV2(N),ALPHA,BNDA,BNDB,CORI,C,MV(M),ZK(N) 0006000
70      COMMON/FOR/DELT,XTIME,itime,ISTEP,ISM0,ITAP0,TBV 0007000
80      C                                                0008000
90      C          REPLACE DATA3 WITH THE NEW VALUES 0009000
100     C                                                0010000
110     C          DO 10 I=1,ND                          0011000
120     C          10 DATA3(I)=DATA1(I)+2.*DELT*DATA2(I) 0012000
130     C          TIME SMOOTHING                        0013000
140     C          C          TIME SMOOTHING              0014000
150     C          C          IF(MOD(ISTEP,ISM0).NE.0)GO TO 30 0015000
160     C          DO 20 I=1,ND                          0016000
170     C          20 DATA2(I)=DATA2(I)+(DATA1(I)+DATA3(I)-2.*DATA2(I))*ALPHA 0017000
180     C          30 CONTINUE                          0018000
190     C          C          FORWARD MARCHING           0019000
200     C          C          DO 40 I=1,ND               0020000
210     C          40 DATA1(I)=DATA2(I)                 0021000
220     C          DO 50 I=1,ND                          0022000
230     C          50 DATA2(I)=DATA3(I)                 0023000
240     C          C          ZERO OUT DATA3 FOR NEXT STEP 0024000
250     C          DO 60 I=1,ND                          0025000
260     C          60 DATA3(I)=0.                      0026000
270     C          RETURN                                0027000
280     C          END                                  0028000
290     C          DO 60 I=1,ND                          0029000
300     C          60 DATA3(I)=0.                      0030000
310     C          RETURN                                0031000
320     C          END                                  0032000
330     C          END                                  0033000

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*** MEMBER CHECK

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1*      SUBROUTINE CHECK                                0001000
2*      PARAMETER MB21,NB21                            0002000
3*      PARAMETER N1M=1,N2M=2,N1N=1,N2N=2              0003000
4*      COMMON/ONE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1), 0004000
5*      1 VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),      0005000
6*      2 B3(M1,N1),P(M1,N1),VZ(M1,N)                  0006000
7*      COMMON/TWO/R1(M),R2(M1),OR1(M1),OR2(M),Z1(N),Z2(N1),CZ1(N1),CZ2(N) 0007000
8*      COMMON/FOR/DELT,XTIME,itime,ISTEP,ISM,ITAPE,TRV  0008000
9*      DIMENSION WORK1(M),WORK2(N)                    0009000
10*     DO 10 J=1,N1                                     0010000
11*     DO 20 I=1,M                                      0011000
12*     20 WORK1(I)=OR2(I)/AMAX1(1.,VR2(I,J))           0012000
13*     MIN=MIN(MAG(WORK1))+1                            0013000
14*     DT=WORK1(MIN)*0.9                               0014000
15*     DT=AMINI(DT,DELT)                               0015000
16*     10 CONTINUE                                     0016000
17*     DT=AMINI(DT,TRV)                                 0017000
18*     IF(DT.GE,DELT)RETURN                            0018000
19*     DELT=0.75*DELT                                  0019000
20*     PRINT 100,DELT                                  0020000
21*     100 FORMAT(//////,'*****DELT IS CHANGED TO',1PE11.2,' S*****') 0021000
22*     RETURN                                           0022000
23*     END                                              0023000

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*** MEMBER ADVECT

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1000 SUBROUTINE ADVECT
1001
1002     COMPLETE THE ADVECTIVE TERMS
1003
1004     PARAMETER M21,M22
1005     PARAMETER M1M=1,M2M=2,N1M=1,N2M=2
1006     COMMON/CNE/VR1(M,N1),VT1(M,N1),B1(M1,N1),VR2(M,N1),
1007     1 VT2(M,N1),B2(M1,N1),VR3(M,N1),VT3(M,N1),
1008     2 B3(M1,N1),P(M1,N1),VZ(M1,N1)
1009     COMMON/TM/R1(M),R2(M1),DR1(M1),DR2(M),Z1(N),Z2(N1),DZ1(M1),DZ2(N)
1010     COMMON/THM/RM1,M1M,R1M(N1),BV2(N),ALPHA,BNDA,BNDB,CORI,G,MH(M),ZK(N)
1011     DIMENSION VR(M,N1),VT(M,N1),B(M1,N1)
1012     EQUIVALENCE (VR,VR2),(VT,VT2),(B,B2)
1013
1014     HORIZONTAL ADVECTION FOR RADIAL VELOCITY
1015
1016     DO 10 J=1,N1
1017     DO 10 I=2,M1
1018     10 VR3(I,J)=0.25*((VR(I,J)+VR(I-1,J))*(VR(I,J)-VR(I-1,J))/DR1(I-1)
1019     1 +(VR(I+1,J)+VR(I,J))*(VR(I+1,J)-VR(I,J))/DR1(I))
1020     2 +VR3(I,J)
1021
1022     HORIZONTAL ADVECTION FOR TANGENTIAL VELOCITY
1023
1024     DO 20 J=1,N1
1025     DO 20 I=2,M1
1026     20 VT3(I,J)=0.25*((VR(I,J)+VR(I-1,J))*(VT(I,J)-VT(I-1,J))/DR1(I-1)
1027     1 +(VR(I+1,J)+VR(I,J))*(VT(I+1,J)-VT(I,J))/DR1(I))
1028     2 +VT3(I,J)
1029
1030     HORIZONTAL ADVECTION FOR SUBVANCY
1031
1032     DO 60 J=1,N1
1033     DO 60 I=2,M2
1034     60 B3(I,J)=B3(I,J)+0.5*(VR(I,J)*(B(I,J)-B(I-1,J))/DR2(I)
1035     1 +VR(I+1,J)*(B(I+1,J)-B(I,J))/DR2(I+1))
1036     DO 70 J=1,N1
1037     70 B3(I,J)=B3(I,J)+0.5*VR(2,J)*(B(2,J)-B(1,J))/DR2(2)
1038     DO 80 J=1,N1
1039     80 B3(M1,J)=B3(M1,J)+0.5*VR(M1,J)*(B(M1,J)-B(M2,J))/DR2(M1)
1040
1041     VERTICAL ADVECTION FOR RADIAL VELOCITY
1042
1043     DO 90 J=2,M2
1044     DO 90 I=2,M1
1045     90 VR3(I,J)=VR3(I,J)+0.25*((VZ(I-1,J)+VZ(I,J))*(VR(I,J)-VR(I-1,J))
1046     1 /DZ2(J)+(VZ(I,J+1)+VZ(I-1,J+1))*(VR(I,J+1)-VR(I,J))
1047     2 /DZ2(J+1))
1048     DO 95 I=2,M1
1049     95 VR3(I,1)=VR3(I,1)+0.25*(VZ(I,2)+VZ(I-1,2))*(VR(I,2)-VR(I,1))
1050     1 /DZ2(2)
1051     DO 96 I=2,M1
1052     96 VR3(I,N1)=VR3(I,N1)+0.25*(VZ(I-1,N1)+VZ(I,N1))*(VR(I,N1)-VR(I,N2))
1053     1 /DZ2(N1)
1054
1055     VERTICAL ADVECTION FOR TANGENTIAL VELOCITY
1056
1057     DO 100 J=2,M2
1058     DO 100 I=2,M1
1059     100 VT3(I,J)=VT3(I,J)+0.25*((VZ(I-1,J)+VZ(I,J))*(VT(I,J)-VT(I-1,J))
1060     1 /DZ2(J)+(VZ(I,J+1)+VZ(I-1,J+1))*(VT(I,J+1)-VT(I,J))
1061     2 /DZ2(J+1))
1062     DO 105 I=2,M1
1063     105 VT3(I,1)=VT3(I,1)+0.25*(VZ(I,2)+VZ(I-1,2))*(VT(I,2)-VT(I,1))
1064     1 /DZ2(2)
1065     DO 106 I=2,M1
1066     106 VT3(I,N1)=VT3(I,N1)+0.25*(VZ(I-1,N1)+VZ(I,N1))*(VT(I,N1)-VT(I,N2))
1067     1 /DZ2(N1)
1068
1069     VERTICAL ADVECTION FOR B
1070
1071     DO 150 J=2,M2
1072     DO 150 I=1,M1
1073     150 B3(I,J)=B3(I,J)+0.5*(VZ(I,J)*(B(I,J)-B(I-1,J))/DZ2(J)
1074     1 +VZ(I,J+1)*(B(I,J+1)-B(I,J))/DZ2(J+1))
1075     DO 160 I=1,M1
1076     160 B3(I,1)=B3(I,1)+0.5*VZ(I,2)*(B(I,2)-B(I,1))/DZ2(2)
1077     DO 170 I=1,M1

```

*** MEMBER ADVECT

78*	170	B3(I,N1)=B3(I,N1)+0.5*VZ(I,N1)*(B(I,N1)-B(I,N2))/DZ2(N1)	0078000
79*	C		0079000
80*	C	INERTIA TERMS FOR HORIZONTAL MOMENTUM	0080000
81*	C		0081000
82*		DO 110 J=1,N1	0082000
83*		DO 110 I=2,M1	0083000
84*		VR3(I,J)=VR3(I,J)+VT(I,J)*(VT(I,J)/R1(I)+CORI)	0084000
85*	110	VT3(I,J)=VT3(I,J)+VR(I,J)*(VT(I,J)/R1(I)+CORI)	0085000
86*	C		0086000
87*	C	PRESSURE GRADIENT FORCE	0087000
88*	C		0088000
89*		DO 120 J=1,N1	0089000
90*		DO 120 I=2,M1	0090000
91*	120	VR3(I,J)=VR3(I,J)-(P(I,J)-P(I-1,J))/(RHO*DR2(I))	0091000
92*	C		0092000
93*	C	STRATIFICATION TERM	0093000
94*	C		0094000
95*		DO 130 J=1,N1	0095000
96*		DO 130 I=2,M1	0096000
97*	130	B3(I,J)=B3(I,J)+0.5*(VZ(I,J)=BV2(J)+VZ(I,J+1)+BV2(J+1))	0097000
98*		RETURN	0098000
99*		END	0099000

*** MEMBER PUTOUT

```

10 SUBROUTINE PUTOUT                                0001000
20 PARAMETER M21,M22                                0002000
30 PARAMETER N1M=1,N2M=2,N1SN=1,N2SN=2            0003000
40 COMMON/ONE/VR1(M,N1),VT1(M,N1),R1(M1,N1),VR2(M,N1), 0004000
50 1 VT2(M,N1),R2(M1,N1),VR3(M,N1),VT3(M,N1),        0005000
60 2 R3(M1,N1),P(M1,N1),VZ(M1,N1)                  0006000
70 COMMON/TWO/R1(M),R2(M1),DR1(M1),UR2(M),Z1(N),Z2(N1),DZ1(N1),DZ2(N) 0007000
80 COMMON/THREE/RMC,RMC(N1),BV2(N),ALPHA,BNDA,BNDB,COR1,G,M(N),ZK(N) 0008000
90 COMMON/FAR/DELTA,XTIME,ITIME,ISTEP,ISMO,ITAPE,TBV 0009000
100 C                                                0010000
110 C          THIS SUBROUTINE PRINT OUT FIELDS FOR A GLYCK LOOK 0011000
120 C                                                0012000
130 DIMENSION IDUM(M,N)                             0013000
140 700 FORMAT(////,' LACIAL VELOCITY (CM/S) AT T=,16,' M') 0014000
150 705 FORMAT(////,' TANGENTIAL VELOCITY (CM/S) AT T=,16,' M') 0015000
160 710 FORMAT(////,' VERTICAL VELOCITY (CM/S) AT T=,16,' M') 0016000
170 715 FORMAT(////,' BUCVANCY FIELD (0.001) AT T=,16,' M') 0017000
180 725 FORMAT(////,' PRESSURE (0.10 DYNE/CM**2) AT TIME=,16,' M') 0018000
190 720 FORMAT(1M1,////,'2CX,'*****' GLTPUT AT TIME M',16,' M' 0019000
200 1 P8.2,' DAY' ISTEP M',17,' *****') 0020000
210 DAY=XTIME/86400.,00,0001 0021000
220 PRINT 720,ITIME,DAY,ISTEP 0022000
230 DO 10 J=1,N1 0023000
240 DO 10 I=1,M 0024000
250 10 IDUM(I,J)=VR2(I,J) 0025000
260 PRINT 700,ITIME 0026000
270 CALL 'AP'(IDUM,R1,Z2,M,N1) 0027000
280 DO 20 J=1,N1 0028000
290 DO 20 I=1,M 0029000
300 20 IDUM(I,J)=VT2(I,J) 0030000
310 PRINT 705,ITIME 0031000
320 CALL 'AP'(IDUM,R1,Z2,M,N1) 0032000
330 DO 30 J=1,N 0033000
340 DO 30 I=1,M1 0034000
350 30 IDUM(I,J)=VZ(I,J) 0035000
360 PRINT 710,ITIME 0036000
370 CALL 'AP'(IDUM,R2,Z1,M1,N) 0037000
380 DO 40 J=1,N1 0038000
390 DO 40 I=1,M1 0039000
400 40 IDUM(I,J)=R2(I,J)*1.E3 0040000
410 PRINT 715,ITIME 0041000
420 CALL 'AP'(IDUM,R2,Z2,M1,N1) 0042000
430 DO 50 J=1,N1 0043000
440 DO 50 I=1,M1 0044000
450 50 IDUM(I,J)=P(I,J)*1.E-1 0045000
460 PRINT 725,ITIME 0046000
470 CALL 'AP'(IDUM,R2,Z2,M1,N1) 0047000
480 RETURN 0048000
490 END 0049000

```

*** MEMBER MAP

1*	30000000	0001000
2*	00000000	0002000
3*	00000000	0003000
4*	00000000	0004000
5*	00000000	0005000
6*	00000000	0006000
7*	00000000	0007000
8*	00000000	0008000
9*	00000000	0009000
10*	00000000	0010000
11*	00000000	0011000
12*	00000000	0012000
13*	00000000	0013000
14*	00000000	0014000
15*	00000000	0015000
16*	00000000	0016000
17*	00000000	0017000
18*	00000000	0018000
19*	00000000	0019000

END

FILMED

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DTIC