POLYMODE NEWS

No. 10 June 25, 1976

EDDY PARTHENOGENESIS

by Mike McCartney

In POLYMODE News No. 8, Lai discussed warm eddies south of the Gulf Stream and posed an interesting question: are these eddies generated by Gulf Stream rings? While it is not directly applicable to a moving ring, my work on Taylor columns (1975) can be modified to produce solutions corresponding to familiar inviscid singularities (point vorticies and point doublets) moving westward (in the sense of f/H contours) in an unbounded, β-plane ocean.

The nondimensional potential vorticity equation for the two-dimensional motion of an inviscid, homogeneous fluid on a constant-depth, β-plane ocean is:

$$\underset{\sim}{q} \cdot \nabla(\nabla^2\psi + k^2 y) = 0 \qquad (1)$$

where ψ is the streamfunction, $k^2 = \beta L/U_o$; U_o is the drift speed of the singularity relative to the fluid; and L is an arbitrary length scale. Solutions to the linear equation

$$\nabla^2\psi + k^2\psi = -k^2 y \qquad (2)$$

will be solutions to equation (1) since $\underset{\sim}{q} \cdot \nabla\psi \equiv 0$. We can set $\psi = -y + \phi$, obtaining

$$\nabla^2\phi + k^2\phi = 0 \qquad (3)$$

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RECENT OBSERVATIONS OF EDDIES SOUTHWEST OF BERMUDA

by Ants Leetmaa

During March and April, 1976, R/V Researcher was engaged in a study of near-surface phenomena in the vicinity of the MODE-I area. Our primary interest was in the three-dimensional structure of small-scale fronts and their interaction with motions in the main thermocline. It is too early to report on these observations; however, we did observe some features that are of interest to POLYMODE scientists.

In Figures 1a and 1b are shown XBT transects through two energetic baroclinic features observed in late April. The section in Figure 1a shows a cold eddy, approximately circular in shape, with a radius of 10-14 km. This eddy has an interesting vertical structure. Below 17°C, the vertical displacement of the warmer isotherms is greater than that of the colder ones. For example, near the eddy's center, the 15°C isotherm has a slope of about 7 m/km while the 10°C isotherm has a slope of about 2 m/km. (As a point of reference, the warm MODE-I eddy had maximum slopes of about 1 or 2 m/km. Also, there is a complete absence of water with temperatures between 17.5° and 19.5°C. This is surprising since

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NOTES from the Editor

We regret that Leigh Stoecker, who has been co-editor of the POLYMODE News for the past two years, will be leaving this position in September. We are currently seeking a replacement to be employed at the Woods Hole Oceanographic Institution in accordance with the position description shown in this issue. Persons interested in this position are encouraged to write to the Personnel Office at the Woods Hole Oceanographic Institution soon, as we hope to have a successor to Leigh available to start some time in August to provide a reasonable period of overlap.

It has been a pleasure to work with Leigh. The evidence of her great contribution has been the consistent quality and regularity of the MODE Hot Line News and the POLYMODE News for the past two years. She will be missed not only by POLYMODE News but also by many friends in Woods Hole.

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We are pleased to note that Henry Stommel of M.I.T. has been elected a foreign member of the Soviet Academy of Sciences. As co-chairman of the U. S. POLYMODE program, Henry probably needs little introduction to readers of the POLYMODE News. However, it is seldom that we have an opportunity to acknowledge the great debt we all owe to Professor Stommel for having been the principal exponent for many years of the scientific ideas that led to the creation of the MODE and POLYMODE programs.

-- F. W.

The POLYMODE* News is produced at the Woods Hole Oceanographic Institution. It is edited by Ferris Webster and Leigh Stoecker.

If you have material of interest for this newsletter, please get in touch with either of the above at the Woods Hole Oceanographic Institution, Woods Hole, MA, 02543, Telephone (617) 548-1400.

*POLYMODE is derived from the names of the U.S.S.R. POLYGON experiments and the Mid-Ocean Dynamics Experiment (MODE).

POLYMODE OFFICE NOTES

On July 1, 1976, Polly Wilbert will leave the POLYMODE Executive Office at M.I.T. to take a new job with Resources Planning Associates, Inc. in Cambridge.

Polly came to what was then the MODE Executive Office in June, 1974 and dived head first into the U. S./U.S.S.R. Summer Institute in Rhode Island. As Secretary and later as Administrative Assistant, Polly is familiar to U. S. and Soviet POLYMODE participants as a first-rate organizer and problem solver. Her organized, enthusiastic, and energetic approach to the job, and her ability to work cheerfully and efficiently under the pressure of deadlines make her a key person in the Executive Office.

Polly will be sorely missed. Her knowledge of the workings of POLYMODE, her resourcefulness, and her ability to get the job done make her, in a real sense, irreplaceable. We wish her the best in her new position.

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A Soviet delegation of the Joint Experimental Design Group will be visiting Woods Hole from 28 June-15 July for discussions regarding the POLYMODE field program. Members of the delegation are: Dr. Mikhael Koshlyakov, Dr. Boris Filyushkin, and Dr. Yuri Shishkov from the Institute of Oceanology in Moscow, and Dr. Konstantin Sabinin from the Acoustical Institute in Moscow. During their stay in Woods Hole, they may be reached via Nick Fofonoff (Tel. (617) 548-1400, ext. 525).

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Copies of a preliminary U. S. POLYMODE Directory containing names, addresses, and telephone numbers of POLYMODE participants have been distributed. A copy may be obtained from the POLYMODE Office, Room 54-1418, M.I.T., Cambridge MA 02139 (Tel. 617-253-7828).

ACKNOWLEDGEMENT

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EDDY PARTHENOGENESIS (continued)

The solutions to equation (3) corresponding to point singularities can then be regarded as either stationary singularities with an eastward flow past them, or as westward-moving singularities in a quiescent fluid. The important thing is that the flow is eastward relative to the singularity.*

Solutions to equation (3) must satisfy one boundary condition: waves should be found downstream (to the east) of the source (Lighthill, 1967). A point vortex-like solution to (3) is:

$$\phi = \frac{-\Gamma}{4} \{Y_0(kr) + \frac{4}{\pi} \sum_{n=1}^{\infty} \frac{J_{2n-1}(kr)\cos[(2n-1)\theta]}{2n-1}\} \quad (4)$$

The infinite sum cancels out the wavy $Y_0(kr)$ on the western half-plane, but reinforces it on the eastern half-plane. For $k \to 0$, $\phi \to \frac{-\Gamma}{2\pi} \ln r$, which is the potential flow solution for a point vortex of strength Γ.

The streamfunction ψ gives the flow field as seen in a frame moving with the singularity, i.e., moving west at a scaled speed of 1. In Figure 3, the dependence of the flow field on the nondimensional circulation Γ for fixed $k = 1.0$ is shown. A negative Γ corresponds to a cyclonic vortex. The point vortex induces a closed cyclonic eddy around it, elongated in the northwest-southeast direction. The highest speeds are on the southwest side of the eddy, the slowest (including a stagnation point) are on the northwest side. The eddy carries with it a trail of Rossby waves of radial character. For a value of $\Gamma = -8.0$ (Figure 3c) a lee anticyclonic eddy is found southeast of the singularity within the anticyclonic meander shown at a radius of 2.5. Given a drift velocity U_0 and a value for β, the strength of a cyclonic vortex sufficient to give birth to a trailing anticyclonic eddy can be estimated. The dimensional circulation magnitude is

$$|\Gamma'| = |\Gamma| U_0 L = |\Gamma| U_0 \sqrt{U_0/\beta}$$

(since $k = 1$). Substituting $|\Gamma| = 8.0$, $\beta = 10^{-13}\text{cm}^{-1}\text{sec}^{-1}$, $U_0 = 5$ cm/sec, then $\Gamma' = 280 \times 10^2 \text{m}^2/\text{sec}$.

Float track no. 1 in Figure 7 of MODE Hot Line News No. 83 (Cheney, et al) shows a moving circular ring of 50 km radius with a relative cyclonic speed of 10 cm/sec. From this we can estimate

$$\Gamma' = 2\pi\, U_c\, R_c = 314 \times 10^2 \text{m}^2\text{sec}^{-1} ,$$

indicating that the intensity of a Gulf Stream ring is sufficient to produce a trailing anticyclonic eddy to the southeast.

The cyclonic meander to the northeast pinches off to form a trailing cyclonic eddy for $\Gamma < -16$ (Figure 3e), corresponding to $\Gamma' = 560 \times 10^2 \text{m}^2\text{sec}^{-1}$. This suggests that while strong trailing cyclonic meanders may be forced northeast of Gulf Stream rings, they will not generally spawn additional cyclonic eddies.

The relative drift speed plays a crucial role in estimating Γ', because $\Gamma' \propto U_0\sqrt{U_0}$. Thus, doubling U_0 increases Γ' by 2.83. The faster the relative drift speed, the less likely a given intensity disturbance is to generate a lee-side eddy.

The wavelength of the trailing disturbance is $2\pi\sqrt{U_0/\beta}$, equal to 440 km for $U_0 = 5$ cm/sec. The anticyclonic feature lies at about half this wavelength from the point vortex, or about 220 km away. The general configuration and scale is similar to that shown in Richardson's Figure 5 (POLYMODE News No. 8), in which an anticyclonic feature was found 200 km southeast of a cyclonic ring with a cyclonic ridge 350 km east of it. This suggests that the cyclonic ridge Richardson contoured along 54°W was not a super Gulf Stream meander, but part of the wavy wake trailing

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*In the Gulf Stream ring region, the mean flow is presumably westward; hence, these solutions correspond to the case in which the ring moves westward faster than this mean flow.

EDDY PARTHENOGENESIS (continued)

the ring as it propagated from the east to its location at 58°W. After this data was collected, however, the ring moved northeastward, so the pattern resemblence may be pure coincidence!

At a stationary sensor in the ring's path (y = 0), the 440 km wavelength disturbance field propagating at 5 cm/sec would give rise to a signal period of about one month. The signal's character would be a dominant cyclonic signal followed by alternate anticyclonic and cyclonic decaying amplitude signals, essentially a damped wave train of period one month. I am presently examining current meter and temperature records to find such signals.

The method outlined by Flierl (POLYMODE News No. 8) can be directly applied to the solution presented here to evaluate the actual particle paths for a comparison with observed float tracks. Flierl's solution is symmetric east-west with waves both upstream and downstream; however, the present solution has a monotonic eddy precursor with wavy character only after the main cyclonic feature has passed by.

Various generalizations of this work can be made for more detailed comparison to observation. Since much of the vertical structure in the North Atlantic seems to be accounted for by a barotropic and single baroclinic mode, the two-layer Taylor column formulation (McCartney, 1975) could be used to model a surface intensified vortex with vertical shear in the basic east-west current within which the vortex is moving. There are other formulations, continuously stratified models, which could also be used, although they appear mathematically more complicated that the two-layer formulation.

References

Lighthill, M. J. (1967) On waves generated in dispersive systems by travelling forcing effects, with applications to the dynamics of rotating fluids. J. Fluid Mech., *27*, 725-752.

McCartney, M. S. (1975) Inertial Taylor columns on a beta-plane. J. Fluid Mech., *68*, 71-95.

JOB OPENING

Applications are invited for the position of Editorial Assistant in the Department of Physical Oceanography at the Woods Hole Oceanographic Institution. The duties of this position follow.

Production of a scientific newsletter in Physical Oceanography: edits copy for spelling, punctuation, and grammatical errors according to accepted rules of style. Rewrites articles for greater consistency, clarity, and adherence to space limitations. Writes headlines and captions. Verifies facts, dates, and statistics in articles from reference sources. Types manuscripts. Prepares layout of pages for final copy incorporating both articles and illustrations, according to accepted techniques of presentation. Drafts figures. Distributes final copies. Maintains information on circulation and handles requests for new subscriptions.

May prepare columns, articles, or feature stories summarizing scientific activities and viewpoints. Solicits manuscripts for publication and confers with authors as needed. Replies to correspondence.

This position requires someone who is self-motivated, who can work independently, and who can meet publication deadlines. The person should be free to travel to scientific meetings and have an interest/aptitude in science.

A B.A. or A.A. with courses in English and/or journalism plus one year related experience is desired. Some drafting and general graphic arts experience is desirable. Competent technical typing skills are required.

This position has been, and is expected to continue, on a full-time basis. However, it may be possible to arrange part-time employment.

Address all inquiries and applications to:

Personnel Manager
Woods Hole Oceanographic Institution
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it is in this area of the ocean that 18°C water is formed during the winter (about 19°C this year).

Have features like this been observed before? It might first be speculated that it is an old Gulf Stream ring. However, even two-year-old rings have a radius of about 50 km, and Gulf Stream rings have never been observed in this area. For old (and young) MODE-ers, this feature is probably an old, though not-too-familiar, friend.

Figure 2 shows two temperature cross-sections taken during MODE-I from northwest to southeast through the MODE-I area. The feature of interest lies at the northwest end of these sections. Since the feature was on the fringe of the STD grid, it is unclear whether it develops locally or propagates into the area. I think there is evidence to argue that it does develop locally. During days 155-169 (4 June-18 June, 1973), this feature looks remarkably similar in vertical structure and horizontal scale to what we observed in April. Also, their relationship to larger-scale features is similar.

Since vorticity can only be created or destroyed at boundaries, one can speculate that what is happening in Figure 2 is the formation of a vortex pair to conserve vorticity. The cyclonic feature just above the main thermocline is accompanied by convergence, and the anticyclonic feature above 300 m is accompanied by a divergence (which explains the absence of water between 17° and 18°C). It is not clear what initiates this process. This feature penetrates to about 700 m vertically, the depth to which intense surface fronts were observed to have effect. So much for an old friend.

It is not hard to guess what our new friend is (Figure 1b). Obviously, it is a blob of real 18°C water. Other observations of similar features were recently reported by Lai in POLYMODE News No. 8. An interesting aspect of this particular feature is the large volume of water between 14° and 15°C (this was also observed in another XBT dropped just before No. 565, but it is not plotted in Figure 1b). Such a convergence might be expected dynamically if this region acquired anticyclonic vorticity (from above?). This feature must be very old since water as cold as 18°C has not been observed to form for many years.

The features shown in Figures 1a and 1b should illustrate that this region of the Sargasso Sea still holds some surprises for us: Perhaps the MODE-I eddy was anomalous; a number of long XBT tracks have been taken and moorings maintained which yield no evidence of features similar in scale or amplitude. It was concluded from MODE-I that a first baroclinic mode representative is a good vertical description of the eddy field; perhaps this conclusion should be examined critically before future experiments are done.

What is the energy source of these features? In the case of the blob of 18°C water, air-sea exchanges that occur over the northern Sargasso Sea during winter are clearly of crucial importance. However, complex processes must be at work to produce a feature whose horizontal scale is 100 km from the large-scale horizontal temperature gradient caused by winter cooling. Each time the cold eddy (Figure 1a) was observed, it was located on the cold side of a surface front. These fronts also require the horizontal variations in temperature that are produced during winter. In a future paper, I will argue that some of the factors that are important during small-scale frontogeneses were, in fact, also important in the development of the MODE-I eddy. In each of these cases, an important energy source for the motions is the north-south density variation in the upper ocean that is produced by winter cooling.

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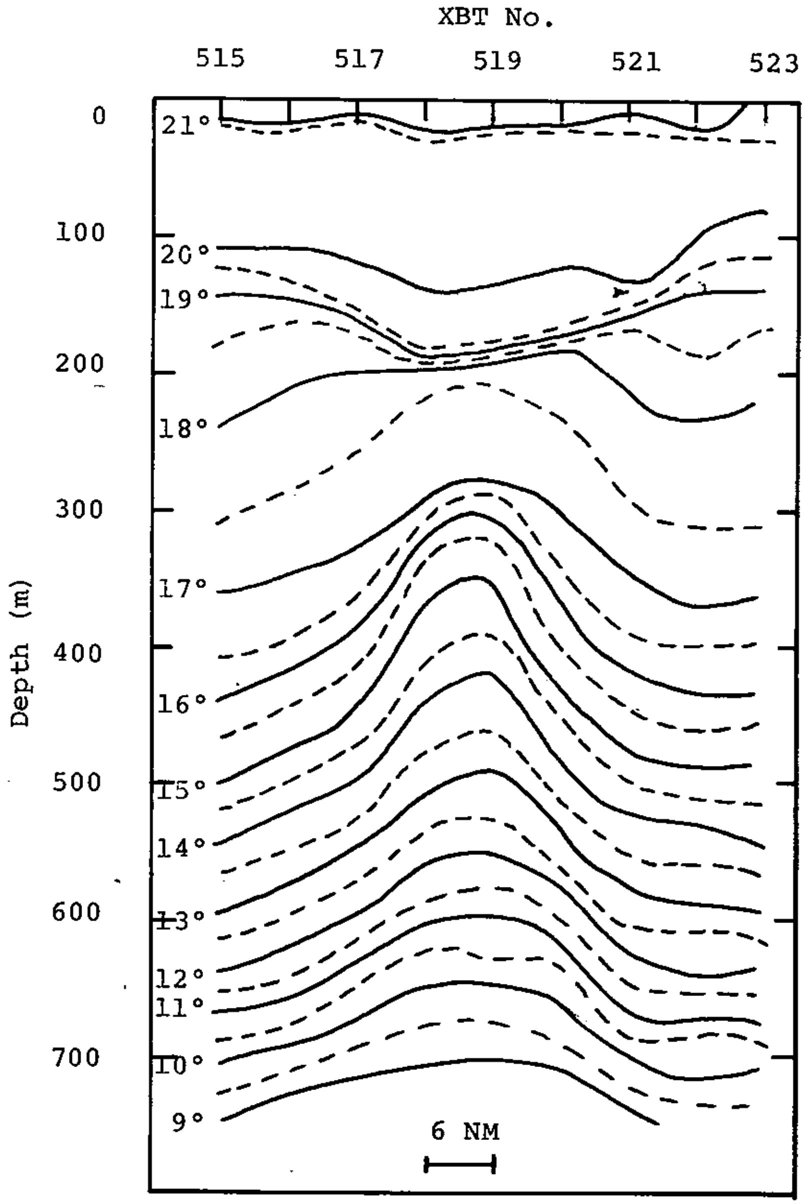


Figure 1a

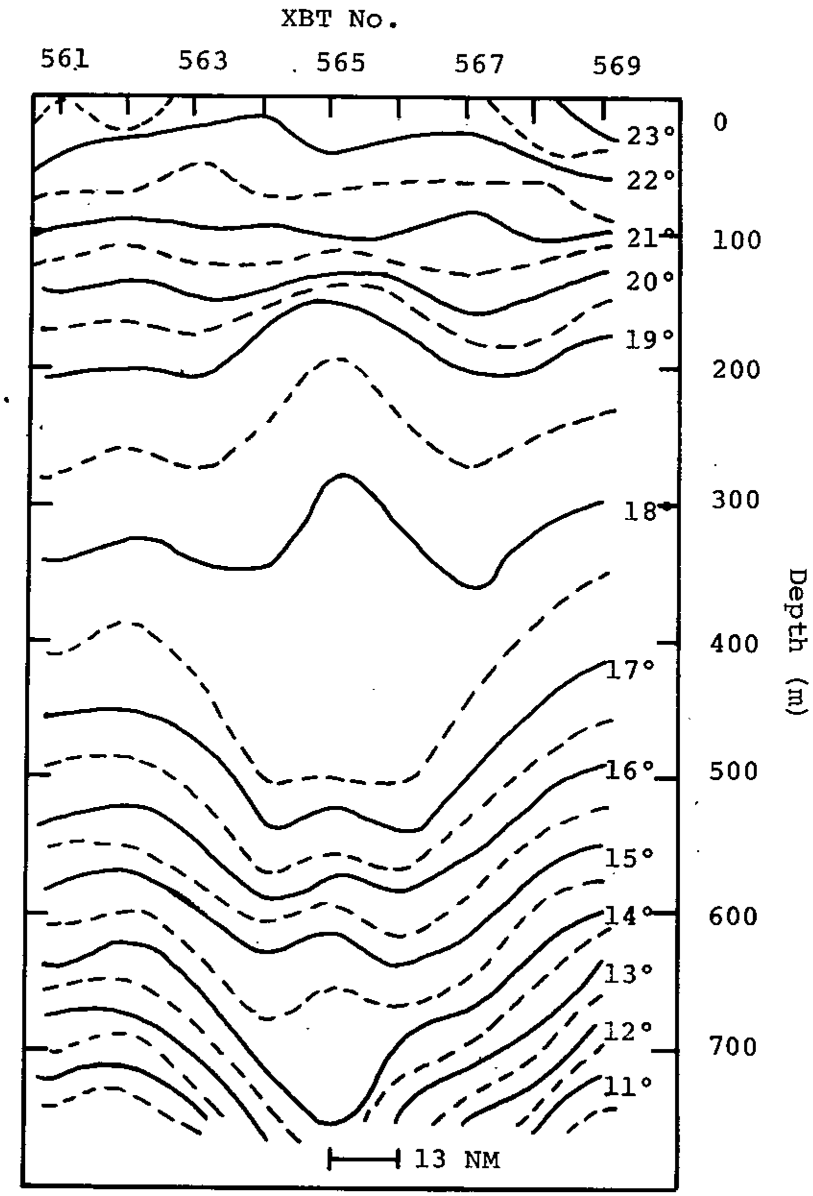


Figure 1b

XBT transects through two energetic baroclinic features observed in late April, 1976: (a) at 30°46'N, 66°18'W, and (b) at 28°21'N, 69°25'W.

Figure 1 (Leetmaa)

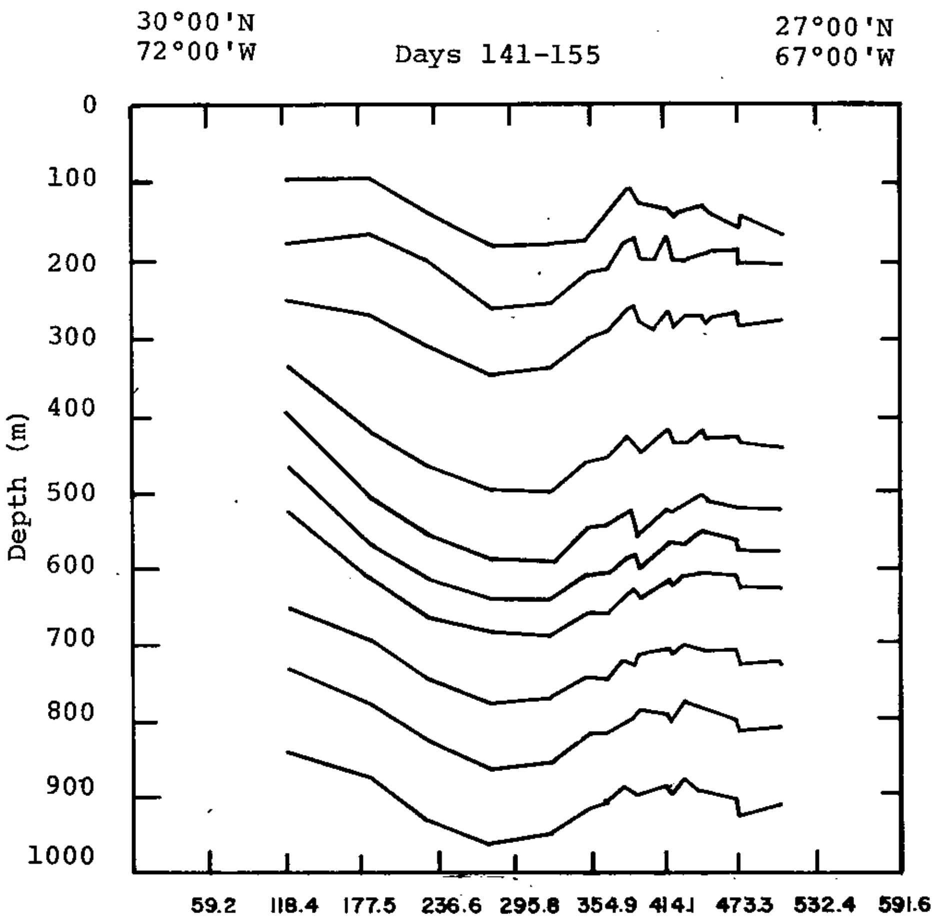


Figure 2a

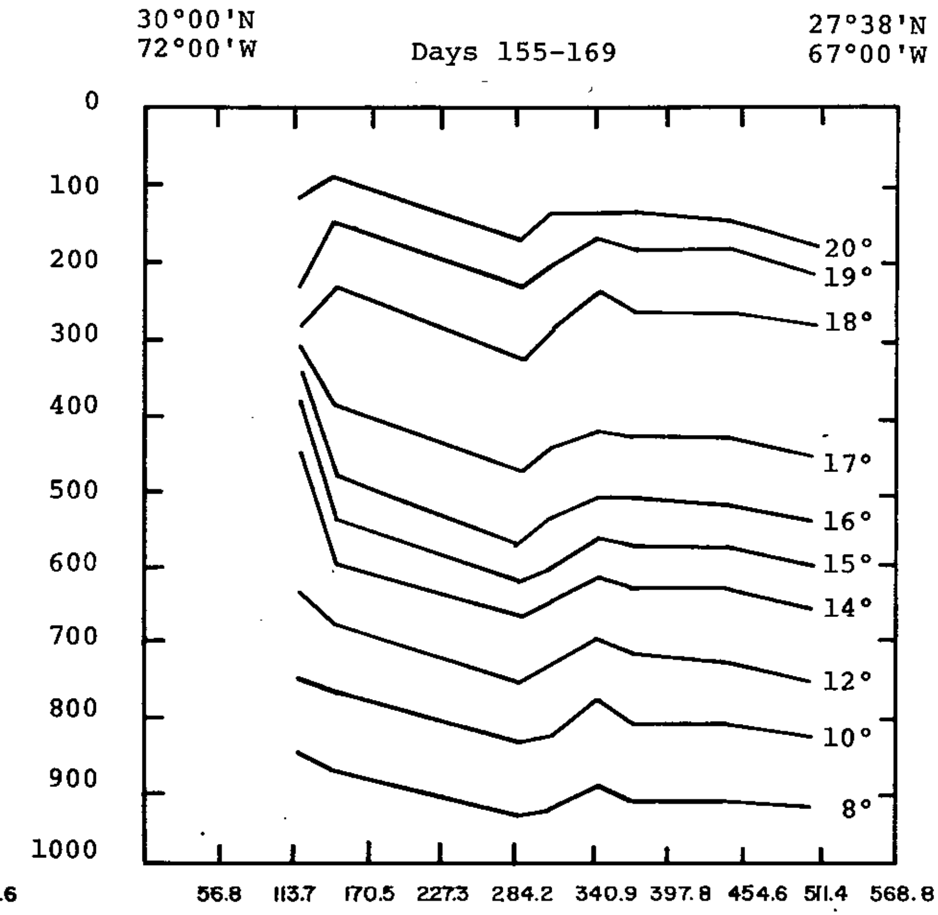
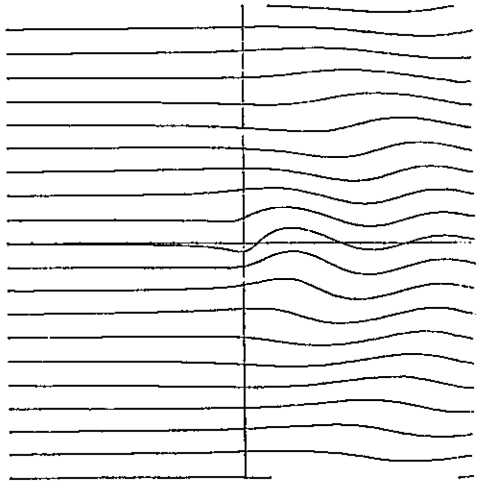


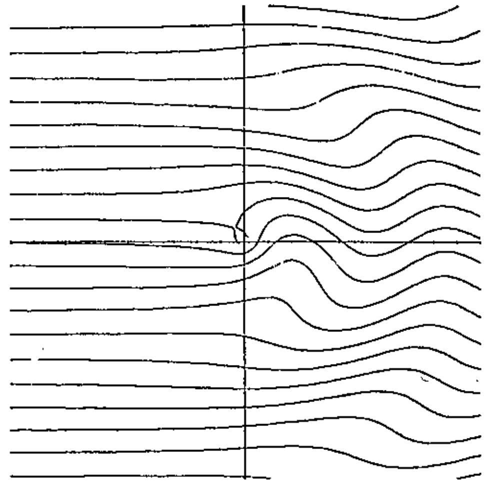
Figure 2b

Two temperature cross-sections taken during MODE-I from northwest-southeast through the MODE-I area.

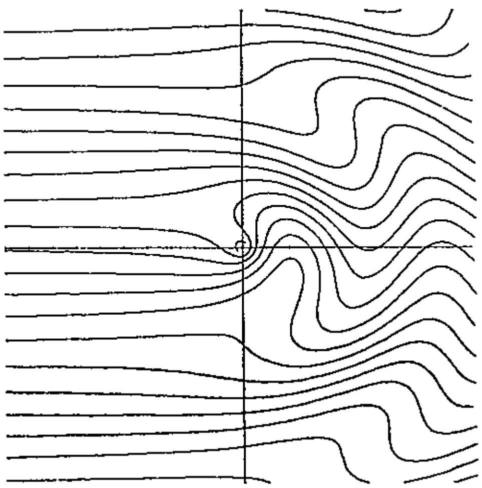
Figure 2 (Leetmaa)



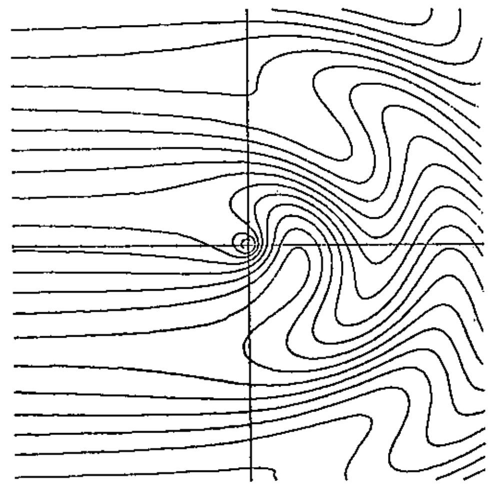
Γ = -2 (a)



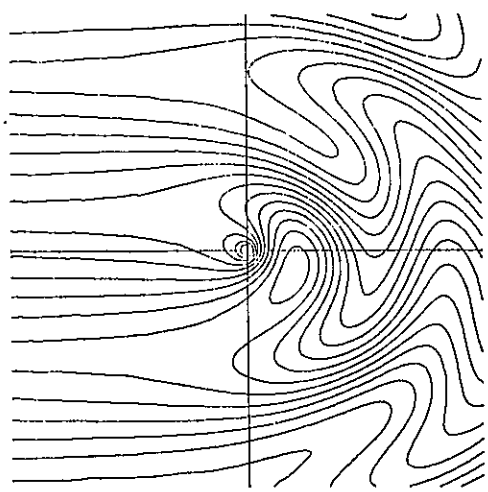
Γ = -4 (b)



Γ = -8 (c)



Γ = -12 (d)



Γ = -16 (e)

Streamlines for k = 1, and vortex strength Γ = -2, -4, -8, -12, -16. The point vortex strength is at the origin, and only integer-valued streamlines (0, ±1, ±2, etc.) are shown. No streamlines are shown within a square of side 0.4 centered at origin. For Γ = -8, the anticyclonic meander to the southeast contains a local ψ extrema, an embryonic anticyclonic eddy. Since only integer-valued streamlines are shown, a closed anticyclonic eddy doesn't appear in the contours until Γ = -16. The cyclonic meander at a radius of ∿5.5, while very elongated, doesn't pinch off until a strength greater than -16.

Figure 3 (McCartney)