Geostrophic Current, Divergence and Convergence in the South China Sea, Area II: Sabah, Sarawak and Brunei Darussalam

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ABSTRACT

Current and circulation patterns for the area where water depth exceeded 500 m were calculated from geostrophic balance. Divergence and convergence inferred from horizontal circulation matched quite well with the observed vertical migration of the pycnocline, i.e. an indication of upwelling and downwelling. The spatial circulation pattern for July-August 1996 was quite different from that for May 1997, despite a generally similar prevailing wind. Eddies and meanders were the main features causing the difference. Interpretation of chemical and biological data of the area should take into consideration these local and sporadic physical phenomena.

Introduction

The net current and water circulation are always important factors for the management of fisheries and living resource in the ocean. These factors can be determined by several approaches, each of them has its own advantages, disadvantages and limitations. Due to the nature of this survey, where the vessel spent only 1 to 1.5 hour at each station, direct observation which requires observation duration of at least 25 hours in order to obtain both semi-diurnal and diurnal components of current was not possible, despite the availability of a Doppler instrument on board the vessel M.V. Seafdec.

There are several indirect methods to determine the net movement of water in the marine environment. Numerical modelling using, for examples Nevier-Stoke type equation, advection-diffusion equation, and mass-momentum balance principles, however requires good knowledge of boundary conditions which was not possible in the present study area. Remote sensing approach using sea surface topography can provide some indication of surface over a large area. However a small area of only 6 x 8 degree will cover only a few Topex-Poseidon tracks so even though this is a promising approach it still needs more refinements and adjustments before it can be sufficiently reliable.

The classical geostrophic balance is most appropriate under the condition and limitation of this survey. It requires accurate temperature, salinity and pressure data which could be provided by high resolution CTD deployed at each station. The current obtained from the method will be relative current between 2 layers. In deep ocean where the current speed at a sufficiently deep layer is usually very slow relative to surface current (e.g. less than 0.01 m/s), a deep layer can be assumed to be the level of no motion. The absolute current at any levels above the level of no motion can be obtained.

The Study Area

The study area—the northwest coast of Borneo Island offshore of Sarawak and Sabah, Malaysia and Brunei Darussalam—is a relatively open area subjected to both Southwest and Northeast Monsoons. Among the total of 79 survey stations of both cruises, Cruise 34 (10 July - 2 August 1996) and Cruise 41 (1 May - 24 May 1997), only 27 stations had bottom depth exceeded 500 meter where level of no motion can be assumed. The location of these stations and the bottom topography of the survey area are shown in Fig. 1.

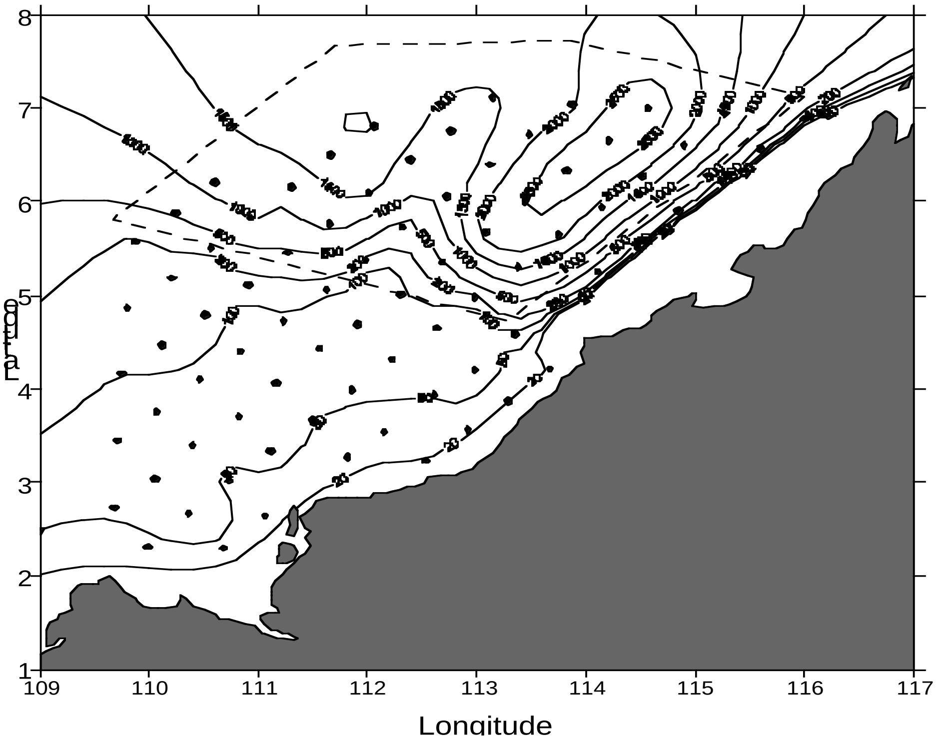

Fig. 1 Depth contour (m) of the study area. The area bound by dashed line is the area where water depth was greater than 500 m and geostrophic balance calculation could be performed.

Dynamic Topography and Geostrophic Balance

The principle of geostrophic balance can be found in any textbooks on physical oceanography, such as Pond and Pickard (1983) and other. The method has been used widely for deep ocean and it may not too exaggerated to say that probably most of the subsurface circulation of the world ocean known to date was obtained by this approach. The basic assumption of this method is that in the case of an isobaric surface, for example, sea surface, to maintain an unequal level then the horizontal pressure gradient force due to gravity (potential energy) must be counteracted or balanced by Coriolis force due the movement of water.

$$f\,u = g \tan(q) \qquad (1)$$

where f = Coriolis factor (function of latitude)

u = current speed in the direction perpendicular to the pressure gradient

g = gravitational acceleration

q = tilt angle of the interested surface relative to reference surface (e.g. level of no motion)

Because it is more difficult of determine q from direct measurement, it can be calculated from dynamic height difference between 2 stations by defining

$$DYNH = g\,z \qquad (2)$$

where DYNH = dynamic height (in dyn.m)

z = vertical distance between the interested surface and the reference surface (in m)

Thus, combining equations 1 and 2 will give

$$f\,u = (DYNH_1 - DYNH_2) / L \qquad (3)$$

where subscript refers to station and L = distance (m) between the 2 stations

Data Collection and Analysis

Raw data for temperature, conductivity and pressure were collected by a Falmouth Scientific CTD on board the vessel using sampling rate of 25 Hz. Temperature was corrected to ITS 90 standard. Salinity was calculated according to PSS 78 scale. Dynamic height relative to the surface was also calculated by the EG&G CTD Post-acquisition Analysis Software at every 1 dbar pressure interval.

The obtained dynamic height was corrected to 500 dbar level, the assumed level of no motion. This observed dynamic height relative to 500 dbar at sea surface, 20, 50, 100 and 200 dbar were converted into gridded data by Krigging Method at 0.2 degree grid size using Surfer (Golden Software). These gridded data were subsequently used to calculate u and v components for each grid cell using the program listed in Appendix 1.

Divergence and convergence were inferred simply from the direction of surface current. In the northern hemisphere the currents that pass each other on the right hand side will create a convergence due to Coriolis effect. Divergence will be created when the surface currents pass each other on their left.

In order to correlate horizontal current field with vertical phenomena that could be important for fisheries purpose, sea surface temperature was taken from CTD data file but to avoid daily heat exchange artifact, the data at 5 m from sea surface was used. The depth of surface mixed layer, another important indicator of upwelling and downwelling processes, was taken from surface to the depth where vertical stratification was strongest as indicated by largest Brunt-Vaisala Stability Frequency at each station.

Results

Current pattern during Cruise 34 (July-August 1996) was dominated by two northward surface plumes. These plumes could be clearly detected down to over 100 dbar but at 200 dbar they were less significant (Figures 2 to 5). A weak anticyclonic eddy was observed near Station 53.

In May 1997 during Cruise 41, there was a strong meander generally from west to east. This meander, however, had quite a shallow core (less than 100 m). There was also a large and strong anticyclonic eddy that covered Station 55, 56, 63 and 64 which penetrated well below 200 m (Figures 6 to 9). The data for dynamic height is given in Appendix 2 and gridded current velocity as u and v components are given in Appendix 3.

Sea surface temperature distribution between the 2 cruises was clearly different. During Cruise 34 (Figure 10), sea surface temperature was ranged from 29.12 to 30.06 ^{o}C while in Cruise 31 (Figure 11) the temperature range increased from to 24.49 to 30.65 ^{o}C. The actual data is given in Appendix 4. The horizontal temperature gradient was generally in north-south direction in July-August 1996 and in east-west direction in May 1996. Sea surface temperature, however, did not appear to have any relationship with neither divergence/convergence zone nor the vertical movement of pycnocline of the area.

The depth of surface mixed layer strongly reflected the divergence and convergence zone in the study areas in both cruises (Figures 12 and 13). Generally the surface mixed layer was deeper on the east side of the survey area during Cruise 34 and the opposite was found in Cruise 41. In most areas where geostrophic circulation suggested a divergence, surface mixed layer tended to be thinner, a good indication of upwelling. Downwelling was also inferred from surface mixed layer to coincide with convergence zones.

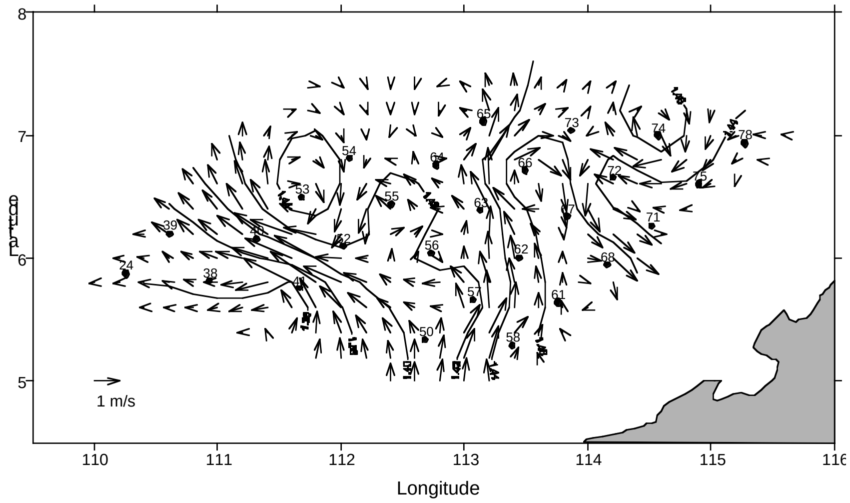

Fig. 2 Dynamic height (dyn.m) at sea surface (0 dbar) for Cruise 34 with current vectors relative to 500 dbar

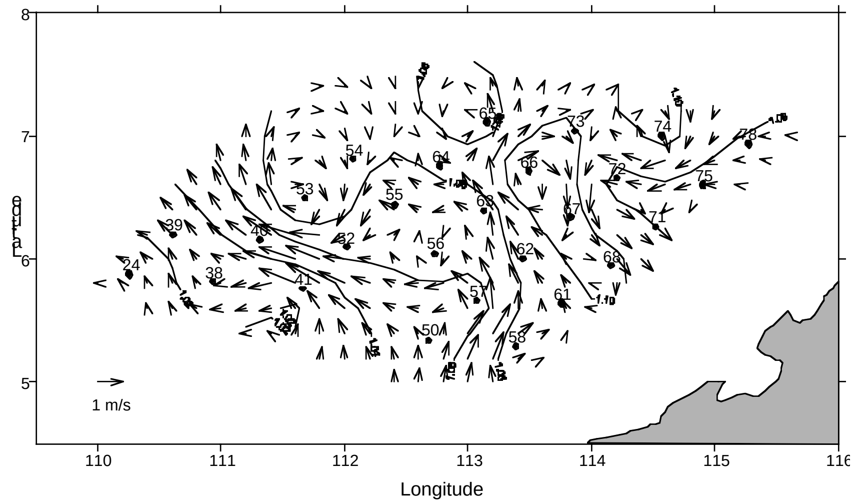

Fig. 3 Dynamic height (dyn.m) at 50 dbar for Cruise 34 with current vectors relative to 500 dbar

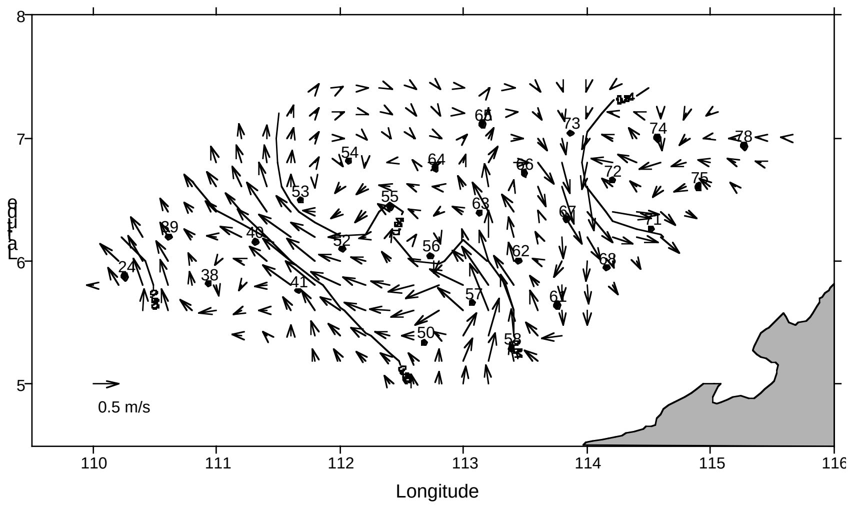

Fig. 4 Dynamic height (dyn.m) at 100 dbar for Cruise 34 with current vectors relative to 500 db

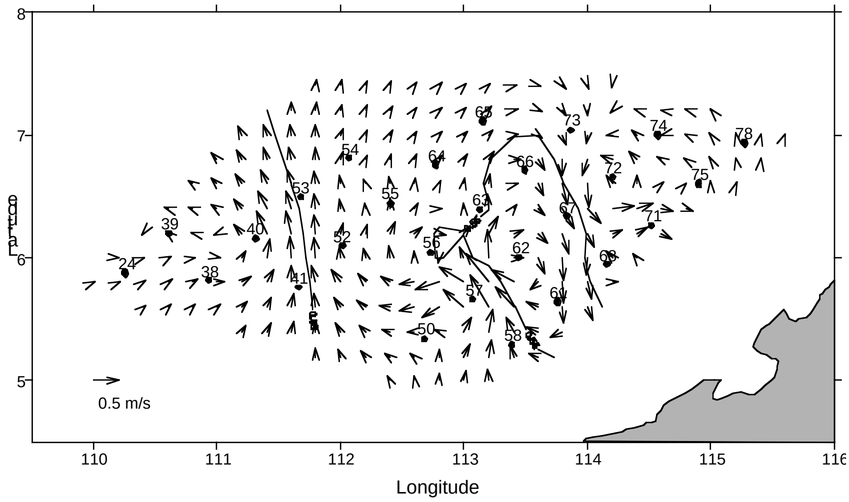

Fig. 5 Dynamic height (dyn.m) at 200 dbar for Cruise 34 with current vectors relative to 500 db

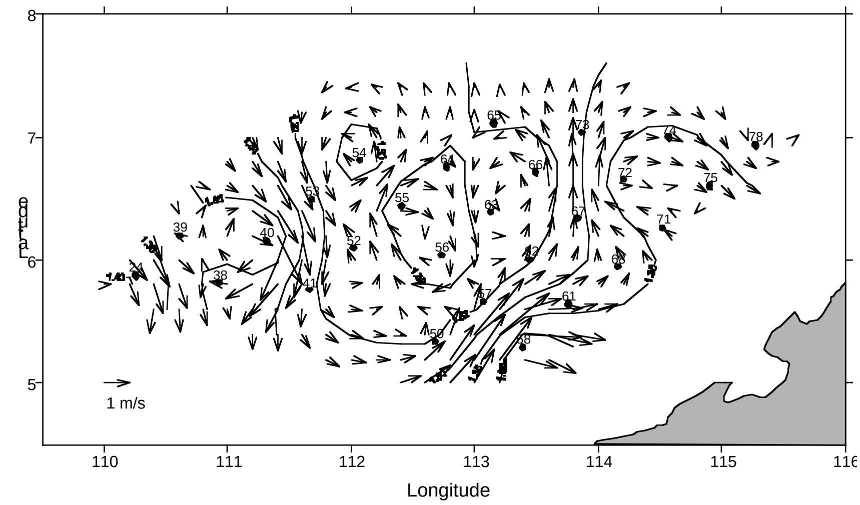

Fig. 6 Dynamic height (dyn.m) at sea surface (0 dbar) for Cruise 41 with current vectors relative to 500 db

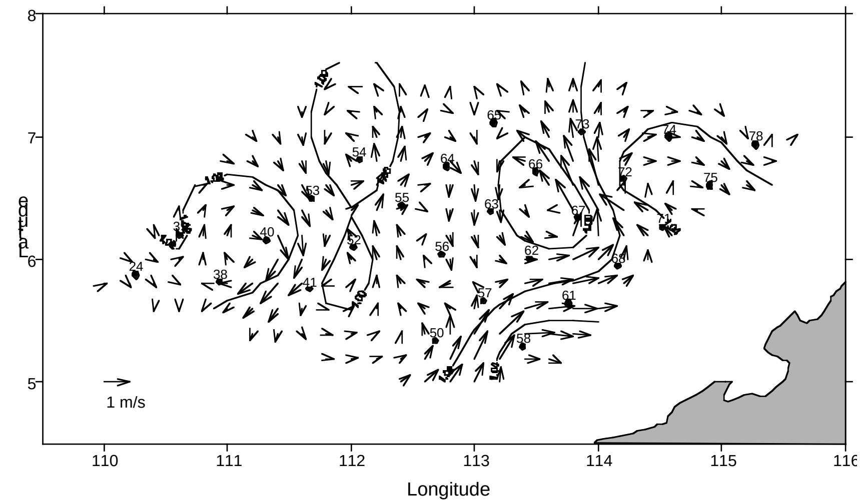

Fig. 7 Dynamic height (dyn.m) at 50 dbar for Cruise 41 with current vectors relative to 500 db

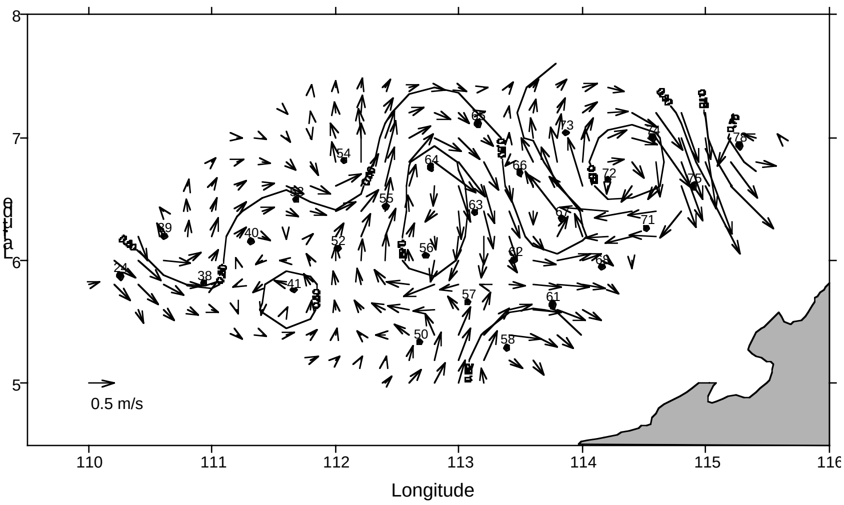

Fig. 8 Dynamic height (dyn.m) at 100 dbar for Cruise 41 with current vectors relative to 500 db

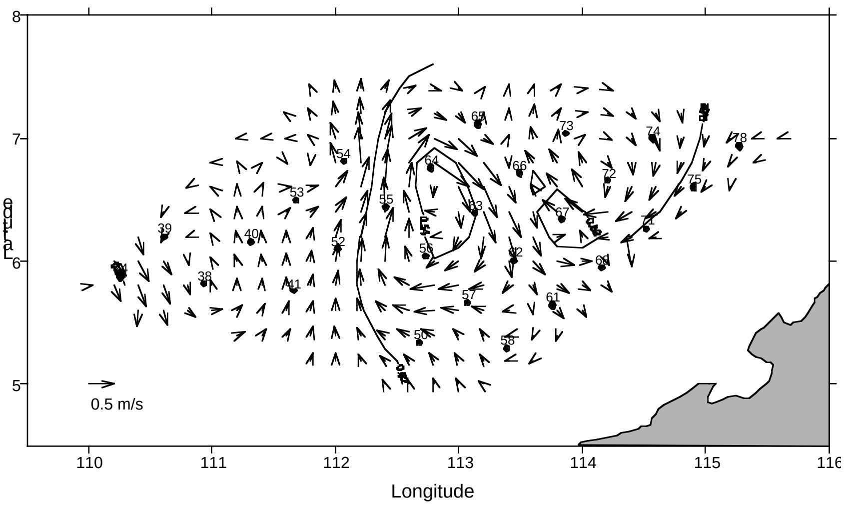

Fig. 9 Dynamic height (dyn.m) at 200 dbar for Cruise 41 with current vectors relative to 500 db

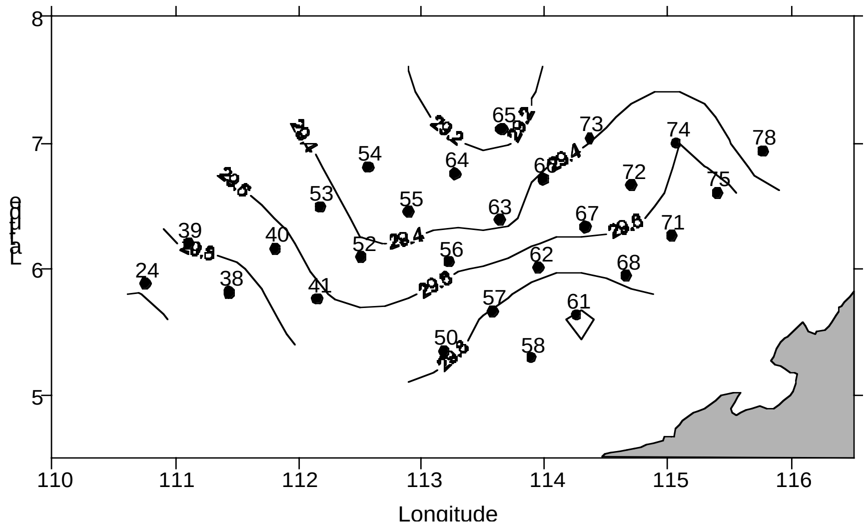

Fig. 10 Sea surface (5m) temperature for Cruise 34

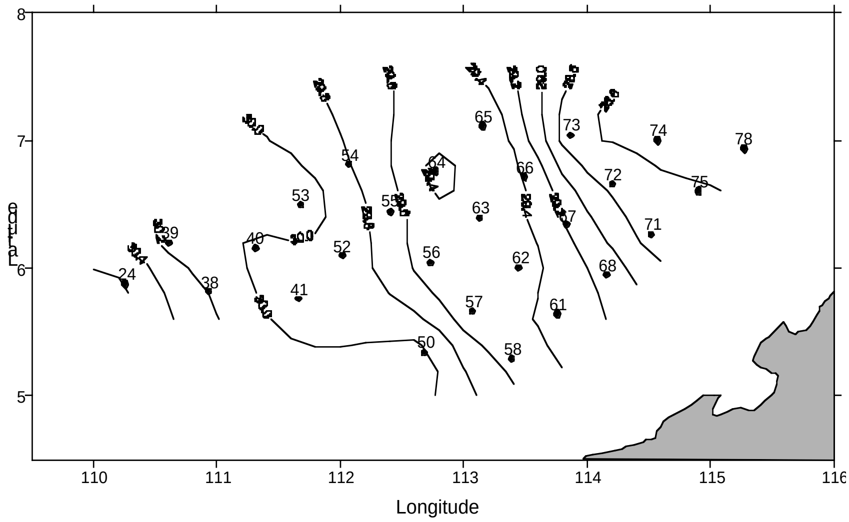

Fig. 11 Sea surface (5m) temperature for Cruise 41

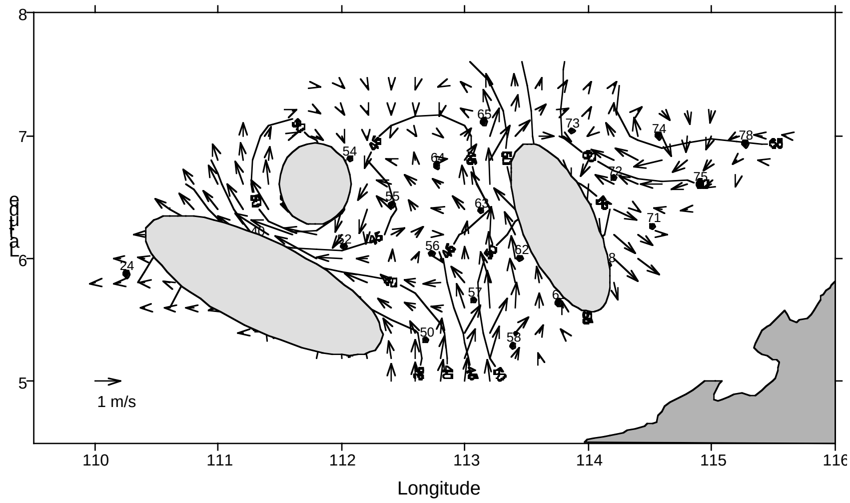

Fig. 12 The depth of stability maximum layer (m) for Cruise 34 with surface current vector relative to 500 dbar. Divergence and convergence zones are shown by vertical hatched and holizontal hatch, respecitive

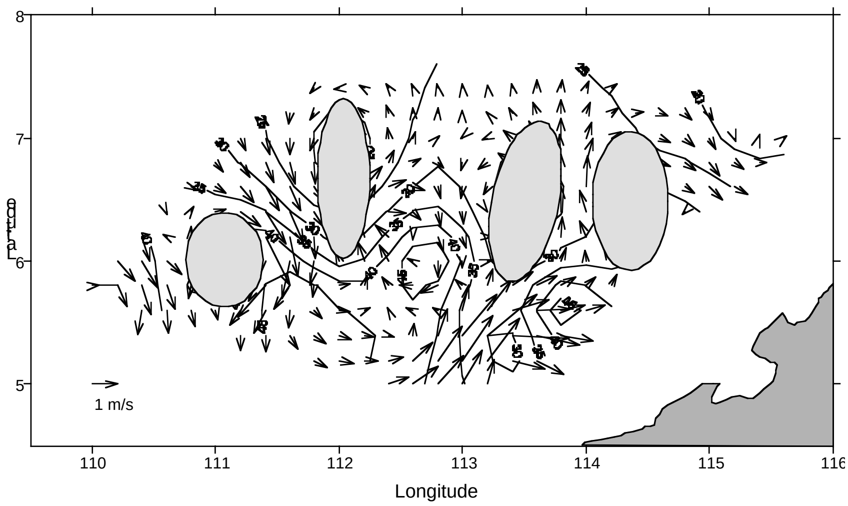

Fig. 13 The depth of stability maximum layer (m) for Cruise 41 with surface current vector relative to 500 dbar. Divergence and convergence zones are shown by vertical hatched and holizontal hatch, respecitive

Discussion and Conclusion

Geostrophic balance calculation appeared to give a reasonably acceptable qualitative result, which was supported by apparent upwelling and downwelling in the survey area. However the absolute magnitudes of several current vectors appeared to be too large to be the net current for this area, i.e. greater than 1 m/s. A possible explanation could be due to the assumption for the level of no motion of 500 dbar. However, with the limited data available not much could be done to correct this problem.

Because the prevailing wind during both cruises was not much different, the wind generally came from the southwest, which could explain the northeastward current in the central part of the survey area. However, eddies and meanders did have strong effect on the circulation pattern in this area. Interpretation of chemical and biological characteristics in this area should take into consideration these local and sporadic physical phenomena which caused apparent circulation pattern to vary from time to time.

APPENDIX 1

```
`
****************************************************
` PROGRAM TO CALCULATE U AND V FOR EACH GRID AND
` GENERATE SURFER BLN FILE FOR VECTOR FIELD
` GRID DATA FROM LON 109-116 STEP 0.2  LAT 4-8 STEP
0.2
`
****************************************************
CLS
DIM dynh(37, 21)
pi = 22 / 7
L = 22320          `m
head = .3          `rad
wing = .1           `wing length adjuster
arrow = .4         `arrow stem length adjuster

OPEN “out.dat” FOR INPUT AS #1
OPEN “x.bln” FOR OUTPUT AS #2
OPEN “pos.dat” FOR OUTPUT AS #3
PRINT #3, “LON,LAT,u (m/s),v (m/s)”
10 INPUT #1, lon, lat, z
x = INT((lon - 109) * 5 + .4): y = INT((lat - 4) * 5
.4)
dynh(x, y) = z / 100        `dyn.m
IF NOT EOF(1) THEN 10
FOR x = 0 TO 35
FOR y = 0 TO 20
IF dynh(x, y) > 5 THEN 20
IF dynh(x + 1, y) > 5 THEN 20
IF dynh(x, y + 1) > 5 THEN 20
lon = 109 + .2 * x: lat = 4 + .2 * y
f = 6.342E-08 * SIN(lat * pi / 180)
u = (dynh(x, y) - dynh(x, y + 1)) / f / L
v = (dynh(x + 1, y) - dynh(x, y)) / f / L
dir = pi / 2 - ATN(v / u)
GOSUB 1000
20 NEXT y
30 NEXT x
’40 PRINT “POSITION OF SCALE BAR”
`INPUT “Lat”; lat
`INPUT “Long”; lon
lat = 5
lon = 110
u = .5          `m/s
v = 0
dir = pi / 2 - ATN(v / u)
GOSUB 1000
CLOSE : END

1000 `
PRINT #3, lon; “,”; lat; “,”; u; “,”; v
PRINT “2,0”
PRINT #2, “2,0”
PRINT lon; “,”; lat
PRINT #2, lon; “,”; lat
PRINT lon + arrow * u; “,”; lat + arrow * v
PRINT #2, lon + arrow * u; “,”; lat + arrow * v

PRINT “2,0”
PRINT #2, “2,0”
PRINT lon + arrow * u; “,”; lat + arrow * v
PRINT #2, lon + arrow * u; “,”; lat + arrow * v
x2 = wing * SIN(dir + head): IF u < 0 THEN x2 = -x2
y2 = wing * COS(dir + head): IF u < 0 THEN y2 = -y2
PRINT lon + arrow * u - x2; “,”; lat + arrow * v - y
PRINT #2, lon + arrow * u - x2; “,”; lat + arrow * v
y2

PRINT “2,0”
PRINT #2, “2,0”
PRINT lon + arrow * u; “,”; lat + arrow * v
PRINT #2, lon + arrow * u; “,”; lat + arrow * v
x3 = wing * SIN(dir - head): IF u < 0 THEN x3 = -x3
y3 = wing * COS(dir - head): IF u < 0 THEN y3 = -y3
PRINT lon + arrow * u - x3; “,”; lat + arrow * v - y
PRINT #2, lon + arrow * u - x3; “,”; lat + arrow * v
y3

RETURN
```