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Deep-Sea Research II 52 (2005) 605–613

DEEP-SEA RESEARCH
PART II

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Energetic subthermocline currents observed east of Mindanao

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Received 12 April 2004; accepted 7 December 2004

Abstract

Two cruises of the JAMSTEC ship Kaiyo, during October 1999 and September 2000, included lowered acoustic Doppler current profiler (ADCP) measurements to 2000 m depth on zonal sections extending east from the Mindanao coast. On the second cruise, the lowered ADCP profiles were augmented by profiles to 1000 m from a 38-kHz shipboard ADCP. All zonal LADCP sections (7°N, 8°, 10°) showed southward flow along the coast extending to at least 2000 m depth. Although the Mindanao current in the upper 500 m forms a continuous narrow stream along the coast, the deeper southward flow appears to be part of a set of subthermocline eddies within 300 km of the coast; northward flow was found 100–200 km offshore during both cruises. Currents mapped by the shipboard ADCP on the second cruise indicate that cyclonic eddies were centered near 7.5°N, 128°E and 10.2°N, 127°E. Maximum speeds of 0.6 m s^{-1} were observed at 800 m depth on the 10°N section, and speeds of 0.2–0.3 m s^{-1} were found below 1500 m on all sections.

1. Introduction

The Mindanao Current (MC) is the western boundary current carrying waters from the North Equatorial Current (NEC) southward along the Philippines coast. Part of the MC turns east to feed the North Equatorial Countercurrent (NECC), and another branch enters the Celebes Sea. A fraction of this second branch is the primary source of the Indonesian Throughflow. See Fine et al. (1994) for a review.

Above 300 m, the structure of the MC has been described based on shipboard acoustic Doppler current profiler (ADCP) surveys. Zonal sections from a cruise in July 1988 (Lukas et al., 1991) show both the maximum speed and the vertical shear in the MC increasing downstream from 12°N to 7°N; the southward flow component at 300 m depth near the coast exceeded 0.6 m s^{-1} on 12°N, but dropped to about 0.1 m s^{-1} on 7°N. In the same sections, the MC core speed increased downstream, from about 0.8 m s^{-1} on 12°N to 1.3 m s^{-1} on 7°N. An ensemble of seven sections at

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0967-0645/$ - see front matter
doi:10.1016/j.dsr2.2004.12.007

8°N (Wijffels et al., 1995) shows a mean flow exceeding 0.9 m s^{-1} at the shelf break, but a standard deviation of only 0.1–0.15 m s^{-1} in most of the high-velocity region. The width of the mean current is 150 km at 300 m depth.

Information about currents below 300 m has come primarily from geostrophic calculations. Based on three annual sections along 7.5°N, Hu et al. (1991), suggested that multiple subsurface northward current cores, some extending as deep as 1000 m, are typically found offshore of the MC. They named this northward subthermocline flow the Mindanao Undercurrent (MUC). Evidence for the MUC was also found in a synoptic hydrographic survey by Lukas et al. (1991).

Individual synoptic sections yield velocity estimates that may be contaminated by ageostrophic fluctuations in dynamic height, such as internal tides, and that include transient as well as mean geostrophic currents (Lukas et al., 1991; Wijffels et al., 1995). To get a better estimate of the mean geostrophic velocity field, Wijffels et al. (1995) averaged eight sections on 8°N, and Qu et al. (1998) included two additional cruises near 8°N in their climatological analysis of a larger region. Relative to 2000 m (their Fig. 6b), Qu et al. (1998) derived southward flow near the coast extending to 1500 m depth, with magnitude exceeding 0.05 m s^{-1} above 800 m. About 100 km offshore they found a northward core exceeding 0.05 m s^{-1} from 700–1300 m, and identified it as the MUC. Qu et al. (1998) concluded that the MUC is most likely a permanent feature of the intermediate circulation.

In addition to geostrophy, water property distributions have been used to infer intermediate-depth flow. Reid and Mantyla (1978) pointed to the broad high-oxygen tongue near 1000 m along the western boundary of the North Pacific, together with the dynamic height field at 1000 dbar relative to 3500 dbar, as evidence for a mean northward western boundary current. High oxygen and low salinity near the 27.2 kg m^{-3} potential density anomaly (σ_θ) mark the influence of Antarctic Intermediate Water (AAIW). Using a recent climatology, Qu et al. (1999) detected AAIW along the Philippine coast to about 12°N.

With additional evidence from maps of acceleration potential on 27.2 σ_θ relative to 1200 dbar, they concluded that the northward flow in the MUC returns offshore; the MUC is part of a local recirculation, rather than a meridionally extensive western boundary current.

Wijffels et al. (1995) concluded that the velocity variance near the Mindanao coast in the 400–2000 m depth range is large relative to the mean flow, casting doubt on any estimate of the mean based on a small number of sections. In this note we present current measurements made during surveys in 1999 and 2000 that confirm their conclusion, and that provide snapshots of the horizontal and vertical structure of the velocity field.

2. Data and methods

As part of the Tropical Ocean Climate Study (TOCS), the R.V. *Kaiyo* surveyed the Pacific low-latitude western boundary region from October 20 to November 6, 1999 (cruise KY9909 leg 1) and from September 13 to October 1, 2000 (KY0006 leg 3). SADCP velocity measurements were made through out each cruise, and lowered ADCP (LADCP) measurements were made on CTD stations, most of which extended to 2000 m (Fig. 1).

Different SADCP systems were used on the two cruises. On KY9909, a Narrow-band model VM-75 ADCP made by RD Instruments (RDI) provided velocity estimates in 16-m intervals starting at 30 m and typically extending to about 550 m. Prior to KY0006, an RDI Ocean Surveyor model OS-38 ADCP was installed. Operating at 38 kHz, this instrument profiled from 37 m to about 1000 m, also in 16-m intervals; in some locations the range extended to 1200 m.

On both cruises, a differential GPS receiver provided position fixes. Heading information came solely from the ship's gyrocompass, which was therefore the largest source of error in the absolute depth-averaged velocity estimates (King et al., 2001); these errors are negligible when the ship was on station, and are probably 0.04 m s^{-1} or less most of the time when underway, assuming 0.4° or smaller heading error remaining after calibration. If we take this as a worst case, then the error in