Naval Postgraduate School

OC 3570 – Operational Oceanography and Meteorology
Cruise Leg II 5–9 August 2001

COMPARISON OF CALCULATED GEOSTROPHIC CURRENTS FROM CTD DATA AND ACQUIRED ADCP DATA IN LEG II

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1 - Introduction

The advent of Acoustic Doppler Current Profilers (ADCPs) represents a progress in the measurement of ocean currents and a great advance in our capability to understand dynamic processes occurring in the ocean. The ADCP velocities can be used to study ageostrophic transport in the surface layer, to characterise the internal wave field, as reference velocities for geostrophic profiles, in transport studies, and mixing studies.

The vessel-mounted ADCP measures profiles in the upper ocean from a ship underway. The hull-mounted ADCP is part of the ship's equipment aboard the R/V Point Sur from Moss Landing Marine Laboratories. The instrument is a 150 kHz unit manufactured by RD Instruments (RDI).

Since then the way that it was possible to compute a component of the ocean current was applying the geostrophic method from measured temperature, conductivity and pressure at hydrographic stations. These data were obtained from Sea-Bird SBE 911Plus Conductivity-Temperature-Depth (CTD) profiler sensors.

The California Current System (CCS) is composed basically by three currents that flow along the west coast of North America. The most widely known of them is the California Current (CC). This current flows at the surface (0-300 m), equatorward between the shelf break and a distance of 1000 km from the coast with average speeds around 25 cm/s (Reid and Schwartzlose, 1962). Below the CC flows the narrow California Undercurrent (CUC) poleward along the continental slope from Baja California to at least Vancouver Island. It has a high velocity core between 100 and 300 m depth and average speeds of 2-10 cm/s. Studies describe that the location, strength and core depth of this current develop great variability related to wind stress and wind stress curl (Hickey, 1979). The Davidson Current (DC) is the third current of the CCS and flows poleward at the surface during fall and winter north of Point Conception. May be the "surfacing" of the California Undercurrent during late fall. The poleward flow over the continental shelf is defined sometimes to be part of the Davidson Current (Hickey, 1979). Studies suggest the presence of the very narrow Inshore Countercurrent flowing poleward comprised over the continental shelf and slope since in July the Southern California Eddy has formed. It extends 100 km offshore with a maximum speed of 4 cm/s (Lynn and Simpson, 1987). Strong coastal upwelling during summer is associated to the surface equatorward flow that prevails as the northwesterlies happen. An inshore poleward flow is seen along central California coast, strenghening in periods of weaker winds (Tomczak and Godfrey, 1984).

The California Cooperative Fisheries Investigation have been examining the seasonal variability of the physical characteristics and of large-scale features of the California Current System since 1949 (Lynn et al., 1987). Historical CalCOFI data provide a well-sampled statistical basis for determining a covariance function, which together with the geostrophic constraint provide a consistent framework in which to combine geostrophic and ADCP velocities into a best estimate of the absolute flow field (Chereskin and Trunnell, 1996).

2 - Objectives

The goal of this report is to develop a comparison between measured ADCP and geostrophic currents calculated from parameters obtained from CTD casts and associate them with expected features to be find in the surveyed area. The dynamic height anomalies from different levels will be compared with ADCP layer plots. Aditionally, the dynamic height anomaly calculated for the surface will be compared with satellite imagery, specifically TOPEX/ERS-2 sea surface height anomaly.

3 - Data Sampling

The OC 3570 cruise was completed aboard the R/V Point Sur from 2 to 9 August 2001. In Leg I, the ship surveyed along California Cooperative Fisheries Investigation (CalCOFI) " Cencal Box" that comprises Lines 67 to Station 67-70, then alongshore to Station 77-70 and finally inshore along CalCOFI Line 77. Leg II investigated on coastal stations distributed along transects perpendicular to the isobaths.

The CTD and ADCP data were collected along the lines explained before. In Leg I the ship established at 35 hydrographic stations (n009 – n043) and in Leg II at 48 hydrographic stations (n044 – n091). The CTD stations for both Legs are displayed on Figures 1 and 2.

CTD casts were made at least a depth of 1000 m when depth restriction allowed. Conductivity, temperature and pressure were acquired at a rate of 24 Hz averaging these to 1 Hz. After each station the cast was processed to have a sample each 2 mb, so the ASCII file ended with latitude, longitude, pressure, primary temperature, secondary temperature, chlorophyll a concentration, transmissivity, dissolved oxygen and primary salinity.

The ADCP have transmitter and receiver in one unit and use reflections of the sound wave from drifting particles for the measurement of the Doppler frequency shift. With at least 3 beams inclined to the vertical the 3 components of flow velocity can be determined. Data were acquired using RDI's data acquisition system DAS, which is configured to average the variables (east, north, vertical and error velocities, automatic gain control, percent good, ship's heading and attitude) over 300 seconds intervals along the cruise track. The shallowest measurement depth is about 15 m and the maximum depth of good data return is about 400 m. The actual sound speed was calculated from measured temperature at the transducer and a constant salinity. The north (u) and east (v) components were rotated so the "v" component was perpendicular to the track, except for the alongshore section of "Cencal Box" and line X where the "u" rotated was perpendicular to the track. ASCII file related to each line had sampled every 20 mb.

4 - Geostrophy Method

The geostrophic method is a procedure to calculate an important component of the ocean current from the oceanographic parameters: pressure, temperature and salinity. The density field also determined from these parameters represents the distribution of mass and can be a good representation of the pressure gradient force. The geostrophic current is originated from the balance between the pressure gradient force and the Coriolis force and is perpendicular to these forces. It is assumed to be in hydrostatic balance.

$$\frac{1}{\rho}\frac{\partial p}{\partial x} = fv, \qquad \frac{1}{\rho}\frac{\partial p}{\partial y} = -fu \qquad\qquad \alpha\frac{\partial p}{\partial x} = \frac{1}{\rho}\frac{\partial p}{\partial x} = -2\Omega v \sin\varphi$$

The change of geopotential is $d\Phi = gdz = -\alpha dp$.

Since $\alpha = \alpha_{35,0,p} + \delta$, the expression for the geopotential anomaly is:

$\Delta\Phi_A = \Phi_2 - \Phi_1 = -\int \alpha_{35,0,p}\, dp - \int \delta\, dp$

$\Delta\Phi = \Delta\Phi_A - \Delta\Phi_B$

The dynamic height anomaly or geopotential distance or simply dynamic height is:

$\Delta D = \Delta\Phi/10$

So the geostrophic current between two stations for a specific depth considering the depth of no motion at 1000 mb is:

$$V = \frac{D_A - D_B}{2\,\Omega \sin\varphi\, L}$$

where:

ρ – density of water

f – Coriolis parameter

$\Omega = 7.292 \times 10^{-5}$ rad/s

φ – latitude

δ – specific volume anomaly

L – distance between stations

MATLAB processes the data (temperature, salinity and pressure) and calculate the density, the specific volume anomaly, the geopotential anomaly relative to the surface and the geostrophic velocity relative to the surface, by applying the programs sw_dens, sw_gvan, sw_gpan and sw_gvel, respectively. From this procedure the geostrophic velocity is directed perpendicular to the cruise track.

To really start calculating horizontal and/or vertical sections of temperature, salinity, sigma-t, geostrophic velocity and dynamic height anomaly was decided to redefine ASCII data files with only the parameters necessary for each station and for each line. Stations from lines 67 and 77 where applyed in order to help in a better comparison (n010-n13 and n036-n043). The computation of the geostrophic current at waters shallower than the level of no motion was developed by extending the last information of salinity and temperature horizontally. The codes used for this project consist of Appendix 1.

5 - Results

5.1 - Comparison of Dynamic Height Anomaly at the Surface integrated from two different levels of no motion

Figure 3 and 4 illustrate how close the dynamic height anomalies at the surface integrated from 500 mb and 1000 mb are well correlated. Both plots show the presence of strong high centered on 35.6˚N and 121.3˚W and a strong low centered on 36.3˚N and 122˚W. There is a relatively high next to this strong low on both figures. What ever 500 mb or 1000 mb is selected as a level of no motion is expected to define geostrophic currents and features in the same way.

5.2 - Comparison of Sea Surface Height from TOPEX/ERS-2 Altimetry and Dynamic Height Anomaly at the Surface

The sea surface height generated from TOPEX and ERS-2 altimeter satellites for 5 and 8 August 2001 are displayed on Figures 5 and 6, respectively. On these images there is a high sea surface height centered at 34.9˚N and 121.4˚W that probably reaches the coast close to it. They indicate the presence of low sea surface heights along Big Sur and to the west of the plots. There is a good correlation between the sea surface height plots and the surface dynamic height anomaly figures.

5.3 - Comparison of Sea Surface Height from Model GLOBAL NLOM Navy Research Laboratory and Dynamic Height Anomaly at the Surface

Even though GLOBAL NLOM model for 7 August 2001 (Figure 7) does not have good precision on the area surveyed it is possible to observe on the zoomed rectangle highs and lows sea surface height features. Again there is a good correlation with the surface dynamic height anomaly plots.

5.4 - Comparison of Dynamic Height Anomaly at several levels and ADCP vector level plots

The dynamic height anomaly was calculated for 20 mb, 100 mb, 200 mb and 300 mb all of them integrated from 1000 mb (Figures 9, 10, 11 and 12). Except for 20 mb-level dynamic height anomaly, all other levels had clearly a very good correlation with the ADCP velocities (Figures 13 and 14). The velocity vectors indicate anticyclonic gyre around highs and cyclonic motion around lows. The flow in all levels is poleward, except for the one at 20 mb. The velocities at 20 mb are very variable certainly affected by the friction due to surface wind stress. Recall that this level is still in the Ekman layer.

5.5 - Comparison of MCSST OI Sea Surface Temperature from MODAS Navy Research Laboratory and CTD Sea Surface Temperature

The Multichannel Sea Surface Temperature (MCSST) Optimum Interpolation image for 6 August 2001 on Figure 8 does not have much detail on the area surveyed.

Zooming a rectangle right over this region show clearly a colder water along the coast. The surface temperature section colected from CTD (Figure 15) show clearly low temperature along the coast, approximately, 10˚C. This temperature does not match the temperature displayed on the zoomed MCSST image, but again some features are similar. The temperature difference is because MCSST is determined for the skin temperature while the CTD data start at 2 mb. The upwelling is noticeable along the coast after analysing temperature and salinity horizontal plots for the surface (actually, 2 mb), 20 mb and 50 mb (9.5˚C and 33.85 psu).

5.6 - Comparison of Temperature and Salinity Horizontal Sections (Figures 15 to 32) and ADCP vector level plots (Figures 13 and 14)

Since the dynamic height anomalies and geostrophic velocities depend on temperature and salinity, it is expected to in some cases correlate the horizontal sections for these parameters with the ADCP vector plots at specific level. High temperature and low salinity can indicate anticyclonic motion. Until 50 mb there is practicaly no correlation between horizontal sections and the ADCP plots. From 100 mb down to 350 mb, the temperature sections show some correlation with ADCP velocities, but the salinities sections still does not indicate much connection.

5.7 - Comparison of ADCP Cross-Section Velocity and Geostrophic Velocity Profiles (Figures 33 and 39)

On both types of plot, positive velocities are in the direction going into the plot for x axis represented as longitude (poleward) and going out the plot for x axis represented as latitude (equatorward). The lines Q, X, Y registered good correlation between the ADCP Cross-Section Velocity and Geostrophic Velocity Profiles. Line Q has high correlation between 150 m and 350 m. There is an equatorward inshore flow and a poleward offshore current that can represent the California Undercurrent “surfacing”. The high sea surface height at 34.9˚N and 121.4˚W may be responsable for this structure. On line Y is displayed a poleward inshore current that extends the whole layer. The lines CUC and R had regular correlation. On line R there is a poleward inshore flow and an equatorward offshore current. Line CUC shows a small correlation along the slope where flows a poleward current. The lines D and Z had a bad correlation. Line D registered an equatorward flow along the slope with the core at 200 mb. Line Z indicates that there had been some data not processed due to loose of navigation data, but there is an indication of poleward inshore flow.

6 - Conclusions

The TOPEX/ERS-2, the ADCP velocities and the dynamic height anomaly computed from the CTD data have a very good correlation. The comparison between the calculated geostrophic currents and the ADCP velocities was a little hard. Three lines presented better agreement the rest of them, but most of them described an inshore poleward flow. This current seems to have a trajectory onshore in the direction of Point Sur and then curve cyclonically to contour a high sea surface height (or dynamic height anomaly). The horizontal sections of dynamic height anomaly were really useful in matching the motion of this current. Unfortunately, the surface velocities weren't able to have a fine concordance by known reasons since they feel the surface wind stress. It was noted that down to 50 mb had poor correlation.

The occurrence of upwelling is noticed by the presence of low temperature and high salinity at upper levels. August is still a month in which many phenomena develop. May be the Southern California Eddy is related to the high sea surface height in the surveyed region. Therefore, changes in the direction of the California Current or even the "surfacing" of the California Undercurrent are possible during summer.

The proximity to the coast also can prejudice the comparison since there are many boundaries involved. The variation of wind stress and the existence of internal waves can difficult this study.

6 - References

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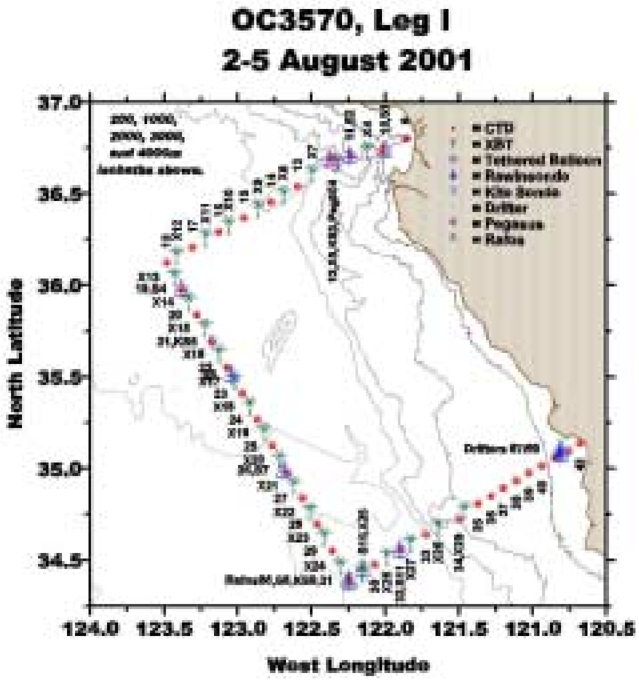

OC3570, Leg I
2-5 August 2001
North Latitude
West Longitude
= CTD
= XBT
= Tethered Balloon
= Rawinsonde
= Kite Sonde
= Drifter
= Pegasus
= Rafos

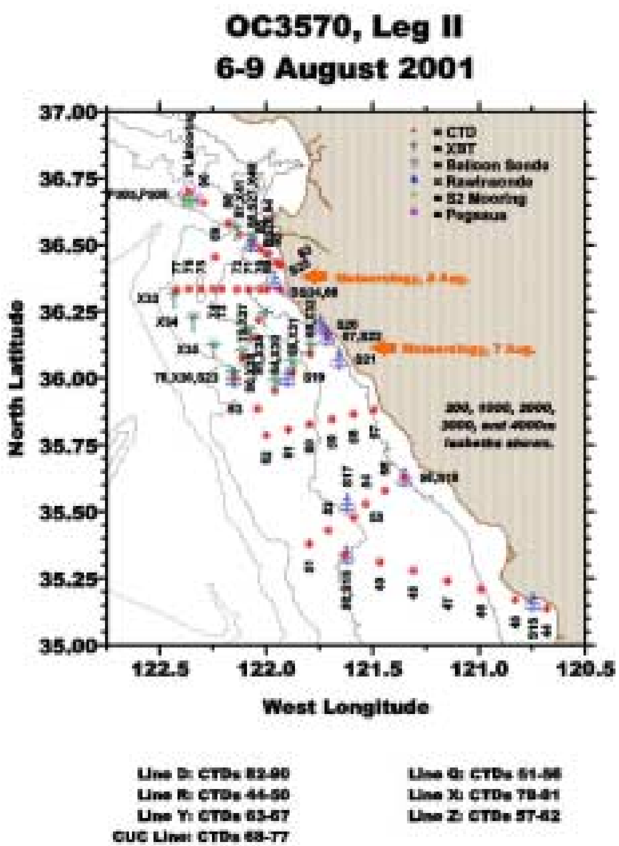
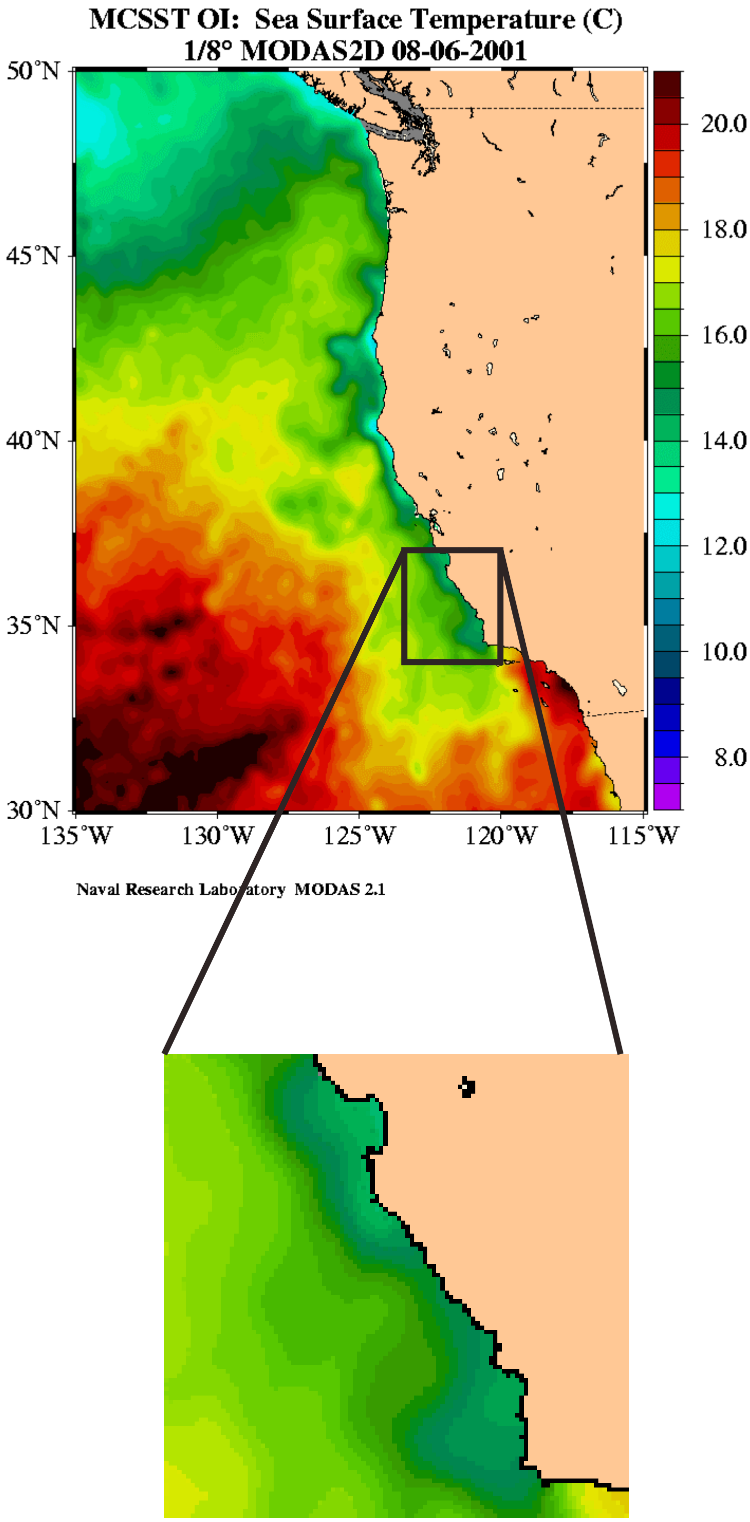

OC3570, Leg II
6-9 August 2001
North Latitude
West Longitude
= CTD
= XBT
= Balloon Sonde
= Rawinsonde
= S2 Mooring
= Pegasus
Line D: CTDs 82-90
Line R: CTDs 44-50
Line Y: CTDs 63-67
CUC Line: CTDs 68-77
Line G: CTDs 51-56
Line X: CTDs 78-81
Line Z: CTDs 57-62

Figure 2

Figure 8


MCSST OI: Sea Surface Temperature (C)
1/8° MODAS2D 08-06-2001
50°N
45°N
40°N
35°N
30°N
135°W
130°W
125°W
120°W
115°W
20.0
18.0
16.0
14.0
12.0
10.0
8.0
Naval Research Laboratory MODAS 2.1

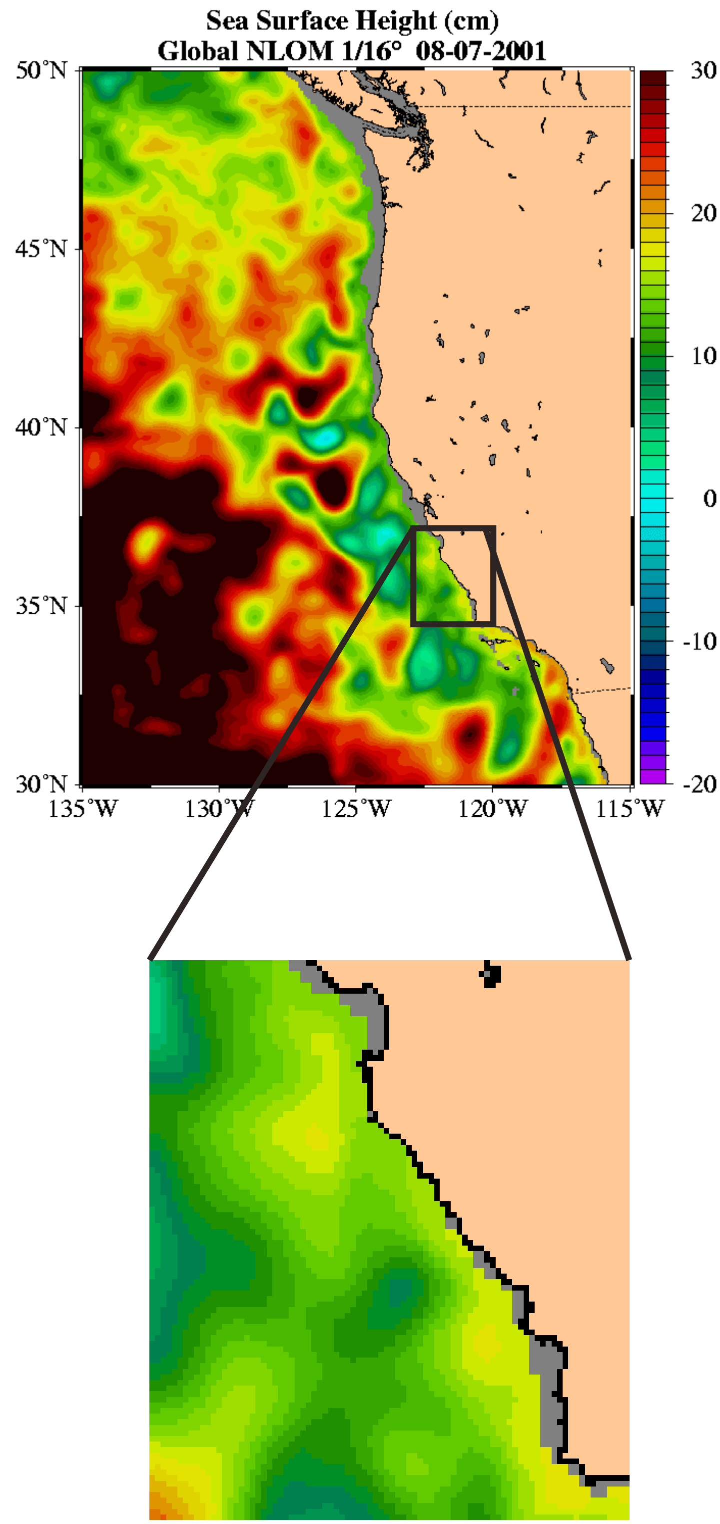

Sea Surface Height (cm)
Global NLOM 1/16° 08-07-2001
50°N
45°N
40°N
35°N
30°N
135°W
130°W
125°W
120°W
115°W
30
20
10
0
-10
-20

Figure 7