Abstract

The goal of the project is to calculate the ocean surface currents off the California coast using Advanced Very High Resolution Radiometer (AVHRR) images of sea surface temperature (SST), combined with altimeter data for the period of September 1993 to whenever the project is complete (estimated around 2004). Knowledge of these currents is necessary to develop a quantitative understanding of the kinetic energy budget of the coastal region and to give a more accurate forecast of the region. Ocean currents are of great interest to shipping and oil industries. A Maximum Cross Correlation (MCC) technique is used to identify motion of the thermal patterns which act as tracers of the current. Altimeter data is combined with the MCC velocities using Optimal Interpolation to produce a gridded stream function. This project necessitates the processing of large amounts of data, for this reason several procedures have been developed which do not require human intervention. The most critical steps to produce viable results are automatic georegistration and navigation, and cloud filtering. The outcomes are still in the preliminary stages; mean velocities, eddy kinetic energies, variances and covariances of velocity vectors, time and space scales, and errors will be determined as the processing goes further.
Introduction

Off the west coast of North America, extending from the Baja Peninsula northward to the Strait of Juan de Fuca, lies a classic eastern boundary current deemed the California Current System (CCS) (Hickey, 1998). Early satellite images of sea surface temperature (SST) illustrated a complex flow structure with large seasonal variations (Strub et al., 1990). The CCS is comprised of several large-scale (> 500 km) along shore currents; these include the California Current (CC), the California Undercurrent (CUC), and the Davidson Current (DC). The CC is the mean dominant flow, this is a broad (~1000 km offshore), shallow (surface to 500 m), relatively slow (~10 cm/s), year-round southward current (Batteen et al. 2001). Within this mean, large-scale structure, there exist perturbations in the form of mesoscale meanders, eddies, and filaments, which have both temporal and spatial variations.

To observe the surface mesoscale structure of the CC, thermal images from the Advanced Very High Resolution Radiometer (AVHRR) instrument flying aboard the National Oceanic and Atmospheric Administration (NOAA) polar orbiting satellites will be utilized. Surface currents are found using the Maximum Cross Correlation technique on sequential AVHRR images. The so-called MCC method objectively defines the displacement of thermal features that occurred between image times, hence the velocity. Studies have shown that the MCC method agrees with in situ observations (Kelly and Strub, 1992). Several critical steps go into producing quality vectors from the images, these include: cloud filtering, navigation, georegistration, and vector filtering, with clouds having sole control of how many vectors this method can produce.

Satellite altimetry has also proven effective in observing the mesoscale structure of surface ocean currents, and has the advantage of being unaffected by clouds. An altimeter measures sea level height along the satellite groundtrack. This can be used to find the velocity component normal to the groundtrack through geostrophy. Due to the lack of certainty in the estimate of the geoid in boundary current regions, long-term means have been removed and this analysis has been limited to sea surface anomalies. It was decided that Optimal Interpolation (OI) was the best method for combining these data sets.
The goal of this project is to calculate surface ocean currents from over 10 years of AVHRR images (from Oct. 93’), and combine those vectors with TOPEX, ERS-1 and ERS-2 altimeter data using OI, characterizing the variability of the region.

**MCC Method**

The MCC method compares features in the first image with the features in the second image using a cross correlation method (Fig. 1). The solid box in the first image has been labeled the ‘template window’; this is the pattern to search for in the second image. The larger dashed box in the second image is called the ‘search window’; this box must be large enough to calculate the maximum velocity possible. The template window must be large enough so that the computed cross correlation will have enough values to give statistical confidence through adequate degrees of freedom (Emery et al., 2003). The values in the template window are fixed in the first image, correlations are then computed as the template window is moved in the second image different positions within the search window. The position with the greatest cross correlation indicates the most likely displacement of the first image feature.
Cloud Filtering

Clouds moving between the two images can contaminate the resulting vectors. The MCC process uses a few different techniques to eliminate the effects of clouds. The first two make use of the fact that clouds are usually brighter and cooler than the ocean surface. An albedo threshold is applied which flags pixels that are brighter than a pre-determined value. This is followed by the second method which identifies pixels which are cooler than a pre-determined representative temperature. Clouds are transitory by nature and their signature in a time series for a given pixel is very characteristic. Thus, the final step is to calculate the mean and the standard deviation for every pixel over the course of ten days. A pixel is considered cloudy if its temperature for a given image is lower than some value, which depends on the maximum of the time series temperature adjusted empirically for temporal variations given by the standard deviation.

Figure 2: Example of the cloud filtering on a Channel 4 AVHRR image.
Georegistration and Navigation

Image Navigation has been defined as a combination of the geometric image corrections (Earth curvature and rotation) that can be calculated from orbital information together with the need for georegistration to an accurate map reference (Emery et al. 2003). MCC method is applied “in reverse” to an image that requires navigation and a base image (navigated by hand). Day/Night and seasonal base images are used to counteract thermal changes so that the differences can be interpreted as offsets in georegistration. Displacement vectors over land are translated into satellite attitude corrections (roll, pitch (time), and yaw) and are added to the orbital image navigation corrections. Attitude corrections computed over land can be carried forward in the satellite’s orbit to accurately navigate imagery over the open ocean where no map reference points are available.

Figure 3: Unnavigated and navigated AVHRR images
Ocean Surface Currents

Once the images have been cloud filtered, navigated, and georegistered, it is now possible to use the MCC method to generate ocean currents on sequential channel 4 images that are 3 to 13 hours apart. Currently a 22 by 22 pixel template window is being utilized, implemented every 11 pixels. Velocities are found by dividing the displacement found by the time between images. Due the automated aspect of the MCC method, it is necessary to filter the vectors strenuously. Two filters are used; the first is a variable correlation cutoff, with the time between images deciding how high to set the cutoff. The second is called a next-neighbor filter. This filter works by looking at the eight vectors around the vector in question, and finds the magnitude of each. If so many vectors are within a certain magnitude, the vector is kept.

Figure 3: Channel 4 image with MCC vectors, from sequential images, overlayed.
**Satellite Altimetry**

The altimeter data used is from the Topex/Poseidon and ERS-2 Geophysical Data Records by applying standard environmental corrections (wet and dry troposphere correction, ionosphere correction, sea-state bias, solid Earth tides and pole tides, the CRS ocean tide correction, and the inverse barometer effect). To remove any signal from an imprecisely known geoid, the long-term mean is removed (using the Goddard mean). To reduce instrument noise, the sea level anomaly data is filtered using an 10-point boxcar filter, then decimated by a factor of 10 to return largely independent observations.

![Groundtracks for 10 days of Jason and Topex.](image)

**Optimal Interpolation**

Also called Objective Analysis, first introduced to oceanography by Bretherton in 1976. OI makes an estimate of a variable from a weighted linear combination of observations made at irregular locations. Weights are chosen so that the estimate has the minimum expected ensemble mean square error. Mapping to a streamfunction is justified because mesoscale circulation is strongly geostrophic and hence weakly divergent. Mapping to a non-divergent streamfunction serves to largely filter out ageostrophic components of flow in the direct observations of velocity. Since we combine MCC velocities with altimetry, from which only geostrophic components of velocity can be derived, mapping to a non-divergent streamfunction is advantageous.
Figure 5: MCC vectors Optimally interpolated to a streamfunction.

Conclusions and Future Work

Even though clouds plague thermal images, it has been shown that in certain regions the volume of MCC data can rival that of a satellite altimeter (Bowen et al. 2001). MCC intermittently achieves higher resolution than altimetry, and the tendency for there to be more observations near the coast where the thermal gradients are pronounced complements altimeter sampling by offering vector observations important for capturing the kinematics of flow in a boundary current.

While altimetry reveals geostrophic flow only, MCC data are interpreted as a total velocity that may include ageostrophic processes that advect thermal patterns, so it has been thought that a difference between the flows could reveal hard to find processes (Eckman flows, etc.). Also in the future, MCC will be applied to MODIS color images, eventually being merged with the SST and altimetry products. Furthermore, more comprehensive comparisons with drifter data must be accomplished to verify the results.
References


