Mapping Mesoscale Surface Currents by Optimal Interpolation of Satellite Radiometer and Altimeter Data

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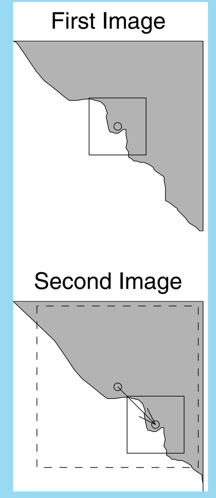
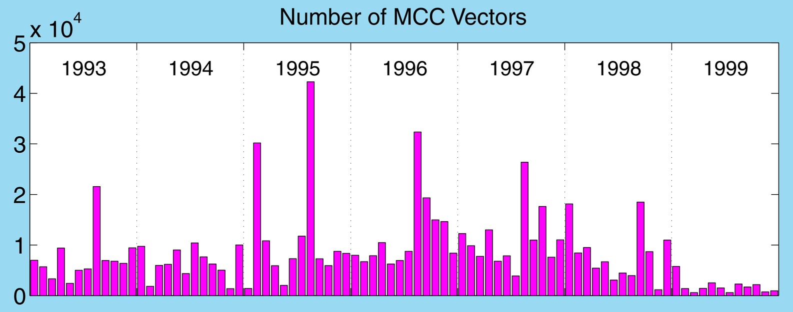
Abstract

A technique for estimating mesoscale surface currents by combining velocities extracted from sequential thermal imagery and altimeter sea surface heights is described and applied to data from the East Australian Current region. Surface velocities were estimated from a six year archive of thermal imagery by tracking features in sequential images using the Maximum Cross Correlation (MCC) technique. The velocities reproduce features found in other data sets in the region. The number of MCC velocities is comparable to the number of observations from one altimeter, but with more variable spatial and temporal distribution. The MCC velocities are combined with the altimeter sea surface heights using an optimal interpolation technique. The covariances of velocity and sea level are consistent with the statistical assumptions of homogeneous, isotropic turbulence used in the interpolation. Augmenting altimeter measurements with MCC velocities improves the resolution of surface currents, especially near the Australian coast, and demonstrates that the two data sources provide consistent and complimentary observations of the surface mesoscale circulation.

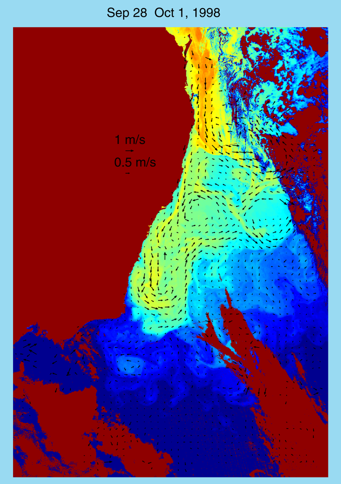
I. Velocities from thermal imagery

Velocities are estimated from satellite radiometer data by tracking thermal features in successive images using the Maximum Cross Correlation (MCC) technique (Emery et al. 1986; Kelly and Strub 1992). The cross correlations are computed between a subwindow in the first image (solid box) and a range of subwindows within a search area (dashed box) in the second image. The location of the subwindow that produces the maximum cross correlation indicates the most likely displacement of the features (vector). The velocity is the displacement divided by the time between the images.





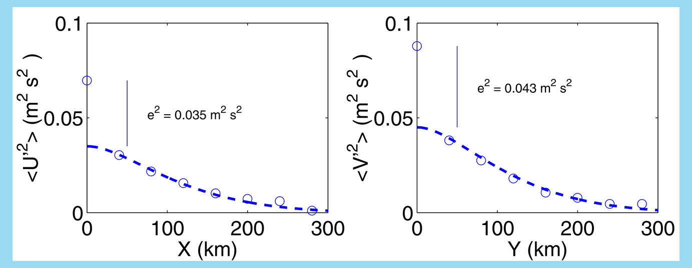
Between 1993 and 1998, about 8000 velocities per month were derived from the thermal imagery with some seasonal and interannual variability. During 1999 heavier cloud cover during La Nina substantially reduced the number of vectors.



During periods of relatively little cloud much of the velocity structure in the current can be captured. Velocities have been averaged into a three day composite and plotted over one thermal image during the image.

Mean flows derived from six years of MCC velocities show the same features as the mean flow derived from a regional dynamic height climatology, with closest correspondence in the northern part of the region where sampling is greater and flows less variable.

Variance ellipses derived from MCC velocities, sea surface heights at altimeter cross over points, and drifting buoy fixes all show the most energetic region of the flow between 31S and 35S, although energy magnitudes and ellipse orientations do differ (Bowen et al., 2002).

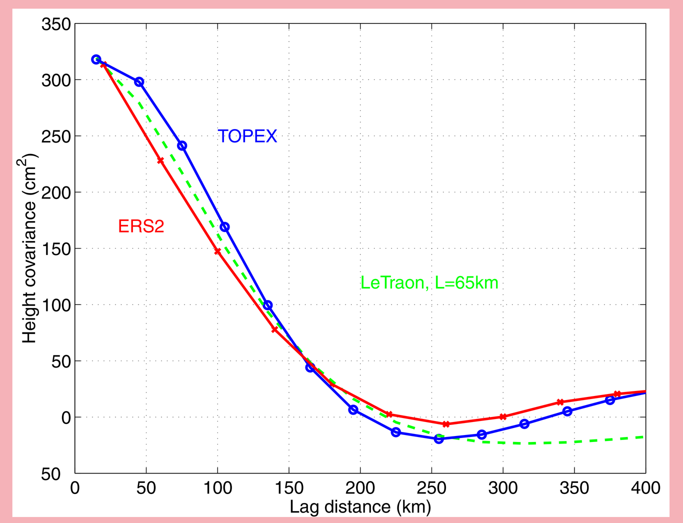


An estimate of noise in the method was found by fitting a covariance function to the autocorrelation of the velocities. Random noise in the velocities should average out at all lags except at zero lag, where the value is the sum of the signal and noise variances. The difference between the functional fit of the covariance function at zero lag and the measured value is an estimate of the noise. For the three day composites, the noise is estimated at about 0.2 m/s. This value is reduced if more restrictions are placed on the velocities that go into the composite.

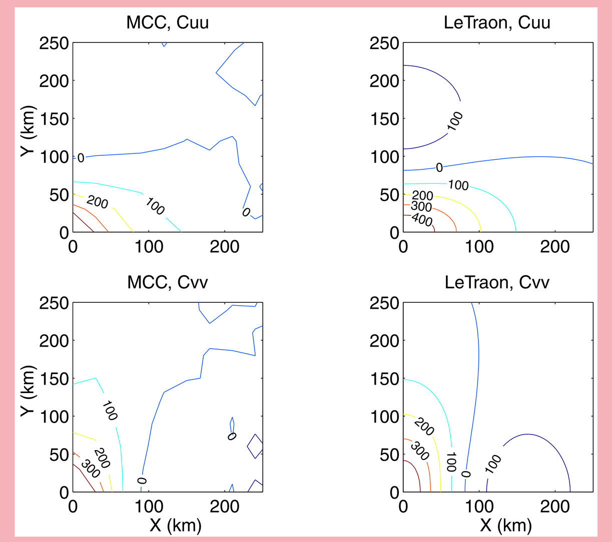
II. Optimal interpolation technique

Anomaly sea surface heights and velocities are mapped to a stream function using covariance functions and error estimates. The covariance of velocity and sea level data is consistent with the statistical assumptions of homogenous, isotropic turbulence, with typical length scales of order 220 km and time scale of 10 days.

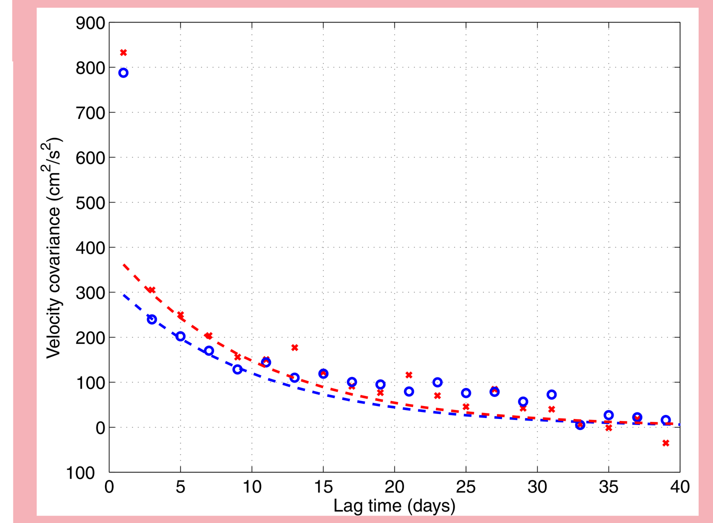
A covariance function with structure from LeTraon and Hernandez (1992) is fit the along-track altimeter data.



The corresponding velocity covariances compare well to those derived from the MCC velocities.



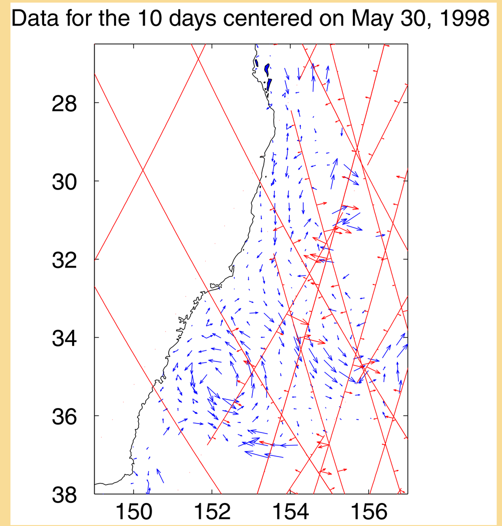
An exponential with a 10 day time scale approximates the temporal covariance of the MCC velocities.

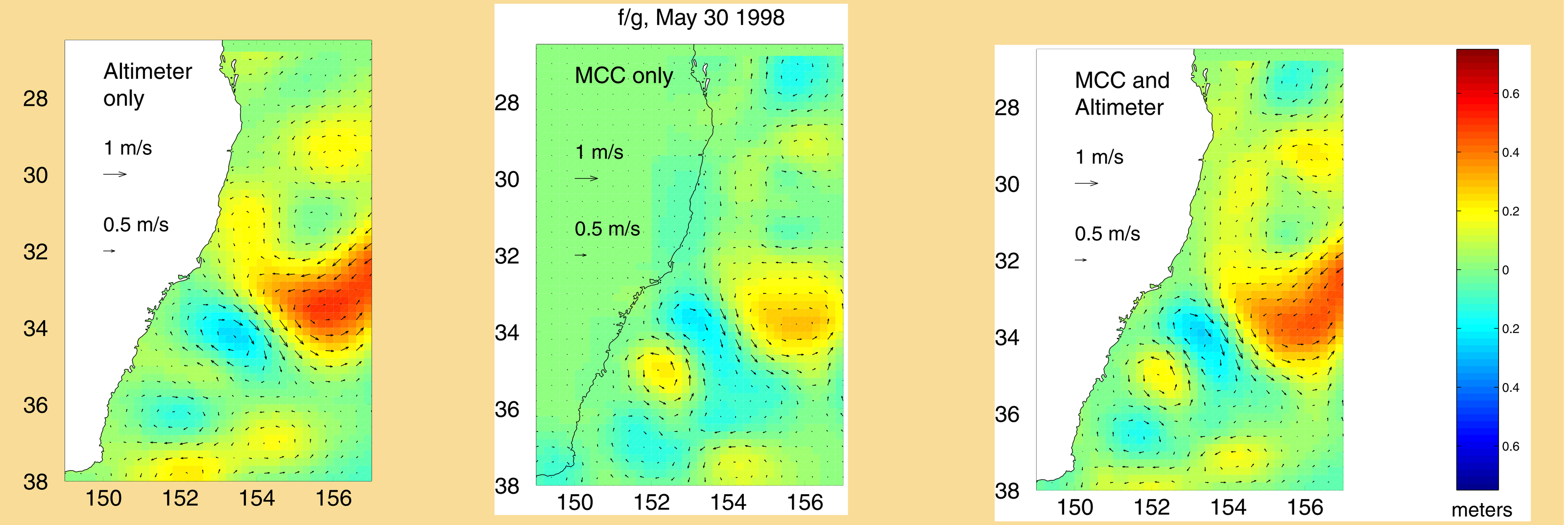


III. Optimal interpolation results

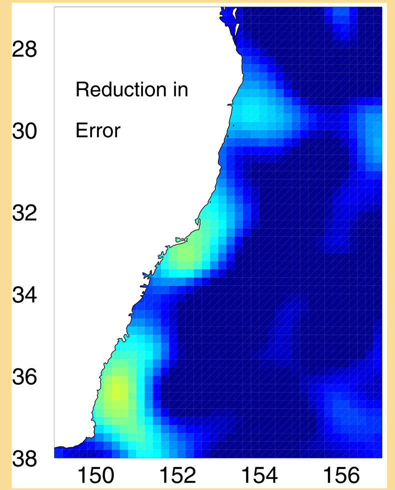
Data for five days before and after 30 May, 1998, (left) contribute most of the information to the optimally interpolated stream function on that day (right).

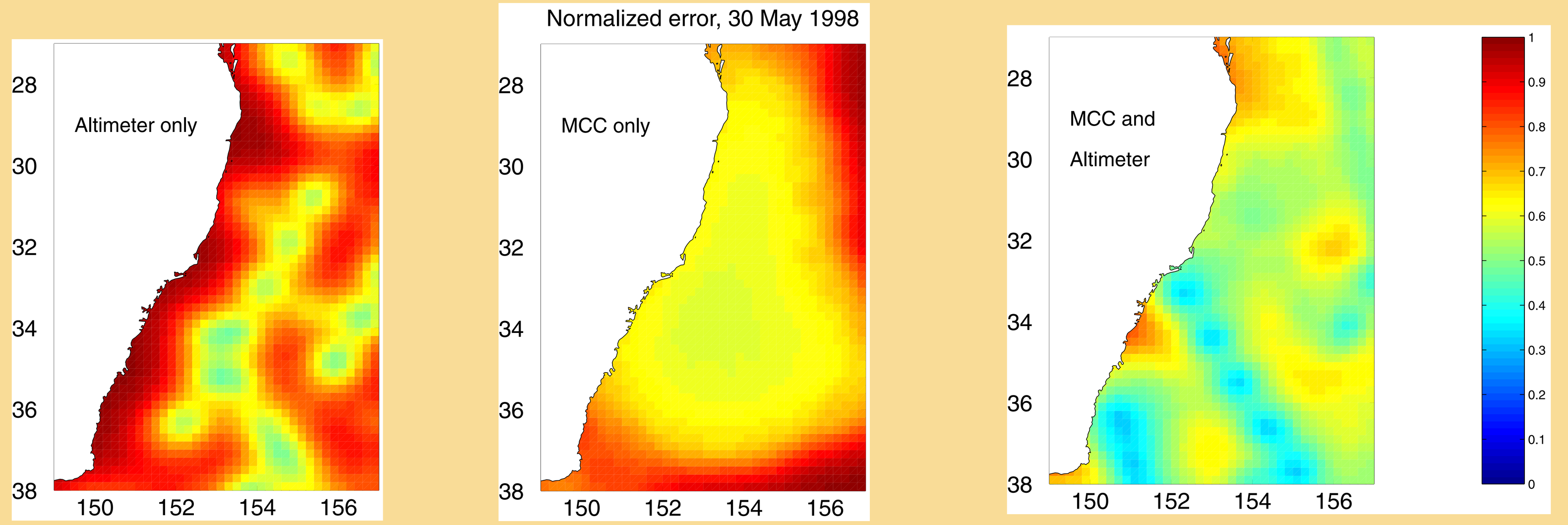
Interpolations with the height or velocity data alone capture the same basic features in the current. Combining the two types of data combines the strengths of the two data sets. The MCC velocities tend to turn flow near the coast parallel to it and add structure inside the altimeter diamonds. The regular spatial coverage of the altimeter ensures high skill in the interpolation along altimeter tracks.



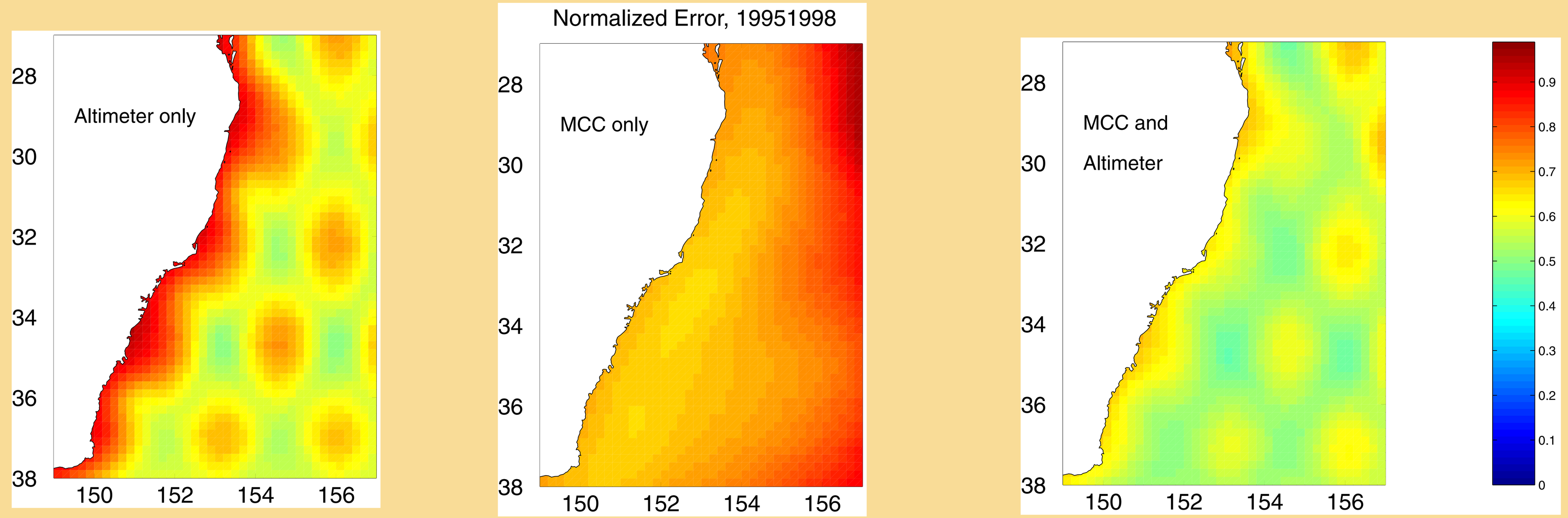


Differencing the error in the altimeter only and the full interpolation shows the contribution of the MCC velocities.





The error statistics from the three types of optimal interpolation are averaged over three years. Skill in the interpolation based on the MCC velocities is higher near the coast where the density of measurements is greater. Skill in the interpolation based on altimeter data is high along the altimeter lines where measurements are frequent. The combined interpolation reduces error inside the altimeter diamonds.



A limited amount of drifting buoy data is available in the region. Comparisons between the optimally interpolated velocities and the drifting buoy fixes indicated improvement with the addition of MCC velocities, but the number of comparisons are too few to discern statistically significant difference. More rigorous validation will be possible in the California Current region where there is more ancillary data.

Summary

Velocities can be extracted from sequential thermal imagery to provide a data set with a volume of data comparable to that derived from an altimeter.

Statistics from the sea surface height and velocities are consistent with the statistical assumptions of homogeneous, isotropic turbulence.

The covariance functions are used to combine the height and velocities measurements into a gridded stream function and error estimate using an optimal interpolation technique.

Optimal interpolations using both data sets improves the resolution of the surface currents, especially near the Australian coast.

References:

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