Secular Trend in Global EKE using Accurately Resolved Mesoscale Currents

B.S. Powell, R.R. Leben, and G.H. Born
Colorado Center for Astrodynamics Research
University of Colorado, Boulder, Colorado 80309-0431 USA

Abstract

Using a novel difference operator to resolve mesoscale currents, a secular trend in the global eddy kinetic energy (EKE) has been found over the history of TOPEX/POSEIDON. The operator optimally minimizes the instrument noise for a given difference length scale. Because the length scales of the environmental corrections are greater than the mesoscale, the corrections are not required allowing the use of high-rate altimetry data for much higher spatial resolution. With a global database of the Rossby radius of deformation (Chelton) and the spectral characteristics of the optimal difference operator, slopes are computed using an operator length at a half-power of twice the rossby radius. With this operation, the mesoscale is accurately resolved (with better than 7 cm/sec precision) at all regions globally, allowing for resolution of mesoscale, geostrophic currents within three degrees of the equator without being affected by the Coriolis singularity.

Optimal Difference Operator

Radar-based altimeters are affected by internally generated white noise that impacts the accuracy of slope estimates in the mesoscale range. This white, instrument noise can dominate errors at these wavelengths because a standard, finite difference operation on the along-track height measurements acts as a high-pass filter. To mitigate the enhancement of this noise, the heights must first be filtered, and further reduction of the noise is possible with longer difference operator lengths. We have developed an optimal difference operator which, in a single operation, both optimally reduces the noise and computes the derivative.

Consider a standard finite difference operator of size N,

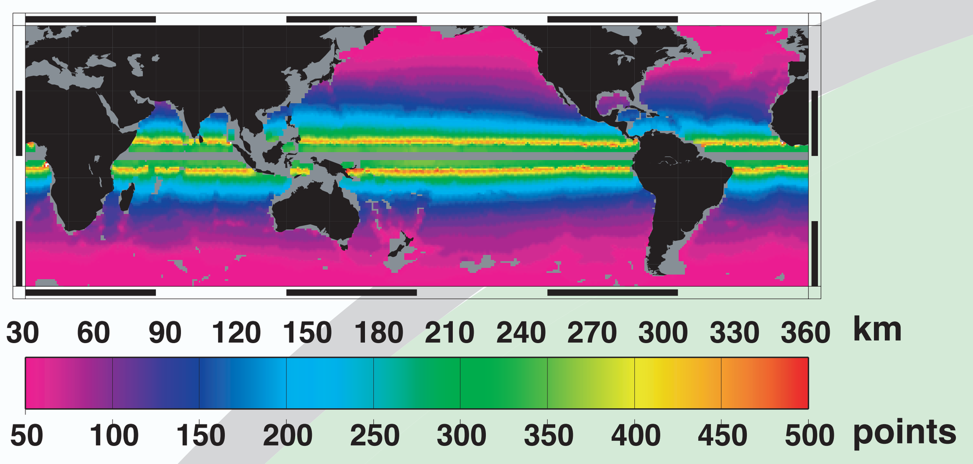
$$\Delta_{Nt}^{pq} = \sum_{\substack{n=-p \\ n\neq 0}}^{q} c_n \left(\frac{h_{i+n} - h_i}{n\Delta t} \right)$$

that computes the change in height with respect to time, weighting each term. The random uncertainty of such a calculation is given by,

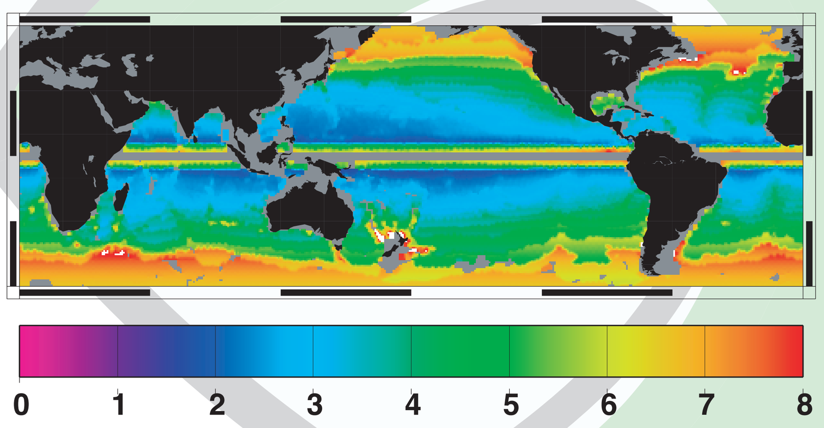
$$\delta v = \delta h \sqrt{\left(\sum_{\substack{n=-p \\ n\neq 0}}^{q} \frac{c_n}{n\Delta t} \right)^2 + \sum_{\substack{n=-p \\ n\neq 0}}^{q} \left(\frac{c_n}{n\Delta t} \right)^2}.$$

In order to minimize the white instrument noise, we must minimize the combination of height uncertainties by finding the optimal weights. By differentiating with respect to each weight and setting the result equal to zero, we find the local minimum in the noise for the number of measurements used. The most straightforward way of solving the minimization problem is to use the method of undetermined multipliers by Lagrange.

The length of the mesoscale is small in comparison to correction scales eliminating the need to apply corrections when one is interested in slopes only over short length scales. More accurate short-scale slopes can be computed without applying corrections (using orbit height minus range measurement) as long as the spatial scale of the derivative operator is smaller than the length scales of the corrections. This allows for the use of high-rate data for increased spatial resolution of mesoscale currents. As shown by Chelton, the mesoscale is determined locally by the baroclinic Rossby radius of deformation. By selecting an optimal filter width with its half-power location equal to twice the Rossby length, we can accurately resolve mesoscale features globally.



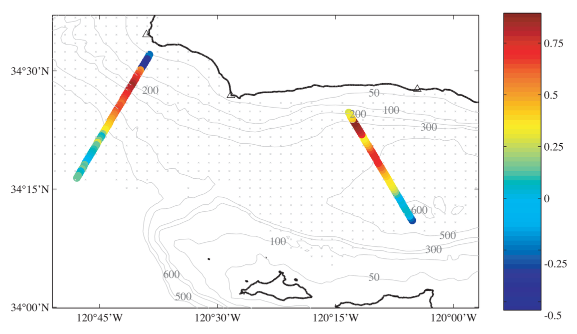
Size of filter used globally to resolve the mesoscale. Filter size is shown as number of 10 Hz points and as the length of the half-power cutoff in the filter band.



White noise present in mesoscale geostrophic currents (cm/s) when using the length of filter shown above. The white noise level of the 10 Hz is assumed to be $1.7\sqrt{10}$ cm, a slight overestimate of the noise as calculated by Leben and Powell. Error at higher latitudes is higher due to the short length scale of the mesoscale features present.

Verification

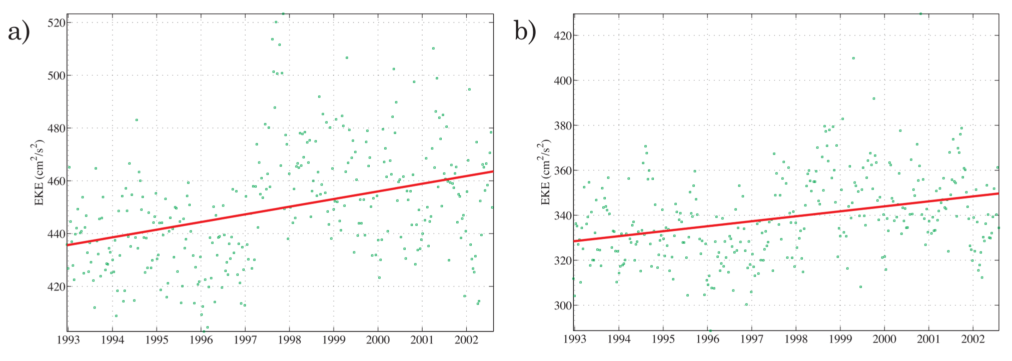
In order to confirm that the optimal difference operator can accurately resolve geostrophic currents, a comparison against an independent measure is required. Near real-time surface currents are available from the Southern Central California CODAR Project managed by Libe Washburn at the University of California, Santa Barbara. Using high-rate data from Jason-1, geostrophic currents in the Santa Barbara channel are calculated and compared with coincident CODAR surface current measurements. Although surface currents from CODAR contain Ekman flows (absent from the geostrophic approximation used in altimetry), the correlation between the two datasets is very good. This geographic region is typically very difficult to work with in altimetry due to the shallow water and the satellite track coming off of land; however, the optimal operator allows for this fine-scale analysis.



Correlation between CODAR measured surface currents and Jason-1 high-rate geostrophic currents. At the edge of the array coverage, the CODAR does not resolve the surface currents as well because the SNR ratio drops and the geometry of the radial velocity become nonorthogonal.

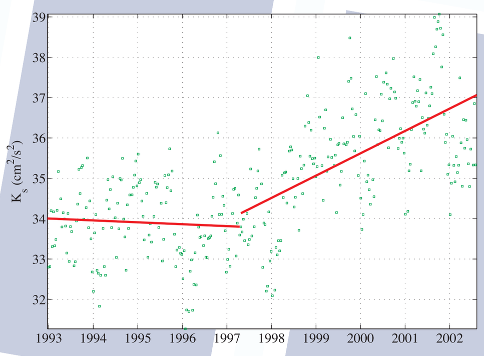
EKE Results

Using the techniques presented to accurately resolve mesoscale eddies, a preliminary look at the eddy kinetic energy (EKE) trend over the first ten years of T/P has been performed. There is no annual cycle in the variability of the global ocean's kinetic energy; however, El Niño events are evident. After fitting for any annual variation, the most interesting aspect is the secular trend of the variability increasing over the ten years. To eliminate the possibility of energy leaking into this trend (through instrument drift, etc.) due to the lack of applying altimeter corrections (particularly sea state bias), each correction was independently analyzed. In every case, the respective correction showed no decadal trend that corresponds with the variability in EKE. Due to the sensitivity of the white noise on $H_{1/3}$, trends were calculated using heights with $H_{1/3}$ values between 1.5 to 2.5 meters at depths greater than 1,000 meters.



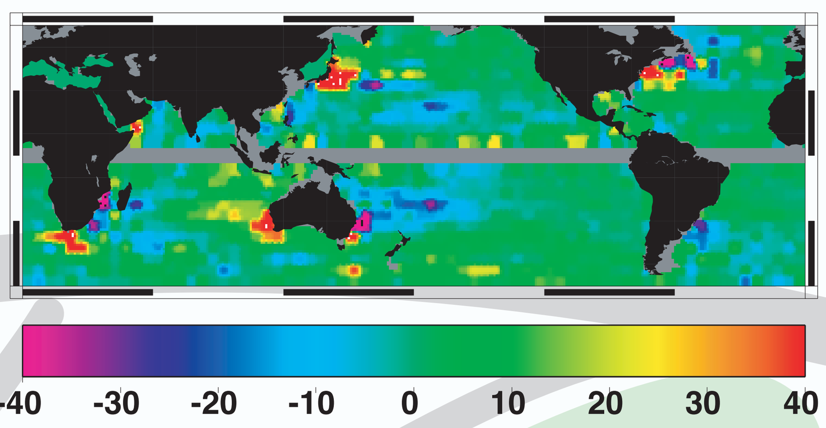
Cycle trend of global (5-60° N/S latitude) EKE using 1Hz data. a) EKE calculated using isotropic assumption; trend line increases 6.4% over 10 years b) EKE calculated using anisotropic data at crossover locations; trend line increases 6.5% over 10 years.

The secular results in EKE presented are different than Stammer and Wunsch; however, by analyzing the slope variance (Ks), the same conclusions can be drawn. During the first four years of the T/P mission, there is virtually no inter-annual trend in the Ks, confirming their results; however, after cycle 170 (April, 1997), the trend begins to increase dramatically. This is extremely interesting as it corresponds with the start of the 1997 El Niño as well as a dramatic change in J_2. It should be pointed out that the switch from the Side-A to Side-B altimeter, which was made at the beginning of 1999, does not appear to influence EKE estimates nor significantly affect the apparent global EKE trend.



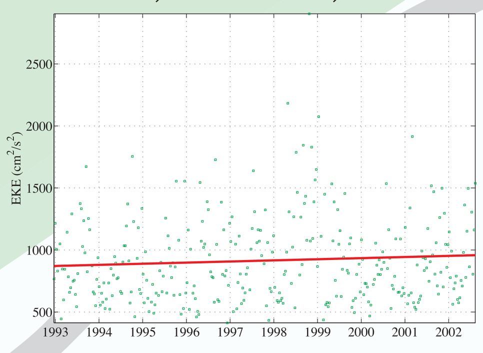
Global K_S: Trend (1Hz) over the first four years decreases 0.6% (similar results to Stammer and Wunsch), over the last six years it increases 8.6%.

On a global scale, the EKE trend is increasing; however, the trend is interesting when viewed on a regional basis. The trend is most dramatic in boundary current regions which may indicate an increase in baroclinic instabilities along the fronts. Much of the global ocean has a slightly increasing in EKE.



Change in EKE (cm^2/s^2/year) over ten years of T/P 1Hz data. Boundary currents are becoming more energetic presumably due to an increase in baroclinic instabilities. Globally, much of the ocean is steadily increasing at slightly less than 10 cm^2/s^2/year.

A preliminary look at using a global 10 Hz database has been performed to compare against the 1 Hz data. The 10 Hz data has a noise floor of approximately root 10 greater than the 1 Hz data causing greater EKE variance; however, the trend is similar.



Cycle trend of global (5-60° N/S latitude) EKE using 10 Hz data. EKE calculated using anisotropic data at crossover locations; trend line increases 10% over 10 years.

Future Work

EKE results must be confirmed by computing the statistical significance of the data and trend. Eddy statistics: eddy momentum flux, velocity variances, and eddy momentum convergence can be computed accurately at the mesoscale to identify regions of increasing energetics in an attempt to explain rising EKE values.

With the addition of the Wide-Swath Ocean Altimeter (WSOA), the ability to measure vorticity will be not only feasible, but by further developing the optimal operator into a two-dimensional operation, will be very accurate. The ability to generate accurate, global vorticity maps will greatly help our understanding of global circulation and mesoscale energetics.

References

Chelton, D.B., R.A. deSzoeke, M.G. Schlax, K. El Naggar, and N. Siwertz (1998). Geographical variability of the first-baroclinic Rossby radius of deformation. *J. Phys. Oceanog.* 28:433-460.

Leben, R.R. and B.S. Powell (2003). Accuracy Assessment of Jason-1 and TOPEX/POSEIDON Along-Track Sea Surface Slope. *Marine Geodesy*. to be published.

Powell, B.S. and R.R. Leben (2003). An optimal filter for geostrophic velocities from along-track satellite altimetry. *J. Oceanic and Atmos. Tech.*, in review.

Stammer, D. and C. Wunsch (1999). Temporal changes in eddy energy of the oceans. *Deep-Sea Res.* 46:77-108.

Acknowledgements

We wish to thank NASA's PO.DAAC and AVISO for providing the GDR data used for this presentation.