Comparison Figures from the New 22-Year Daily Eddy Dataset
(January 1993 - April 2015)

The figures on the following pages were constructed from the new version of the eddy dataset that is available online at http://wombat.coas.oregonstate.edu/eddies/. This eddy dataset spans the 22-year time period January 1993 through April 2015 and is based on DT-2014 version of the sea-surface height (SSH) fields distributed and referred to by AVISO as the daily “two-sat merged” sea level anomaly (MSLA) fields that are documented on the AVISO website at http://www.aviso.altimetry.fr/en/data/products/sea-surface-height-products/global/msla-uv.html#c10312

The figures that follow based on the new daily eddy dataset can be compared with the figures published in Progress in Oceanography by Chelton et al. (2011) based on the 1st version of the eddy dataset, which consisted of eddy trajectories at weekly intervals spanning the 16-year time period October 1992 through December 2008.

These new figures are generally consistent with the conclusions of Chelton et al. (2011). The primary differences are that the eddies in this new dataset have somewhat larger amplitudes, smaller radii and higher rotational speeds. They are thus somewhat more nonlinear and have somewhat higher eddy kinetic energy than those in our previous eddy datasets. Statistically, the eddies have longer lifetimes and propagating longer distances. These changes from the eddy characteristics in our previous datasets are attributable mostly to the changes in the AVISO processing to produce the DT-2014 MSLA dataset.

Reference

Figure 1. An example of global maps of SSH on 28 August 1996 constructed from TOPEX/Poseidon (T/P) data only (top) and from the merged T/P and ERS-1 data in the AVISO DT-2014 (also known as V5) “two-sat merged” SSH fields (middle). The bottom panel is the SSH field from the merged T/P and ERS-1 data after spatially high-pass filtering with half-power filter cutoffs of 20° of longitude by 10° of latitude.
Figure 2. Histograms (left) and upper-tail cumulative histograms (right) of the lifetimes of the cyclonic (upper thick lines) and anticyclonic (upper thin lines) eddies over the 22-year period January 1993–April 2015. The ratios of these histogram values are shown by the thin lines in the bottom panels and the thick lines in the bottom panels are 21-week running averages of the ratios. (The two lines are almost indistinguishable in the ratio of the upper-tail cumulative histograms.) The lower thick and thin lines in the top panels are, respectively, for only those cyclonic and anticyclonic eddies for which the net displacement was eastward. The vertical dashed lines indicate the 16-week lifetime cutoff for the eddies that are the focus of this study.
Figure 3. Histograms (left) and upper-tail cumulative histograms (right) of the great-circle propagation distances of cyclonic (thick lines) and anticyclonic (thin lines) eddies with lifetimes ≥16 weeks over the 22-year period January 1993–April 2015. The ratios of these histogram values are shown by the thin lines in the bottom panels and the thick lines in the bottom panels are 500-km running averages of the ratios. (The two lines are almost indistinguishable in the ratio of the upper-tail cumulative histograms.) The lower thick and thin lines in the top panels are, respectively, for only those cyclonic and anticyclonic eddies for which the net displacement was eastward.
Figures 4a and b. The trajectories of cyclonic (blue lines) and anticyclonic (red lines) eddies over the 22-year period January 1993–April 2015 for a) lifetimes ≥ 16 weeks; and b) lifetimes ≥ 16 weeks for only those eddies for which the net displacement was eastward. The numbers of eddies of each polarity are labeled at the top of each panel.
Figures 4c and d. The same as Fig. 4a, except: c) lifetimes $\geq 26$ weeks; and d) lifetimes $\geq 52$ weeks.
Figures 4e and f. The same as Fig. 4a, except: e) lifetimes $\geq 78$ weeks; and f) lifetimes $\geq 104$ weeks.
Figure 5. Census statistics for the numbers of eddy centroids (top), and eddy interiors (bottom) for eddies with lifetimes ≥16 weeks that passed through each 1° x 1° region over the 22-year period January 1993–April 2015. The eddy interiors are defined by the contour of SSH around which the average geostrophic speed is maximum (corresponding approximately to a contour of zero relative vorticity).
Figure 6. Census statistics for eddies with lifetimes ≥16 weeks showing the numbers of a) eddy originations, and b) eddy terminations, for each $1^\circ \times 1^\circ$ region over the 22-year period January 1993–April 2015.
Figure 7. Lower-bound estimates of the eddy kinetic energy that is accounted for by eddies with lifetimes ≥16 weeks (upper panel) and lifetimes ≥4 weeks (lower panel).
Figure 8. The ratio of the numbers of cyclonic to anticyclonic eddy centroids for eddies with lifetimes ≥16 weeks that propagated through each 1°×1° region over the 22-year period January 1993–April 2015.
Figure 9. The distributions of the amplitudes $A$, speed-based scale $L_s$, and rotational speeds $U$ (left to right) of eddies with lifetimes $\geq$16 weeks in a) the northern hemisphere, and b) the southern hemisphere. Upper-tail cumulative histograms and histograms are shown in the first and second rows of panels, respectively, with blue and red lines corresponding, respectively, to histograms for cyclonic and anticyclonic eddies. The ratios of cyclonic to anticyclonic are shown in the third rows of panels. The global two-dimensional histogram of the joint distribution of the amplitudes $A$ and scales $L_s$ is shown in panel c. The contours near the far right and near the top of this two-dimensional histogram arise because all of the eddies with amplitudes and scales larger than the maximum values of the abscissa and ordinate have been placed in the last bins along each axis (see the spikes in the last bins of the individual histograms in the second rows of panels a and b).
Figure 10. Maps of the average amplitude of eddies with lifetimes $\geq 16$ weeks (top left) and the standard deviation of the $20^\circ \times 10^\circ$ spatially high-pass filtered SSH from which the eddies are identified (bottom left) for each $1^\circ \times 1^\circ$ region. The upper right panel shows meridional profiles of the average (solid line) and the interquartile range of the distribution of eddy amplitudes within each $1^\circ$ latitude bin (i.e., the 25 and 75 percentage points of each distribution, shown by the gray shading) and the zonal average of the SSH standard deviation (dashed line). The lower right panel shows binned averages of the eddy amplitudes from the top left panel as a function of the standard deviation of spatially high-pass filtered SSH from the bottom left panel, with the interquartile range of the distribution in each bin overlaid as gray shading.
Figure 11. Cumulative histograms of the lifetime distributions of all of the tracked eddies (lifetimes ≥4 weeks) within the lower, middle and upper 25 percentiles of the distribution of eddy amplitudes averaged over the lifetime of each eddy: $A < 3.5$ cm (thin line), $4.6 \leq A \leq 7.5$ cm (medium line thickness), and $A > 10.0$ cm (thick line).
**Figure 12.** Map of the average speed-based eddy scale $L_s$ for eddies with lifetimes $\geq 16$ weeks (left) for each $1^\circ \times 1^\circ$ region. The right panel shows meridional profiles of the average (solid line) and the interquartile range of the distribution of $L_s$ (gray shading) in $1^\circ$ latitude bins. The dashed line represents the $0.4^\circ$ feature resolution limitation of the SSH fields of the AVISO SSH fields for the zonal direction (see Appendix A.3) and the dotted line is the meridional profile of the average Rossby radius of deformation from Chelton et al. (1998).
Figure 13. Cumulative histograms of the lifetime distributions of all of the tracked eddies (lifetimes \( \geq 4 \) weeks) in the latitude range 20° to 60° of both hemispheres within the lower, middle and upper 25 percentiles of the distribution of speed-based eddy scales (averaged over the lifetime of each eddy): \( L_s \leq 66.7 \text{ km} \) (thin line), \( 75.3 \text{ km} \leq L_s \leq 94.8 \text{ km} \) (medium line thickness), and \( L_s > 107.8 \text{ km} \) (thick line).
Figure 14. Histograms (left) and upper-tail cumulative histograms (right) of estimates of the Rossby number, \( U/(fL_s) \), of the observed mesoscale features with lifetimes \( \geq 16 \) weeks for three different latitude bands. Top to bottom: 20°N to 60°N, 20°S to 20°N, and 60°S to 20°S. The blue and red lines in each panel correspond to cyclonic and anticyclonic eddies, respectively. The labels on the right panels, color coded to their associated line color, indicate the percentages of eddies of each polarity for which the Rossby number exceeds the value of 0.05 indicated by the vertical dashed line. See text for details.
Figure 15. Composite profiles of the distribution of SSH as functions of radius along east-west and north-south sections computed from every realization of all of the eddies with lifetimes $\geq 16$ weeks. The SSH profiles along these sections were doubly normalized by the amplitude $A$ and the speed-based scale $L_s$ for each eddy (see text). The gray shading represents the interquartile range of the distribution of values in each normalized radius bin for the east-west section; the interquartile range for the north-south section was essentially the same. The pairs of blue and red lines are the east-west and north-south transects of the average and the mode, respectively, of the doubly normalized SSH. The mode profiles have been smoothed slightly. The thick short dashed line corresponds to a Gaussian profile with a normalized e-folding scale of $L_e=0.64$ and the vertical dotted lines are the normalized radius $L=2^{1/2}L_e$ of maximum rotational speed for this Gaussian. The thick long dashed line corresponds to a quadratic profile with zero crossings at normalized radii of 0.95.
Figure 16a. Histograms of three measures of the degree of nonlinearity of the observed mesoscale features with lifetimes ≥16 weeks for three different latitude bands. Top to bottom: 20°N to 60°N, 20°S to 20°N, and 60°S to 20°S. The three measures of nonlinearity are (left to right): the advective nonlinearity parameter $U/c$; the quasi-geostrophic nonlinearity parameter $U/(\beta L_s^2)$; and the upper-layer thickness nonlinearity parameter $\delta H/H$. The blue and red lines in each panel correspond to cyclonic and anticyclonic eddies, respectively. See text for details.
Figure 16b. The same as Fig. 16a, except the associated upper-tail cumulative histograms for the three nonlinearity parameters in the three different latitude bands. The labels, color coded to their associated line color, indicate the percentages of eddies of each polarity for which the nonlinearity parameter exceeds the value indicated by the vertical dashed line in the respective panel.
Figure 17. Maps of the average values of the three nonlinearity parameters in Fig. 16 for each 1°×1° region. Top to bottom: the advective nonlinearity parameter $U/c$; the quasi-geostrophic nonlinearity parameter $U/\beta L_s^2$; and the upper-layer thickness nonlinearity parameter $\delta H/H$. 
Figure 18. The trajectories of all of the cyclonic (blue lines) and anticyclonic (red lines) eddies over the 22-year period January 1993–April 2015 that had lifetimes $\geq$16 weeks and propagated westward a minimum of $10^\circ$ of longitude. The horizontal lines show the latitude ranges of $10^\circ$ to $50^\circ$ that were considered for the analyses in Figs. 19 and 20.
Figure 19. The distribution of the average azimuths of the trajectories of the combined cyclonic and anticyclonic eddies with lifetimes $\geq$ 16 weeks and starting points at latitudes between 10º and 50º of both hemispheres that propagated westward a minimum of 10º of longitude (see Fig. 18). To combine the eddies from both hemispheres, the azimuth is defined as positive poleward and negative equatorward of due west, rather than north and south. The labels indicate the percentages of negative (left) and positive (right) eddy azimuths. The average azimuth is defined as the angle with respect to due west formed by the great circle connecting the starting and ending points of the trajectory.
Figure 20. The meridional deflections of the cyclonic (upper panels) and anticyclonic (lower panels) eddies with lifetimes ≥16 weeks and starting points at latitudes between 10° and 50° of both hemispheres that propagated westward a minimum of 10° of longitude (see Fig. 18). The left panels show the changes in longitude (negative westward) and latitude (positive for poleward and negative for equatorward of due west) relative to the initial location of each eddy. The right panels show histograms of the average azimuth of each eddy trajectory, defined as in Fig. 19. The labels in the right panels indicate the percentages of negative (left) and positive (right) eddy azimuths. The black line overlaid in the lower right panel corresponds to the histogram computed from the azimuths of the cyclonic eddies in the upper left panel that have been reflected about 0° and then shifted to have a median equal to the equatorward median of the anticyclonic eddies.
Figure 21. The 45 zonal sections along which the Radon transform estimates of westward propagation speed and the average of the eddy speeds were computed for the black and red dots in Fig. 22.
Figure 22. The latitudinal variation of westward zonal propagation speeds estimated by a variety of different methods. The black dots are the Radon transforms of the 20°×10° high-pass filtered SSH fields of the 45 zonal sections shown in Fig. 21 and the red dots are the average of the propagation speeds of eddies with lifetimes ≥16 weeks within ±1.5° of latitude of the center latitudes of the same 45 zonal sections. The latitudinal profile of the global zonal average of the propagation speeds of all of the eddies with lifetimes ≥16 weeks is shown by the red line, with gray shading to indicate the interquartile range of the distribution of the eddy speeds in each latitude band. The black line is the latitudinal profile of the zonally averaged westward phase speeds of long baroclinic Rossby waves. The ratios of the various speed estimates to the local long baroclinic Rossby wave phase speed are shown in the bottom panel. The blue line in the upper panel (barely distinguishable from the red line over much of the southern hemisphere) is the latitudinal profile of the global zonal average of the eddy propagation speeds estimated by space-time lagged cross correlation analysis by Fu (2009).
Figure 23. Scatter plot comparisons between various estimates of westward propagation speed along the 45 zonal sections shown in Fig. 21: a) The mean eddy speeds versus the Radon transforms of the 20°×10° high-pass filtered SSH fields; b) The Radon transforms of the 20°×10° high-pass filtered SSH fields with 3° zonal low-pass filtering versus without 3° zonal low-pass filtering; c) The mean eddy speeds versus the Radon transforms of the 20°×10° high-pass filtered SSH fields with 3° zonal low-pass filtering; and d) The mean eddy speeds versus the Radon transforms of the 20°×10° high-pass filtered SSH fields with 3° zonal high-pass filtering.
Figure 24. Distributions of eddy speeds normalized by the local long baroclinic Rossby wave phase speed for the latitude range 15° to 40°. The distributions for cyclonic and anticyclonic eddies combined are shown in panel a) for the northern and southern hemispheres as thick and thin lines, respectively. The distributions for cyclonic and anticyclonic eddies (blue and red lines, respectively) are shown separately for the northern and southern hemisphere in panels b) and c). The mean value \( \mu \) and standard deviation \( \sigma \) of each distribution is labeled in each panel with lettering coded to the associated line thickness (panel a) and colors (panels b and c).
Figure 25. The same as Fig. 24a, except separately for the eddies with a) smallest 1/3 amplitudes \( A \); b) largest 1/3 amplitudes \( A \); c) smallest 1/3 scales \( L_s \); and d) largest 1/3 scales \( L_s \). In each panel, the distributions for cyclonic and anticyclonic eddies combined are shown for the northern and southern hemispheres as thick and thin lines, respectively, and the mean value \( \mu \) and standard deviation \( \sigma \) of each distribution is labeled in each panel with lettering thickness coded to the associated line thickness.
Figure A1. Maps (left panels) and zonal cross sections along the latitudes 34.25°N and 20.75°N of T/P ground track crossovers (right panels) of the standard deviation of gridded SSH fields constructed from altimeter data with various amounts of smoothing with a 3-dimensional loess smoother (cf., Chelton and Schlax, 2003). Top to bottom: T/P data with 5°×5°×20-day smoothing; T/P data with 5.5°×5.5°×20-day smoothing; T/P data with 6°×6°×20-day smoothing; T/P data with 3°×6°×20-day smoothing; and the SSH fields of the AVISO DT-2014 “two-sat merged” dataset with no additional smoothing applied. The horizontal bar in each of the right panels is the zonal spacing of the crossovers of ascending and descending T/P ground tracks. The red and blue arrows along the right border of each map indicate the latitudes of the zonal sections in the right panels. The T/P data in the top four rows are smoothed onto a 0.5°×0.5° grid and the standard deviations are calculated from 9.5 years of gridded data. The merged dataset in the bottom row is on a 1/4°×1/4° grid and spans the 22-year period January 1993–April 2015.