A 34-Year Record of Loop Current Eddy Separation Events

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Abstract

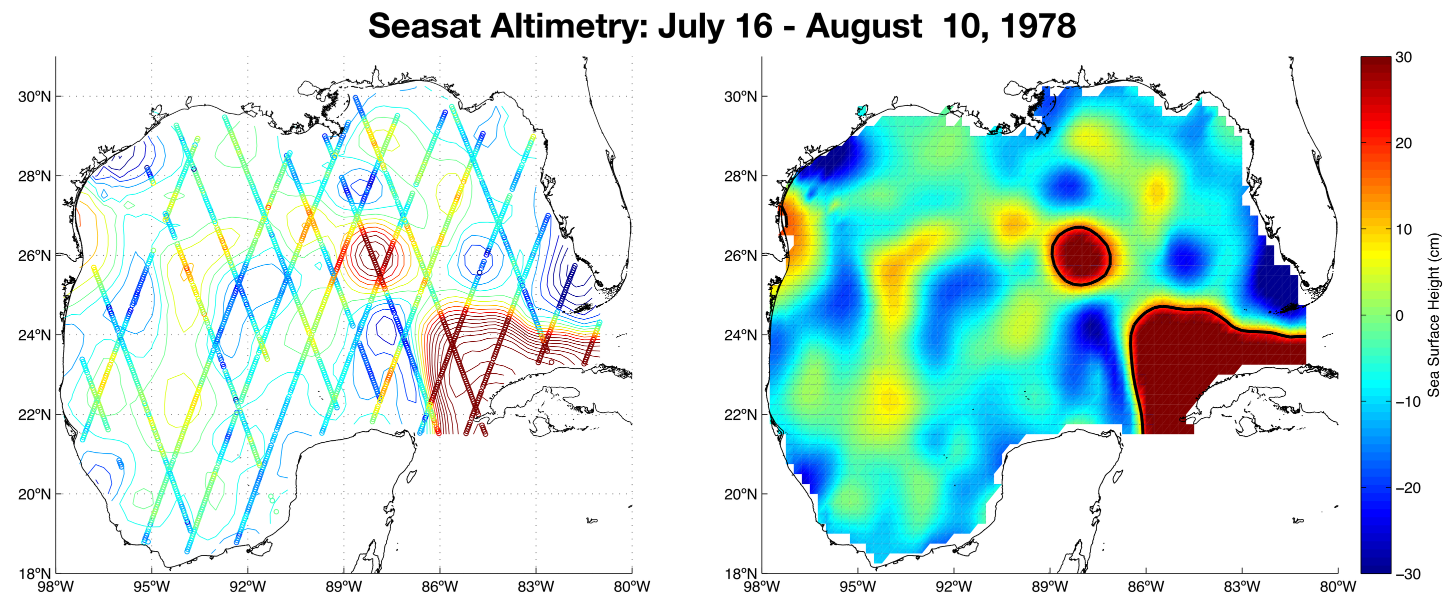
The intrusion of the Loop Current (LC) into the Gulf of Mexico deep basin varies with time and at irregular intervals becomes great enough to produce large anticyclonic rings of recirculating current, commonly called Loop Current eddies (LCEs). A reanalysis of observational records spanning the last 34 years is used to identify LC intrusion events leading to LCE separation, where separation is defined as the final detachment of an eddy from the LC with no later reattachment. Nearly continuous monitoring is needed to identify separation events since eddies frequently detach from and reattach to the LC during intrusion before the ultimate eddy detachment or separation occurs. Satellite observations, including ocean color, sea surface temperature, and satellite altimetry, facilitate this monitoring and now allow nearly continuous monitoring of the LC from the late 1970s onward. Our reanalysis finds 49 eddy separation events from July 1978 through June 2012. In contrast to earlier published records, there is a pronounced variation in the frequency of eddy separation as a function of season, even in the time period before continuous altimetric sampling became available over 20 years ago. This signal was obscured in earlier studies by undercounting of summer and fall separation events in the 1980s and poor sampling in earlier decades. A strong seasonal cycle is now evident in the time of eddy separation with separation occurring most frequently in late winter/early spring and late summer/early fall.

The 14-Year Pre-"Altimetric" Record

Analysis of the NASA Seasat SAR/altimetry (Figure 1), NASA Coastal Zone Color Scanner (CZCS) ocean color (Figure 2), and Advanced Very High Resolution Radiometer (AVHRR) SST data (Figure 3) were supplemented by LC and LCE positions determined from Horizon Marine, Inc. EddyWatch reports and industry drifters. Seasat data are available from July through October 1978. CZCS color data are available from November 1978 through December 1985 and are from the NASA Ocean-Color Webpage (http://oceancolor.gsfc.nasa.gov). The AVHRR data are from the NODC Pathfinder SST Program (http://www.nodc.noaa.gov/SatelliteData/pathfinder4km). Animations of the combined time series of color and SST images and HMI/EddyWatch charts were used to identify LCE separation and LC retreat following separation.

CZCS coverage was sufficient to determine that there were no LCE separation events from November 1978 through 1979. The one separation event reported in the literature during this time period, in April 1979 (Vukovich, 2012), was identified in the reanalysis as an eddy detachment, not an eddy separation. The first LCE separation event was identified in proprietary industry drifters in July 1978, after which we were able to derive a continuous record of separation events and retreats using the satellite and industry data records. Remarkably, the short-lived Seasat mission sampled this initial event with both a satellite altimeter and SAR (Figure 1), confirming the industry observations.

Seasat Altimetry: July 16 - August 10, 1978



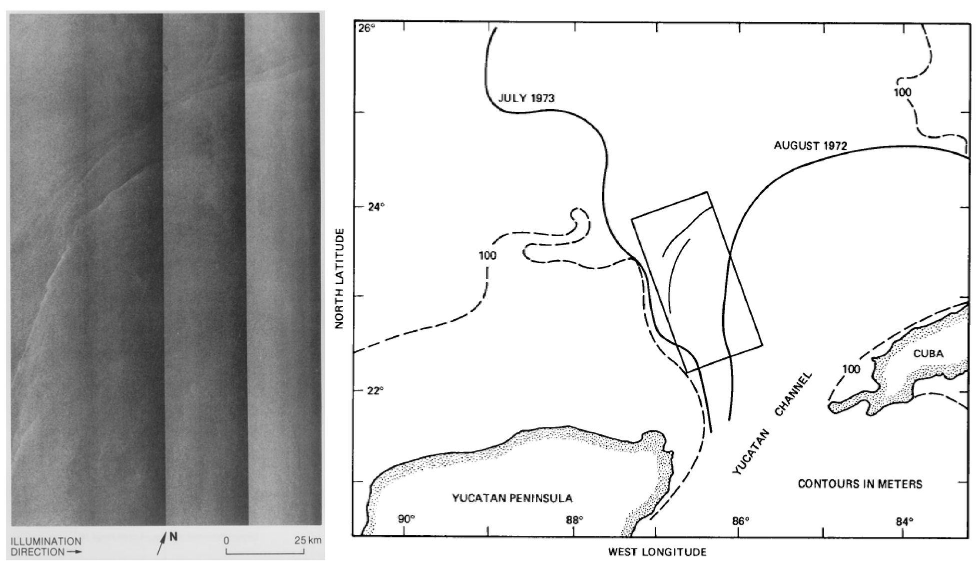


Figure 1: Seasat altimetry (above) and SAR (right) were used to verify the initial LCE separation event in July 1978. The SAR image and analysis shown to the left is from Fu and Holt (1982) using data from Seasat Rev 393, 11:47 GMT on July 24, 1978.

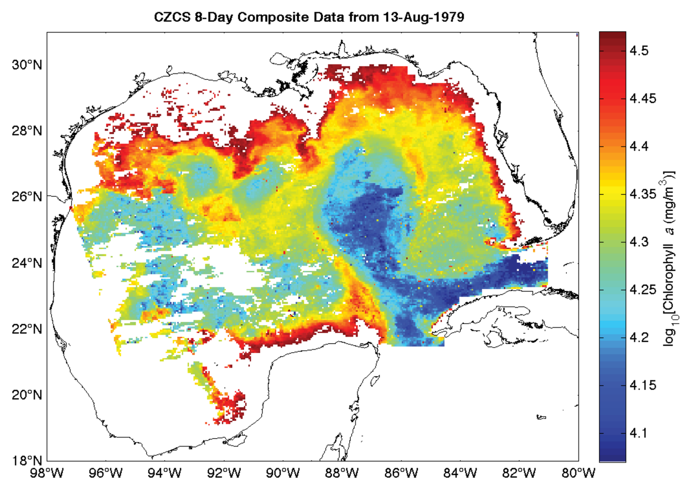


Figure 2: One of the best CZCS images.

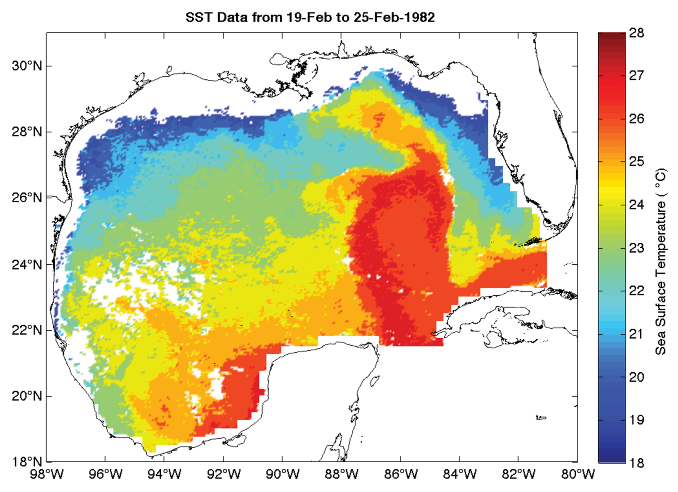


Figure 3: One of the best AVHRR images.

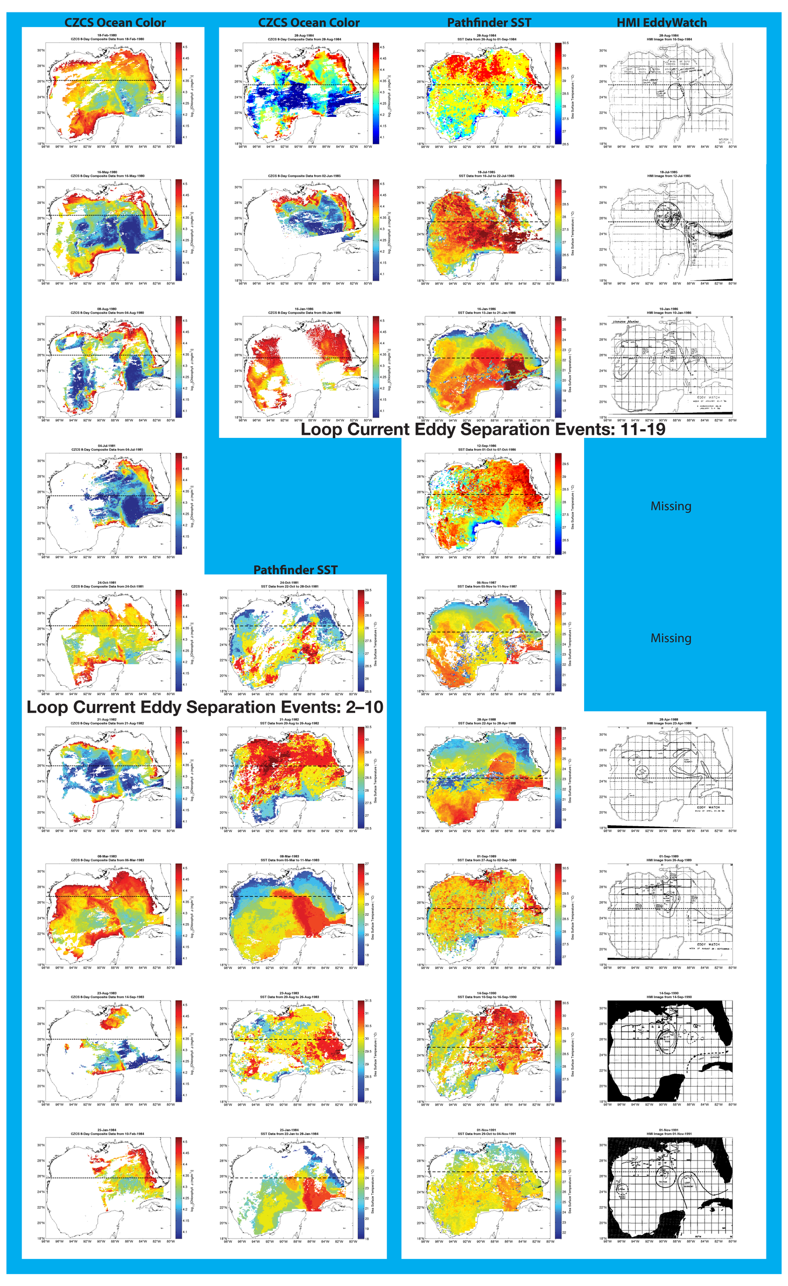


Figure 4: Pre-altimetric separation analyses.

The second LCE separation event was detected in color images in February 1980. The complete reanalysis of the pre-altimetric record found a total of 19 separation events in the time period from July 1, 1978 through December 31, 1991. Table 1 lists the information that we were able to retrieve. Eddies are listed with a year-letter designation for years with multiple separation events per year since many of these eddies were not named. Beginning in 1984, industry names are also listed. We also list the date of the source image or data product used to determine separation and latitude of retreat. For independent evaluation of the reanalysis effort, we have included plots of all of these events on this poster in Figure 4. Comparisons of our reanalysis to the published record of Loop Current eddy separations during this time period (Vukovich, 2012) show that summer and fall events were missed and/or misreported as earlier events.

Table 1. Loop Current eddy separation period and retreat latitude from the pre-1992 observational record.

	Year-Letter	Industry Name	Source* and Separation Date	Separation Period (days)	Retreat Latitude (°N)	Confirmation Datasets
1	1978	-	D 15-Jul-78	-	24.70	Seasat/Drifter
2	1980a	-	C 18-Feb-80	583	26.15	Color
3	1980b	-	C 16-May-80	88	26.40	Color
4	1980c	-	C 08-Aug-80	84	26.00	Color
5	1981a	-	C 04-Jul-81	330	25.50	Color
6	1981b	-	C 24-Oct-81	112	26.40	SST/Color
7	1982	-	C 21-Aug-82	301	26.00	SST/Color
8	1983a	-	A 08-Mar-83	199	26.80	SST/Color
9	1983b	-	A 23-Aug-83	168	26.00	SST/Color
10	1984a	-	A 25-Jan-84	155	25.80	SST/Color
11	1984b	Arnold	H 28-Aug-84	216	25.60	HMI/Color/SST
12	1985	Fast	H 18-Jul-85	324	25.55	HMI
13	1986a	Hot-Core	H 16-Jan-86	182	25.65	HMI/SST
14	1986b	Instant	S 12-Sep-86	239	25.70	HMI/SST
15	1987	Kathleen	A 06-Nov-87	420	25.60	SST
16	1988	Murphy	H 28-Apr-88	174	24.45	HMI
17	1989	Nelson	H 01-Sep-89	491	25.25	HMI
18	1990	Quiet	H 14-Sep-90	378	25.00	HMI/SST
19	1991	Triton	H 01-Nov-91	413	26.40	HMI/SST
***Source Key: D – Drifter, C – color, A – AVHRR SST, H – HMI/EddyWatch**						

Table 2. Comparison of reanalysis with Loop Current eddy separation record published by Vukovich (2012).

	Year-Letter	Industry Name	Reanalysis	Vukovich (2012)
1	1978		15-Jul-78	June 1978
2	1979			Apr 1979
3	1980a		18-Feb-80	Jan 1980
4	1980b		16-May-80	
5	1980c		08-Aug-80	
6	1981a		04-Jul-81	Mar 1981
7	1981b		24-Oct-81	
8	1982		21-Aug-82	May 1982
7	1983a		08-Mar-83	Mar 1983
8	1983b		23-Aug-83	
9	1984a		25-Jan-84	Feb 1984
10	1984b	Arnold	28-Aug-84	
11	1985	Fast	18-Jul-85	Jul 1985
12	1986a	Hot	16-Jan-86	Jan 1986
13	1986b	Instant	12-Sep-86	Oct 1986
14	1987	Kathleen	06-Nov-87	Nov 1987
16	1988	Murphy	28-Apr-88	May 1988
17	1989	Nelson	01-Sep-89	May 1989
18	1990	Quiet	14-Sep-90	Sep 1990
19	1991	Triton	01-Nov-91	Sep 1991

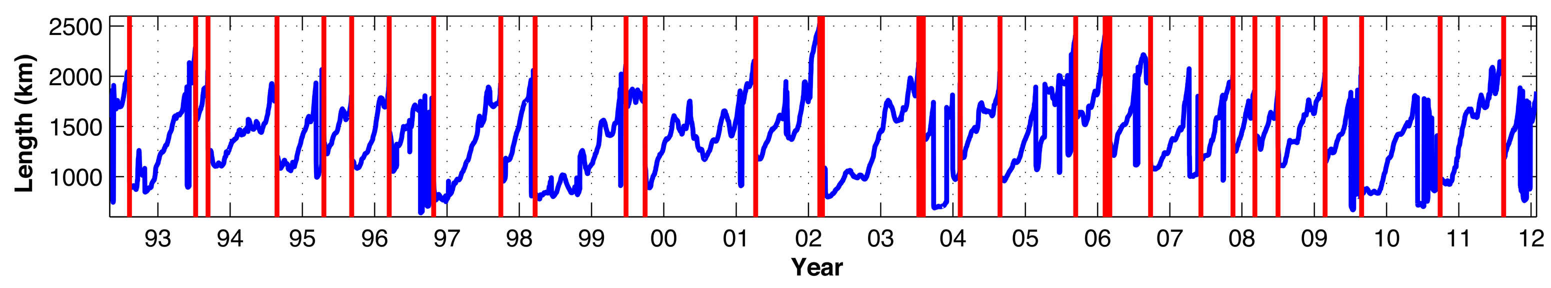


Figure 5. A continuous time series of LC length determined from automated tracking of the 17-cm LC contour in the CCAR Gulf of Mexico SSH data product since the placement of ERS-1 in the 35-day repeat multi-disciplinary orbit during ERS-1 Mission Phase C in April 1992. LCE separation events are identified by the vertical red lines.

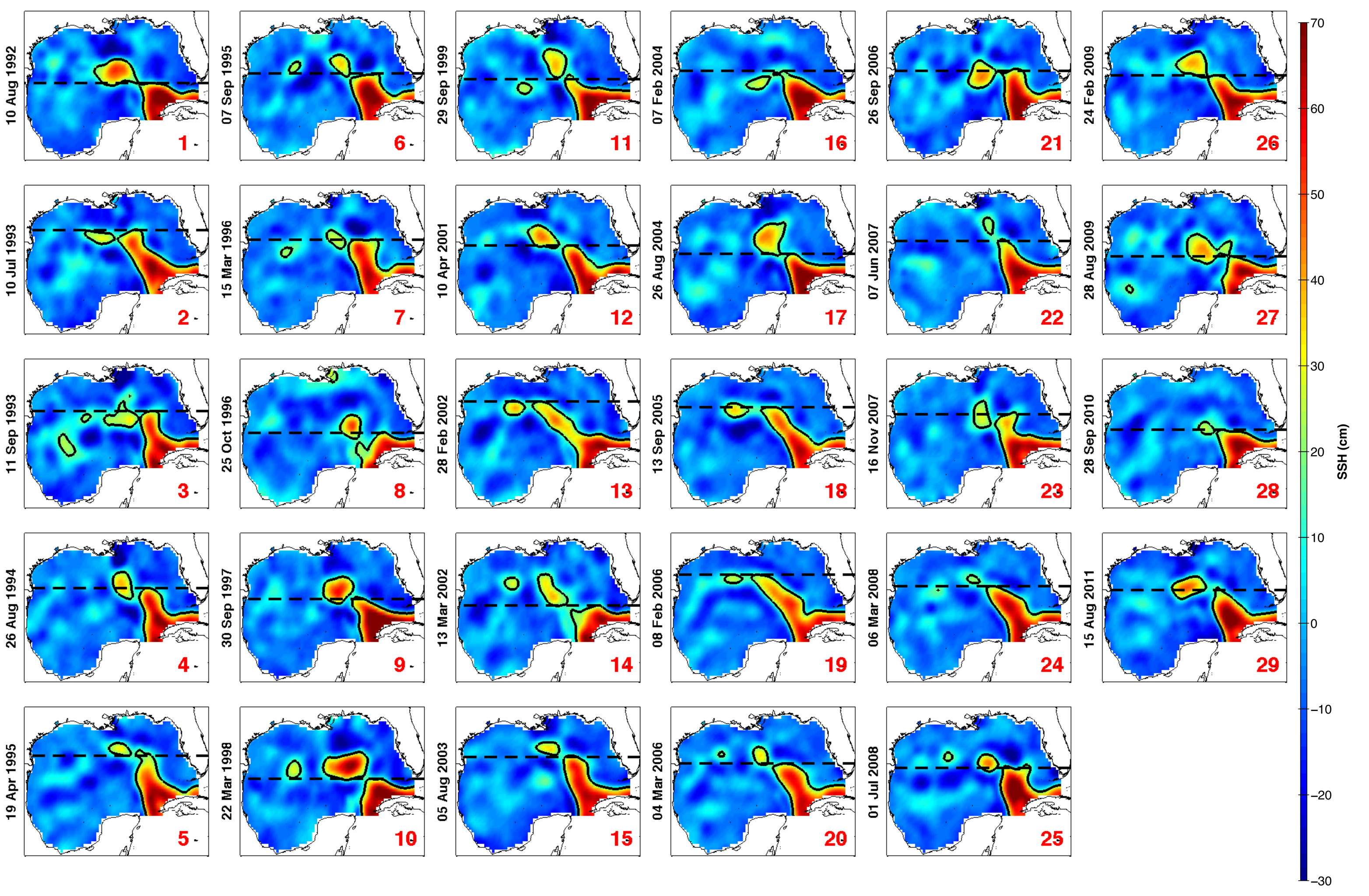


Figure 6. Composite of SSH maps on the "date of separation" of a LCE from the LC in the 20-year altimeter record.

The 20-Year Altimetric Record

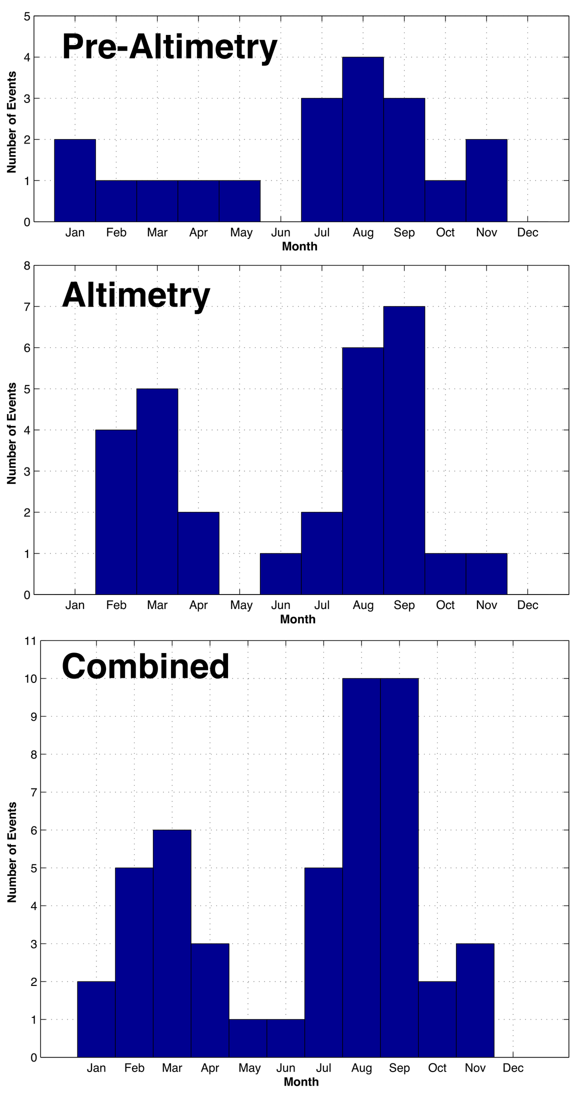
The CCAR Gulf of Mexico historical mesoscale satellite altimeter data reanalysis product from April 1992 to present is used in this study of LC separation. This new Gulf of Mexico product is based on CCAR's global historical mesoscale altimeter reanalysis data product. The global mesoscale reanalysis system and data product was developed with OSTM Science Team funding and came online last year. The updated historical mesoscale processing system uses the Radar Altimeter Database System (RADS) (Naeje et al., 2000) to generate historical data products and produces both 1-Hz along-track SSHA and daily global gridded 1/4-degree resolution products. The reanalysis was completed using our new suite of MATLAB processing tools. The historical reanalysis gridded product is based on a multigrid Cressman analysis of all of the available satellites data. The gridding process has been parallelized using MATLAB computational threads for parallel processing of daily gridded maps. The entire gridded reanalysis can be performed in less that 24-hours on our current server with the 8 available threads. The satellite altimetry missions used to produce the historical reanalysis data product include Geosat-ERM, ERS-1, TOPEX/Poseidon, ERS-2, GFO, Jason-1, Envisat and OSTM/Jason-2. The website for the new system is: **http://ccar.colorado.edu/~realtime**.

Separation of LCEs from the LC is identified by the breaking of the 17-cm SSH contour in the CCAR Gulf of Mexico historical SSH data product. In this product, the 17-cm SSH contour closely tracks the edge of the high-velocity core of the LC that enters through the Yucatan Channel and exits through the Florida Straits. This is an objective method for tracking the LC and detecting LCE separation events that gives separation periods comparable to, but more repeatable than, those determined by subjective tracking methods. The day that the tracking contour breaking occurs is identified as the nominal "time" of eddy separation. In some cases, a detached eddy will reattach to the LC. In those cases, the time associated with the final detachment of the LCE from the LC is referred to as the eddy separation time. Although we quote an exact day of separation determined by the breaking of the tracking contour in the daily analyses, estimated uncertainties in separation periods may be as large as one month. In addition to the objective identification of LCE separation, the objective tracking of the LC using the 17-cm SSH contour allows detailed monitoring of LC metrics such as northern/western extent, boundary length, enclosed area, volume, and circulation. For example, the Loop Current length time series over the altimetric record is shown in Figure 5. A composite of the LCE separation events observed in the record is shown in Figure 6. Table 3 lists the information generated from the altimetric LC tracking.

Table 3. Loop Current eddy separation period and retreat latitude from the altimetric record – 1992 through June 2012.

	Year-Letter	Industry Name	Separation Date	Separation Period (days)	Previous Retreat Latitude
1	1992	Unchained	10-Aug-92	283	26.400
2	1993a	Whopper	10-Jul-93	334	24.738
3	1993b	Xtra	11-Sep-93	63	27.071
4	1994	Yucatan	26-Aug-94	349	26.483
5	1995a	Zapp	19-Apr-95	236	26.190
6	1995b	Aggie	07-Sep-95	141	26.765
7	1996a	Biloxi	15-Mar-96	190	25.544
8	1996b	Creole	25-Oct-96	224	26.222
9	1997	El Dorado	30-Sep-97	340	24.557
10	1998	Fourchon	22-Mar-98	173	25.255
11	1999	Juggernaut	29-Sep-99	556	24.718
12	2001	Millennium	10-Apr-01	559	25.046
13	2002a	Pelagic	28-Feb-02	324	25.754
14	2002b	Quick	13-Mar-02	13	27.285
15	2003a	Sargassum	05-Aug-03	510	24.683
16	2003b	Titanic	07-Feb-04	186	26.643
17	2004	Ulysses	26-Aug-04	201	25.769
18	2005	Vortex	13-Sep-05	383	25.025
19	2006a	Walker	08-Feb-06	148	26.817
20	2006b	Xtreme	04-Mar-06	24	27.343
21	2006c	Yankee	26-Sep-06	206	26.050
22	2007a	Zorro	07-Jun-07	254	25.769
23	2007b	Albert	16-Nov-07	162	26.102
24	2008a	Brazos	06-Mar-08	111	26.187
25	2008b	Cameron	01-Jul-08	117	26.332
26	2009a	Darwin	24-Feb-09	238	25.651
27	2009b	Ekman	28-Aug-09	185	25.397
28	2010	Franklin	28-Sep-10	396	24.789
29	2011	Hadal	15-Aug-11	321	24.835
30	2012	Icarus	Feb-12	-	-

Figure 7: Monthly Histograms



Summary: Combining the events listed in Tables 1 & 3 gives a total of 49 separation events over the 34-year record. Histograms of separation times binned by month are shown in Figure 7 for each of the analysis records and the combined analyses. A clear seasonal signal is seen in each of the monthly distributions with separation occurring in late winter/early spring and late summer/early fall, with a preference for late summer/early fall separation events. Uncertainties based on the seasonal distribution of our reanalysis need to be evaluated more rigorously, but the empirical evidence is now quite strong that there is a seasonal component to the timing of Loop Current eddy separations that is relatively consistent over the entire 34-year record analyzed.

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Acknowledgement: This work was supported by NASA OSTM Science Team Grant NNX08AR60G and BOEM contract M08PC2043.