Loop Current Study:

The Relationship Between Loop Current Separation Period and Retreat Latitude Revisited

Robert R. Leben,

Cody A. Hall & Nicholas G. Hoffmann

Colorado Center for Astrodynamics Research

University of Colorado at Boulder

Study Motivation

Funding of CU as the remote sensing component of the ongoing BOEMRE Loop Current Study is being used to extend CCAR's existing archive of ocean color, sea surface temperature, and altimetry measurements.

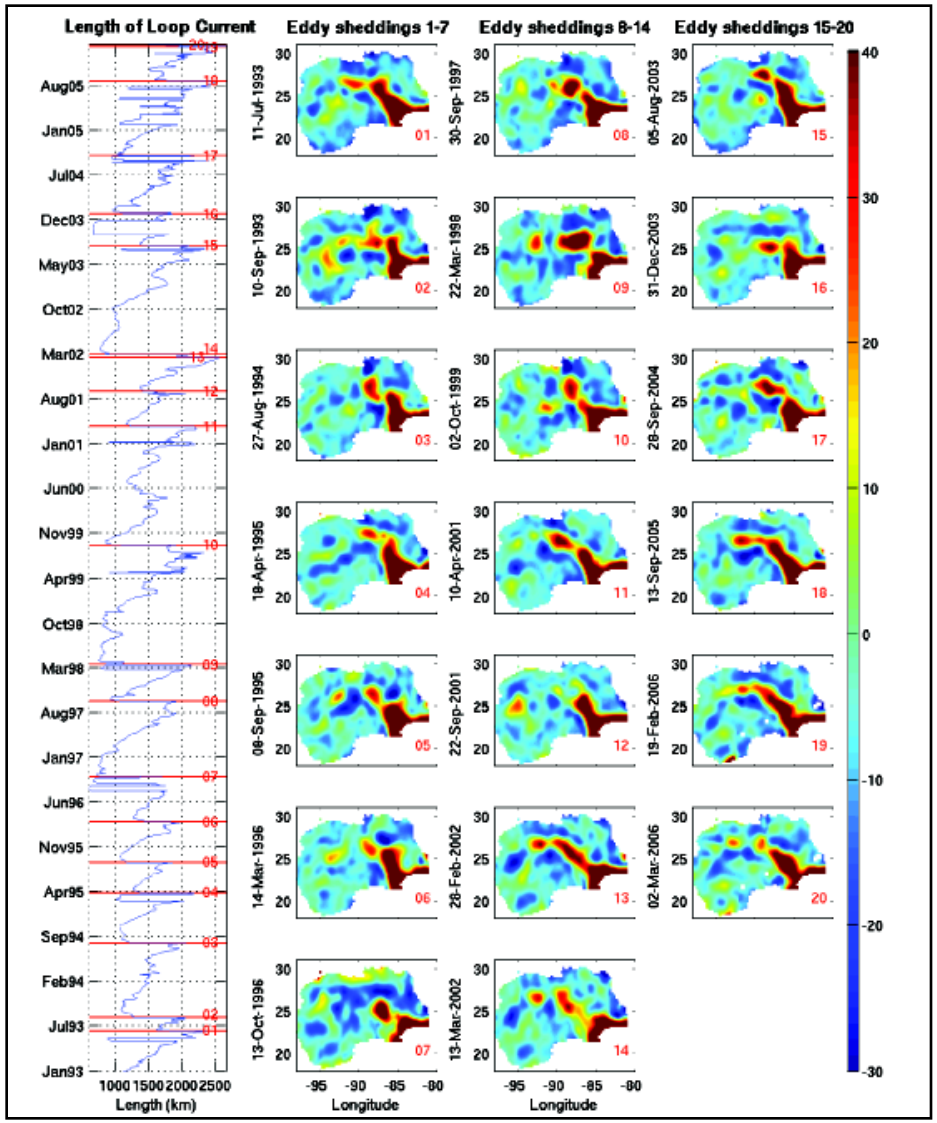
GOALS:

- Quantify Loop Current (LC) variability over the past 30 years.
- Provide an observational/historical perspective for the *in-situ* measurement and modeling programs.
- Revisit and evaluate peer-reviewed literature on LC separation period and retreat latitude.
- Investigate seasonality of LC metrics.

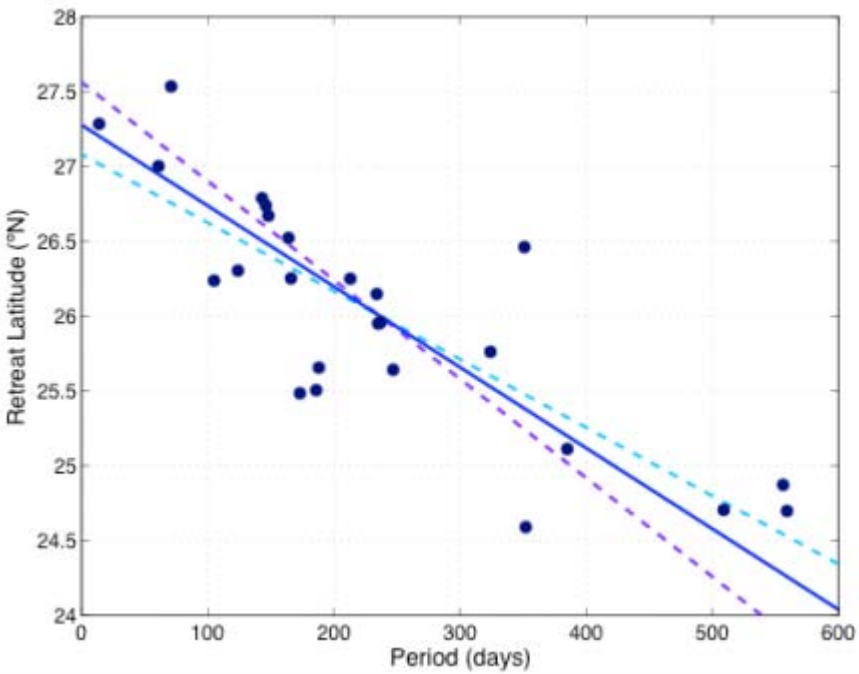
Loop Current Eddy Separation

A total of 26 eddy separation events have been observed using altimetry since 1993 (20 are shown to the right).

- Dominant physical mechanisms controlling LC intrusion and eddy separation are poorly understood.
- Over a dozen dynamical mechanisms have been proposed to explain eddy separation.
- Most recently a “Kelvin Wave Trigger” was proposed as a possible mechanism in Sturges, Hoffmann & Leben (2010).
- No eddy separation precursor had been identified until Leben (2005) first showed that LC retreat after eddy separation is a good predictor of the subsequent eddy shedding period using the 11.5-year altimeter record January 1993 through June 2004.



Linear Relationship Between Loop Current Retreat Latitude and Separation Period



A simple LC vorticity model (Lugo-Fernández and Badan 2007) provides a semi-theoretical basis for this empirical relationship.

After suitable scaling approximations, the theory predicts that the LC separation period is a linear function of retreat latitude, which agrees well with altimeter-derived empirical results. Specifically, the predicted slope and y intercept agree to within 9% and 2%, respectively, with the altimetry-derived values.

Question: How stable are the altimetry values?

For details see Leben (2005) and Lugo-Fernández and Badan (2007 and 2010). Full references appear on Slide 31.

Historical Data

NASA Coastal Zone Color Scanner (CZCS): 8-day composite chlorophyll concentration images from Nov 1978–Dec 1985.

NOAA Pathfinder AVHRR: Weekly composite SST images from Sep 1981–Dec 1992.

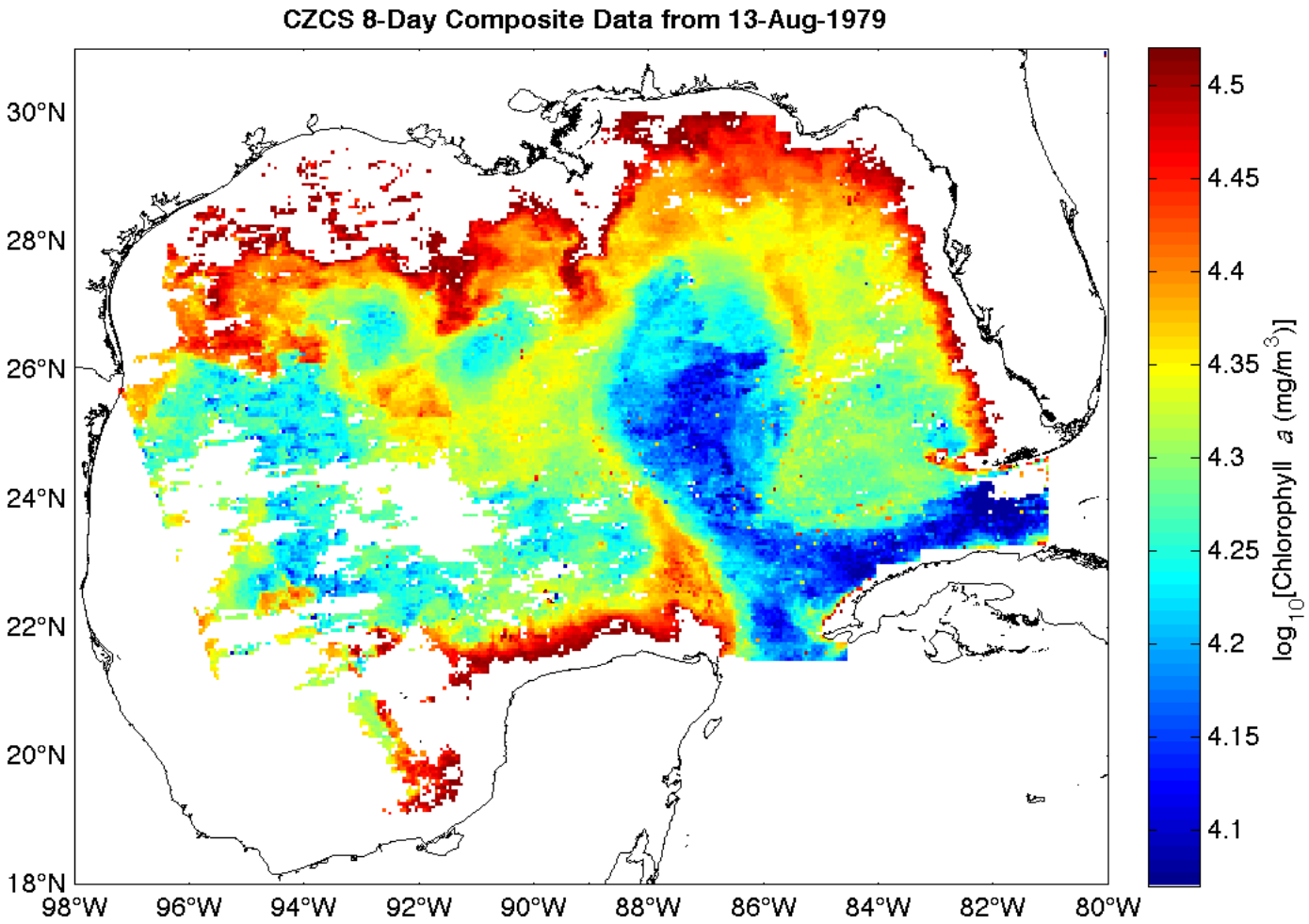
HMI/Eddy Watch Reports: LC and LCE frontal analyses from 4 Sep 1984–31 Dec 1992.

GEM Path and Configuration Files: GEM PnC files were overlaid on satellite images when available for further verification. (This is a confidential industry data set and will not be shown).

Altimetry: Objective tracking of LC separation events from 1993 through 2009. May be able to use Seasat, GEOSAT, and ERS-1 altimetry for specific separation events, e.g. 1992.

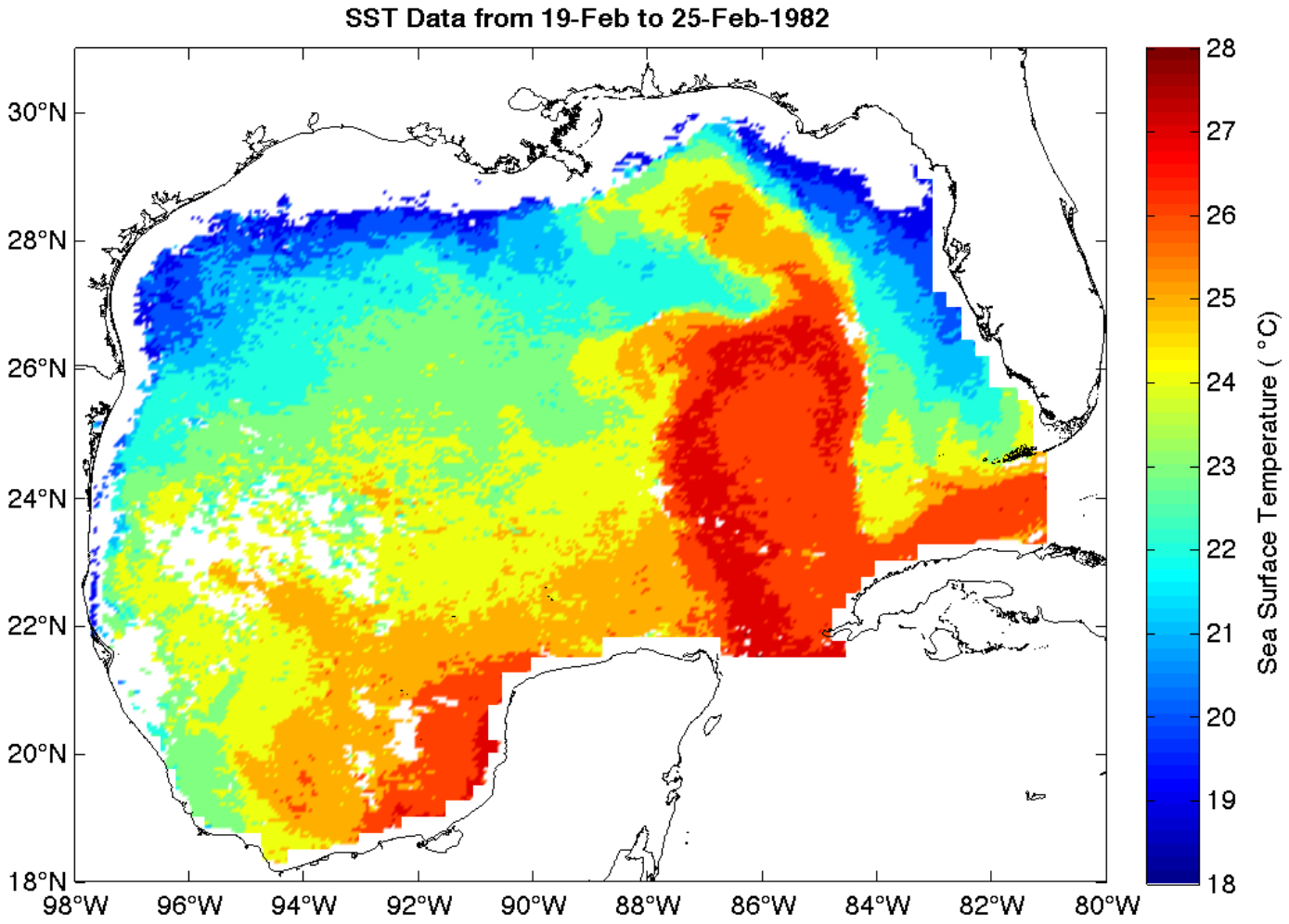
Coastal Zone Color Scanner (CZCS) Data

http://oceancolor.gsfc.nasa.gov/CZCS/czcs_processing/



Pathfinder SST – Version 5.1

http://podaac-old.jpl.nasa.gov/DATA_CATALOG/avhrrinfo.html

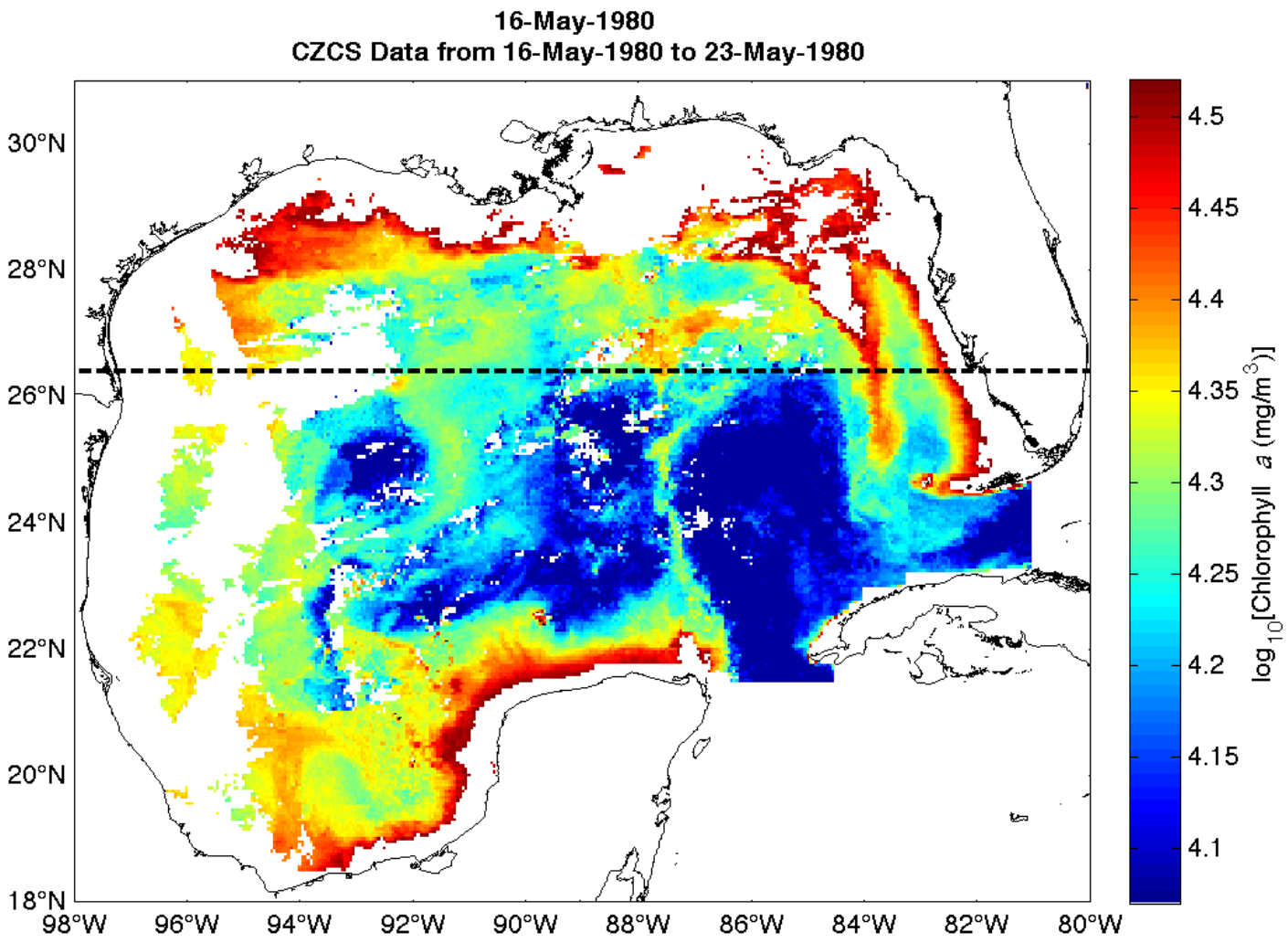


Methods

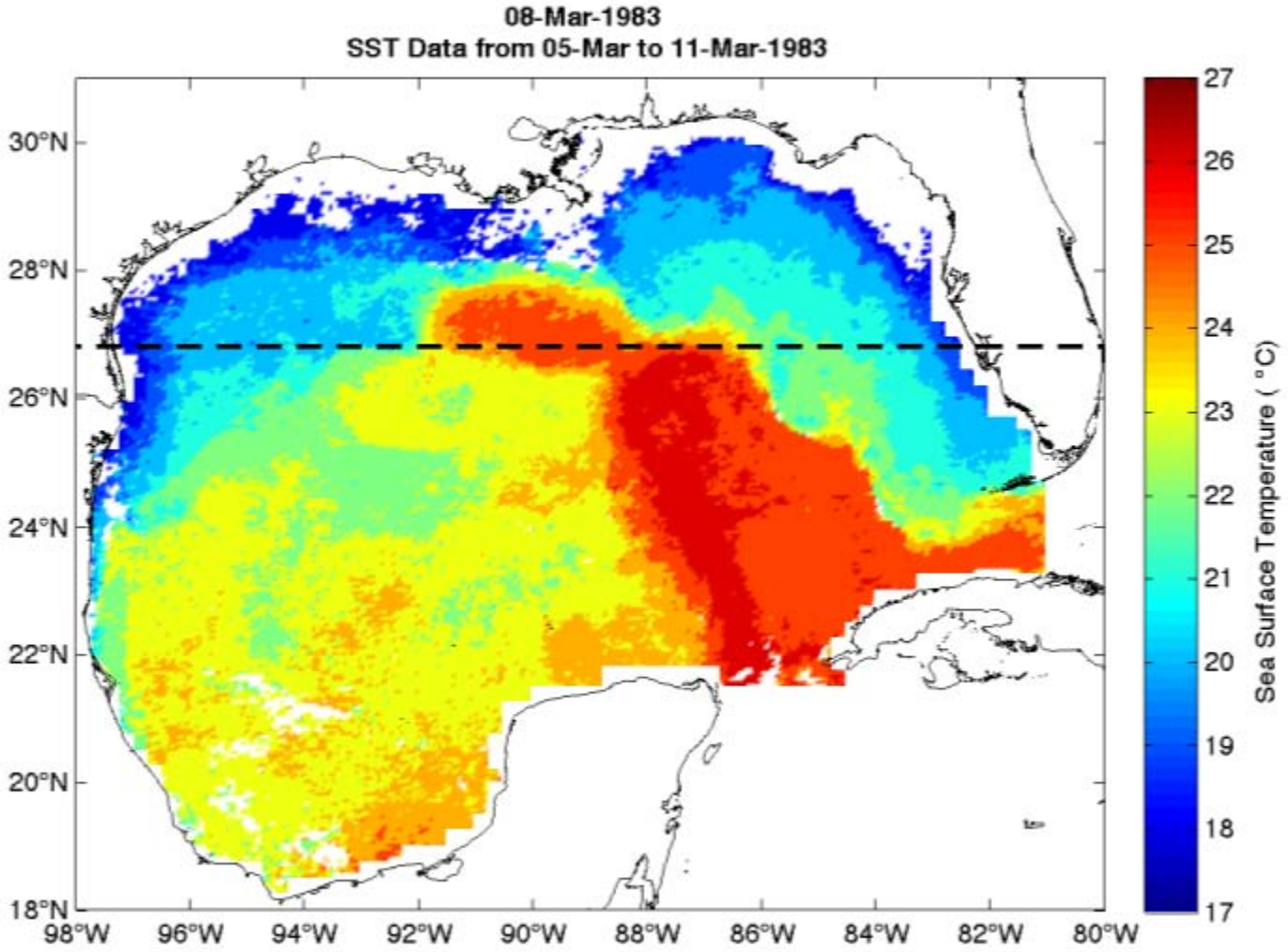
The combined time series of ocean color and SST images, HMI/EddyWatch charts, and GEM PnC files were used to *manually* identify LC separation events and LC retreat following separation.

- Care was taken to discriminate separation events from eddies detaching and reattaching to the LC.
- Animations of the available records were used as an aid in the identification process.
- Satellite coverage was sufficient to determine that there were no separation events in 1979.
- A separation event was identified in July 1978, but no retreat could be estimated. Separation of 1980a in February 1980.

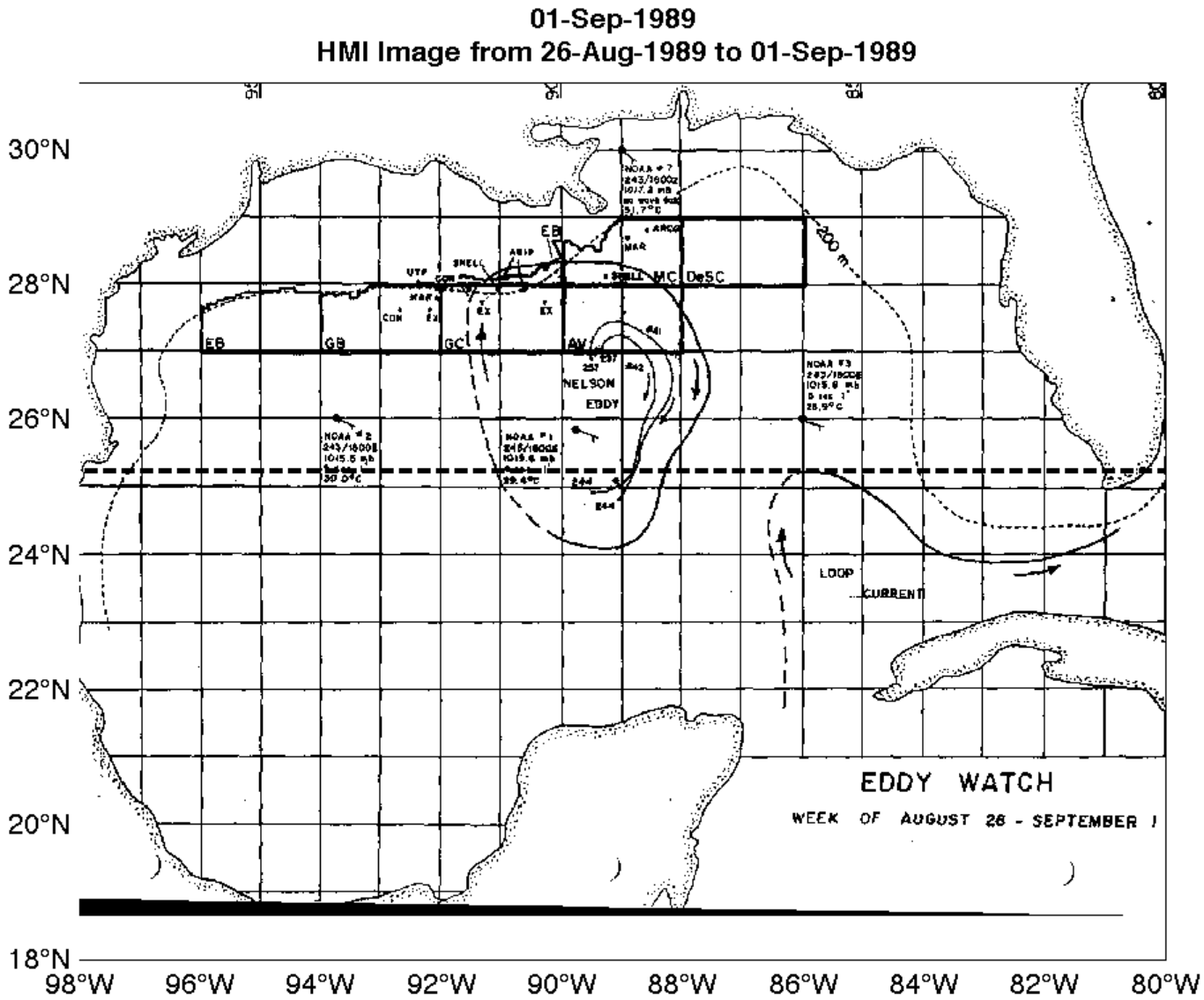
Sample Ocean Color Analysis: LCE 1980b



Sample SST Analysis: LCE 1983a

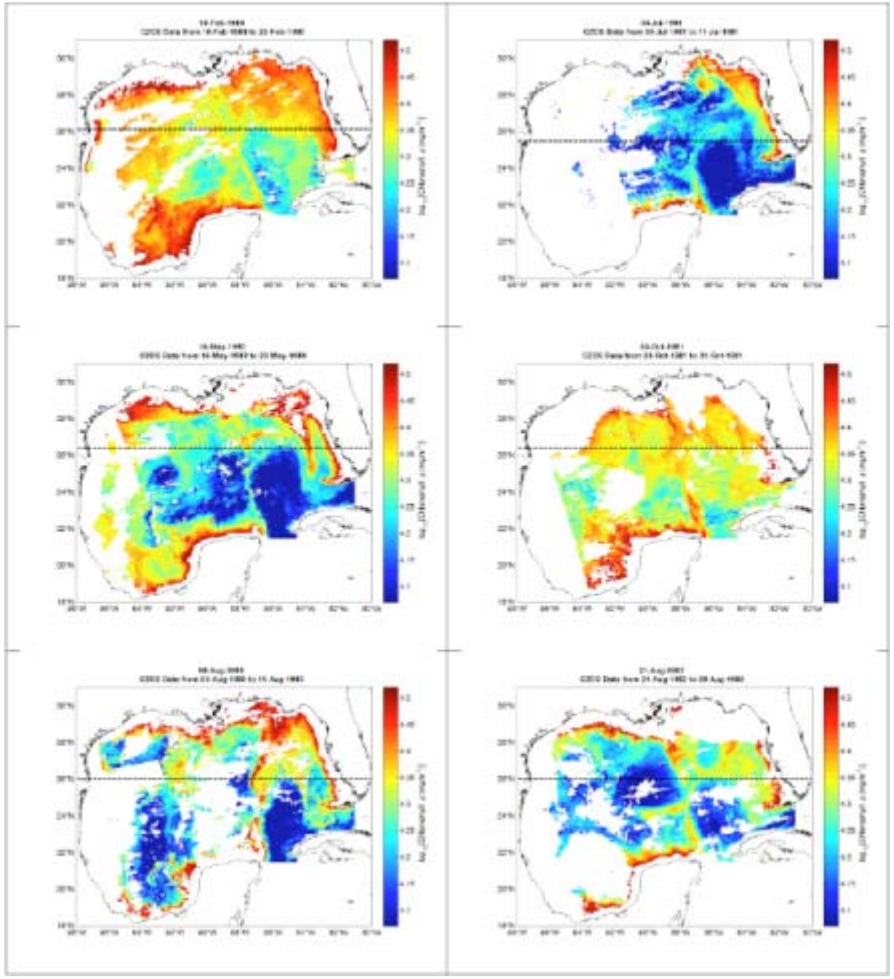


Sample Eddy Watch Analysis: LCE 1989

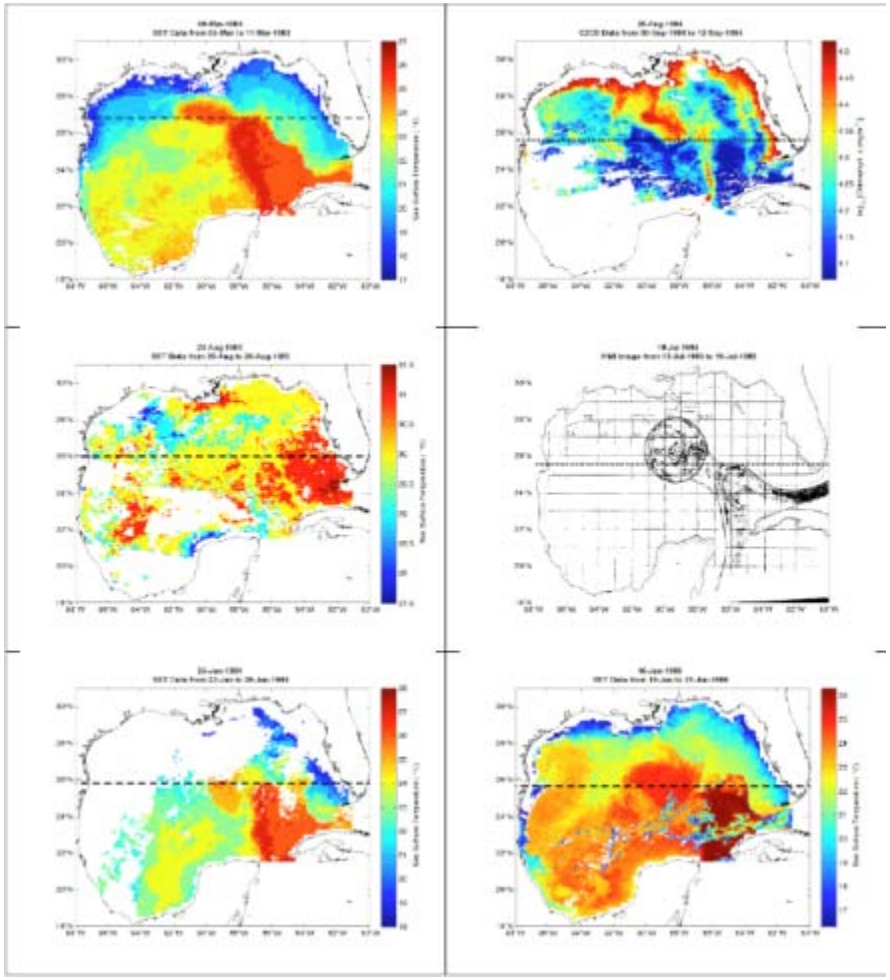


Reanalysis Results

1980a – 1982

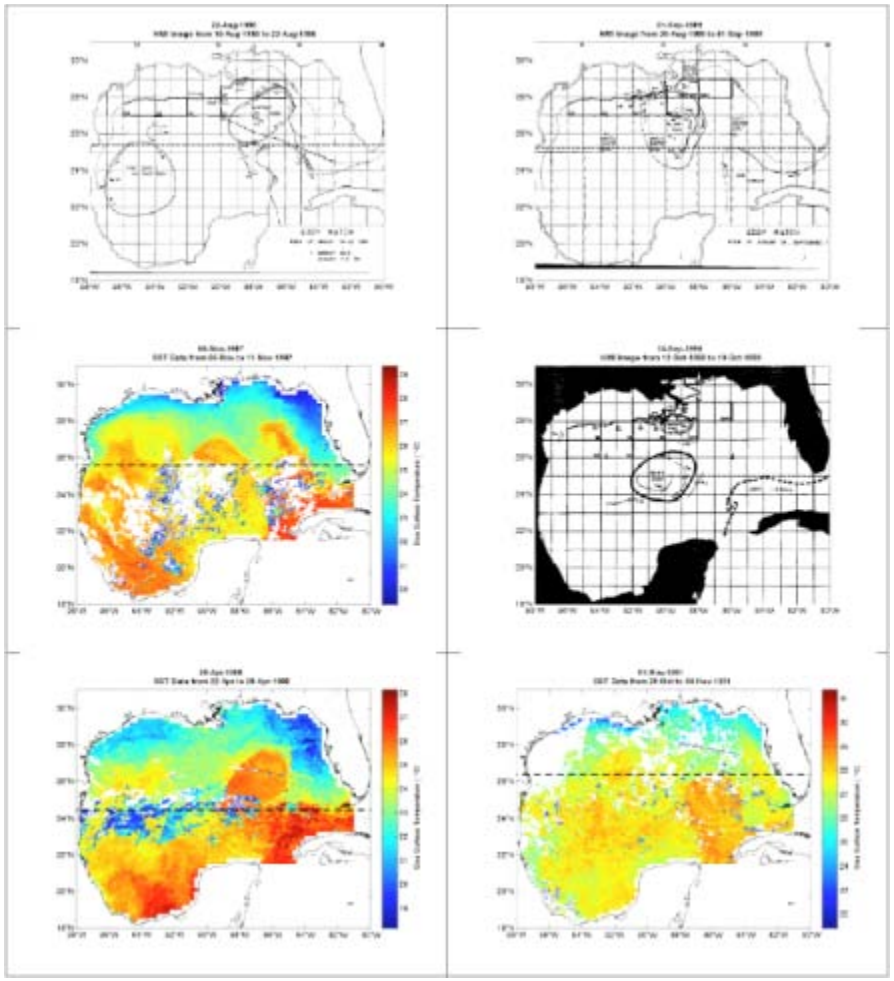


1983a – 1986a



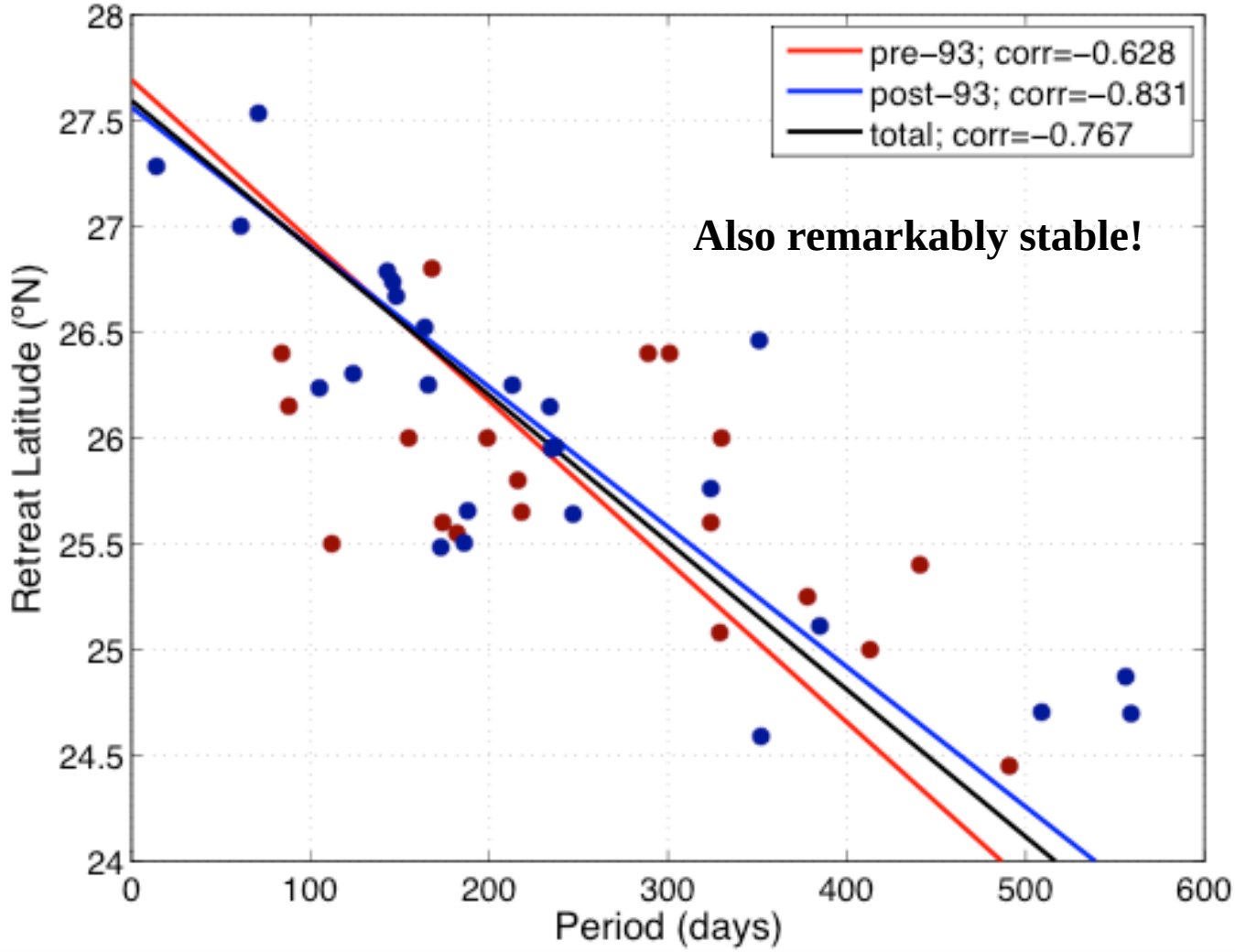
Reanalysis Results (cont.)

1986b – 1991



- A total of 18 separation events were identified in the 12-year pre-altimetry record 1980–1991.
- A total of 27 separation events were identified in the 18-year altimetry record 1992 through 2009.
- A total of 45 separation events over 30-year time period.
- 8-month average period is remarkably stable!

Stability of "Prediction" Regression Line



30-Year Record of Loop Current Eddy Separation Events

45 Events

LCE Separations 1980 – 1992

Table 1. Loop Current eddy separation period and retreat latitude from the pre-1993 observational record.

	Year-Letter	Industry Name	Source* and Separation Date	Separation Period (days)	Retreat Latitude (°N)	Confirmation Datasets
1	1980a		C 18-Feb-80		26.15	Color
2	1980b	minor?	C 16-May-80	88	26.39	Color
3	1980c		C 08-Aug-80	84	26.01	Color
4	1981a	minor?	C 04-Jul-81	330	25.52	Color
5	1981b		C 24-Oct-81	112	26.39	SST/Color
6	1982		C 21-Aug-82	301	25.99	SST/Color
7	1983a		A 08-Mar-83	199	26.80	SST/Color
8	1983b		A 23-Aug-83	168	26.02	SST/Color
9	1984a		A 25-Jan-84	155	25.80	SST/Color
10	1984b	Arnold	C 28-Aug-84	216	25.60	HMI/Color/SST
11	1985	Fast	H 18-Jul-85	324	25.55	HMI
12	1986a	Hot-Core	H 16-Jan-86	182	25.65	HMI/SST
13	1986b	Instant	H 22-Aug-86	218	25.40	HMI/SST
14	1987	Kathleen	A 06-Nov-87	441	25.60	SST
15	1988	Murphy	H 28-Apr-88	174	24.42	HMI
16	1989	Nelson	H 01-Sep-89	491	25.25	HMI
17	1990	Quiet	H 14-Sep-90	378	25.00	HMI/SST ?
18	1991	Triton	H 01-Nov-91	413	26.40	HMI/SST
19	1992	Unchained	E 16-Aug-92	389	25.08	Altimetry

***Source Key: C – color, A – AVHRR SST, H – HMI/EddyWatch, E – ERS-1 altimetry.**

LCE Separations 1993 – 2009

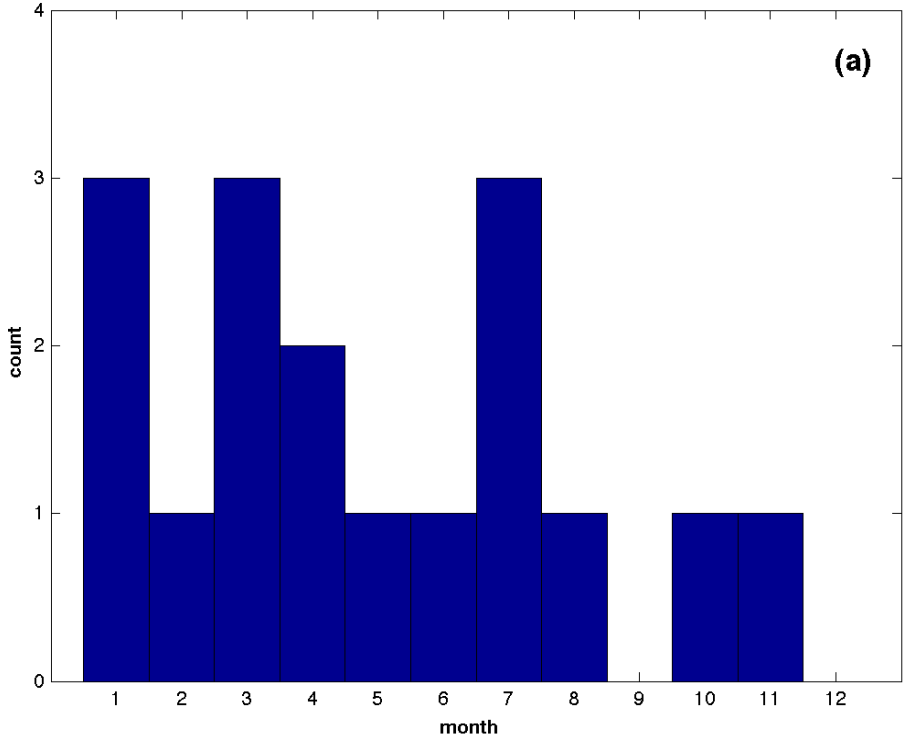
Table 2. Loop Current eddy separation period and retreat latitude from the altimetric record – 1993 through 2009.

	Year-Letter	Industry Name	Separation Date	Separation Period (days)	Retreat Latitude
1	1993a	Whopper	11-Jul-93	329	27.001
2	1993b	Xtra	10-Sep-93	61	26.460
3	1994	Yucatan	27-Aug-94	351	26.148
4	1995a	Zapp	18-Apr-95	234	26.787
5	1995b	Aggie	08-Sep-95	143	25.655
6	1996a	Biloxi	14-Mar-96	188	26.249
7	1996b	Creole	13-Oct-96	213	24.591
8	1997	El Dorado	30-Sep-97	352	25.484
9	1998	Fourchon	22-Mar-98	173	24.698
10	1999	Juggernaut	02-Oct-99	559	24.872
11	2001a	Millennium	10-Apr-01	556	25.761
12	*2001b*	*O/N**	*21-Sep-01*		†
13	2002a	Pelagic	28-Feb-02	324	27.283
14	2002b	Quick	14-Mar-02	14	24.705
15	2003a	Sargassum	05-Aug-03	509	26.670
16	2003b	Titanic	31-Dec-03	148	25.958
17	2004	Ulysses	24-Aug-04	237	25.111
18	2005	Vortex	13-Sep-05	385	26.738
19	2006a	Walker	06-Feb-06	146	27.534
20	2006b	Xtreme	18-Apr-06	71	26.522
21	2006c	Yankee	29-Sep-06	164	25.641
22	2007a	Zorro	03-Jun-07	247	26.251
23	2007b	Albert	16-Nov-07	166	26.237
24	2008a	Brazos	06-Mar-08	111	26.266
25	2008b	Cameron	30-Jun-08	116	25.988
26	2009a	Darwin	05-Mar-09	248	25.754
27	2009b	Ekman	27-Aug-09	175	26.076

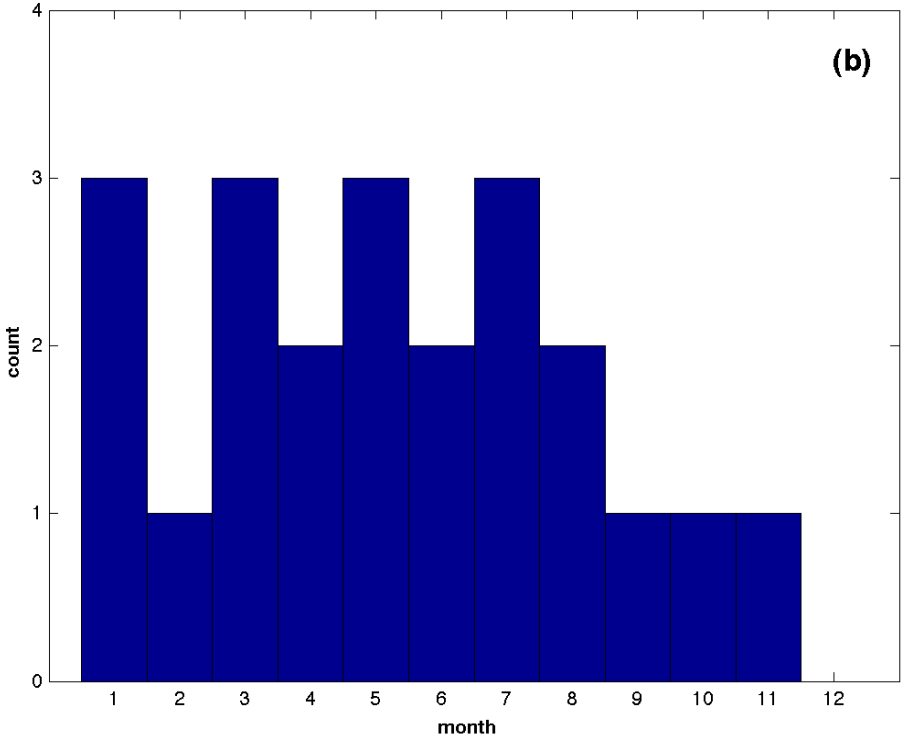
NOTES:
* Separation event edited from list published in Leben (2005).
† Retreat latitude after separation of 2001a (Millennium).

No seasonal preference for LC eddy separation:

Vukovich (1988)



Sturges (1993)

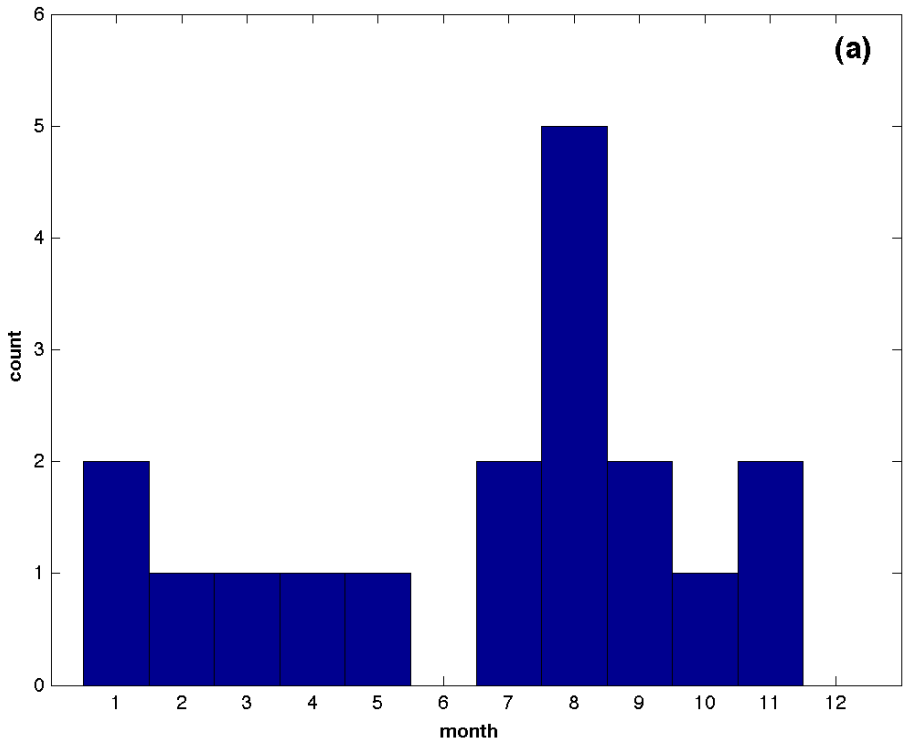


Comparison of Select Reanalysis Separation Dates with those from Vukovich (1988) and Sturges (1993)

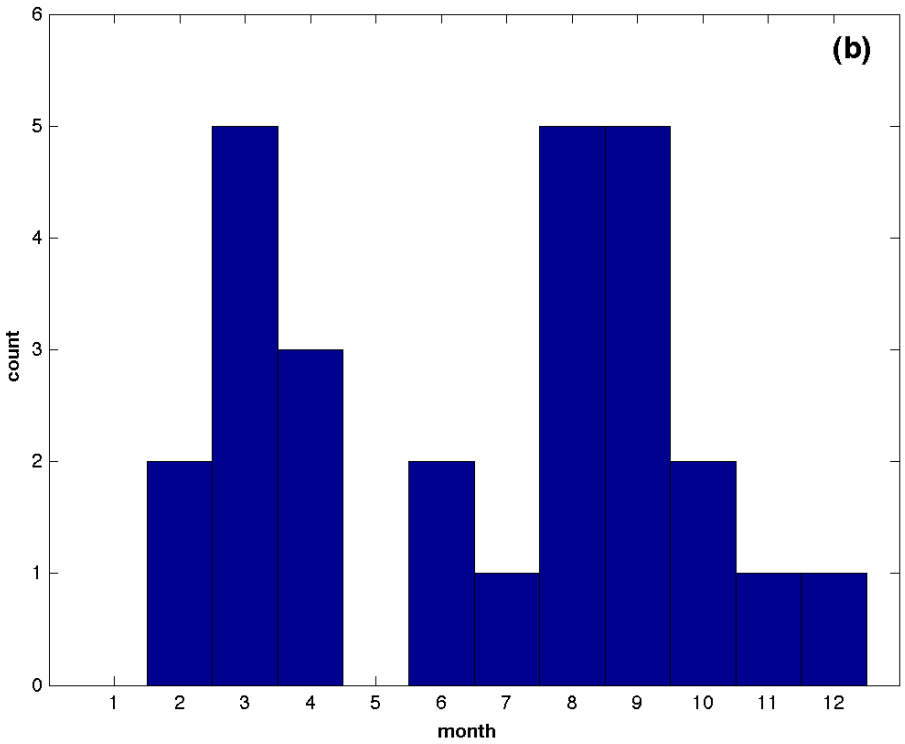
No.	Year-Letter	Industry Name	Reanalysis	Vukovich (1988) *
1	1980a	-	18 February 1980	January 1980
2	1980b	-	16 May 1980	-
3	1980c	-	08 August 1980	-
4	1981a	-	04 July 1981	March 1981
5	1981b	-	24 October 1981	-
6	1982	-	21 August 1982	May 1982
7	1983a	-	08 March 1983	March 1983
8	1983b	-	23 August 1983	-
9	1984a	-	25 January 1984	February 1984
10	1984b	Arnold	28 August 1984	-
11	1985	Fast	18 July 1985	July 1985
12	1986a	Hot Core	16 January 1986	January 1986
13	1986b	Instant	22 August 1986	October 1986
14	1987	Kathleen	06 November 1987	November 1987
				Sturges (1993) §
15	1988	Murphy	28 April 1988	June 1988
16	1989	Nelson	01 September 1989	May or June 1989
-	-	-	-	July 1990 †
17	1990	Quiet	14 September 1990	September 1990

Reanalysis

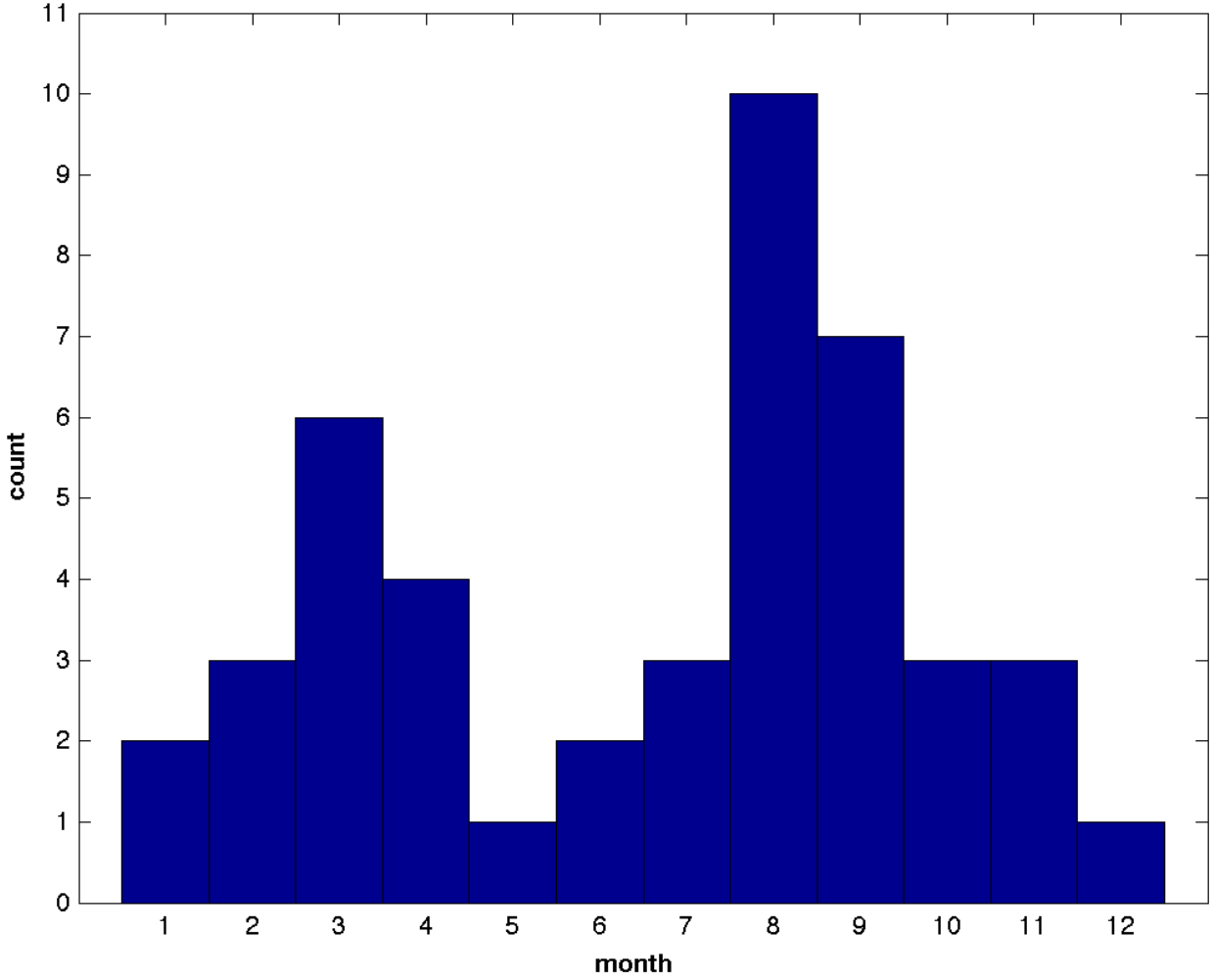
“Pre-Altimetry” 1980 – 1992



“Altimetry” 1993 – 2009

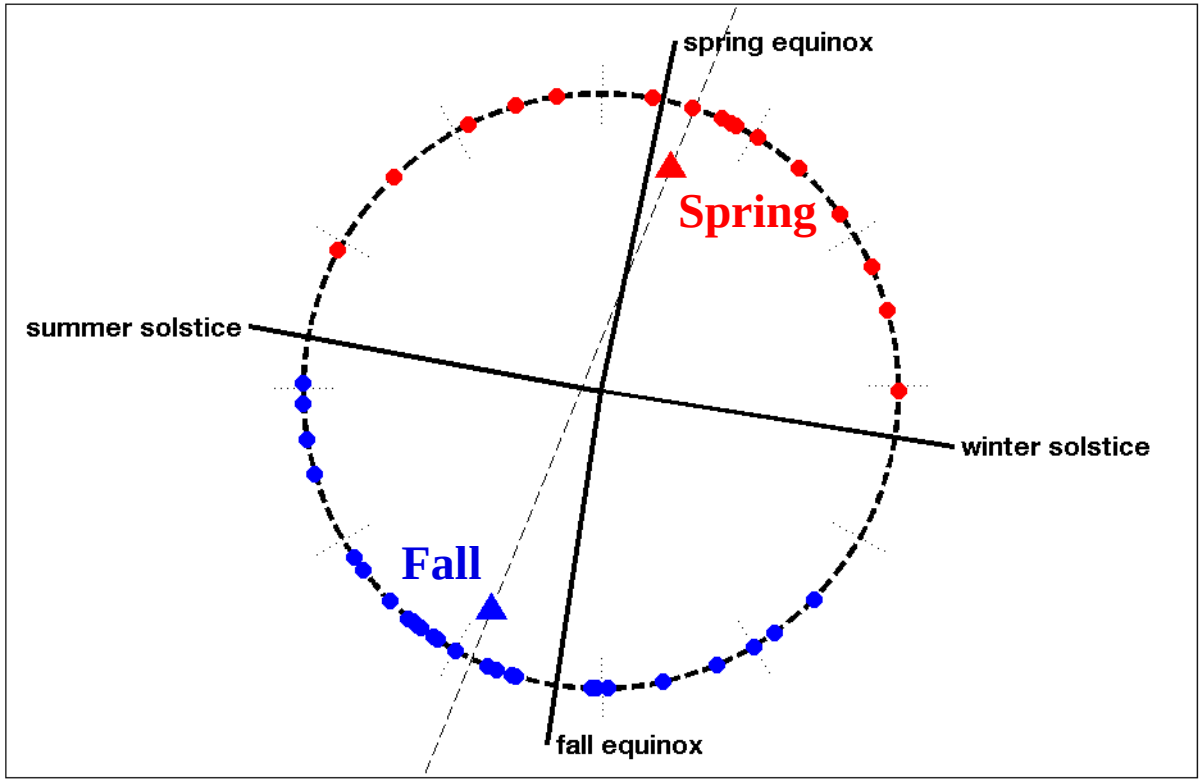


30-Year Record Monthly Histogram



LC Separation "Season" Statistical Analysis

The "two" separation seasons were determined objectively using a 2-mean clustering analysis based on circular statistics.



Spring Statistics:

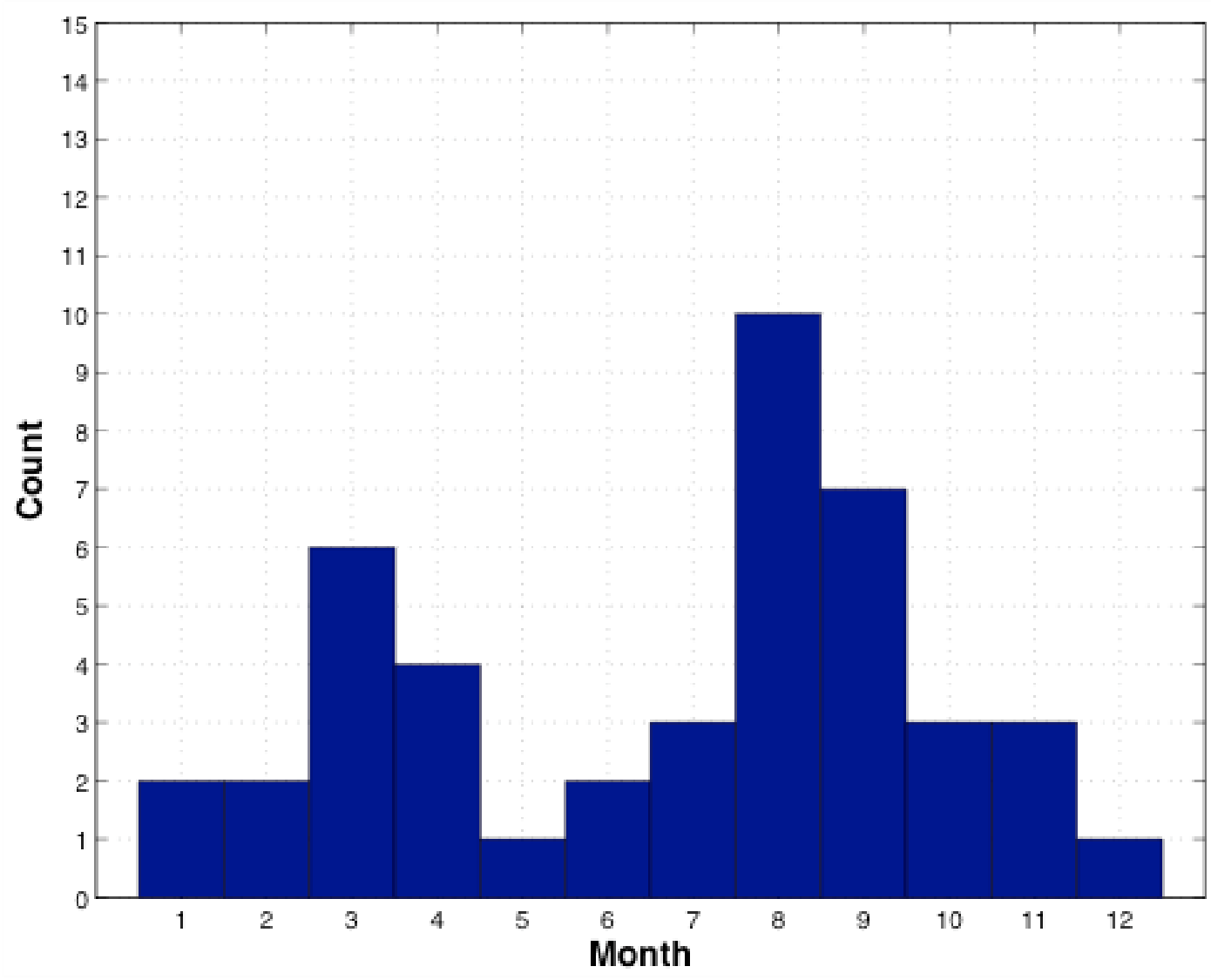
- 18 events
- mean: March 15
- std dev: 38 days
- average separation period: 192 days

Fall Statistics:

- 27 events
- mean: August 30
- std dev: 34 days
- average separation period: 279 days

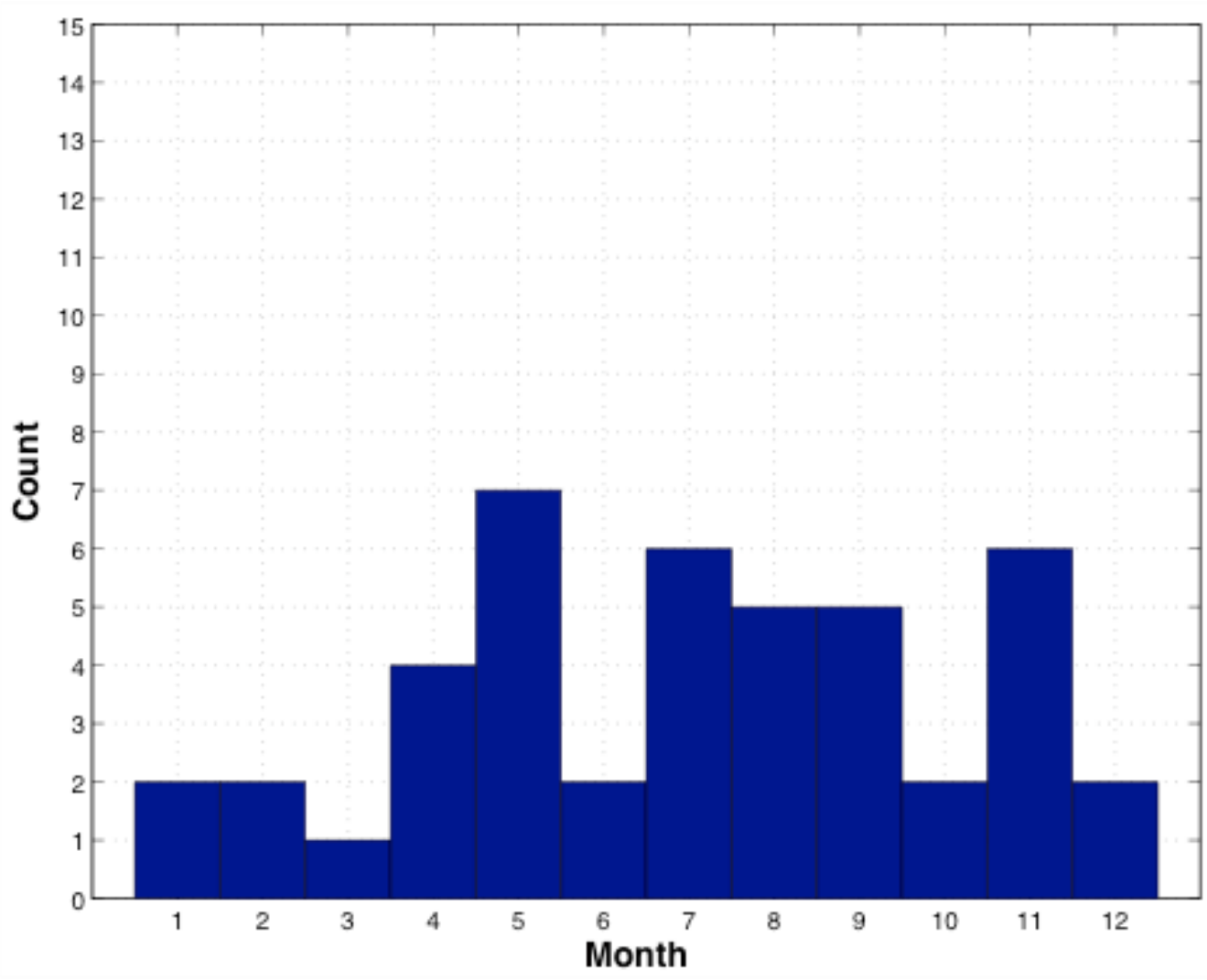
30-Year Record Monthly Histogram

Observed

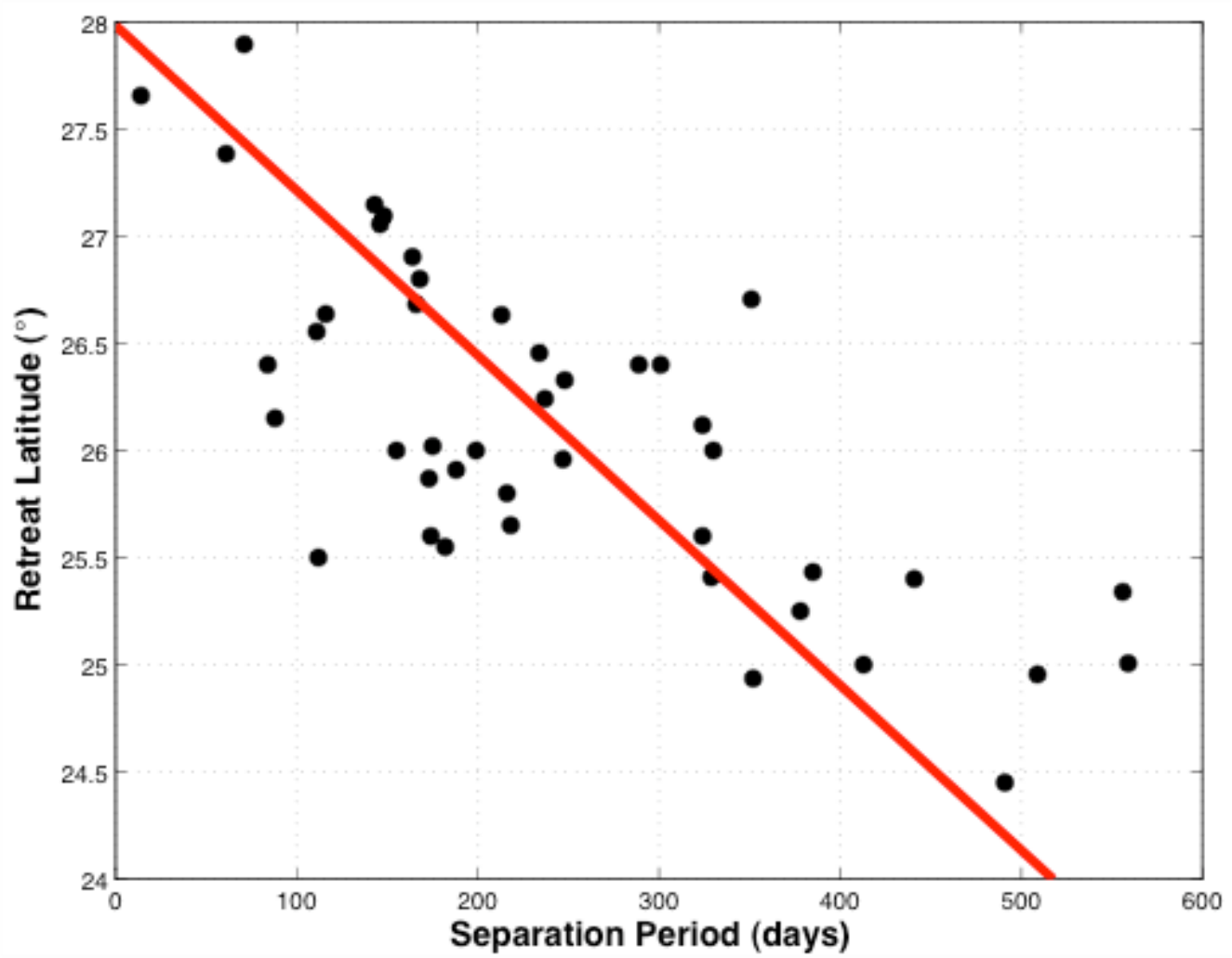


30-Year Record Monthly Histogram

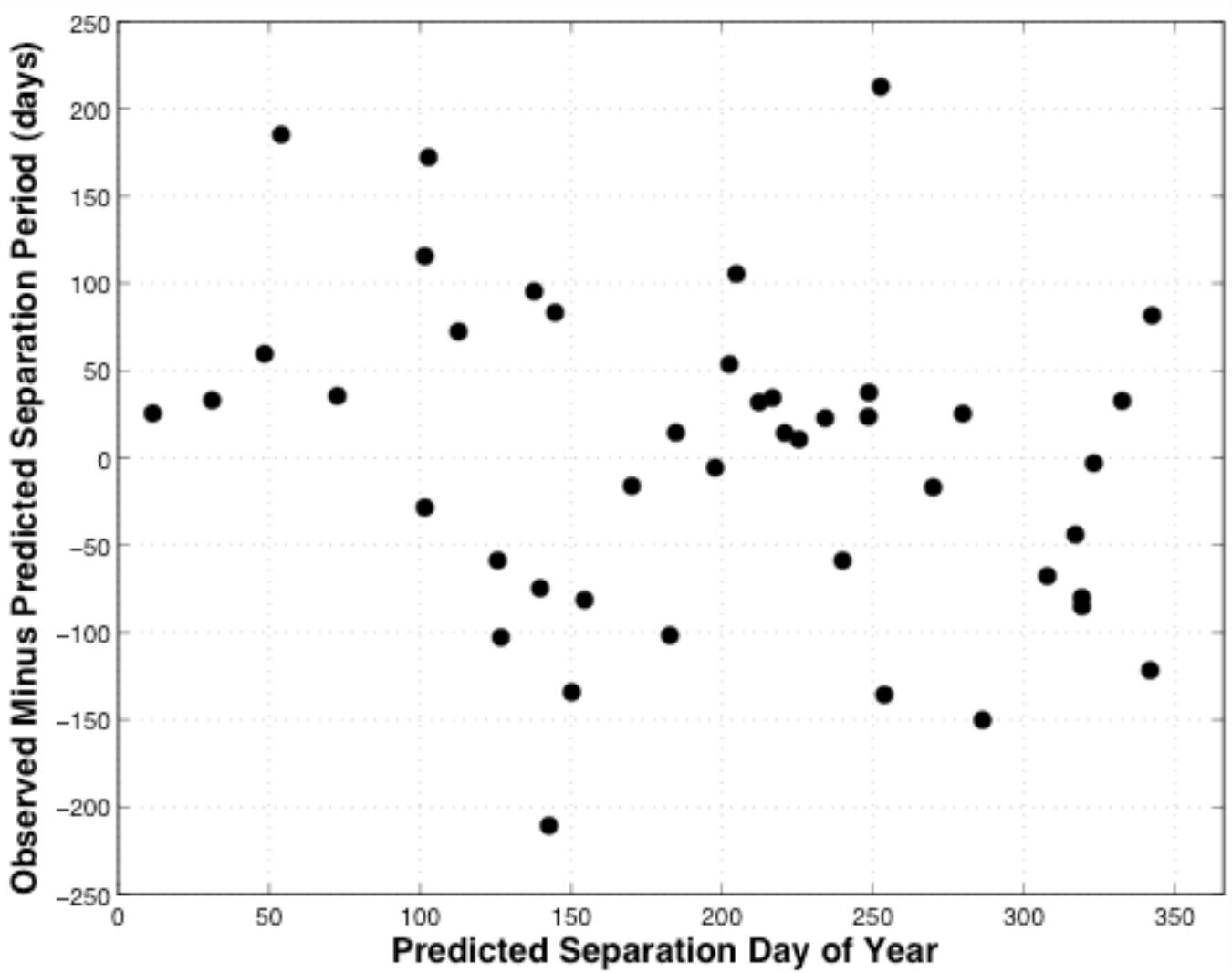
"Latitude Retreat" Predicted Separation Dates



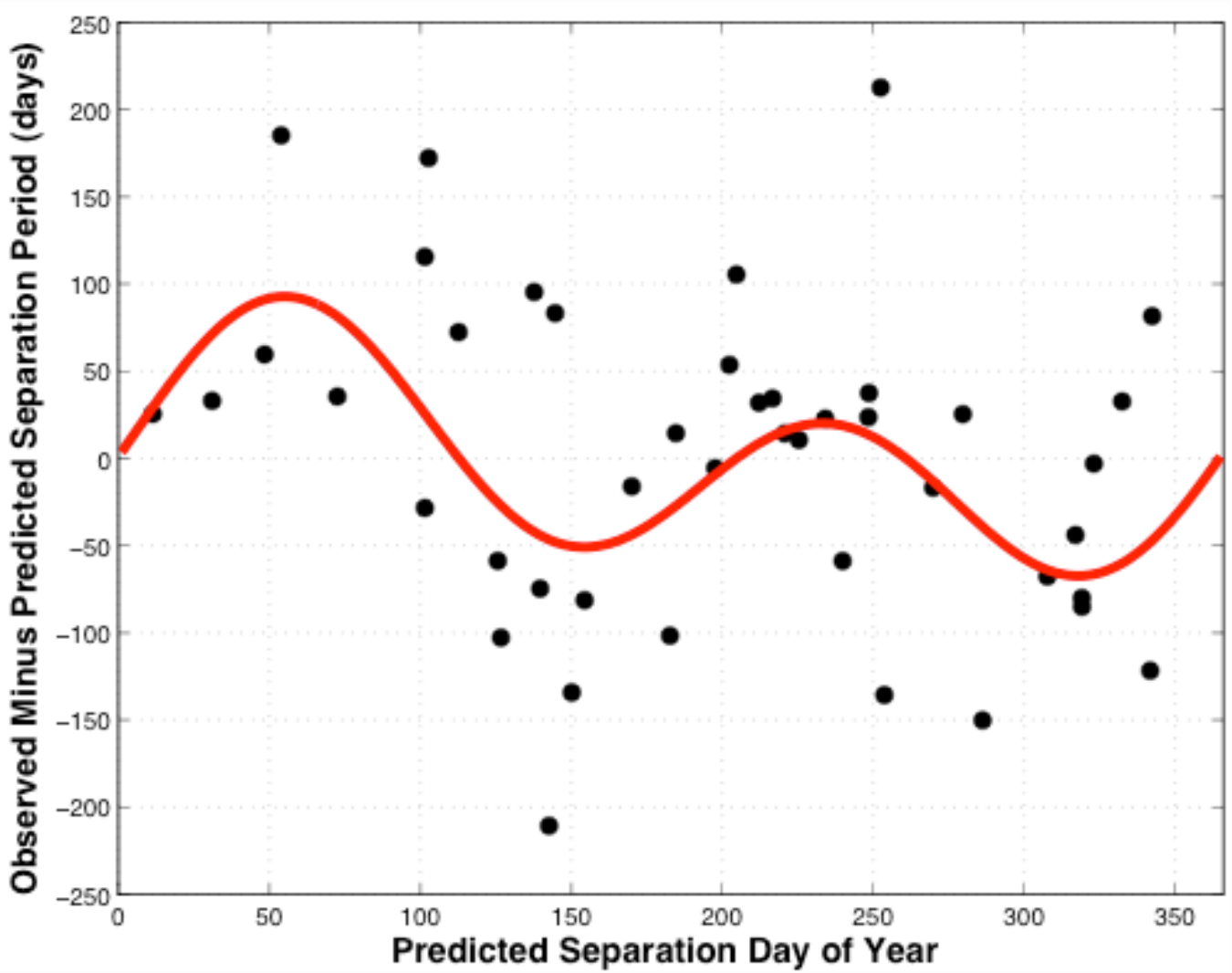
“Prediction” Linear Model



Observed Minus Predicted Error

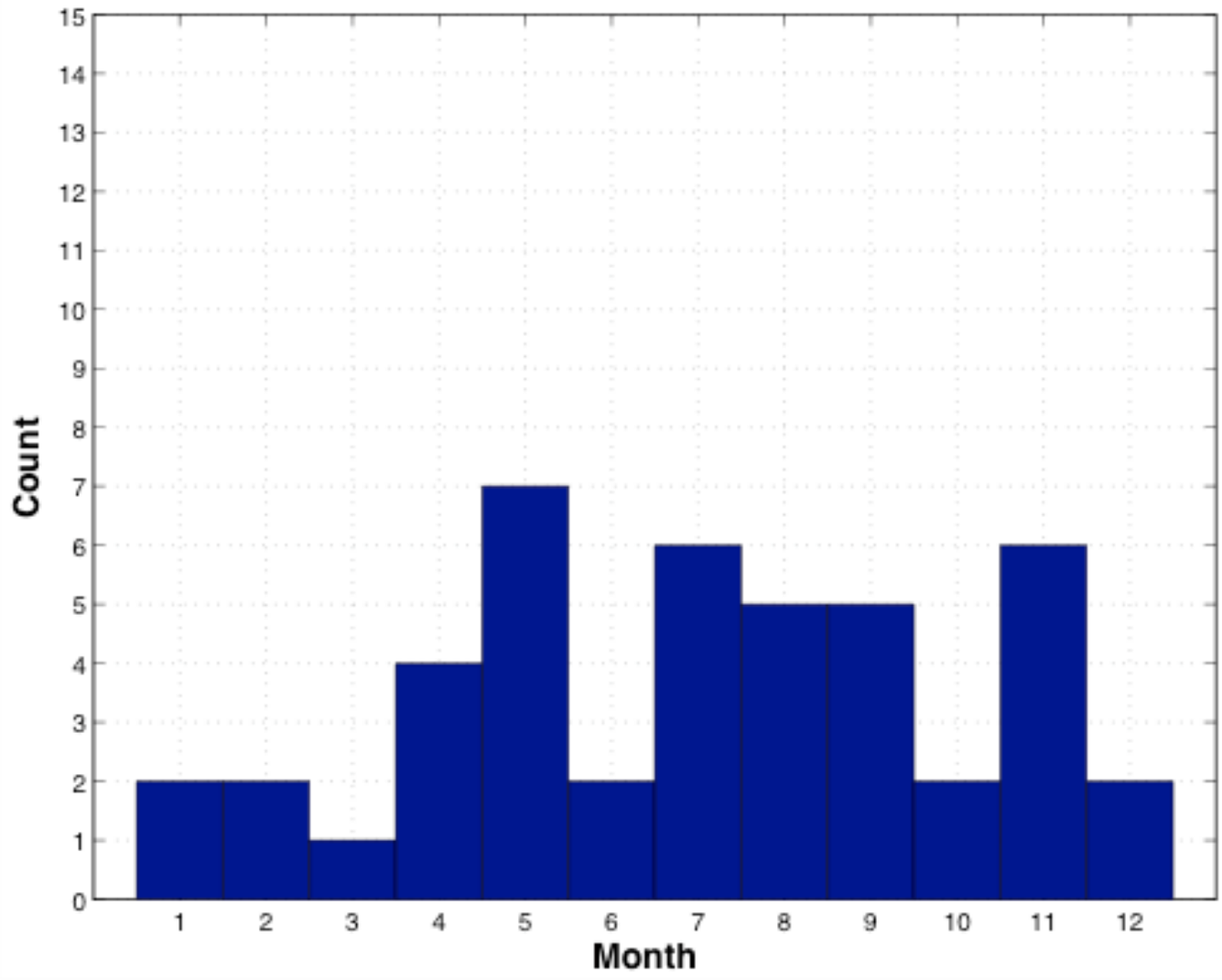


Observed Minus Predicted Error



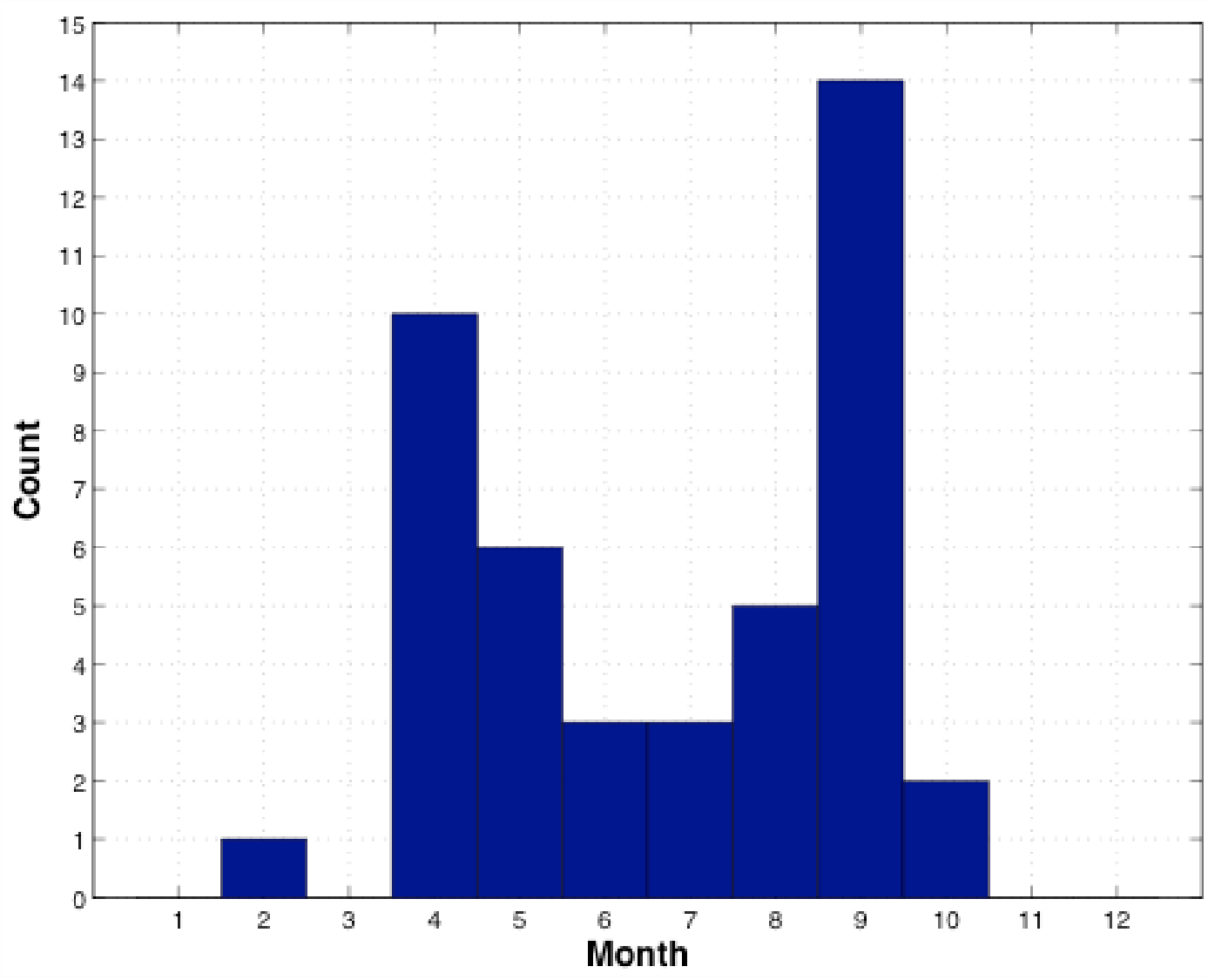
30-Year Record Monthly Histogram

“Latitude Retreat” Predicted



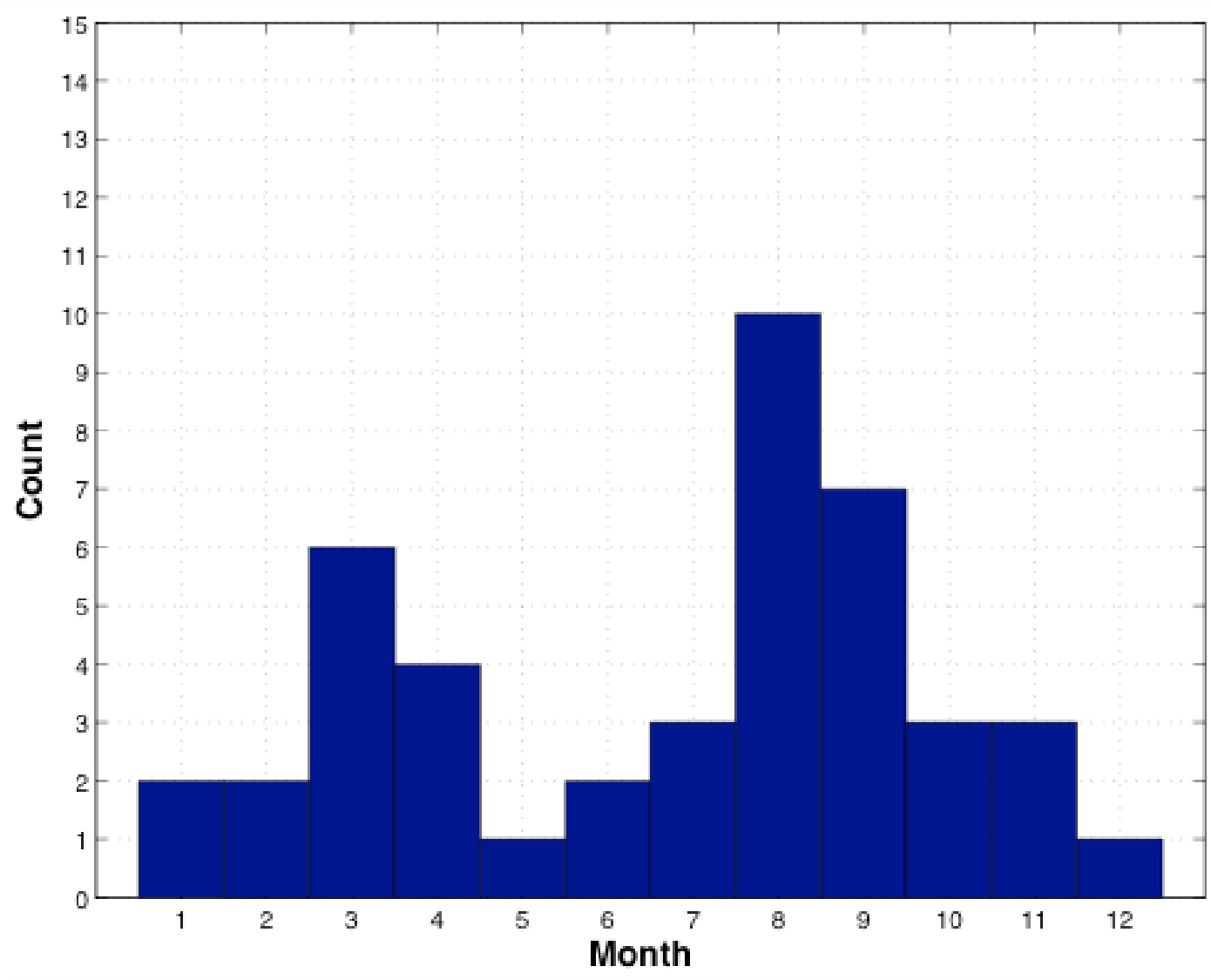
30-Year Record Monthly Histogram

"Latitude Retreat plus Seasonal Correction" Predicted



30-Year Record Monthly Histogram

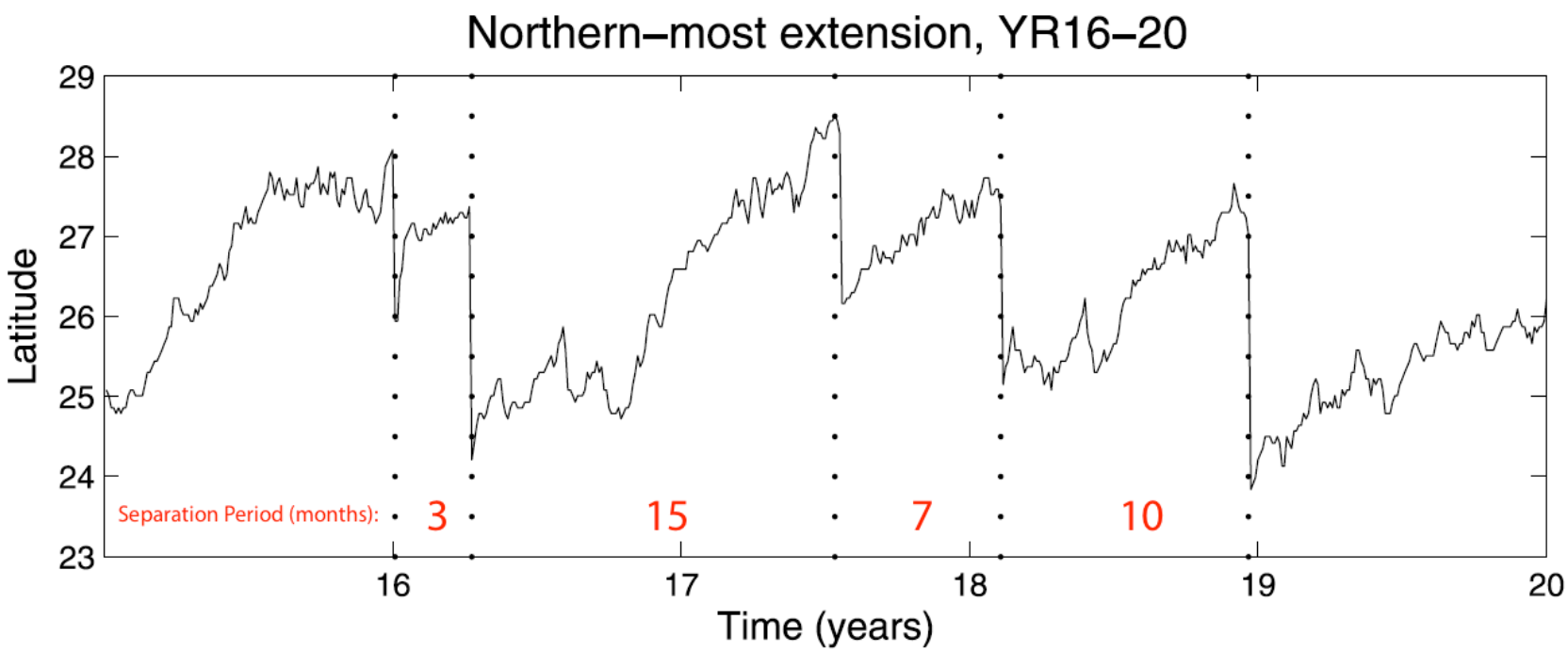
Observed



How Does a Model Do?

See Romanou, Chassignet, and Sturges (2004).

ROMANOU ET AL.: GULF OF MEXICO CIRCULATION FROM A LAYER MODEL



Acknowledgments

Support for RRL, CAH, and NGH from BOEMRE Contracts M08PC20043 and M10PC00112 to Science Applications International Corporation and from NASA Ocean Surface Topography Mission Science Team Grant NNX08AR60G is gratefully acknowledged.

Discussions with Cortis Cooper and George Forristall contributed substantially to the genesis of this work, as did funding and guidance from the Climatology and Simulation of Eddies/Eddy Joint Industry Project (CASE/EJIP).

References

Leben, R.R. 2005. Altimeter-derived Loop Current metrics. In: Sturges, W. and A. Lugo-Fernández, eds. Circulation in the Gulf of Mexico: Observations and Models. AGU Geophysical Monograph 161. Pp. 181–202.

Lugo-Fernández, A. and A. Badan. 2007. On the vorticity cycle of the Loop Current. Journal of Marine Research 65: 471–489.

Lugo-Fernández, A. and R.R. Leben. 2010. On the linear relationship between Loop Current retreat latitude and eddy separation period. Journal of Physical Oceanography 40:2778–2784, doi: 0.1175/2010JPO4354.1.

Romanou, A., E.P. Chassignet, and W. Sturges. 2004. Gulf of Mexico circulation within a high-resolution numerical simulation of the North Atlantic Ocean. Journal of Geophysical Research 109(C01003), doi:10.1029/2003JC001770.

Sturges, W. 1993. The annual cycle of the Western Boundary Current in the Gulf of Mexico. Journal of Geophysical Research 98(C10):18053–18068.

Sturges, W., N.G. Hoffmann, and R.R. Leben. 2010. A trigger mechanism for Loop Current ring separations. Journal of Physical Oceanography 40:900–913, doi: 10.1175/2009JPO4245.1.

Vukovich, F.M. 1988. Loop Current boundary variation. Journal of Geophysical Research 93(C12):15585–15591.