Back to the Future: Elkhorn Coral Returns to Texas Reefs after 6,000-Year Hiatus

William F. Precht

Battelle Memorial Institute

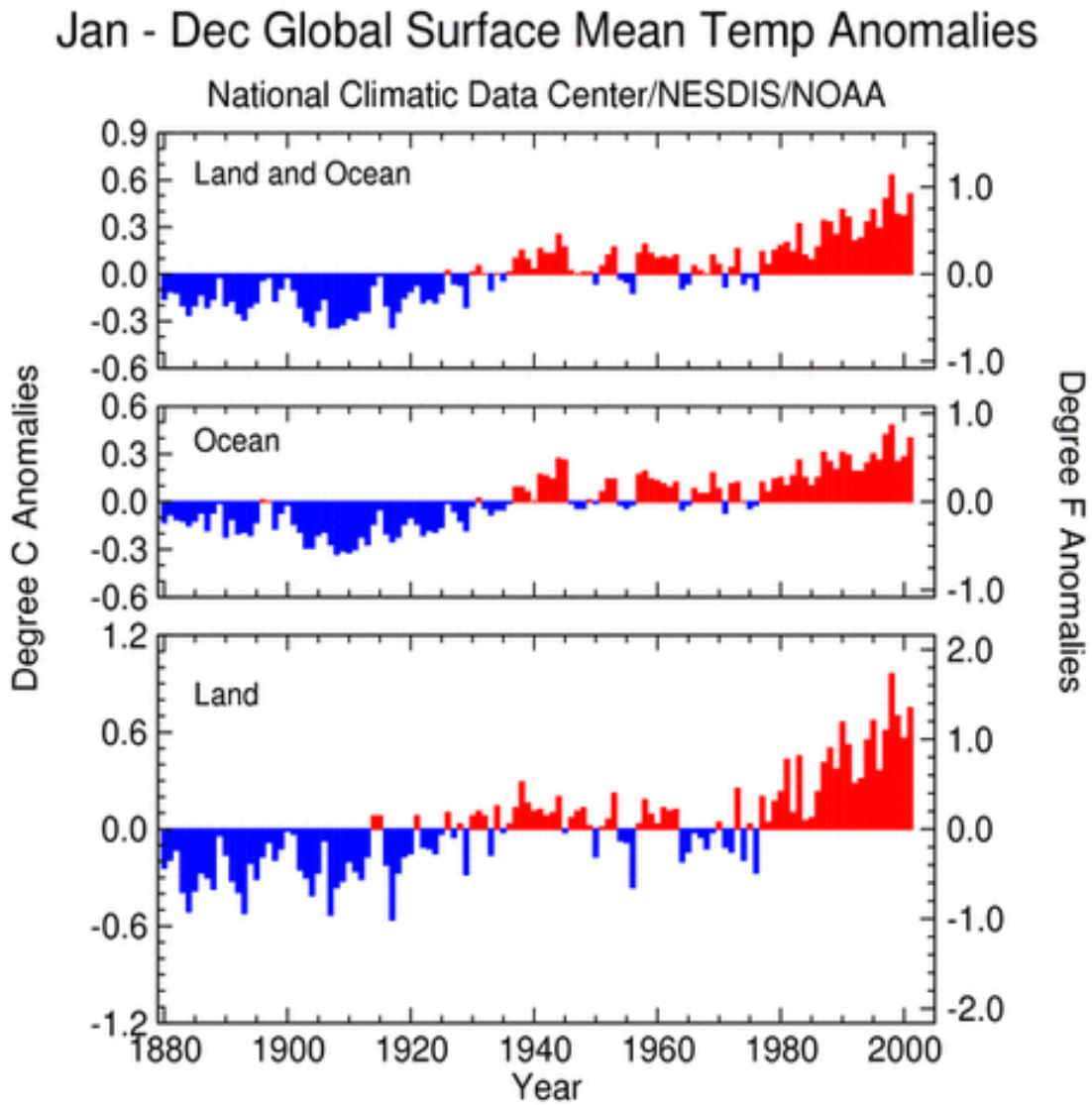
Ken J. P. Deslarzes

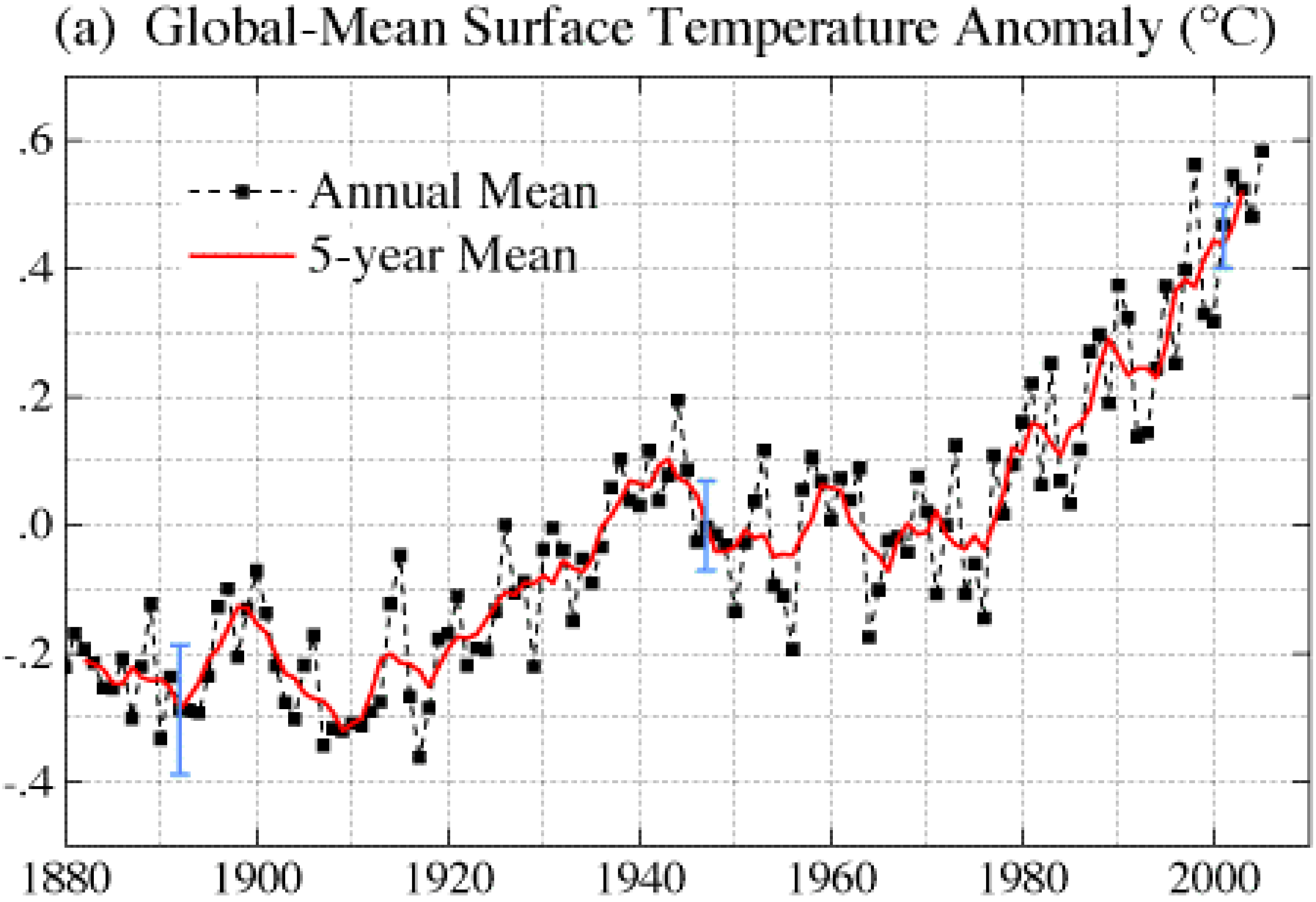
Geo-Marine, Inc.

Richard B. Aronson

Dauphin Island Sea Lab

- Perched atop salt domes
- Northernmost coral reefs in the continental United States
- Reef foundation formed by large, stony corals (e.g. brain and star corals)
- About 23 coral species
- Over 850 other reef invertebrate species
- ~250 fish species
- 125+ algae species

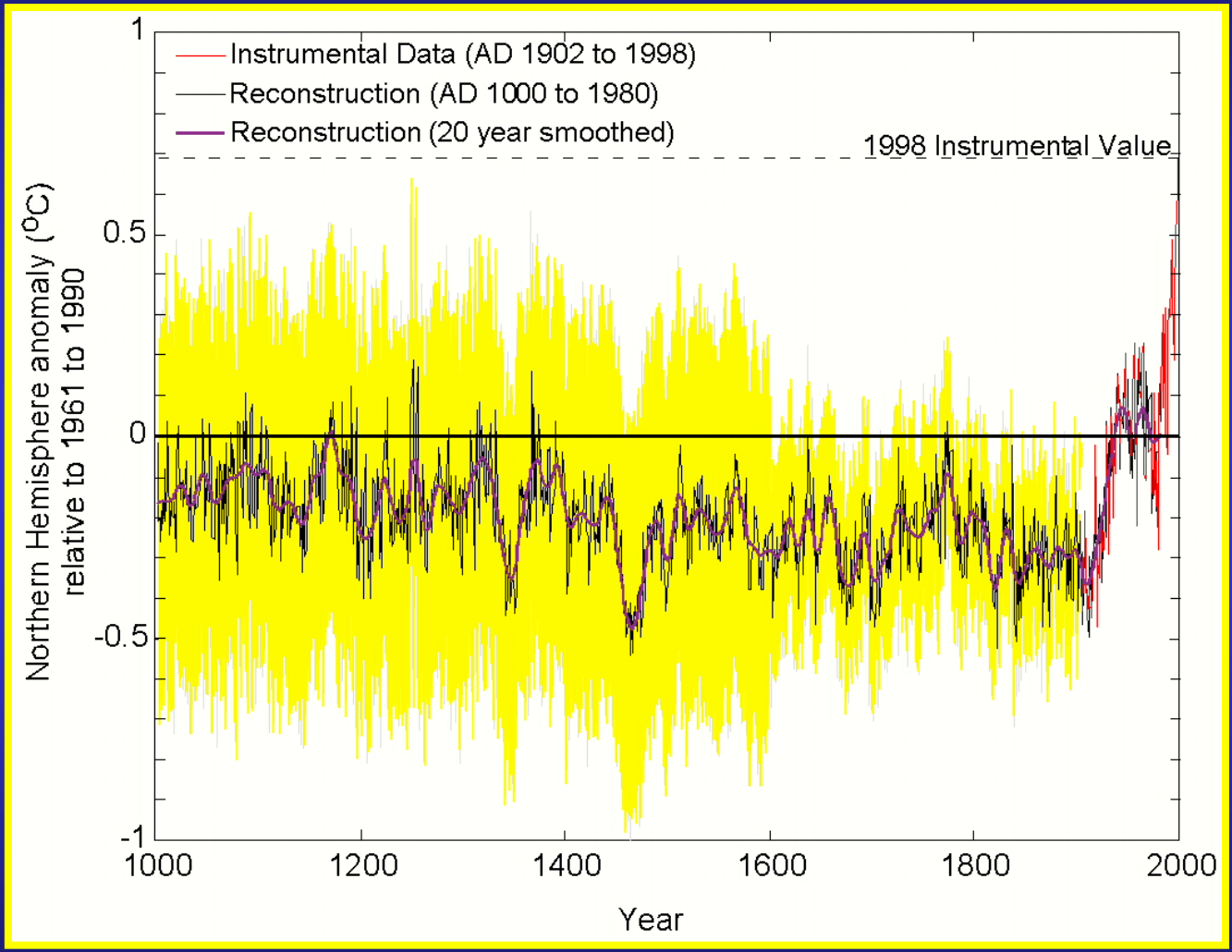

Jan - Dec Global Surface Mean Temp Anomalies
National Climatic Data Center/NESDIS/NOAA
Land and Ocean
Ocean
Land
Degree C Anomalies
Degree F Anomalies
0.9
0.6
0.3
0.0
-0.3
-0.6
1.2
-1.2
1.0
2.0
-1.0
-2.0
1880
1900
1920
1940
1960
1980
2000
Year


(a) Global-Mean Surface Temperature Anomaly (°C)
Annual Mean
5-year Mean
.6
.4
.2
.0
-.2
-.4
1880
1900
1920
1940
1960
1980
2000

NOAA

Is Recent Warming Unusual?

- Recent warm decades unprecedented in last 1,000 years

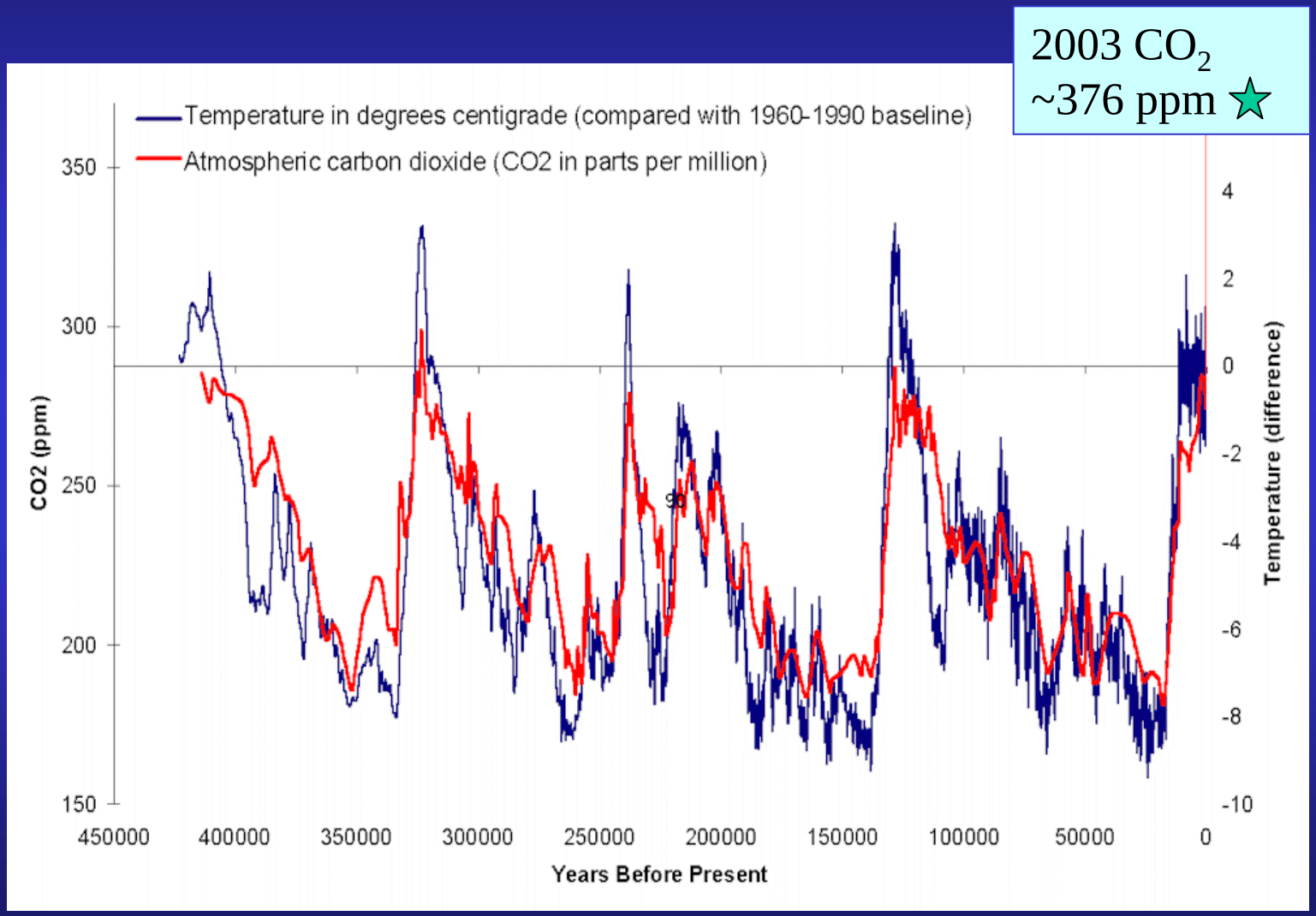


After Mann et al. 1999

Past Climate Change

CO_2 levels have not exceeded 350 ppm since the Miocene (~24 my ago)—when coral/algal reef development increased

Petit et al. 1999



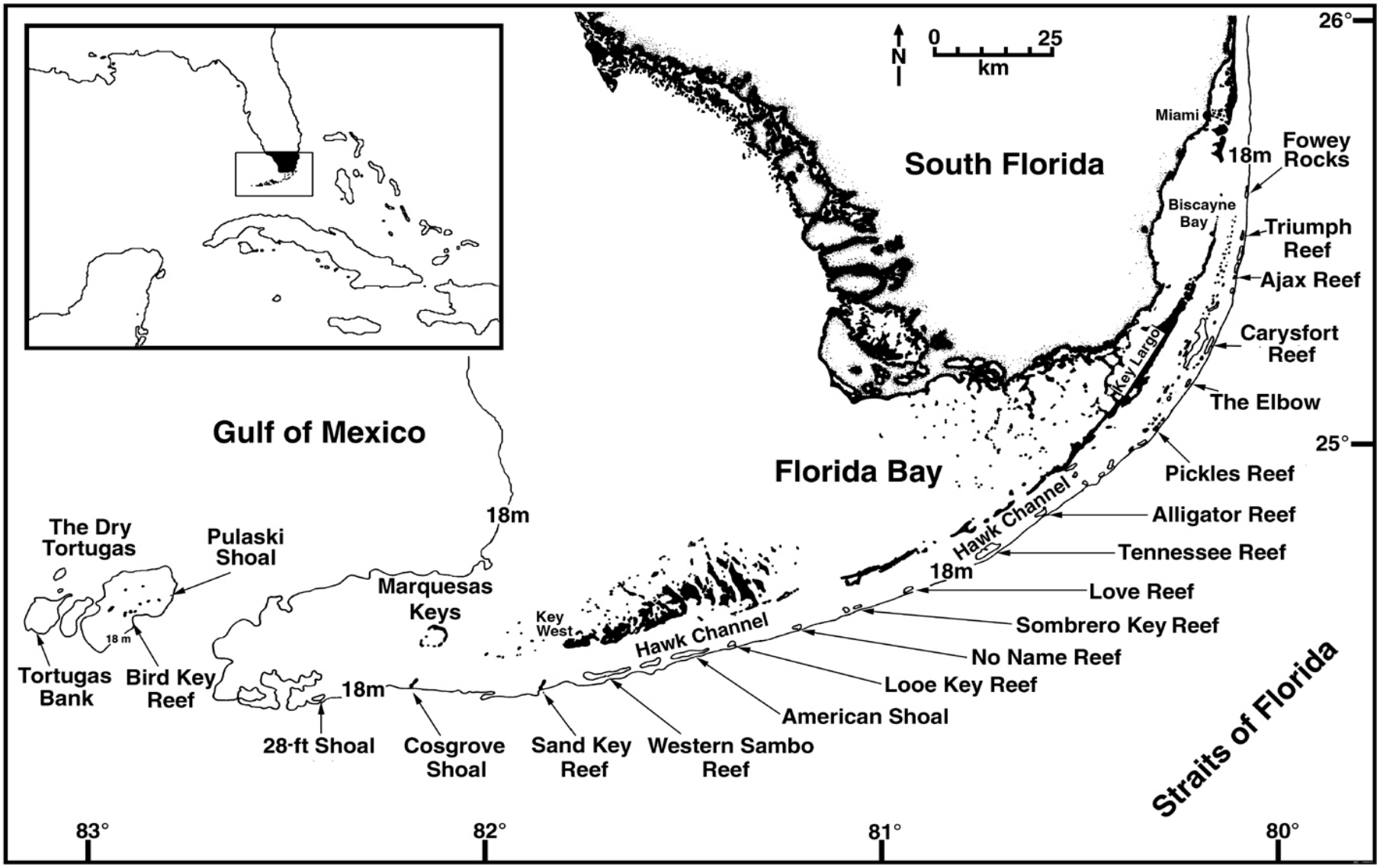
Biological Response

- The fingerprint of global climate change can be mapped via the response of species to changes in their physiographic environmental settings.
- In terrestrial systems, numerous species have recently responded to warming trends by expanding their ranges to higher latitudes, as well as by changing the timing and duration of their migrations and phenologies.

However, most predictions of the effects of global climate change on coral reefs have been confined to temperature-induced coral bleaching (Hoegh-Guldberg 1999; Walther et al. 2002), rising sea level (Graus and Macintyre 1998), and changing ocean chemistry (Kleypas et al. 2001).

We are faced with two essential questions related to global temperatures:

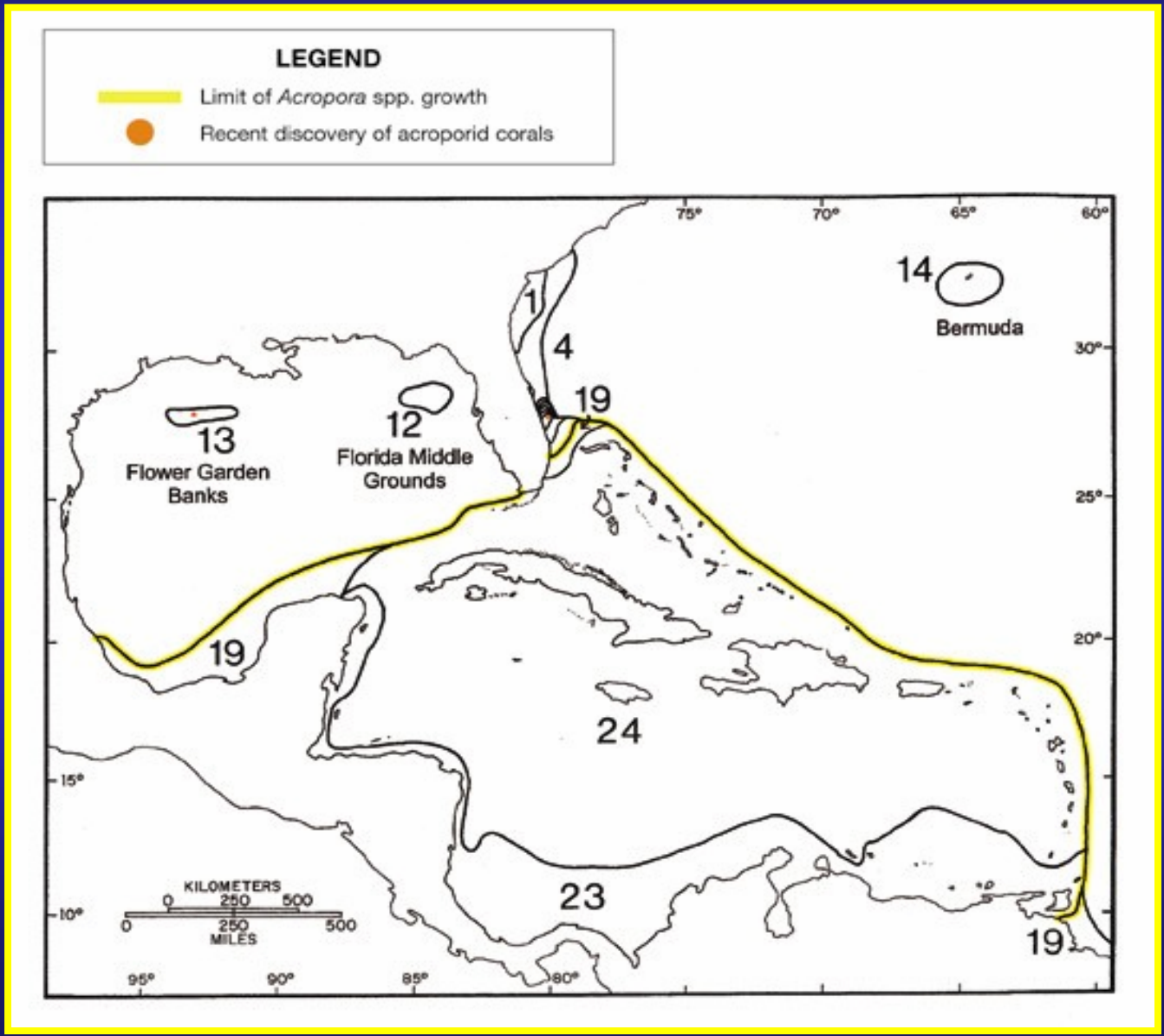
1. Will the latitudinal ranges of coral species and coral reefs expand towards the Poles? and
2. Will corals and coral reefs be eliminated from low-latitude tropical regions?


N
0
25
km
26°
25°
83°
82°
81°
80°
South Florida
Miami
18m
Fowey Rocks
Biscayne Bay
Triumph Reef
Ajax Reef
Carysfort Reef
Key Largo
The Elbow
Pickles Reef
Alligator Reef
Tennessee Reef
Hawk Channel
18m
Love Reef
Sombrero Key Reef
No Name Reef
Looe Key Reef
American Shoal
Western Sambo Reef
Sand Key Reef
Cosgrove Shoal
28-ft Shoal
18m
Hawk Channel
Key West
Marquesas Keys
18m
Gulf of Mexico
Florida Bay
Straits of Florida
The Dry Tortugas
Pulaski Shoal
18 m
Tortugas Bank
Bird Key Reef

In the recent historical past (pre-1980s), the Florida Reef Tract was dominated by acroporid corals.

The northernmost limit of reef-building was equivalent to the northern range of the *Acropora* species.

This is located at the 18°C Isotherm.

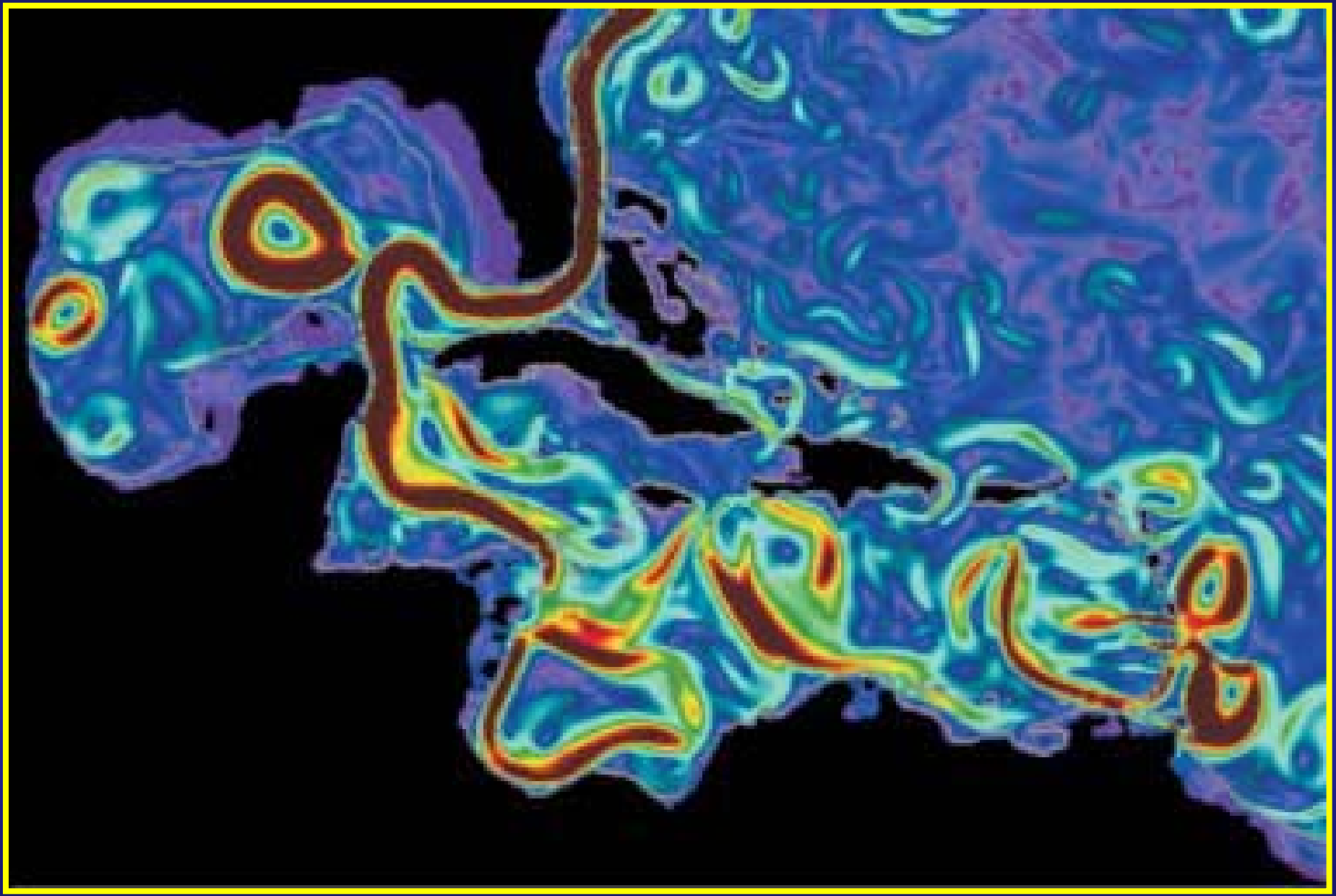


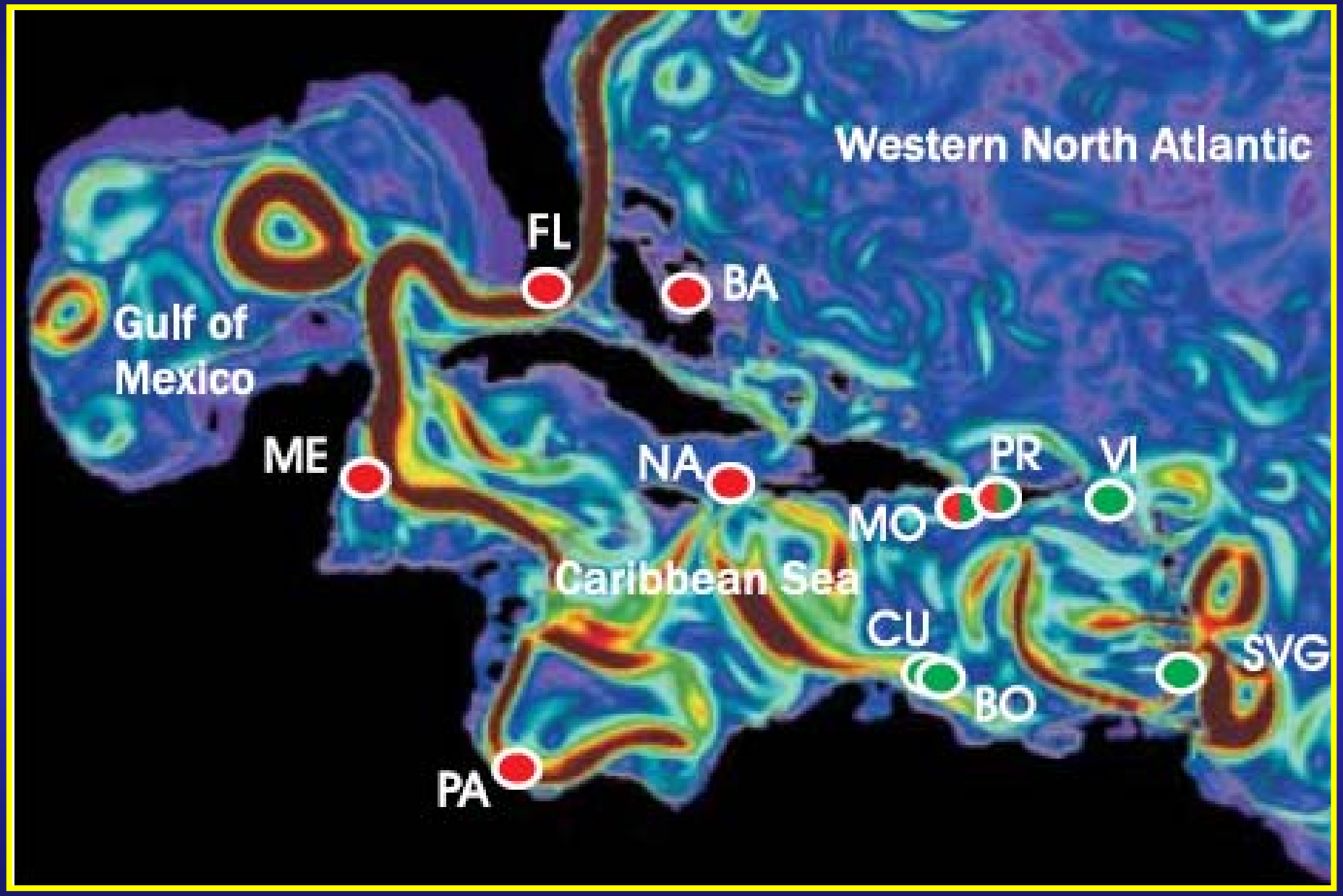
Numerous reef-coral assemblages dominated by spatially expansive thickets of the staghorn coral *Acropora cervicornis* (up to 700 m^2 in area) were discovered off Fort Lauderdale, Florida in 1998, where they had not been observed before.

The recent discovery of the northernmost *A. palmata* colony off Pompano Beach on the Broward – Palm Beach County line, some 50 km north of Miami.

Pompano Beach Pier – Northern Broward County – 2003

Recent Discoveries of Sexual *Acropora* Recruits from the Northernmost Bahamas



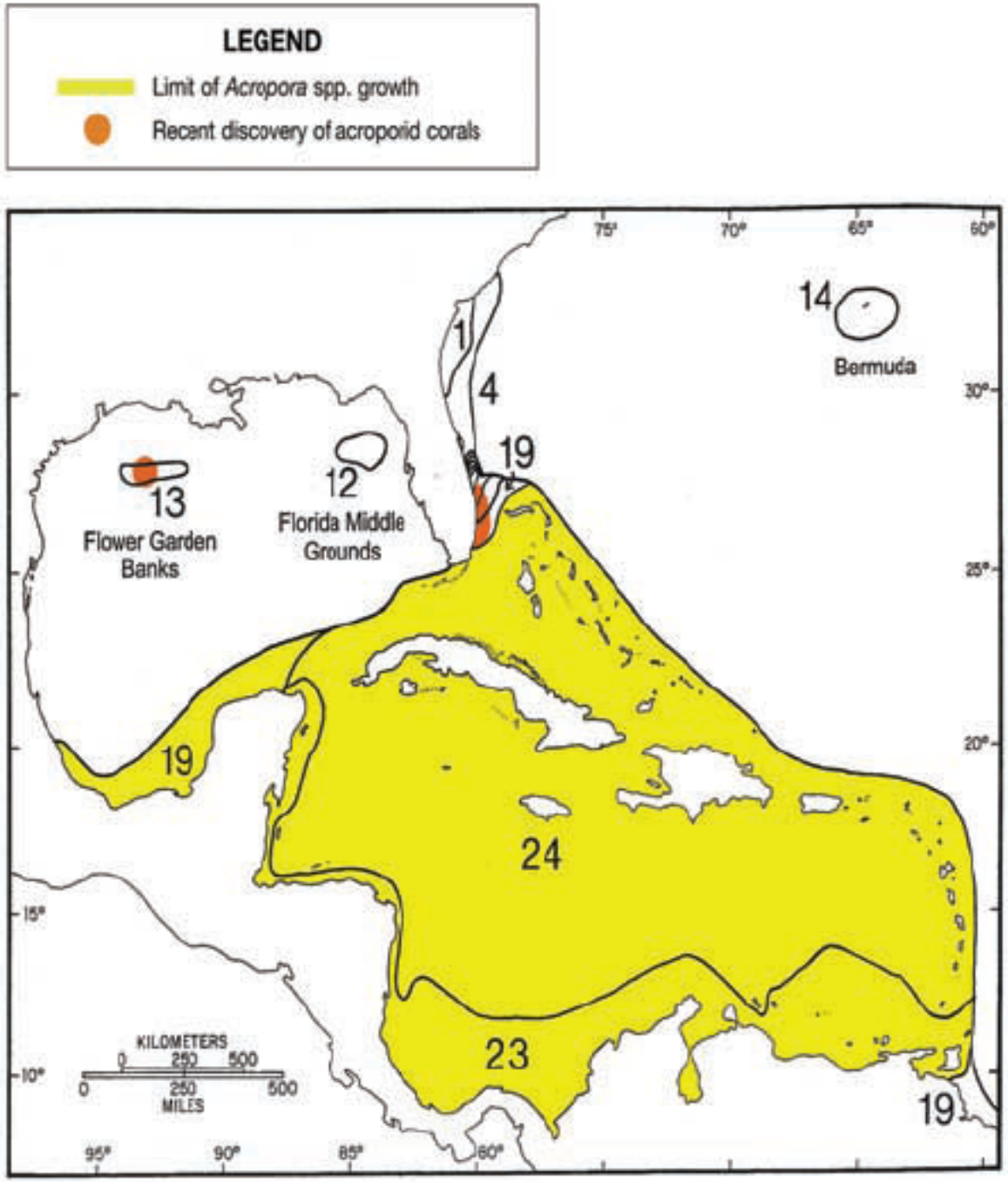


From Baums et al. 2005

- *A. palmata* releases gametes into the water column once a year, generally after the August full moon, in a synchronized spawning effort.
- Each colony simultaneously releases eggs and sperm in bundles that float to the surface where they break apart and mix with gametes from other colonies (*A. palmata* is a poor self-fertilizer).
- After fertilization, *A. palmata* larvae undergo a 78-h period of development before showing first signs of motility.
- Pelagic larvae become competent to settle within 5 d, but can remain planktonic for up to 20 d.

From Baums et al. 2005

In 2002, the first-ever observation of a reef-building species of *Acropora* was found on the West Flower Garden Bank in the northern Gulf of Mexico.


LEGEND
Limit of Acropora spp. growth
Recent discovery of acroporid corals
75°
70°
65°
60°
30°
25°
20°
15°
10°
95°
90°
85°
80°
14
Bermuda
1
4
19
12
Florida Middle Grounds
13
Flower Garden Banks
19
24
23
19
KILOMETERS
0 250 500
0 250 500
MILES

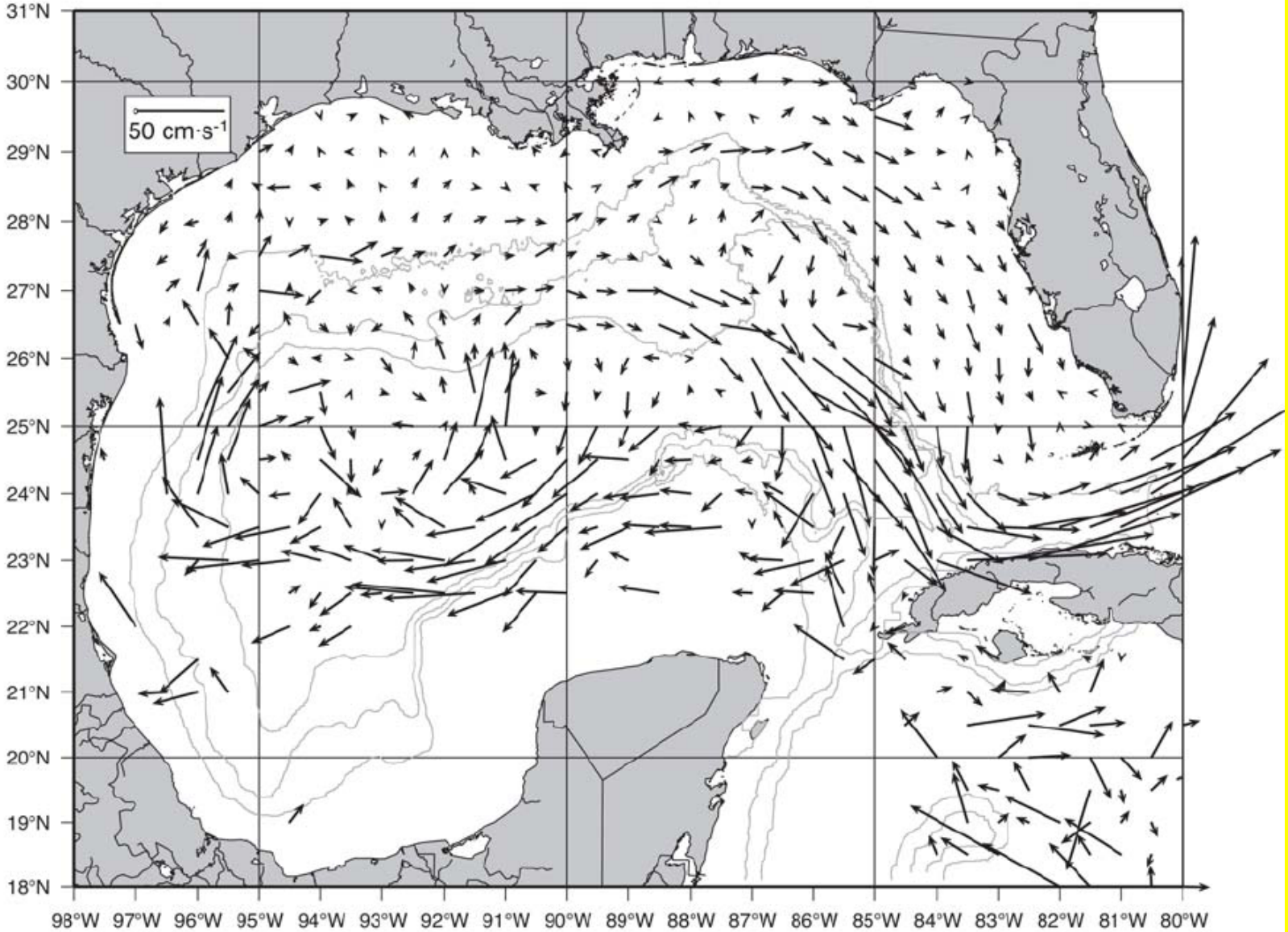


Figure 1B. Surface velocity from satellite tracked drifters from Nowlin et al. (2001) used to estimate drifting time.

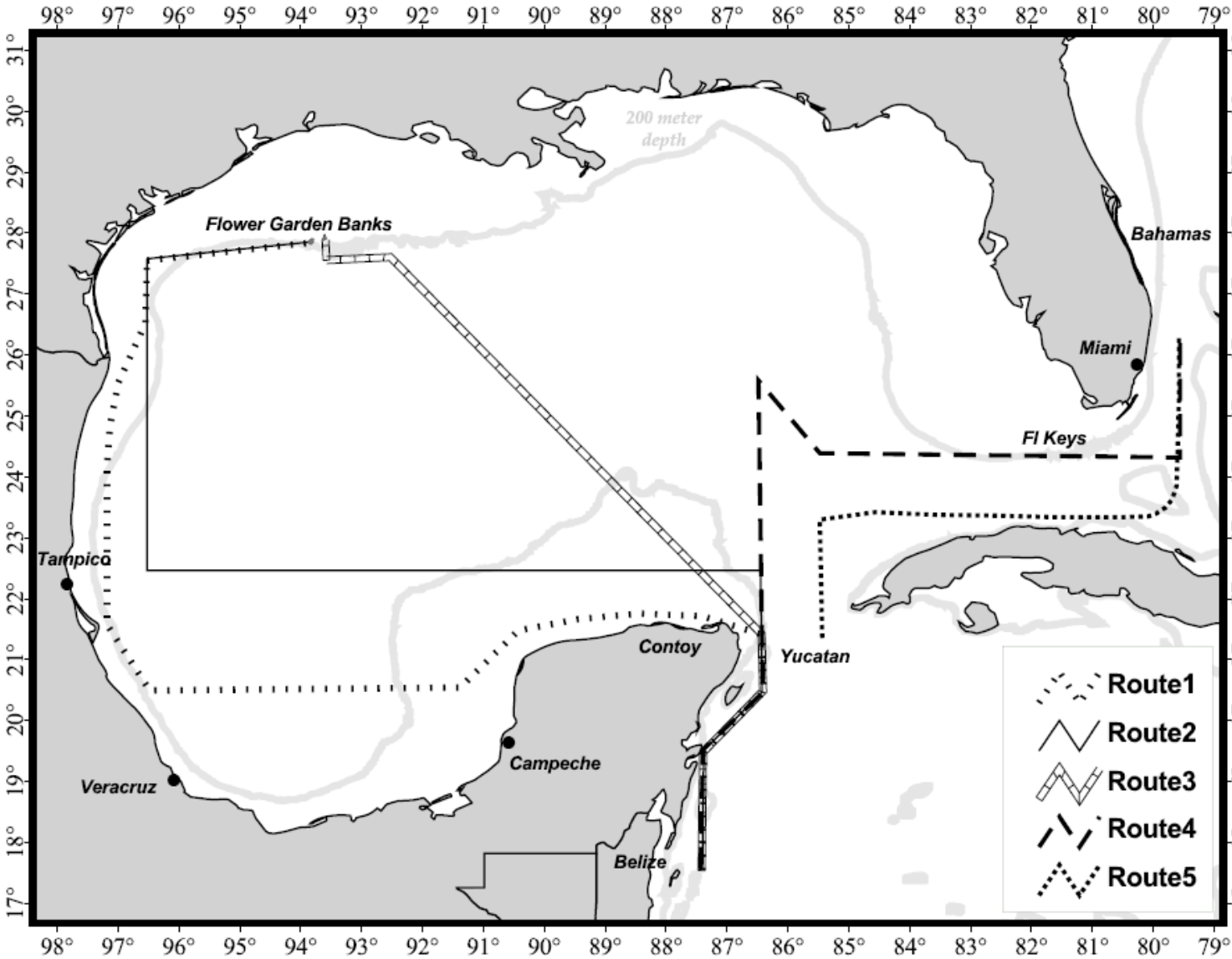


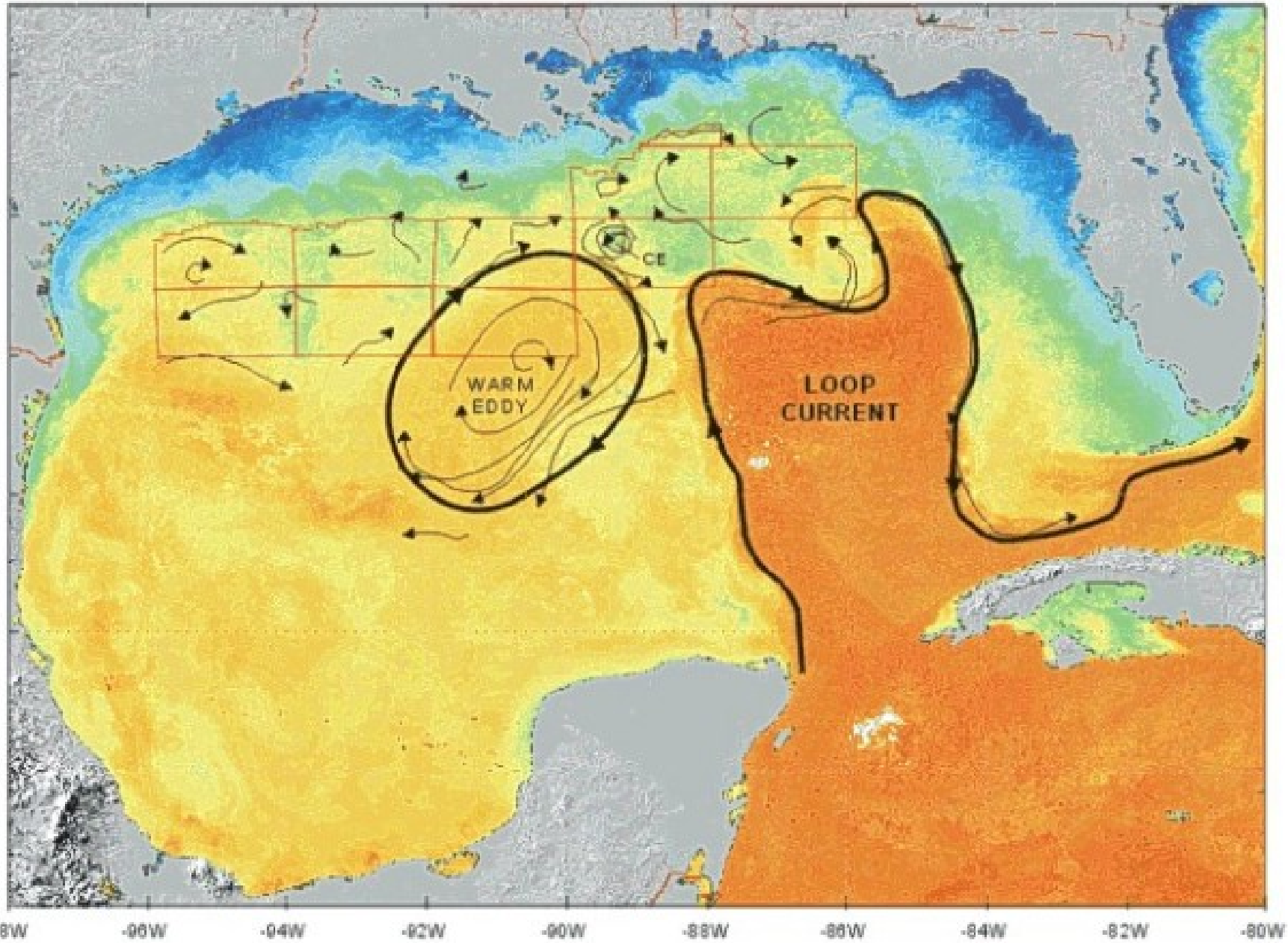
Figure 2. Study area depicting the five routes employed in this work. *Route* 1: Belize to Flower Garden Banks (FGB) along Mexico-Texas; *Route* 2: Belize-FGB along the southern Gulf; *Route* 3: Belize-FGB across the central Gulf; *Route* 4: Belize-Bahamas along the eastern Gulf; and *Route* 5: Yucatan-Bahamas.

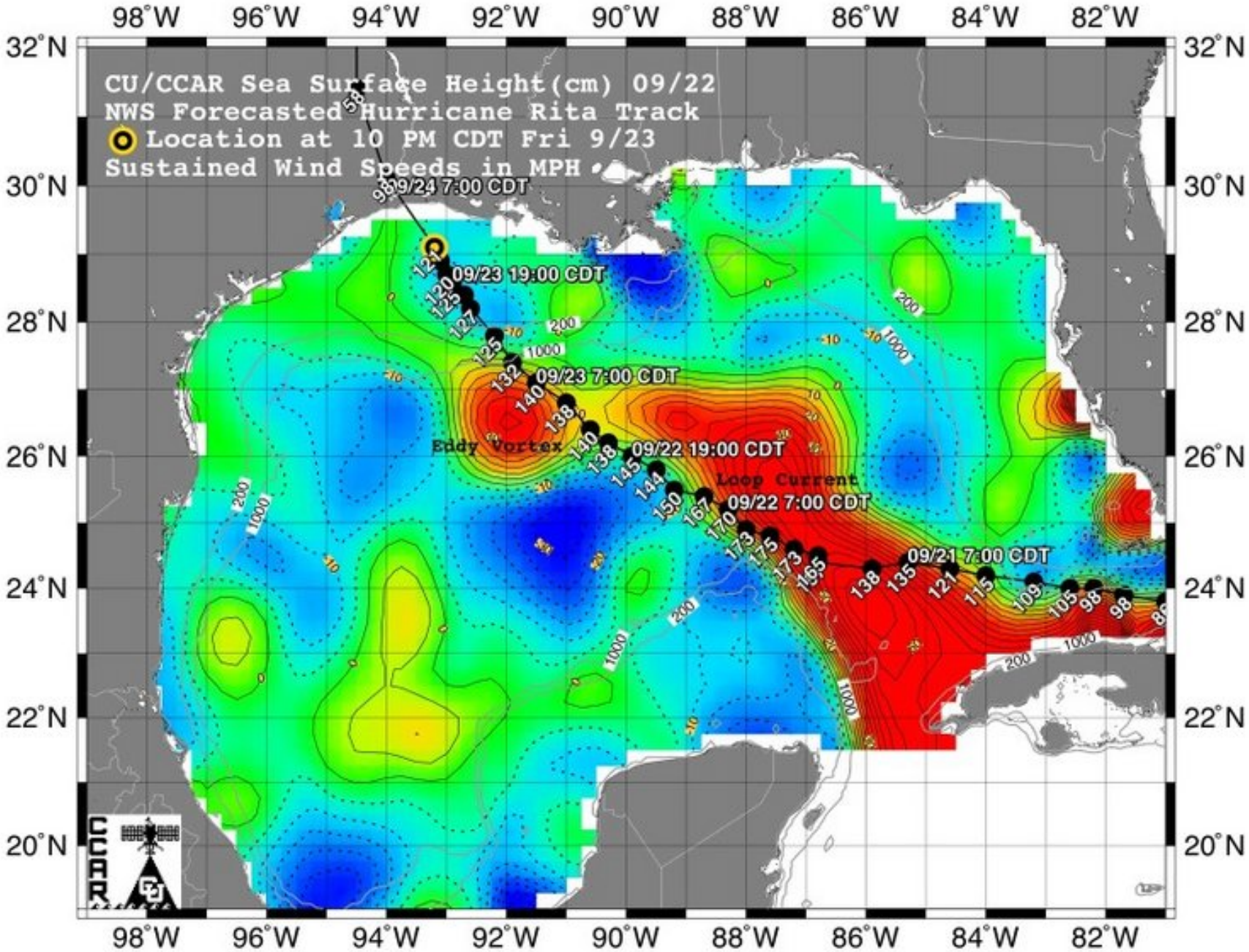
Table 1. Estimated travel times (days) between selected points along routes.

Segments/ Routes	Route 1	Route 2	Route 3	Route 4	Route
Belize-FGB	135	110	55	-	-
Contoy-FGB	125	99	45	-	-
Campeche-FGB	97	-	-	-	-
Vera Cruz-FGB	66	65	-	-	-
Belize-Contoy	11	11	11	11	-
Contoy-Campeche	27	-	-	-	-
Campeche-Vera Cruz	31	-	-	-	-
Western Campeche Bank-South Texas	-	38	-	-	-
Vera Cruz-South Texas	15	-	-	-	-
Belize-Bahamas	-	-	-	42	-
Contoy-Vera Cruz	58	34	-	-	-
Contoy-Bahamas	-	-	-	32	-
Contoy-Fl. Keys	-	-	-	30	-
Yucatan-Bahamas	-	-	-	-	26
Fl. Keys-Bahamas	-	-	-	2	-

A. palmata larvae is pelagic for ~ 20 days (Baums et al. 2005) and it takes 55–135 days to get to the FGB. The 135-day trip along route 1 implies a very low probability of recruitment since coral larvae are viable for only 120 days. If it is assumed that the release of larvae occurs in August, then the 135-day estimated travel time falls in winter when temperature stress and the high wave and strong currents could combine to exert large stresses on the larvae, making recruitment and dispersal arduous.

Lugo-Fernandez 2006

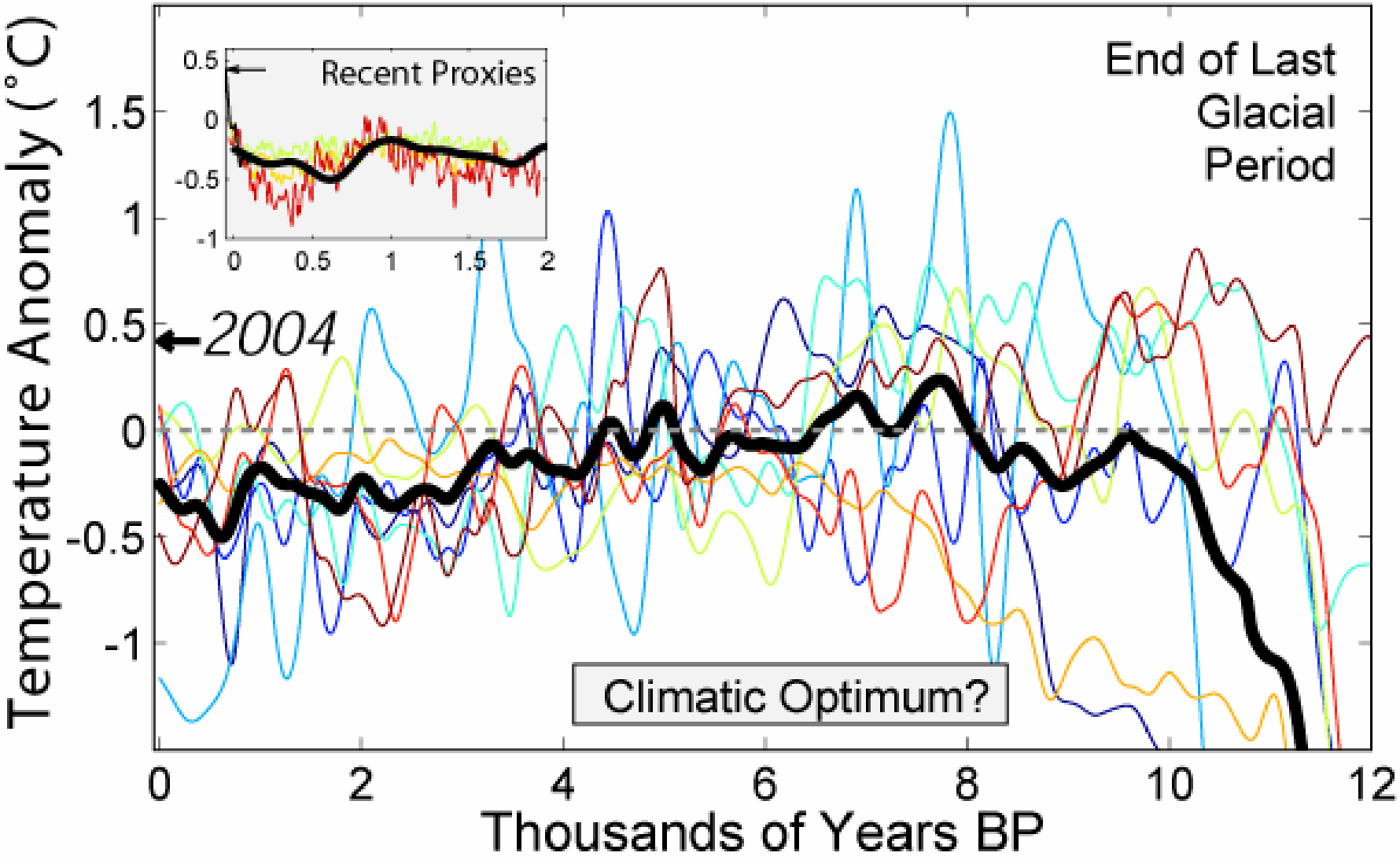

30N
28N
26N
24N
22N
20N
18N
-98W
-96W
-94W
-92W
-90W
-88W
-86W
-84W
-82W
-80W
WARM
EDDY
CE
LOOP
CURRENT


CU/CCAR Sea Surface Height(cm) 09/22
NWS Forecasted Hurricane Rita Track
Location at 10 PM CDT Fri 9/23
Sustained Wind Speeds in MPH
09/24 7:00 CDT
09/23 19:00 CDT
09/23 7:00 CDT
09/22 19:00 CDT
09/22 7:00 CDT
09/21 7:00 CDT
Eddy Vortex
Loop Current
98°W
96°W
94°W
92°W
90°W
88°W
86°W
84°W
82°W
32°N
30°N
28°N
26°N
24°N
22°N
20°N
CCAR

The Mid-Holocene Warm

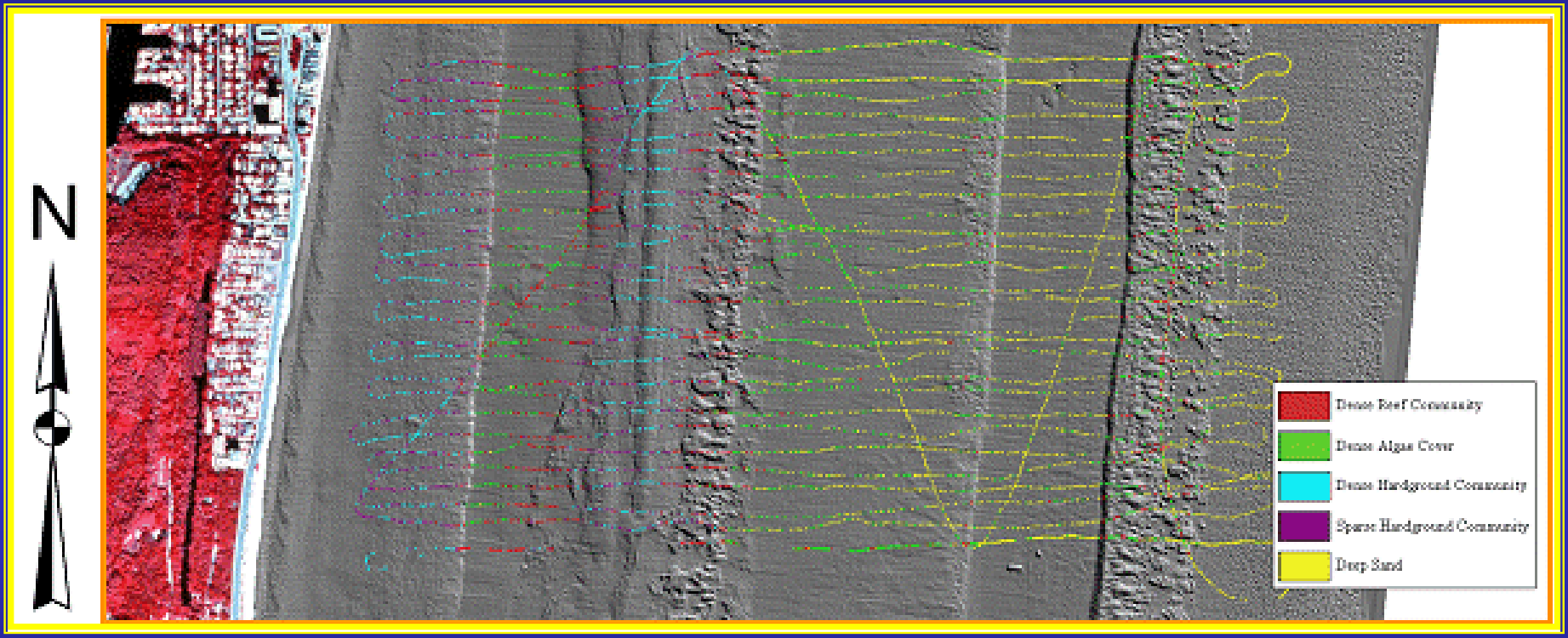
Evidence from both terrestrial and coastal environments shows that the millennial-scale, high-amplitude climate flicker during the mid-Holocene caused many organisms to increase their ranges northward.

Holocene Temperature Variations

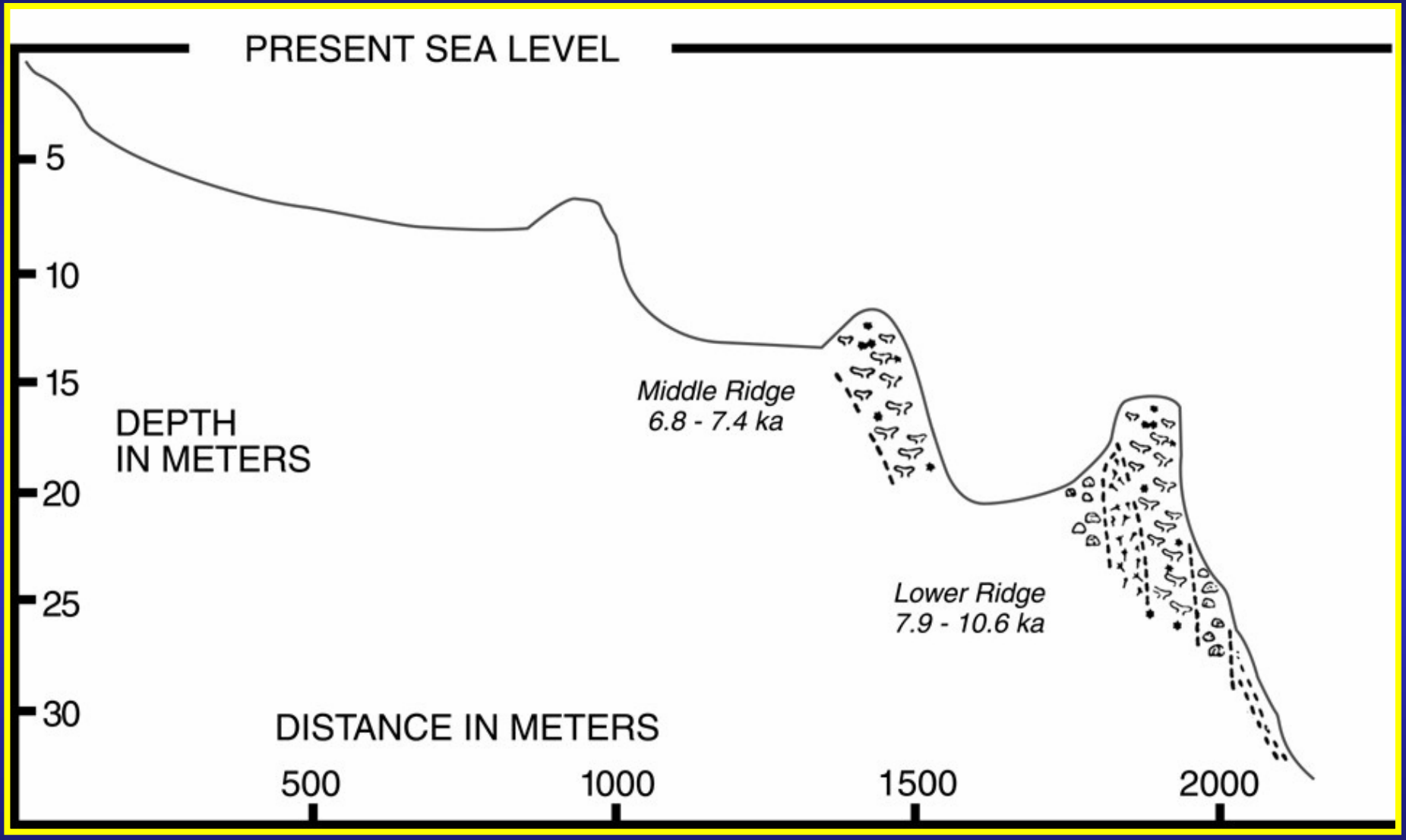


IPCC

During the early to middle Holocene (10,000 to 6,000 years before present), oceanic conditions favored the growth and accumulation of *A. cervicornis* and its congener, the elkhorn coral *A. palmata*, along the shelf margin of the Florida reef tract.



From Moyer et al.



Modified from Lighty (1977)

Acropora-dominated reefs up to 10 m thick ranged as far north as Palm Beach County, indicating that the environment there was more conducive to coral growth in the early and middle Holocene than in the recent past.

The accumulation of thick deposits dominated by *Acropora* as far as 150 km north of their present limit implies that *Acropora* spp. are capable of responding rapidly to climate change through range expansions.

The mid-Holocene climate flicker resulted in poleward range shifts of numerous marine and coastal species including :

- Boreal molluscs in Greenland
- Warm water oysters and scallops off Sable Island

(Funder and Weidick 1991)

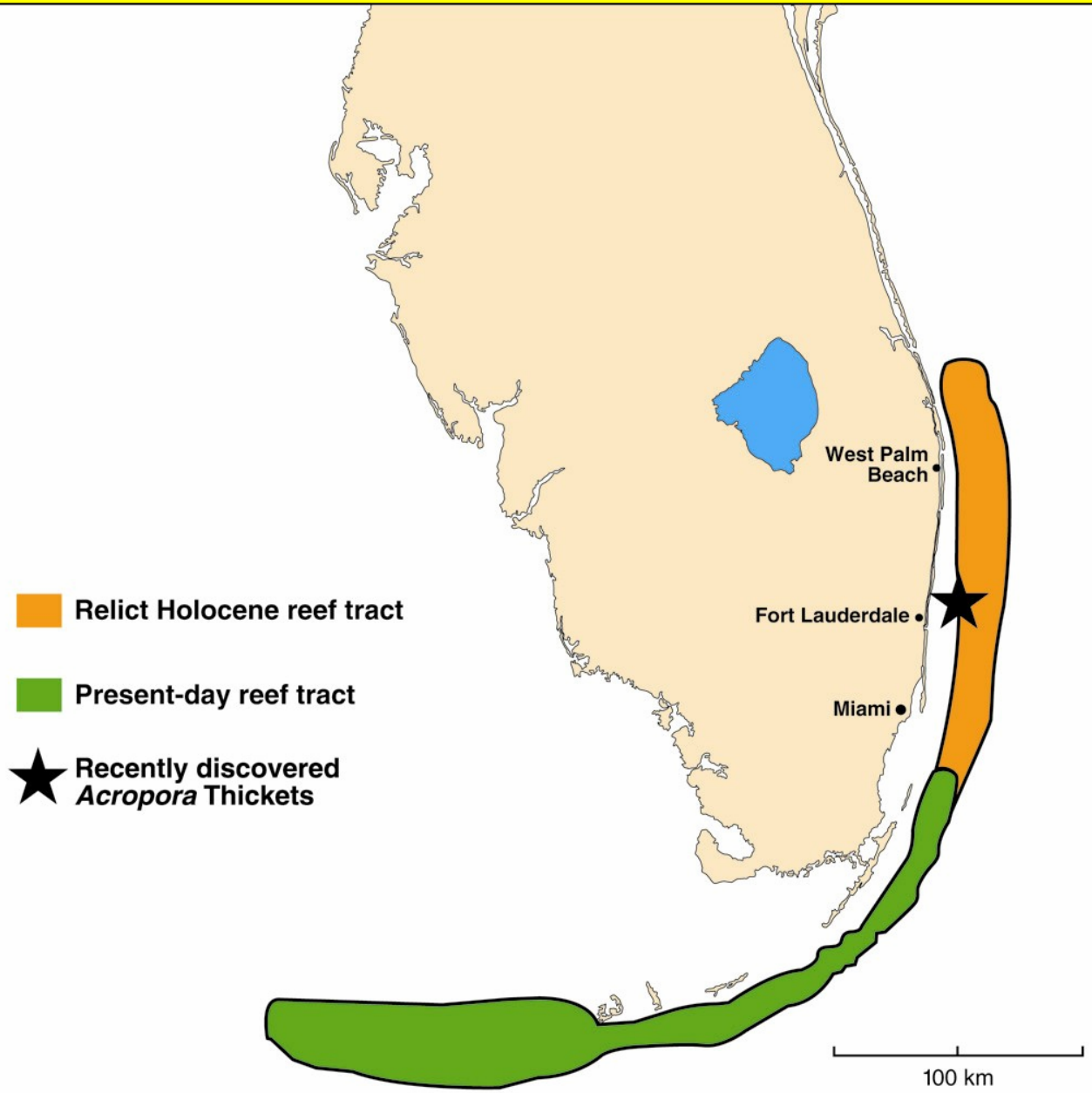
The mid-Holocene climate flicker also correlates with the northernmost expansion of coral reefs in the Pacific.

(Taira 1979; Veron 1992)

The mid-Holocene climate flicker also correlates with the maximal development of Hawaiian reefs.

(Grossman et al. 2004)

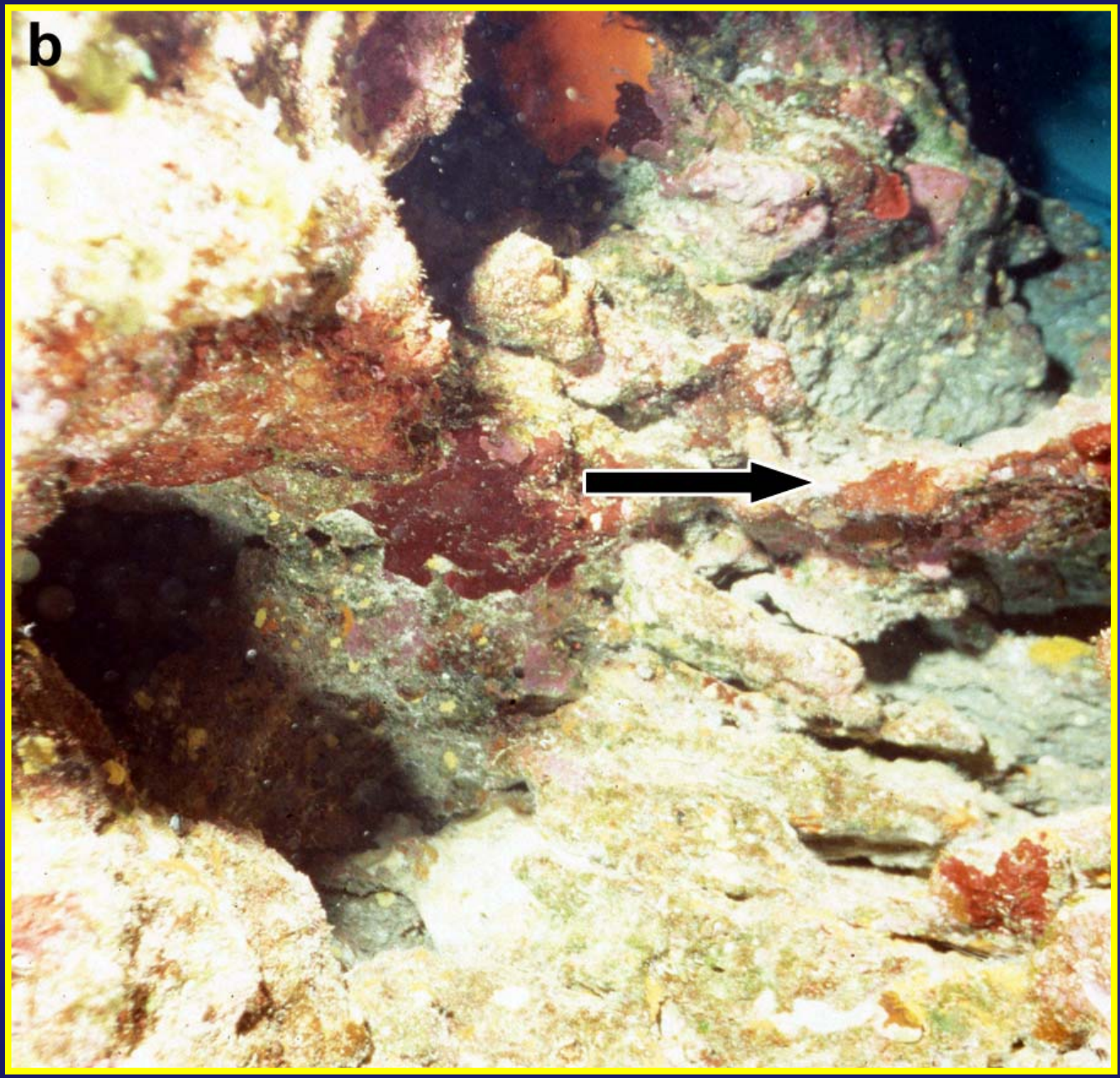
As temperatures cooled after the mid-Holocene, the northern limit of acroporid reef growth in the Atlantic regressed south to the northern Florida Keys.


West Palm Beach
Fort Lauderdale
Miami
Relict Holocene reef tract
Present-day reef tract
Recently discovered *Acropora* Thickets
100 km

The appearance of acroporid corals north of their previously-known range may be associated with decadal-scale increases in annual sea-surface temperature.

- These are the first known examples of poleward expansion of a Caribbean coral genus.
- These are most probably a response to recent patterns of climatic warming (see Levitus et al. 2000; Levitus et al. 2001)

In June 2006, while diving on the southeast corner of the coral cap of the East FGB, we examined an open cave (swim through) that exposed in cross section a few meters of the reef understory. Within that exposure, at a depth of about 21 m, we found large branches and trunks (>1m in length) of fossil *A. palmata* in growth position.


b

3•0
5
4•0
5
5•0

The fortuitous discovery of fossil *Acropora* from the FGB has profound implications on the history of reef development at the FGB.

Radiocarbon dating of one of the branches revealed a calibrated corrected age of 6,930 to 6,650 BP. This age is within the window of dates recovered from the northernmost fossil *Acropora*-reefs in Florida and also corresponds with the later portion of Holocene Thermal Optimum.

Dr. William F. Precht

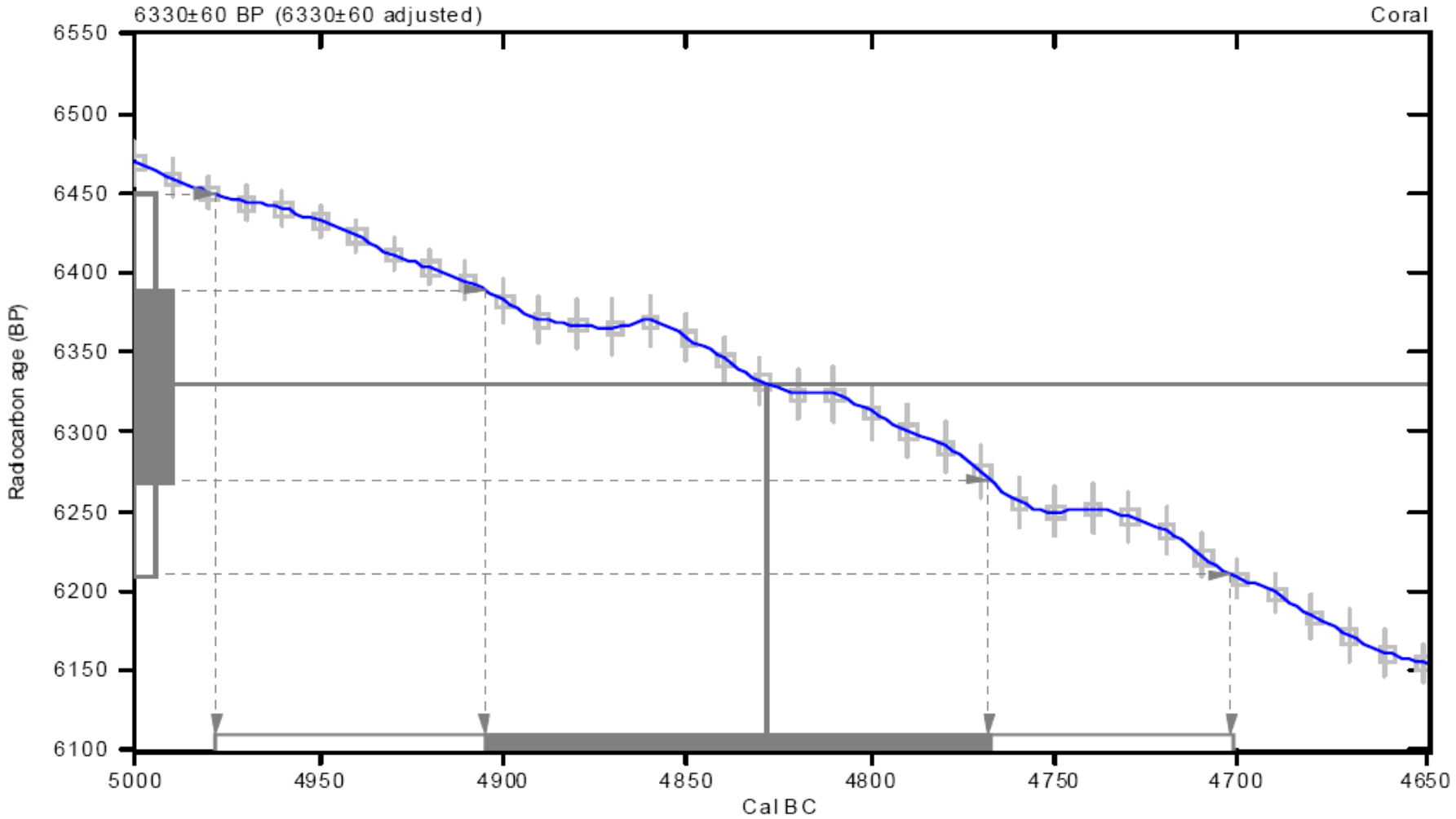
Report Date: 7/17/2006

PBS & J

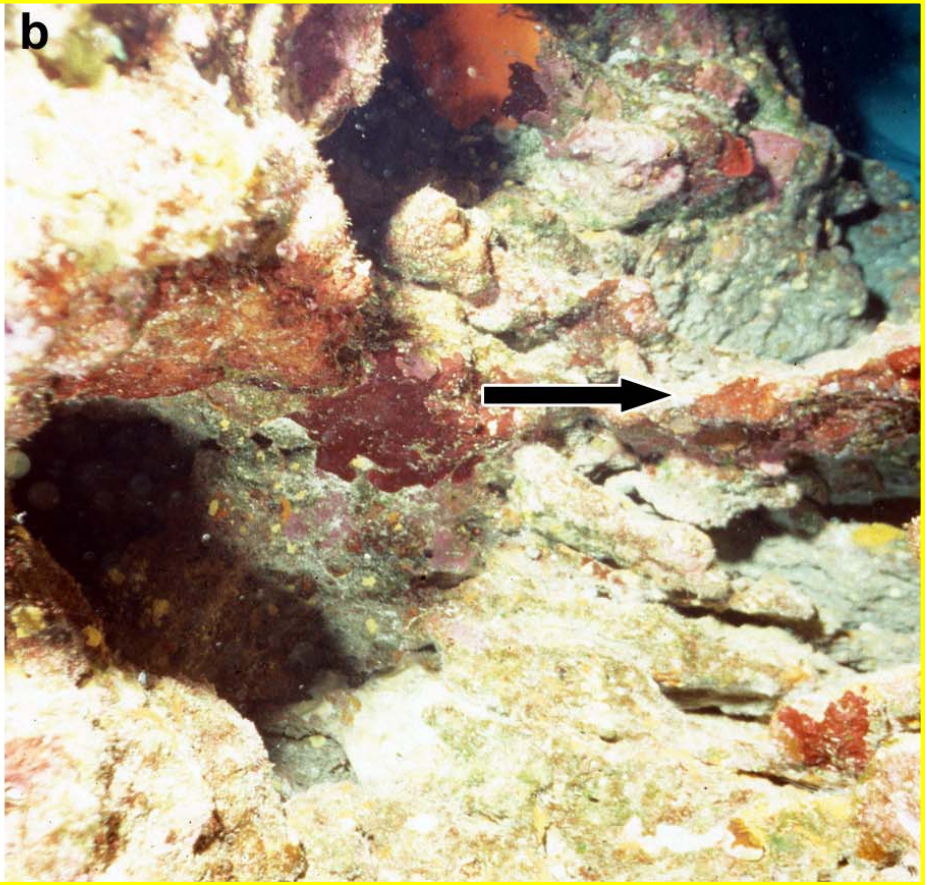
Material Received: 7/10/2006

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 218521	6010 +/- 60 BP	-5.5 o/oo	6330 +/- 60 BP

SAMPLE : EFGB-2006-01
ANALYSIS : Radiometric-Priority delivery
MATERIAL/PRETREATMENT : (coral): acid etch
2 SIGMA CALIBRATION : Cal BC 4980 to 4700 (Cal BP 6930 to 6650)


6330±60 BP (6330±60 adjusted)
Coral
Radiocarbon age (BP)
6550
6500
6450
6400
6350
6300
6250
6200
6150
6100
5000
4950
4900
4850
4800
4750
4700
4650
Cal BC

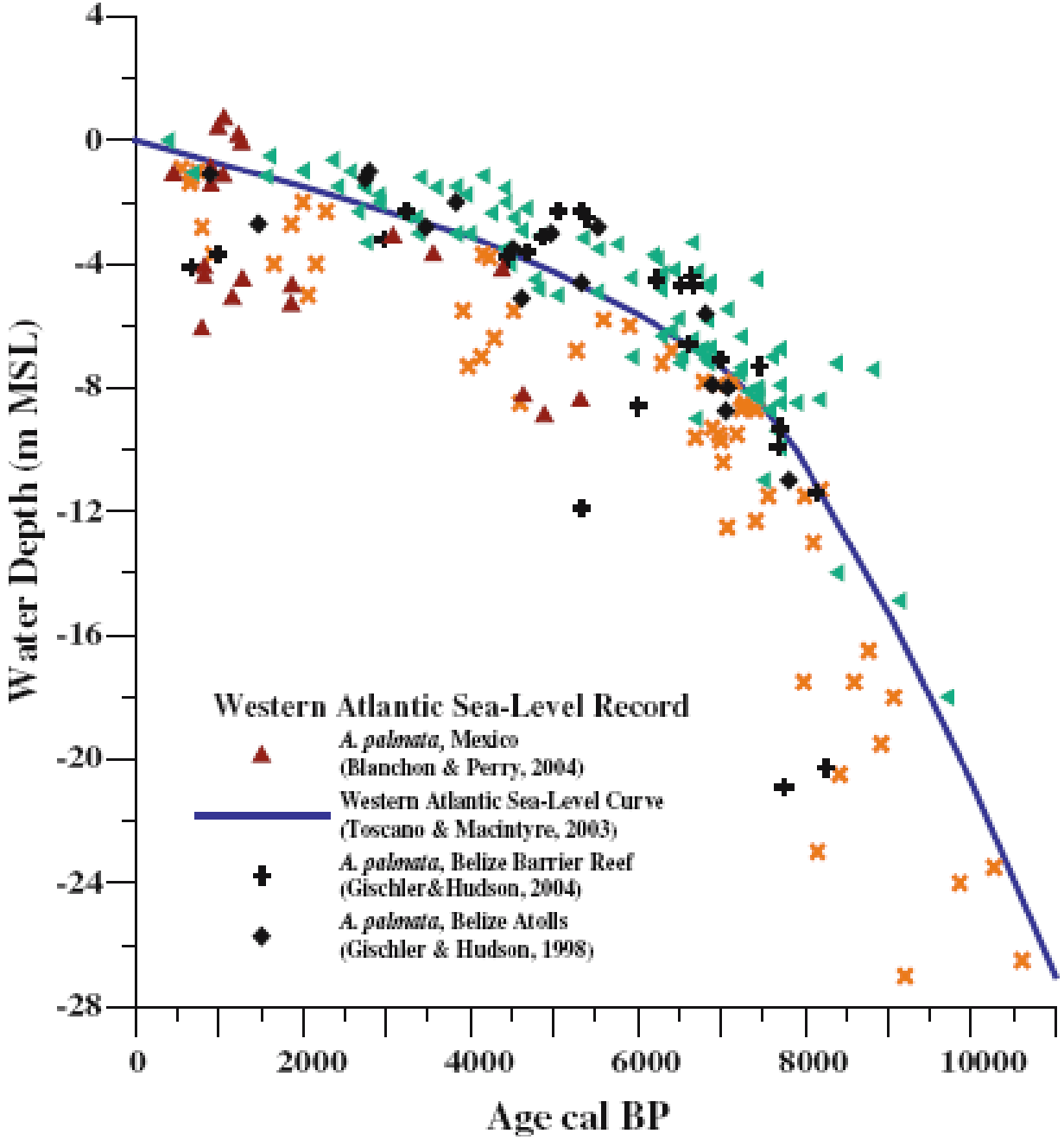
a


b

Using the known latitudinal expansion of fossil acroporid reefs in the early-middle Holocene with the extent and thickness of the late Pleistocene-to-recent reef sediments capping the structures of the FGB and the post-glacial record of bank flooding and submergence, we speculated that an *Acropora*-dominated reef could underlie and form the foundation of the living reef community at the FGB.

Comparing the age of this sample with the corrected sea level curve for the western Atlantic places this coral in approximately 10 m of water depth at the time of formation.

Toscano and Macintyre 2004


Western Atlantic Sea-Level Record
A. palmata, Mexico (Blanchon & Perry, 2004)
Western Atlantic Sea-Level Curve (Toscano & Macintyre, 2003)
A. palmata, Belize Barrier Reef (Gischler&Hudson, 2004)
A. palmata, Belize Atolls (Gischler & Hudson, 1998)
Water Depth (m MSL)
4
0
-4
-8
-12
-16
-20
-24
-28
0
2000
4000
6000
8000
10000
Age cal BP

Reconstructing the development of the FGB reefs in light of this new information shows there is a deepening-upwards succession from a shallow reef community that evidentially lagged behind the rapidly rising sea level of the early-middle Holocene and was eventually drowned and subsequently capped by the present reef community.

CONCLUSIONS

- Geological evidence from sub-fossil Holocene reef assemblages yields clues to predicting the future of coral reefs under the influence of global climate change.
- While this discovery raises more questions than it answers, especially with regard to the local turn-on and turn-off mechanisms of the *Acropora* reef facies, it shows that *Acropora* species have a history of responding to local changes in environmental conditions throughout the Holocene.

CONCLUSIONS (cont.)

- It is our hypothesis that the recent occurrence of *A. cervicornis* thickets off Fort Lauderdale and *A. palmata* at the Flower Garden Banks are a harbinger of impending global change.

THE FUTURE?

- Under current scenarios of global warming, the continued northward expansion of *Acropora*-dominated reefs is a strong possibility, mimicking the geographic distribution of reefs in the mid-Holocene.

THE FUTURE? (cont.)

- In addition to temperature, however, light, carbonate saturation state, and other factors such as disease exert control over reef development. At present, it is unknown how these controls will interact and whether further climate change will cause the latitudinal ranges of coral reefs to expand, remain stable, or even contract.

References

Baums, I.B., M.W. Miller, and M.E. Hellberg. 2005 Regionally isolated populations of an imperiled Caribbean coral, *Acropora palmata*. Molecular Ecology 14(5):1377–1390.

Funder, S. and A. Weidick. 1991. Holocene boreal molluscs in Greenland: Paleoceanographic implications. Palaeogeography, Palaeoclimatology, Palaeoecology 85:123–135.

Graus, R.R. and I.G. Macintyre. 1998. Global warming and the future of Caribbean coral reefs. Carb. Evap. 13:43–47.

Grossman, E.E. and C.H. Fletcher, III. 2004. Holocene reef development where wave energy reduces accommodaton space, Kailua Bay, Windward Oahu, Hawaii, U.S.A. Journal of Sedimentary Research 74(1):49–63.

Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world’s coral reefs. Mar. Freshwat. Res. 50:839–66.

References (cont.)

Kleypas J.A., R.W. Buddemeier, and J-.P. Gattuso. 2001. The future of coral reefs in an age of global change. Geol. Rundsch. 90:426–37.

Levitus, S., J.I. Antonov, J. Wang, T.L. Delworth, K.W. Dixon, and A.J. Broccoli. 2001. Anthropogenic warming of earth's climate system. Science 292(5515):267–270.

Levitus, S., J.I. Antonov, T.P. Boyer, and C. Stephens. 2000. Warming of the world ocean. Science 287:2225–2228.

Lighty, R.G. 1977. Relict shelf-edge Holocene coral reef, southeast coast of Florida. Proc. Third Int. Coral Reef Symp., Miami 2:215–221.

Lighty, R.G. 1977. Relict shelf-edge Holocene coral reef: southeast coast of Florida. In: Taylor, D.L., ed. Proceedings of Third International Coral Reef Symposium, Vol. 2: Geology. Rosenstiel School of Marine and Atmospheric Science, Miami, FL. Pp. 215-221

References (cont.)

Lugo-Fernandez, A. 2006. Travel times of passive drifters from the Western Caribbean to the Gulf of Mexico and Florida-Bahamas. Gulf of Mexico Science 24(1/2):61–67.

Mann, M., R. Bradley, and M. Hughes. 1999. Northern Hemisphere temperatures during the past millennium: Inferences, uncertainties, and limitations. Geophysical Research Letters 26(6):759.

Moyer, R.P., B. Riegl, K. Banks, and R.E. Dodge. 2003. Spatial patterns and ecology of benthic communities on a high-latitude South Florida (Broward County, USA) reef system. Coral Reefs 22:447–464.

Nowlin, W.D., Jr., A.E. Jochens, S.F. DiMarco, R.O. Reid, and M.K. Howard, 2001. Deepwater physical oceanography reanalysis and synthesis of historical data: Synthesis report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2001-064. 530 pp.

References (cont.)

Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.-M. Barnola, I. Basile, M. Bender, J. Chappellaz, M. Davis, G. Delaygue, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. PÉpin, C. Ritz, E. Saltzman, and M. Stievenard.1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. Nature 399:429–436.

Taira, K. 1979. Holocene migrations of the warm-water front and sea-level fluctuations in the northwestern Pacific. Palaeogeography, Palaeoclimatology, Palaeoecology 28:197–204.

Toscano, M.A. and I.G. Macintyre. 2003. Corrected western Atlantic sea-level curve for the last 11,000 years based on calibrated 14C dates from Acropora palmata and mangrove intertidal peat. Coral Reefs 22:257–70.

Veron, J.E.N. 1992. Environmental control of Holocene changes to the world's most northern hermatypic coral outcrop. Pac. Sci. 46:405–25.

Walther, G-R, E. Post, P. Convey, A. Menze, C. Parmesan, T.J.C. Beebee, J.-M. Fromentin, O. Hoegh-Guldberg, and F. Bairlein. 2002. Ecological responses to recent climate change. Nature 416:389–95.