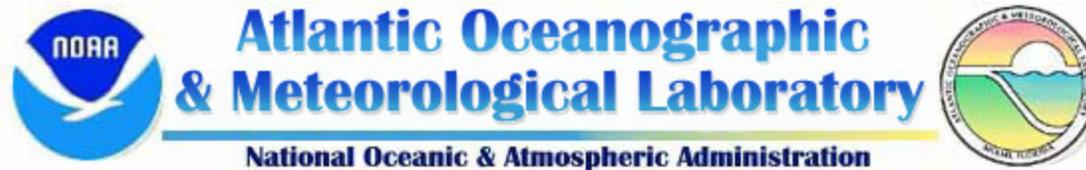


CO₂ Flux Dynamics in the Gulf of Mexico

Rik Wanninkhof



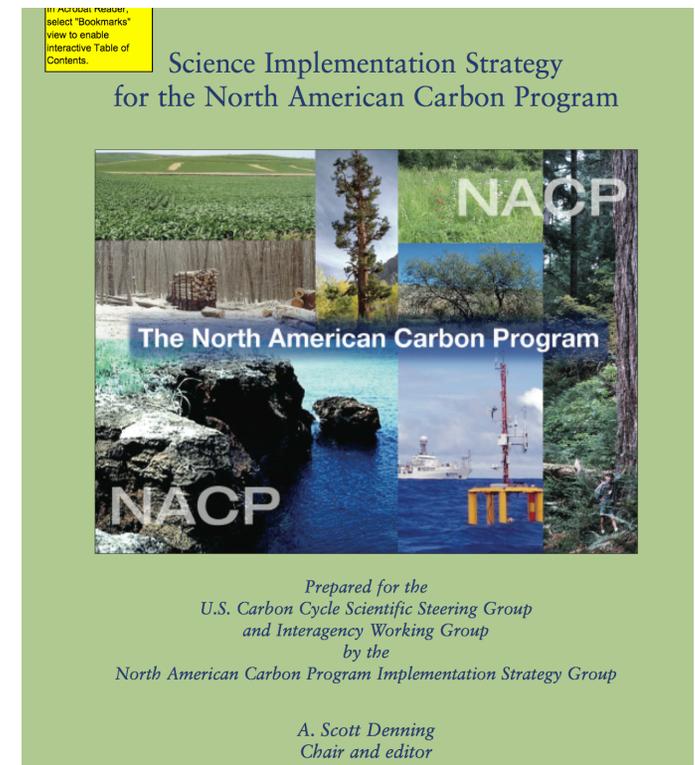
Miami, FL USA

Outline

- Overall motivation
- Calculation of air-sea CO₂ flux
- Previous work
- Approach to create flux maps
- Remote sensing and modeling products
- Means of extrapolation/interpolation
 - Determining $\Delta p\text{CO}_2$ fields*
 - Determining gas transfer velocities*
- Recommendations

North American Carbon Program Science Implementation Plan

1. “The ocean component will define the net effect of the marine system on the CO₂ concentration of the air exchanging with continental air masses.”
2. “Critical for the NACP goals are the Tier 2 observations that, together with local time-series and satellite remote sensing, will be used to generate regional to basin scale CO₂ flux maps.”
3. “Some studies have suggested that the “continental shelf pump” could be responsible for as much a 1 Pg C sink annually on a global basis. A coordinated large-scale coastal carbon exchange program is necessary to address the goals of the NACP. ”



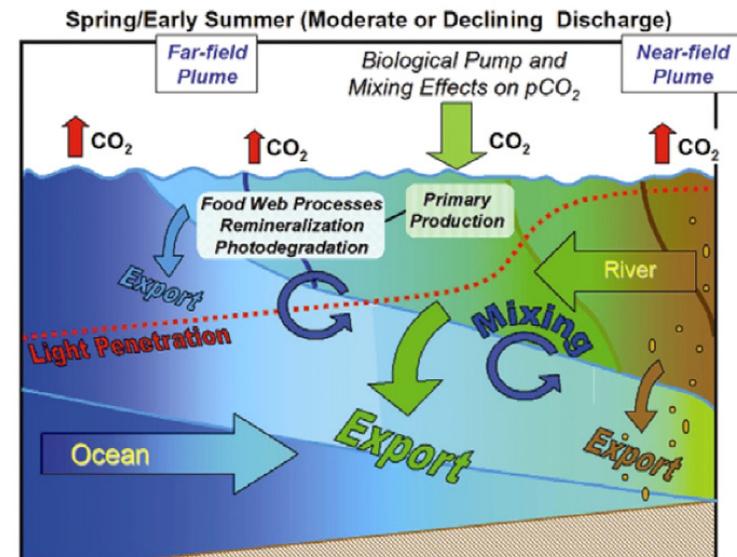
Gulf of Mexico- Objectives

Determine air-sea CO₂ fluxes in the GOM

(Global coastal flux estimates range from -1 to +0.2 Pg C/yr)

Elucidate the processes that control the pCO₂ levels

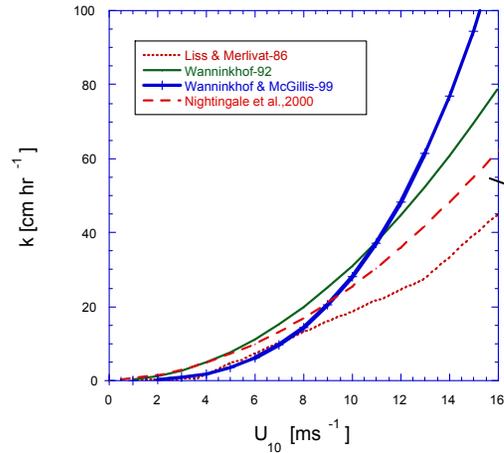
(Determine the large scale effects of continental/riverine input)



Lohrenz

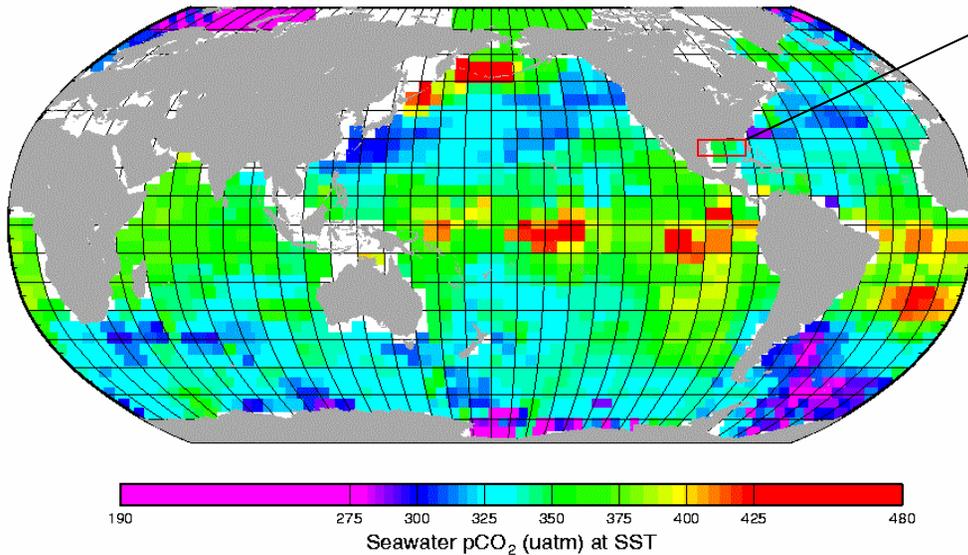
Motivation

Determination of Air-Sea CO₂ Fluxes in the Gulf of Mexico



$$F = (k s \Delta p\text{CO}_2)_{av}$$

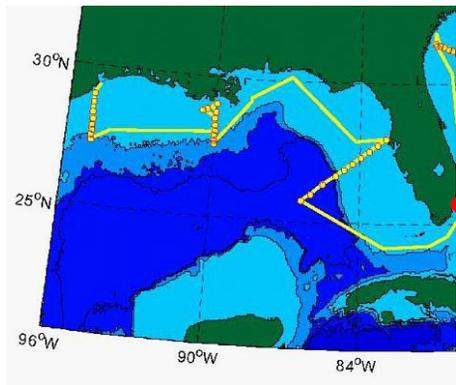
(B) Climatological pCO₂ in Surface Water for February 1995



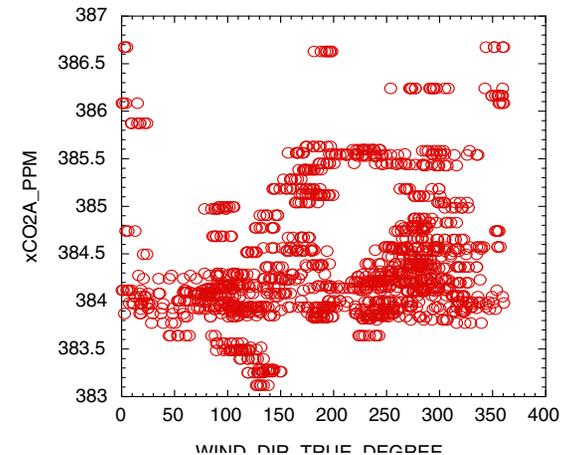
???? Pg C yr⁻¹

The net effect of the marine system on the CO₂ concentration of the air exchanging with continental air masses

GOMECC cruise July 2007



xCO_{2A}_PPM

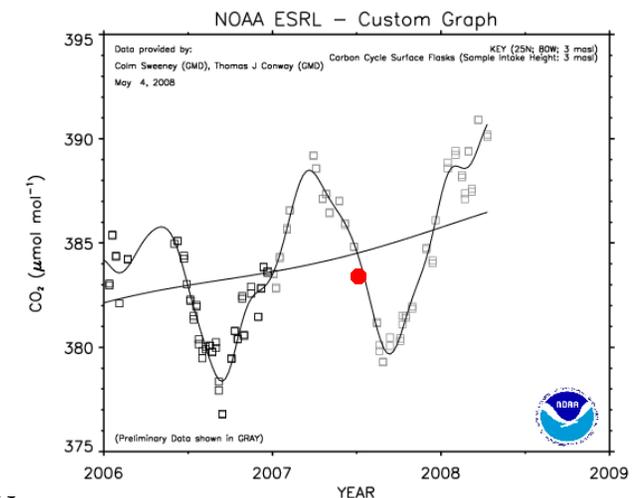


Direction	xCO _{2air}	sd	# point
0-90° (N-E)	384.3	0.6	20
90-180° (E-S)	384.2	0.6	50
180-270° (S-W)	384.5	0.7	52
270-360° (W-N)	384.6	0.7	48

XCO₂ higher than KEY station

Subtle differences in XCO₂ with wind direction, if any

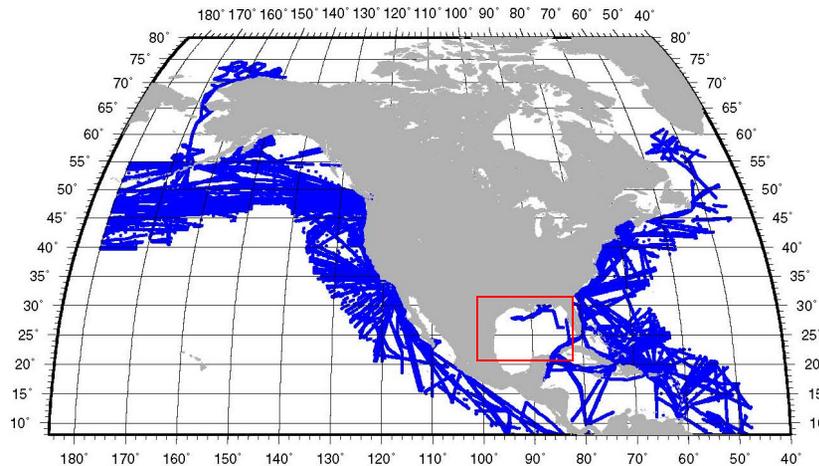
Need a dedicated effort/augmentation for air measurements



<http://www.esrl.noaa.gov/gmd/>

Estimates of Air-Sea CO₂ Fluxes in the Gulf of Mexico

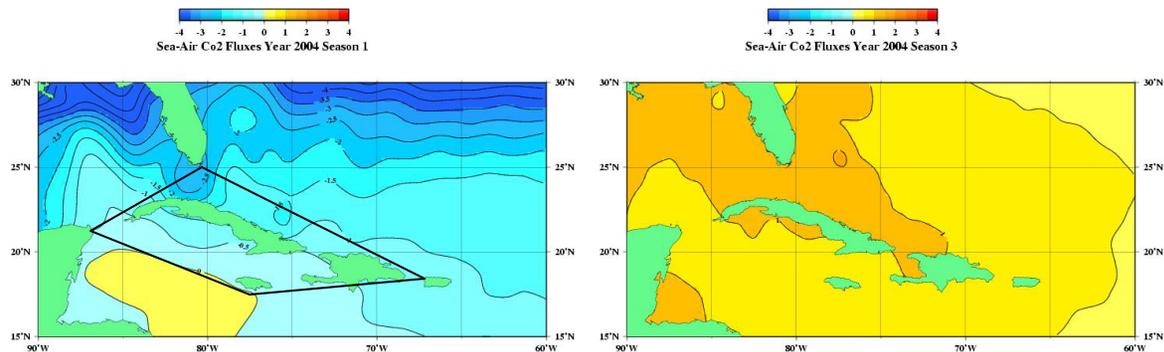
Very little CO₂ data



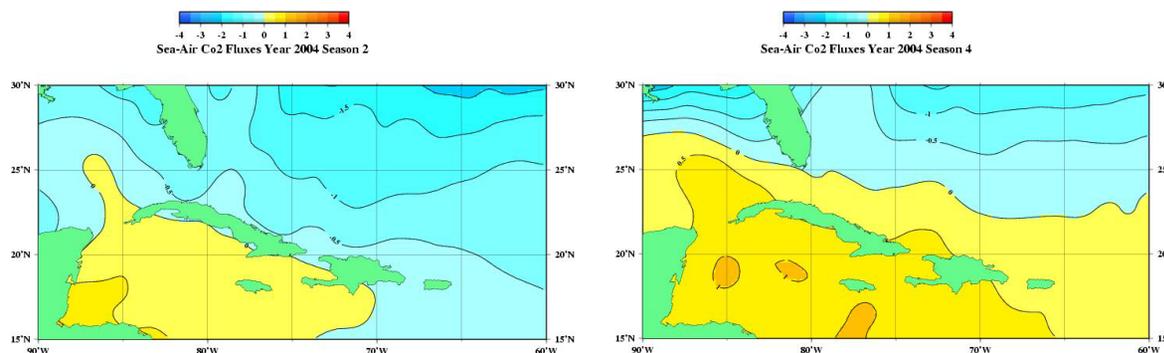
“Although observations are limited, **it appears that these waters are a CO₂ source** and the coastal waters have similar pCO₂ and SST as the offshore waters.” (*Chavez, Takahashi, et al., 2007 SOCCR report*)

Regional Patterns of Seasonal Fluxes in the Caribbean

2004 Explorer of the Seas



$$\Delta p\text{CO}_2 = f(\text{SST, position})$$

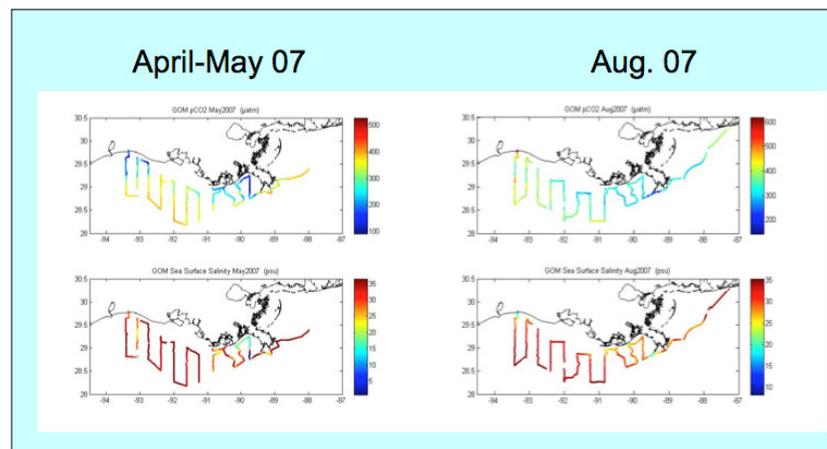
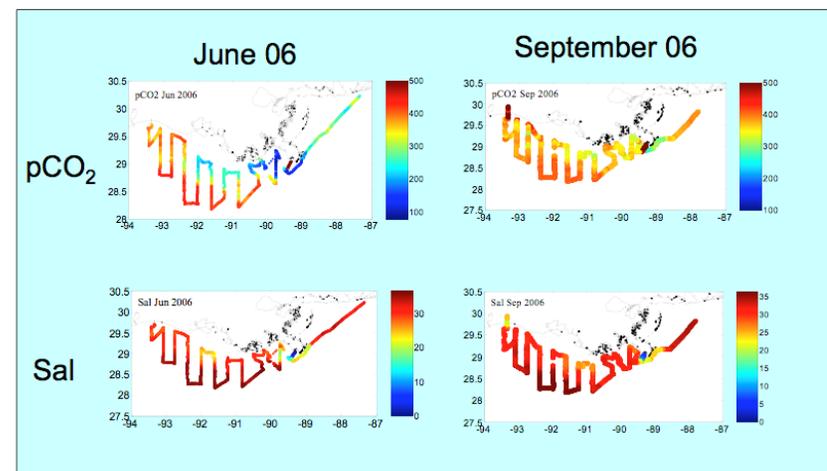
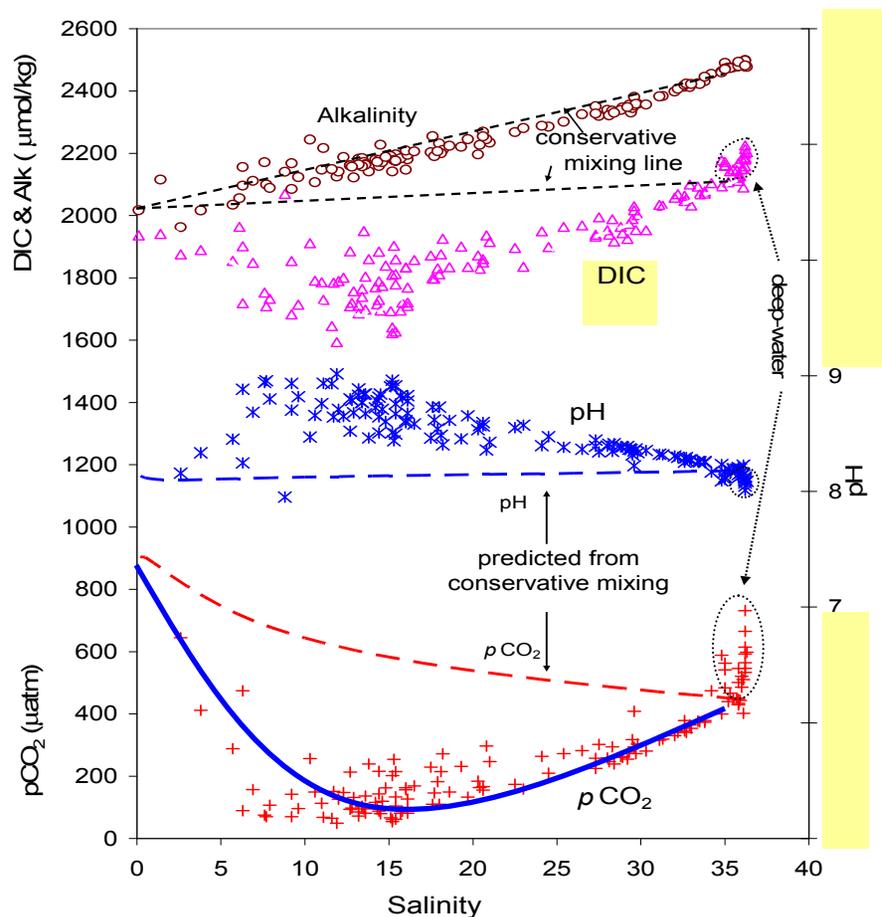


Based on algorithms on SST and data, at Southern edge of GOM,
the region is a CO₂ sink

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Riverine effects on pCO₂

High nutrient input causes pCO₂ drawdown



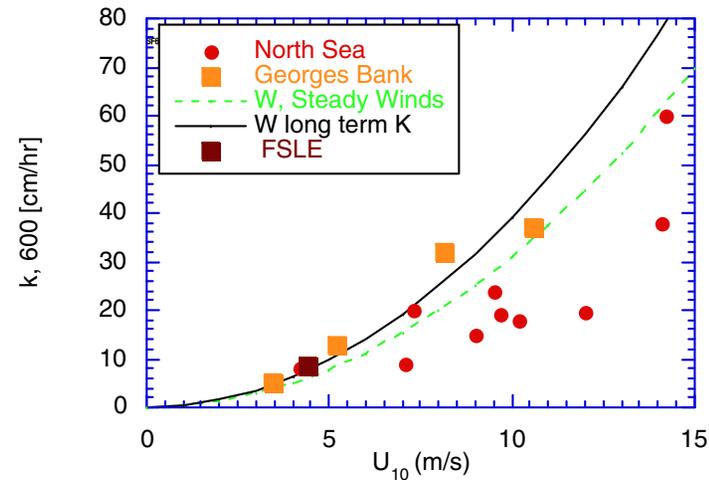
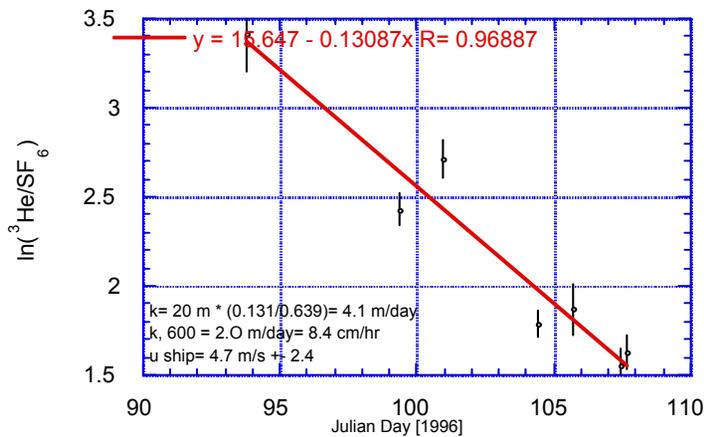
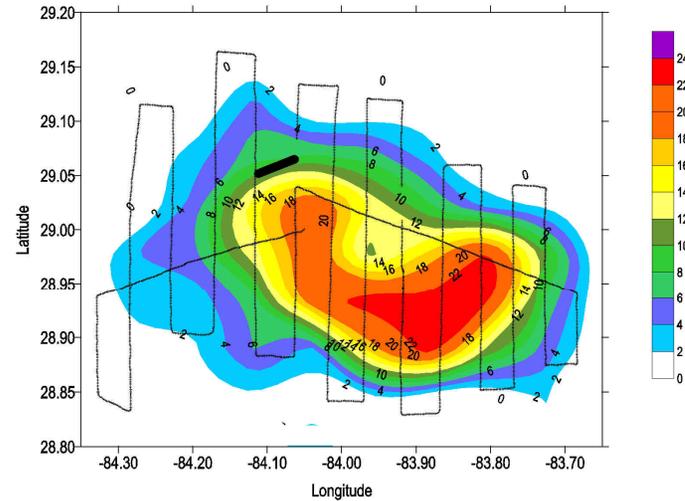
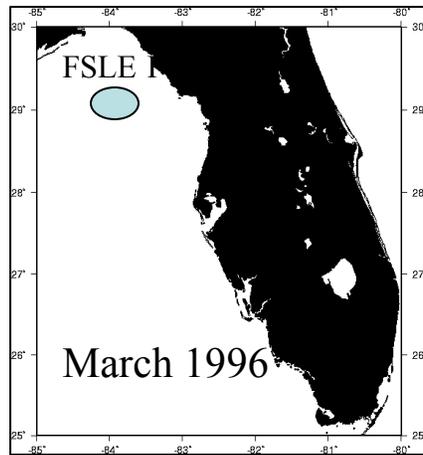
Cia and Lohrenz pers. com.

Previous Work

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

Gas Transfer Velocity Estimates

Gas transfer estimates is on the high side of the gas exchange-wind speed envelope



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Wanninkhof et al. 2007

Previous Work

Creation of Flux Maps in the Gulf of Mexico

- * Obtain data from ships and other platforms (moorings, small boats)
- * Create regional algorithms with biogeochemical and physical parameters that are measured at higher frequency and with regional coverage
- * Use high data coverage to create flux maps that captures spatial and temporal variability

(High frequency) products available:

Q-Scat Wind: for gas transfer

Reynolds SST: for $p\text{CO}_{2w}$ (tied to ship SST)

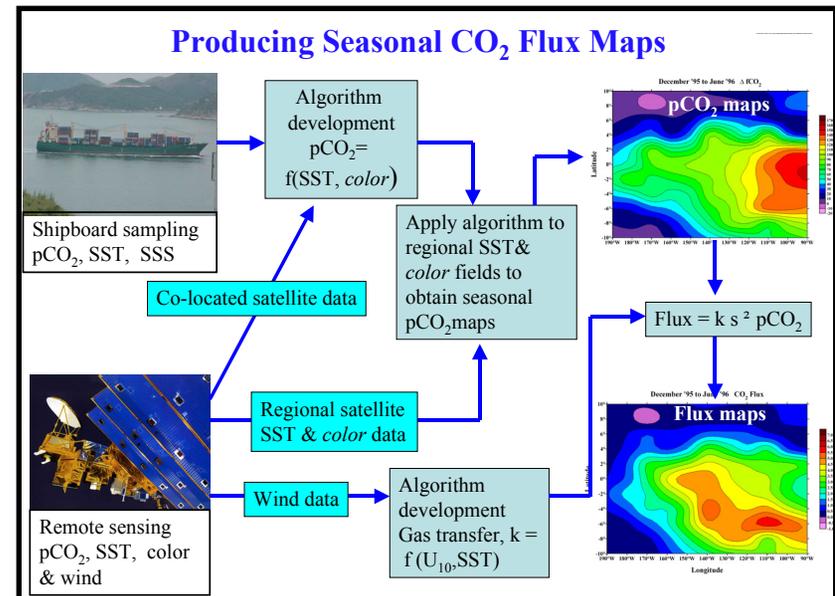
Location: different biogeochemical provinces (SOM)

Chlorophyll: productivity

Mixed layer depth: entrainment

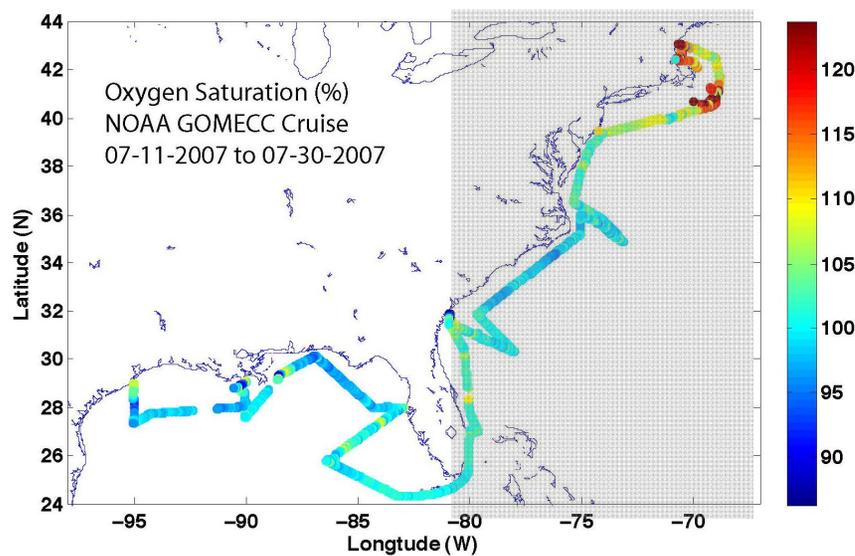
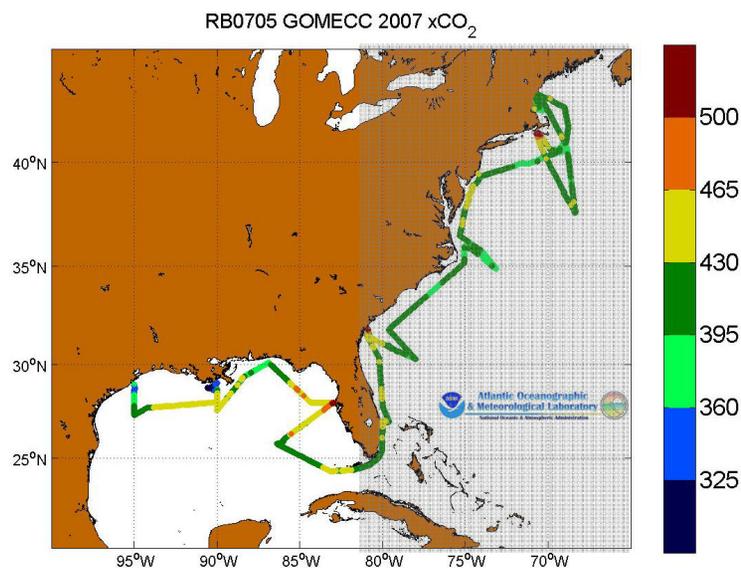
Salinity: delineation of provinces

Sea surface height: entrainment



Determination of pCO₂ fields

1. pCO₂ data - GOMECC cruise- July 2007



Langdon and Salisbury

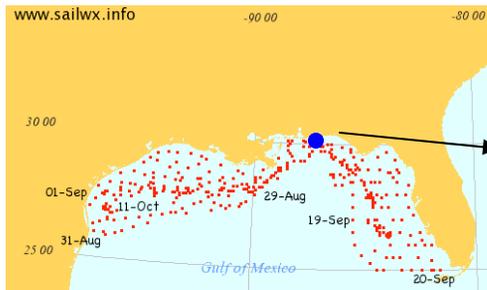
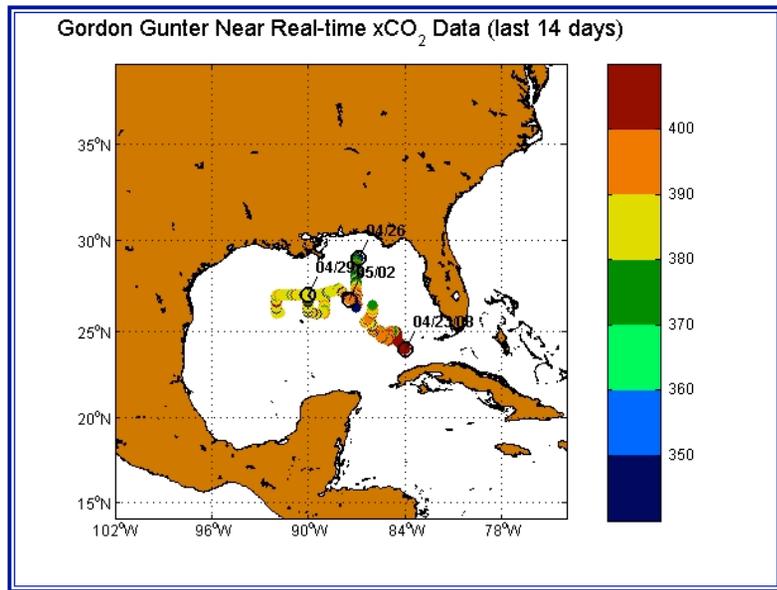
Anti-correlation pCO₂ and O₂ supersaturation near the coast

Determination of pCO₂ fields

2. Underway data NOAA fisheries ship *Gordon Gunter*



R/V Gordon Gunter cruise track showing color coded xCO₂ data. This display is updated every morning.

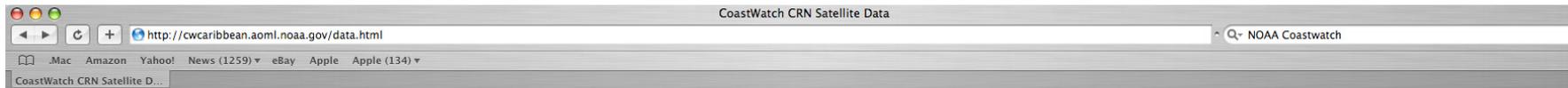


pCO₂ mooring Sabine&Lohenz

6-week cruise track Sept-Oct 2007

QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

Remotely Sensed Data / Assimilation models



Satellite Data

[Information](#) | [Data](#) | [Software](#) | [Sites](#) | [Education](#) | [Feedback](#) | [Gallery](#)

The Caribbean/Gulf of Mexico Regional Node web site is designed to supply users with satellite data files and previews in near-real-time. Image data is available for a number of different [regions](#) and product [data types](#). Access to CoastWatch satellite data is free and unrestricted.

CoastWatch users can download data files for use with one of the CoastWatch [software](#) packages, plot data using the web site online preview, or convert data to other [data formats](#) for use in GIS or scientific plotting packages.



Visual Catalog: Look through the most recent CoastWatch satellite data passes using a catalog of color images. High resolution sea surface temperatures can be immediately viewed by clicking on cloud-free areas of the coast.



Database Query: Submit a database query to the CoastWatch web server to find specific dates, regions, and types of data. The query generates a table of the CoastWatch data files online matching your criteria.



Processed Data Directory: Browse the CoastWatch data archive manually by navigating through a directory tree of satellite passes. Be sure to read the README file for the directory and file naming conventions.



SST Anomalies: View 5-day (pentad) SST anomaly maps for the Caribbean Region. Spatial resolution is 9.28 km.



Near Real Time Wind Data: Display and retrieve surface wind data from a variety of sensors(QuikSCAT, SSML, TMI, ERS-2, TOPEX, Jason-1, GFO and Drifters).



Altimeter and GTS Data: Sea Height Anomalies (SHA), geostrophic currents, and other data from GTS (drifters, XBT, ...). By [Joaquin A. Trinanes](#) and [Gustavo Goni](#).



Upper Ocean Heat Content: Upper ocean thermal structure derived from the Sea Surface Height and Sea Surface Temperature fields. Updated daily. By [Gustavo Goni](#) and [Joaquin Trinanes](#).



Atlantic SST maps: Display and retrieve daily and pentad Sea Surface Temperature maps for the Atlantic Ocean. These maps are created using data from the POES satellites.



XBT Data: XBT profiles distributed via GTS. Other databases available are: Historical Kriged Drifter data, GTS TESAC and BUOY reports, ... GIF, ASCII and PDF outputs.



CO2 Flux Maps: We have developed algorithms to create CO2 flux maps in the Caribbean using satellite data. Details can be found in Olsen, A., J. Trinanes and R. Wanninkhof, "Sea-air flux of CO2 in the Caribbean Sea estimated using in situ and remote sensing data, Remote Sensing of Environment", 89, 309.325, 2004.]



VRML Wind Page: Explore Global Wind data using VRML Technology.



Color Data: The CoastWatch Search Interface provides access to MODIS and SeaWiFS color data for a selected geographic region. Besides Ocean Color, GOES and POES SST products are also available here.

[Back to main page](#)

[USDOC](#) | [NOAA](#) | [NESDIS](#) | [CoastWatch](#)

NOAA Coastwatch Caribbean/Gulf of Mexico Regional Node:
<http://cwcarribbean.aoml.noaa.gov/data.html>

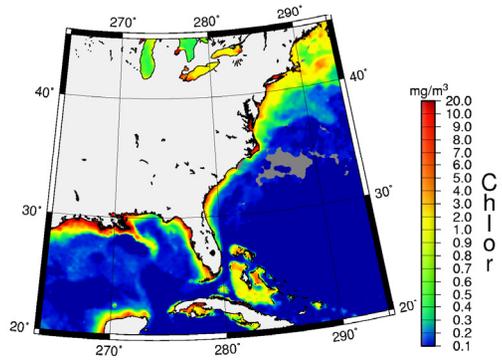
QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Data products

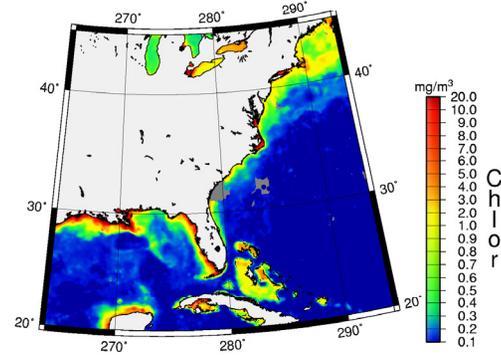
Remotely Sensed Data / Assimilation models

Color:

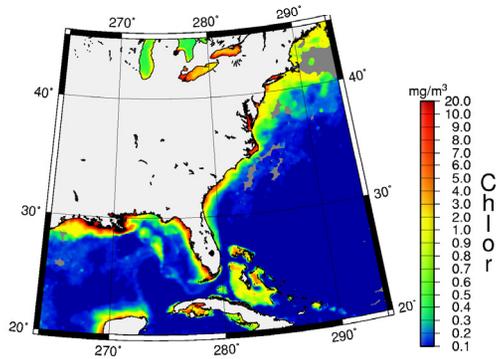
JD 190-194, 2007



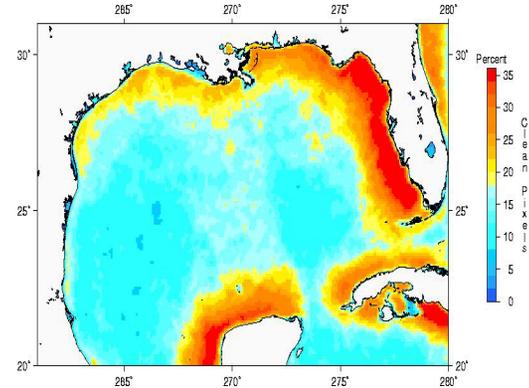
JD 215-219, 2007



JD 200-204, 2007



% clean pixels MODIS GOM

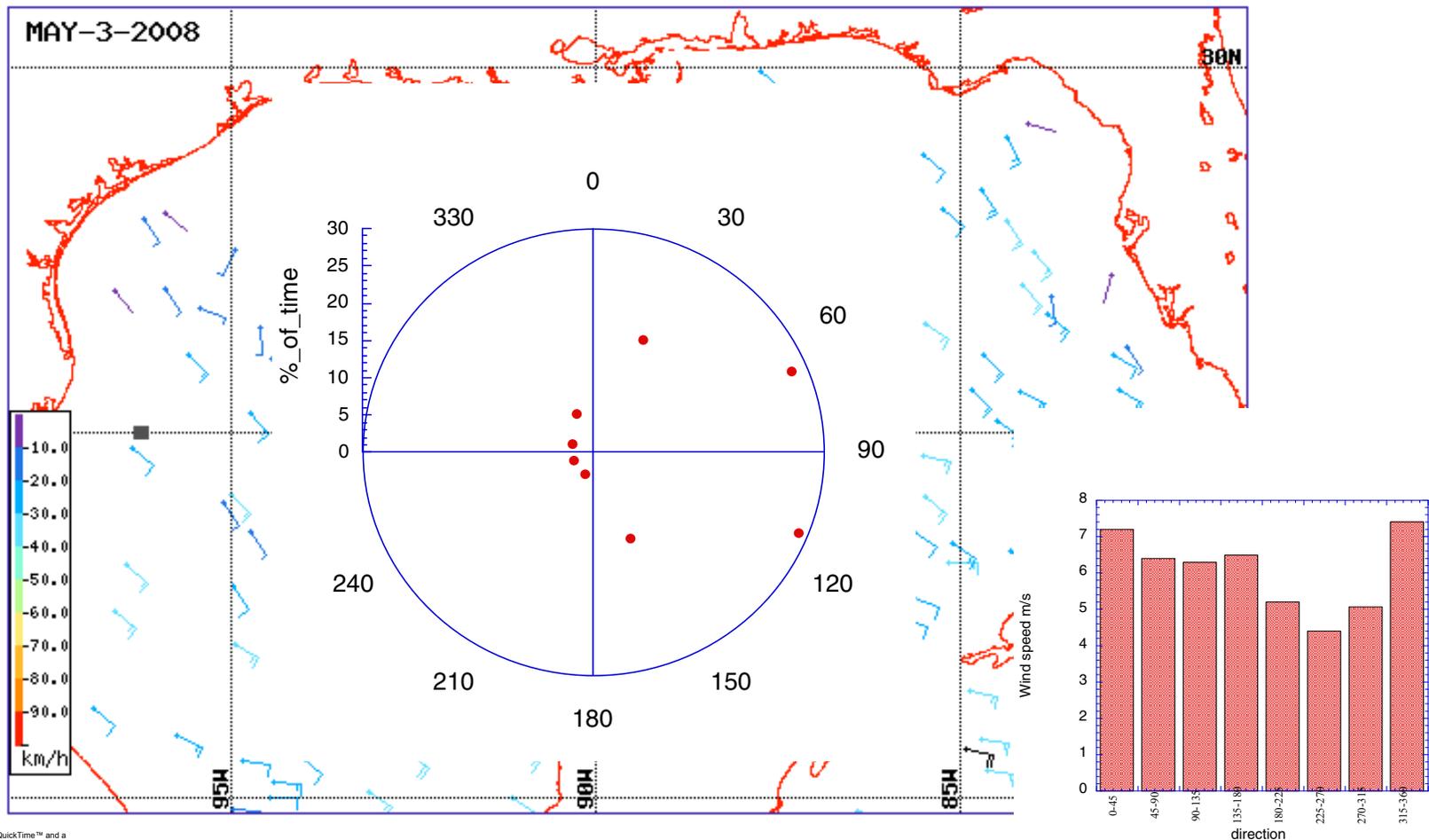


QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Data products

Wind:

QuickScat - 25 km resolution 2 passes/day



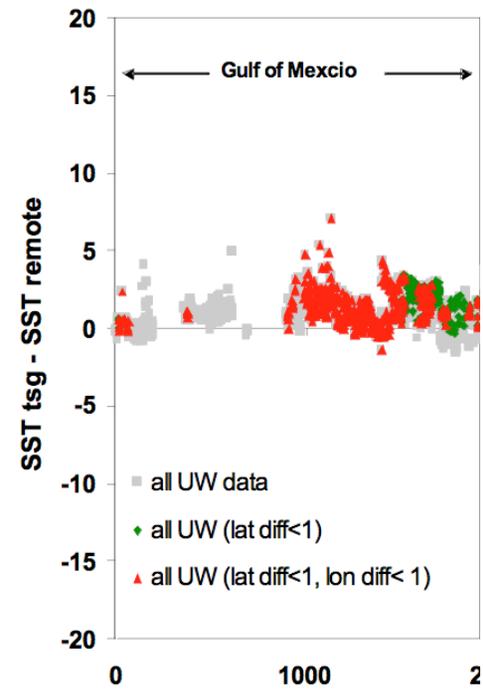
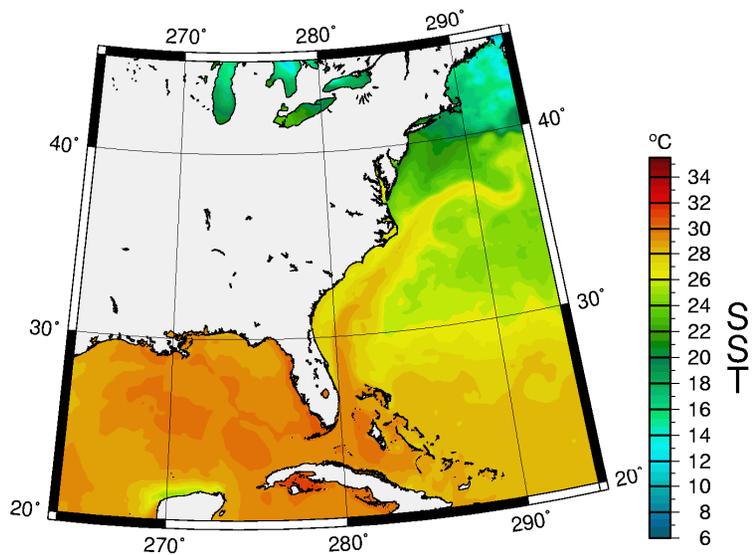
QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

Data products

SST-

Issues: skin temperature, near surface gradients, haze

Causing a cold bias

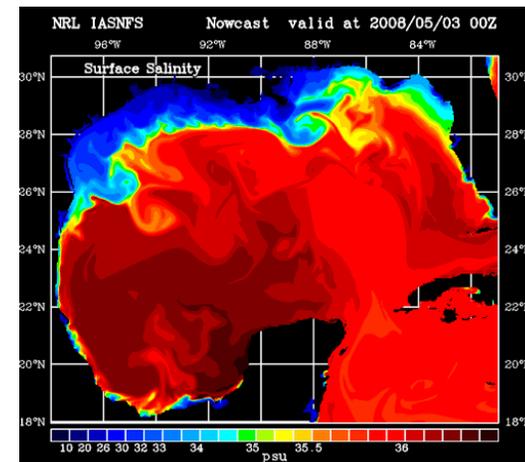
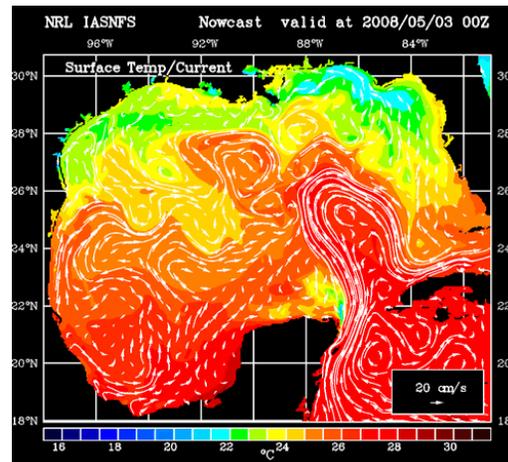
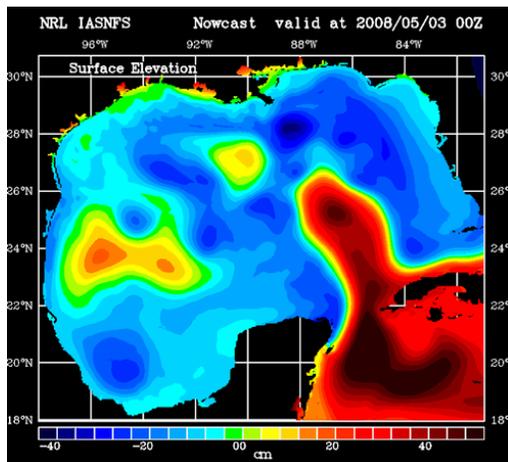


QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

Data Assimilation models

IASNFS

Experimental Real-Time □ *Intra-Americas Sea Ocean Nowcast/Forecast System*



http://www7320.nrlssc.navy.mil/IASNFS_WWW/IASNFS_intro.html

A potential powerful tool for regional interpolation/extrapolation

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

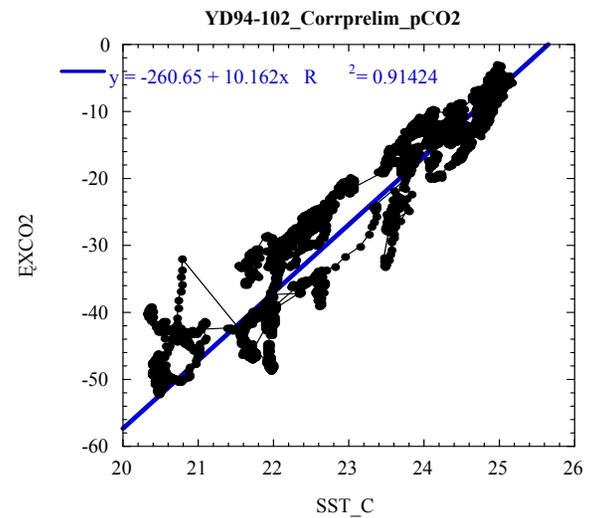
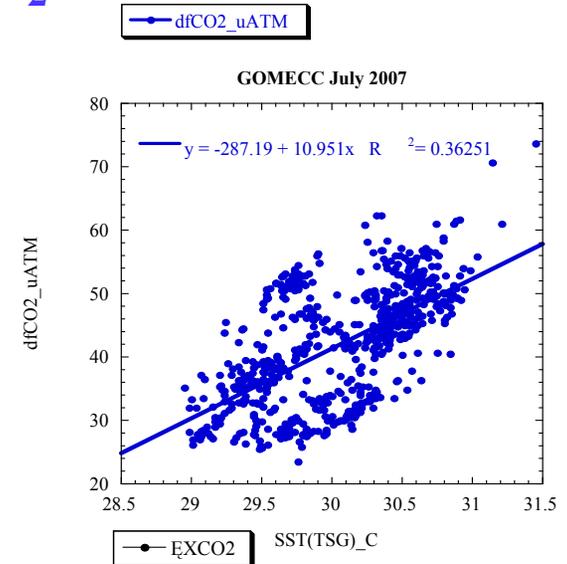
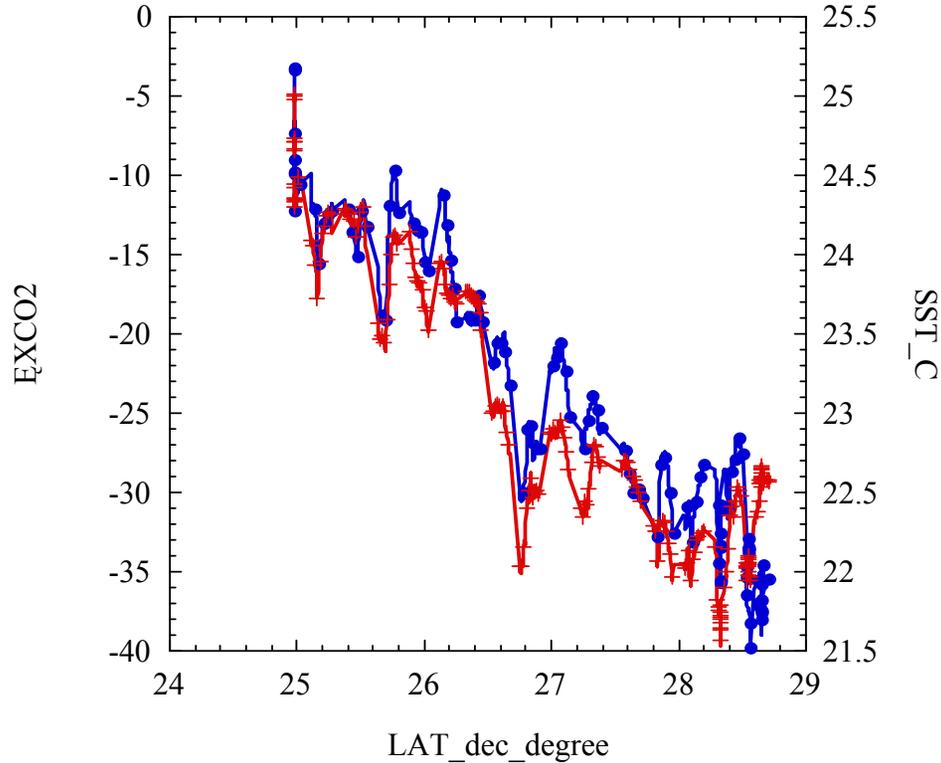
Data products

Algorithms for pCO₂

For > 80 % of GOM pCO₂ is strongly correlated with SST

Gordon Gunter 2008

YD94-102_Corrprelim_pCO2



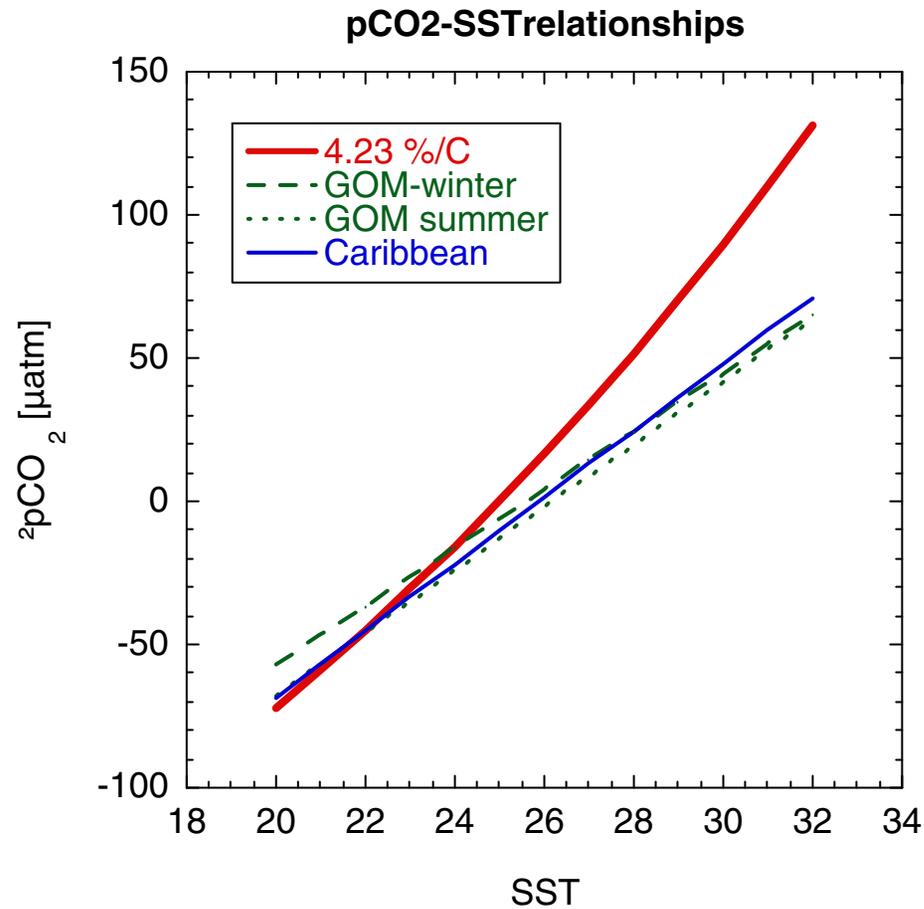
QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

Algorithms for pCO₂

Similar relationship as for Caribbean Sea 2003-2005:

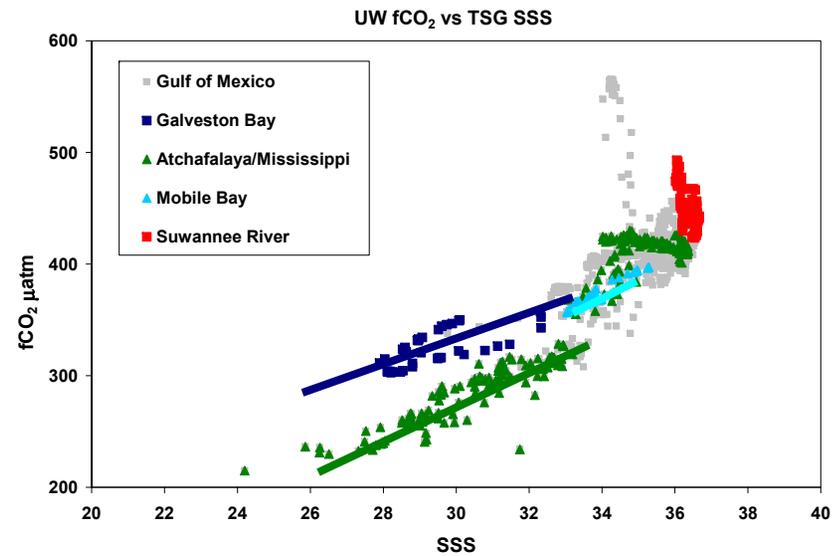
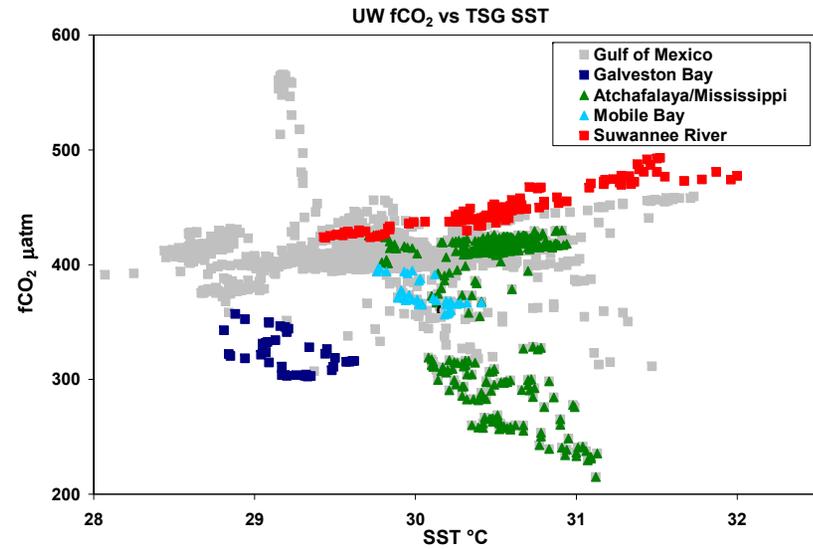
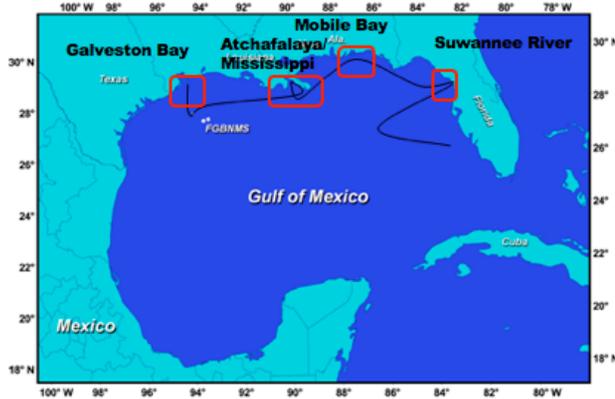
$$\Delta f\text{CO}_2 = 11.63 \text{ SST} + 0.77 \text{ Lat} - 0.42 \text{ Long} - 361$$

$$\Delta f\text{CO}_2 = 11.63 \text{ SST} - 301$$



Algorithms for pCO₂

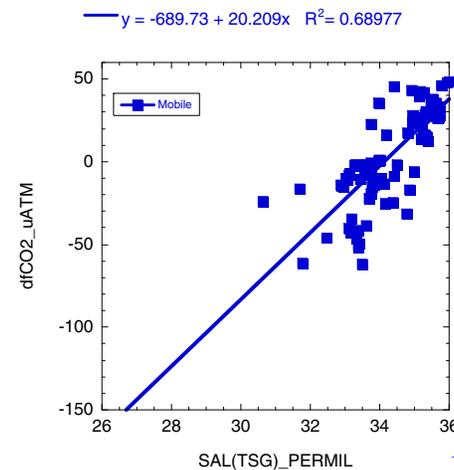
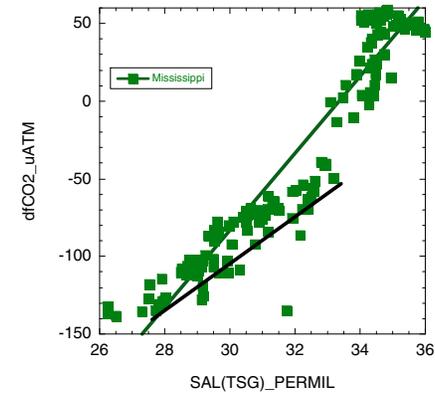
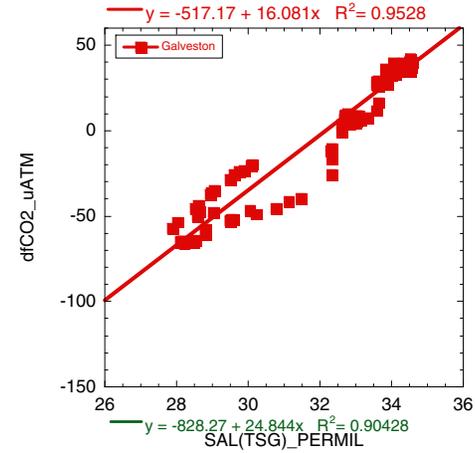
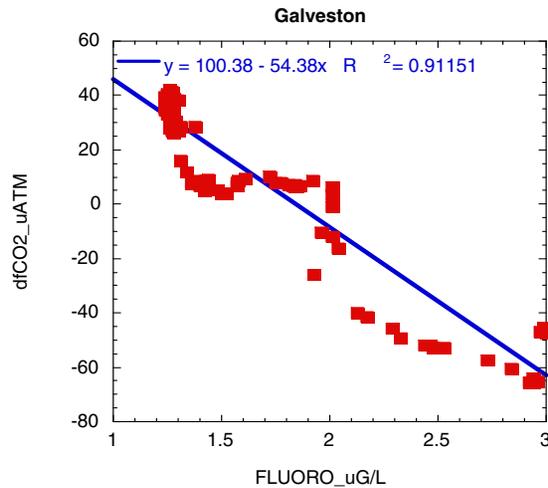
Now for the remaining 20 % ????



QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

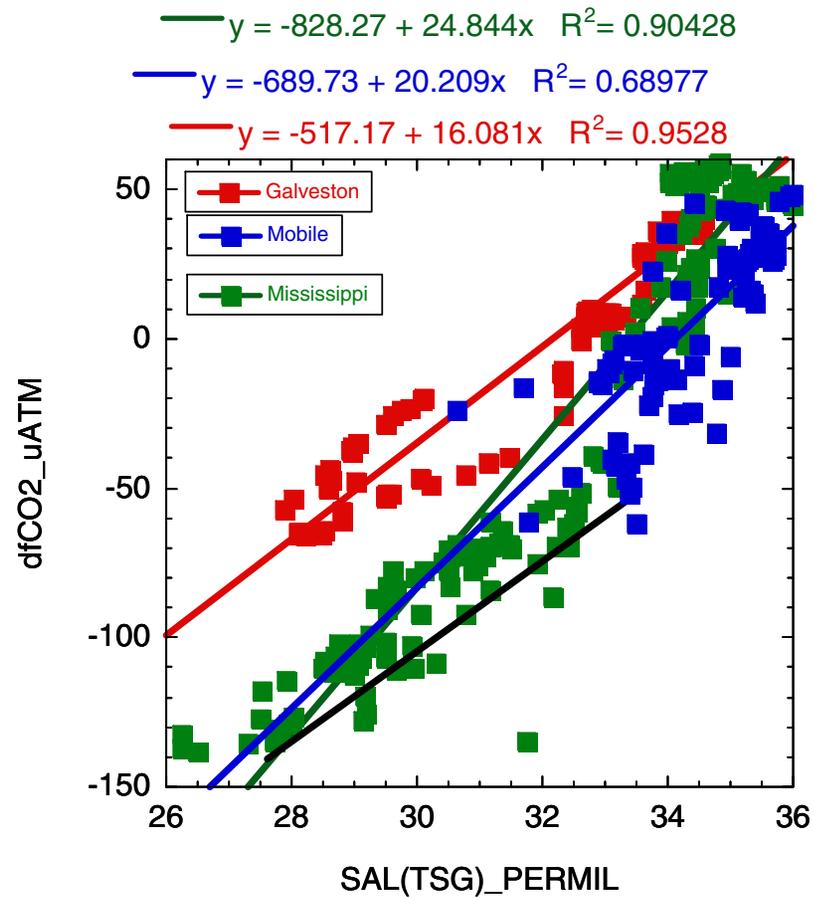
Algorithms for pCO₂

“Near-shore”: GOMECC
Correlations with salinity and color



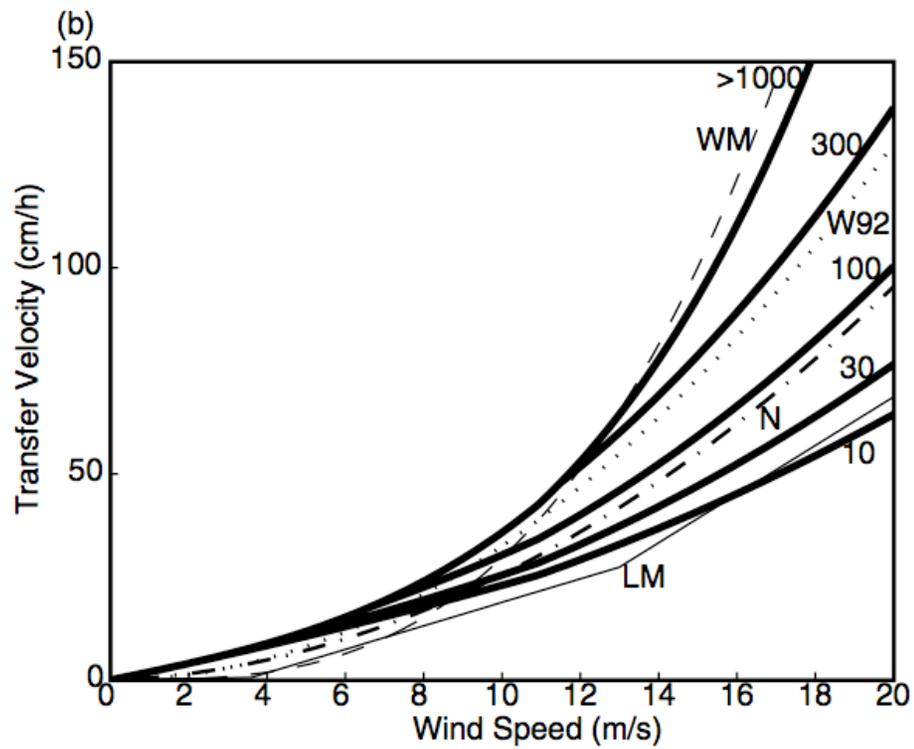
See: Joe Salisbury, UNH
Steve Lohrenz, USM

Algorithms for pCO₂



Gas Transfer Velocities

GOM- Fetch, low winds, chemical enhancement, surfactants?



Woolf, Tellus 2005

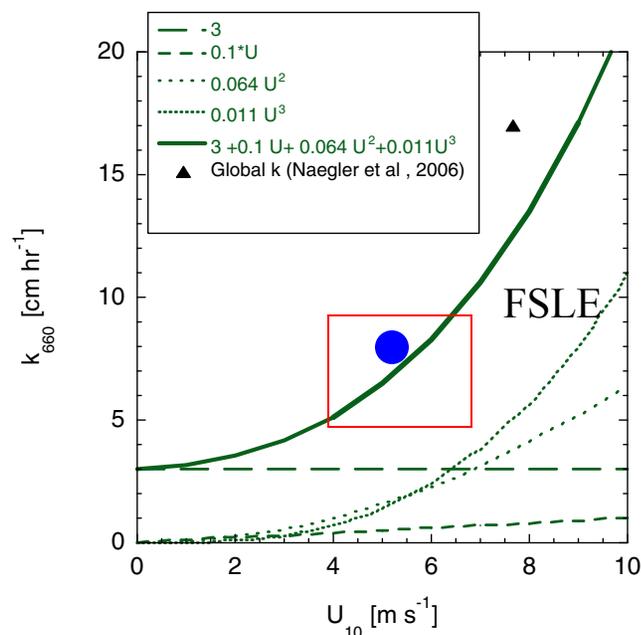
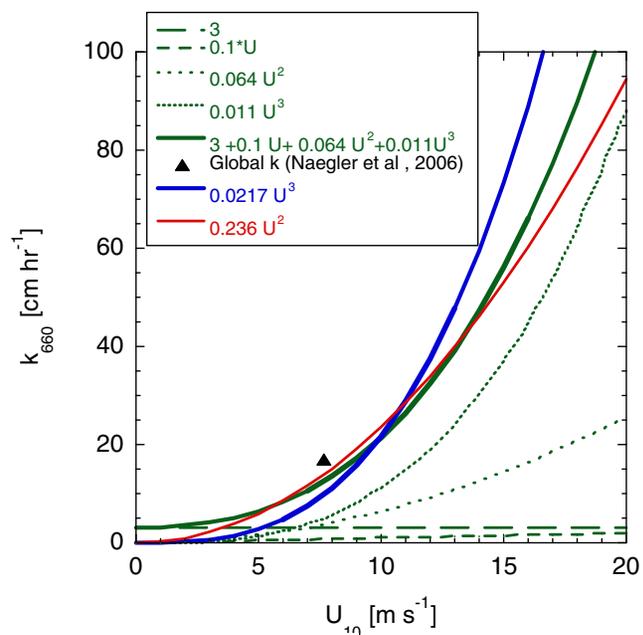
Gas Transfer Velocities

An inclusive parameterization of gas exchange with wind

Wanninkhof, Asher, Sweeney, Ho, McGillis, Annual reviews, submitted

$$k = a + b U + c U^2 + d U^3$$

Constant:	Chem enhancement, non-wind induced turbulence
Linear:	Transfer across solid boundary
Quadratic:	Wind stress
Cubic:	Dissipation, bubbles



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

k vs u

Recommendations

To constrain air-sea fluxes in GOM and its effect on North America:

- Provide support for surface water pCO₂ observing system (ship and mooring)
- Develop robust algorithms in regions affected by riverine input (Use color!)
- Perform process study for direct measurement CO₂ fluxes (year-long study on platform)
- Establish robust air sampling program