

NOAA Coral Reef Watch Calcification Index of Coral Reef Ecosystems

NOAA's Coral Reef Watch:

Global Satellite Component of CREIOS

Al Strong (NOAA/NESDIS)

C. Mark Eakin (NOAA/NESDIS)

Jessica Morgan (NOAA/NESDIS, IMSG)

Tyler Christensen (NOAA, IMSG)

Gang Liu (NOAA/NESDIS, STG)

Dwight Gledhill (NOAA/NESDIS, Knauss Fellow)

William Skirving (NOAA/NESDIS, QSEC)

Scott Heron (NOAA/NESDIS, QSEC)

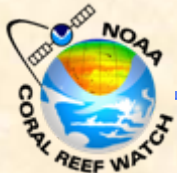
NOAA/NESDIS/STAR/SO

and

Coral Reef Conservation Program (CRCP)

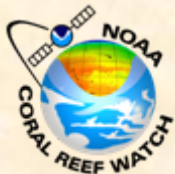
NOAA Coral Matrix

Silver Spring, Maryland



Presentation Outline

- NOAA Coral Reef Watch – Mission and Challenges
- Research Impetus
 - Impact of rising CO₂ on ocean chemistry
 - Potential threat to marine calcifiers
- Reef Calcification Index (RCI) – Product Development
 - Calcification and its effect on ‘reef water’ CO₂
 - Modeling pCO₂ from space
- Proof of Concept: Caribbean Sea
- Next Steps
- Application and Stakeholders
- Significance, Mission Goal, Cross-Cutting Priorities





The Mission:

The mission of NOAA's Coral Reef Watch Program is to utilize remote sensing and in-situ tools for near real-time and long term monitoring, modeling and reporting of physical environmental conditions of coral reef ecosystems. Coral Reef Watch aims to assist in the management, study and assessment of impacts of environmental change on coral reef ecosystems.



Why Do We Care?

Value of Reefs

- Seafood: \$247 million in commercial fishing on U.S. reef fish
- New medicines: cancer research, bone grafts, antivirals
- Other products: jewelry
- Recreation: \$17 billion in U.S. tourism
- Coastal protection: buffer from wave action and the impact of storms

One kilometer of reef valued at between \$137,000 to almost \$1.2 million!

Global Decline:

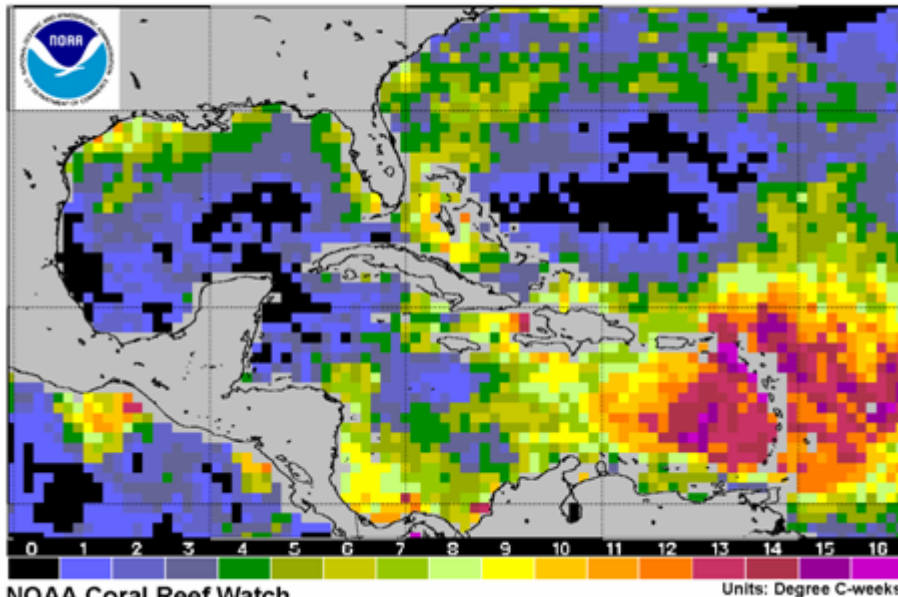
- 1/3 world's reefs severely damaged (U.S. COP)
- 50 – 60% may be lost in 30 years (U.S. COP)
- '97-'98 El Niño mass bleaching event (16% global mortality)
- '05 Caribbean Sea bleaching event (15 – 16 weeks!)

NOAA Caribbean Bleaching Response Effort

- A major coral bleaching event is underway in the Caribbean
- Thermal stress reached record levels, exceeding 15 Degree Heating Weeks (DHWs) at some sites
- NOAA Coral Reef Watch Satellite Bleaching Alert (SBA) monitoring system first alerted possible bleaching conditions:
 - Florida Keys in late Aug.
 - Puerto Rico and US Virgin Islands in early Oct.
- The DHW and SBA products have been invaluable to researchers and managers who have redirected efforts to monitor the resulting bleaching.
- NESDIS is leading an international effort to fully document the extent of the bleaching event.

Bleaching report data for July-November 2005	
Location	Percent Bleached
Bahamas	16-75
Belize	1-77
British Virgin Islands	90-100
Colombia	1-90
Cuba	8-75
Jamaica	20-80
Mexico	1-50
Panama	70
Trinidad and Tobago	6-100
US Florida	3-80
US Puerto Rico	50-75
US Texas	35-100
US Virgin Islands	10-100
Venezuela	21
Compiled from more than 400 bleaching observations obtained from Coral Reef Watch, ReefBase, Coral List, and other sources	

2005 Annual Composite of Maximum Twice-weekly Degree Heating Weeks

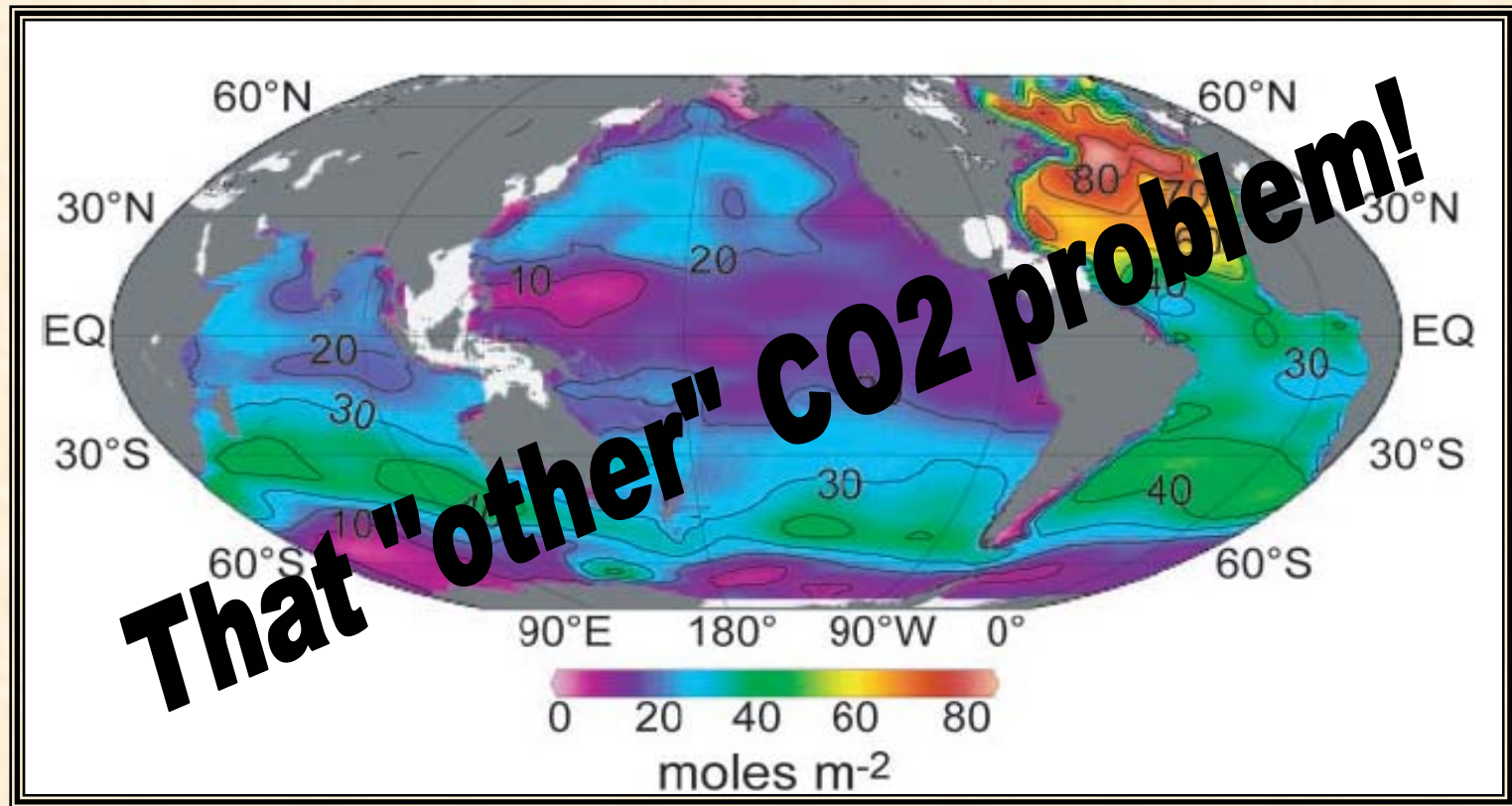


Stressors to Coral Reefs

- Thermal stress
- Eustatic sea level rise
- Nutrient stress
- UVB stress
- Salinity stress
- Siltation stress
- Carbonate mineral saturation state

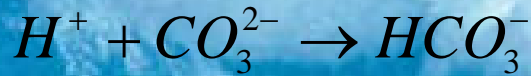


Rising Levels of Ocean Carbon Dioxide



Total oceanic uptake of anthropogenic CO₂ of approximately 118±19 Pg C between 1800 and 1994.

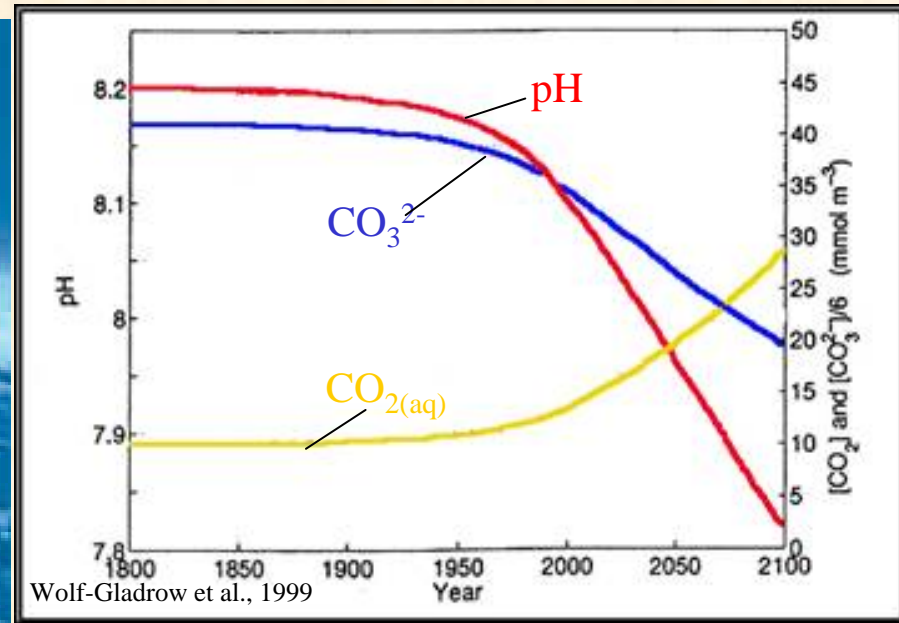
Ocean 'Acidification'



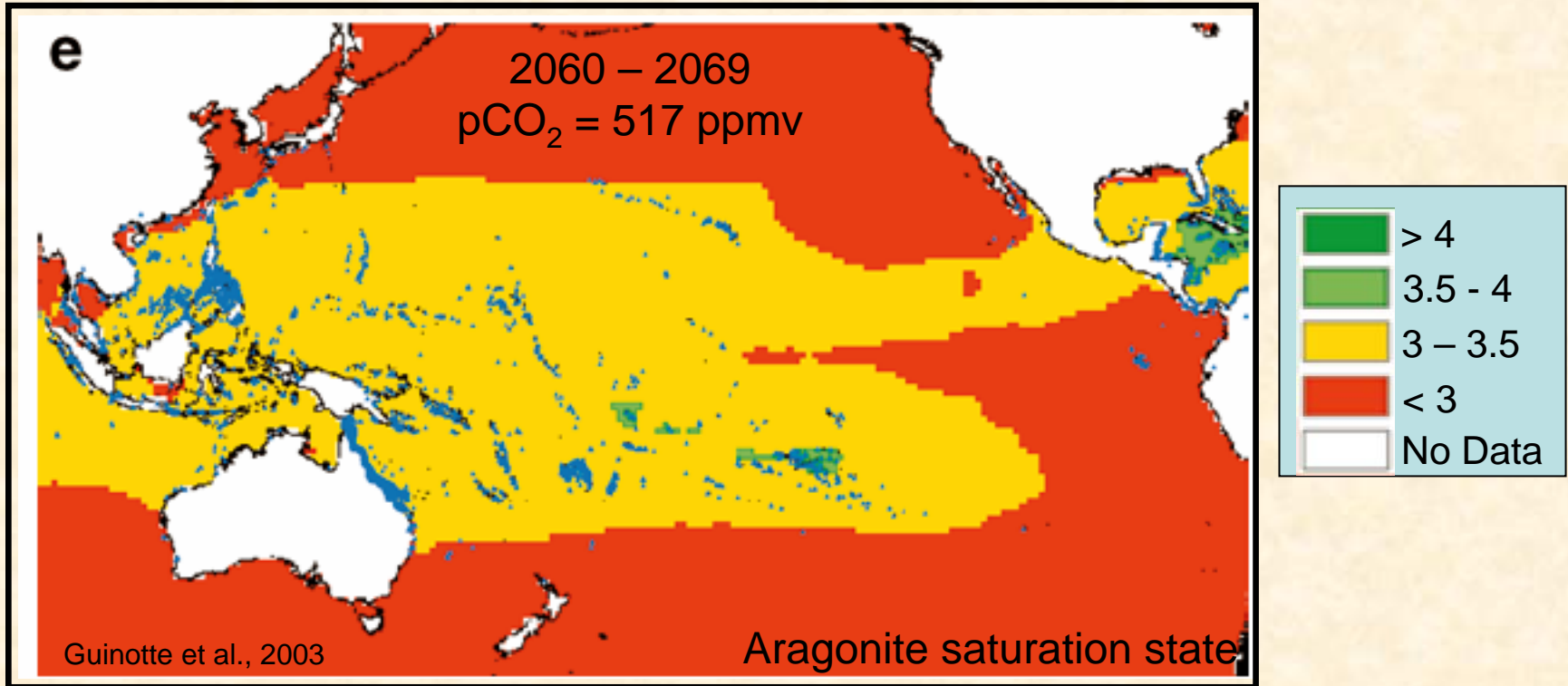
Net:



www.niwascience



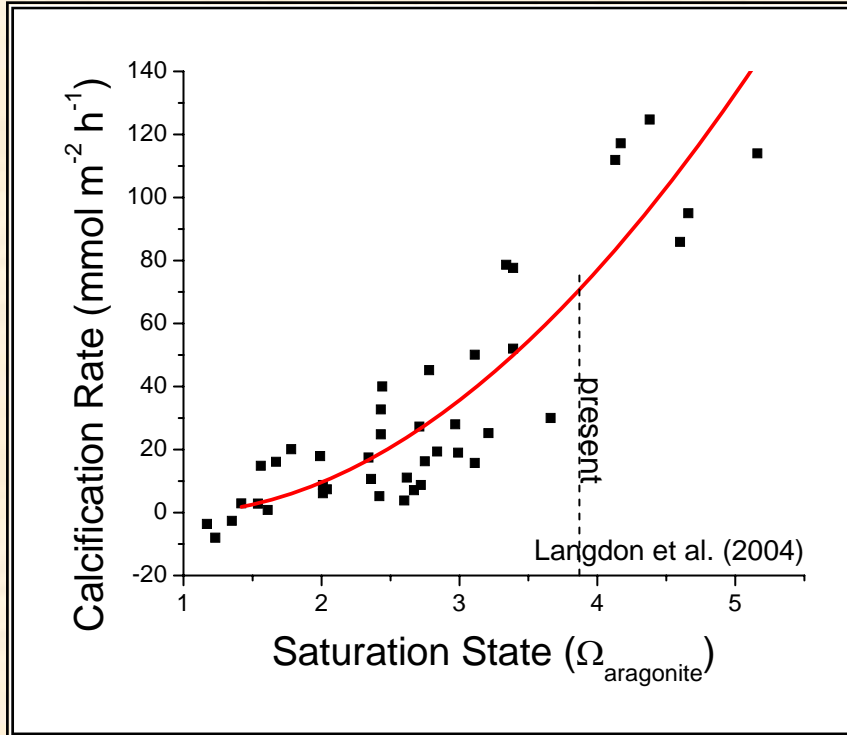
Projected Changes in Saturation State



NCAR Community Climate System Model CCSM v 1.0
IPCC SRES B2 scenario

Saturation state in the tropics may decrease by 30% over the next century with a proportional reduction in calcification rates

Impact on Marine Calcifiers

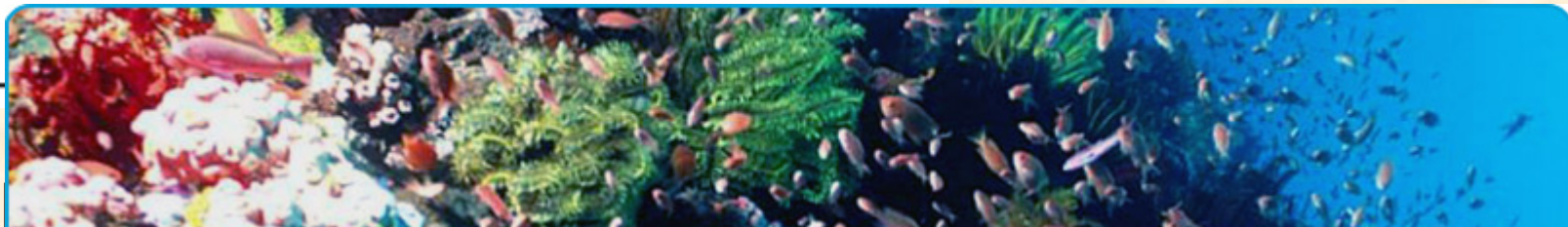


Decrease in *calcification rate!*

- ✿ Weaker skeletons
- ✿ Reduced extension rates
- ✿ Increased susceptibility to erosion
- ✿ Submersion

BIOSPHERE II Coral Reef Mesocosm

**SYMPOSIUM ON THE OCEAN IN A HIGH-CO₂ WORLD
PARIS
10-12 MAY 2004**



Workshop on the Impacts of Increasing Atmospheric CO₂ on Coral Reefs and Other Marine Calcifiers

**18-20 April 2005
USGS Center for Coastal and Watershed Studies
St. Petersburg, Florida**



 **THE ROYAL
SOCIETY**

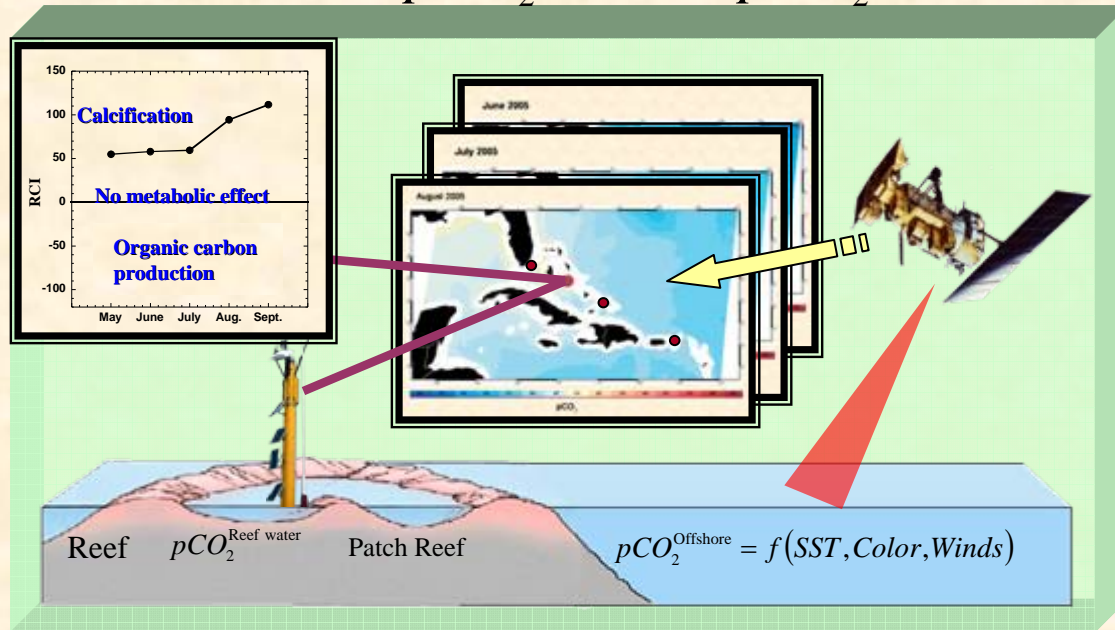
30 June 2005

Identified priority research areas and recommended approaches from small-scale laboratory experiments to large-scale field experiments, and modeling.

Ocean acidification due to increasing atmospheric carbon dioxide

The Reef Calcification Index (RCI)

$$RCI = pCO_2^{\text{Reef water}} - pCO_2^{\text{Offshore}}$$

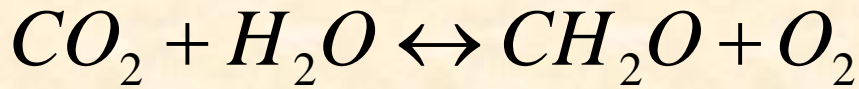


- The RCI couples remote sensing and *in situ* observations of carbon dioxide partial pressure (pCO₂) to monitor changes in reef community structure.
- Monitoring the balance between organic carbon and calcium carbonate production, the RCI reflects ecosystem-level changes and reef responses to a series of environmental stresses including ocean acidification.
- The RCI adds to the suite of CRW products, providing an important tool in monitoring coral reef response to mounting environmental stresses related to climate change.

Coral Reef Impact on CO₂

Photosynthesis

Respiration

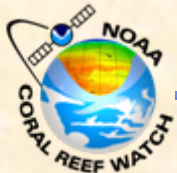
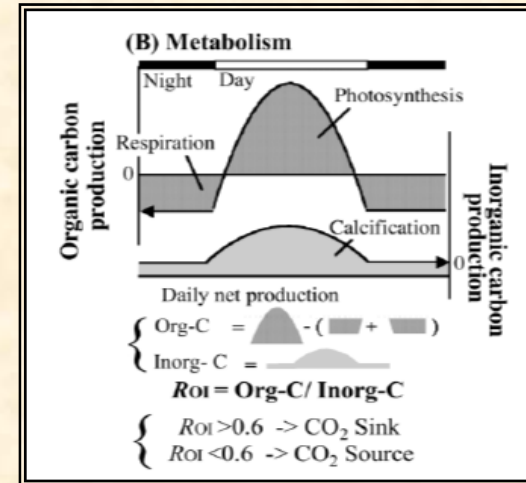
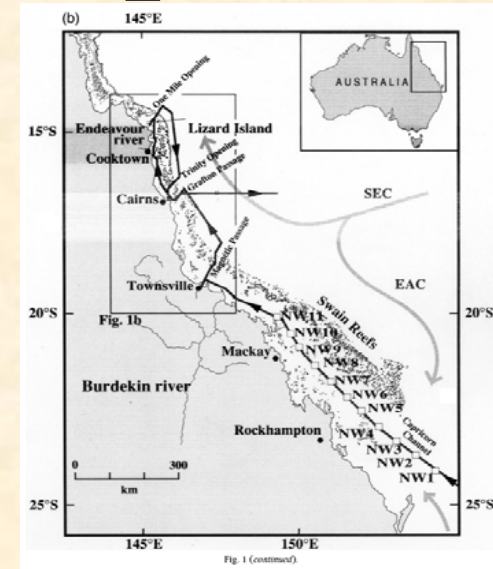
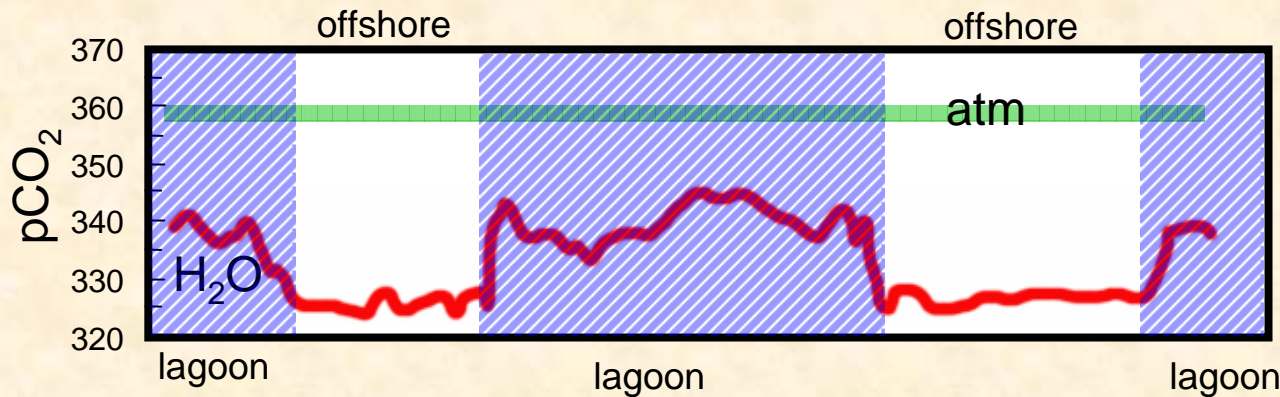


Calcification

Dissolution

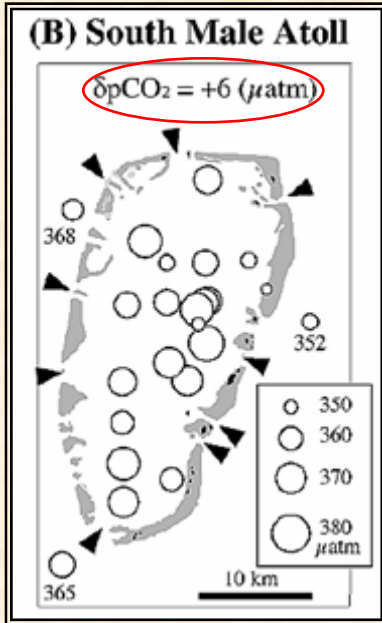


Southern and Central GBR

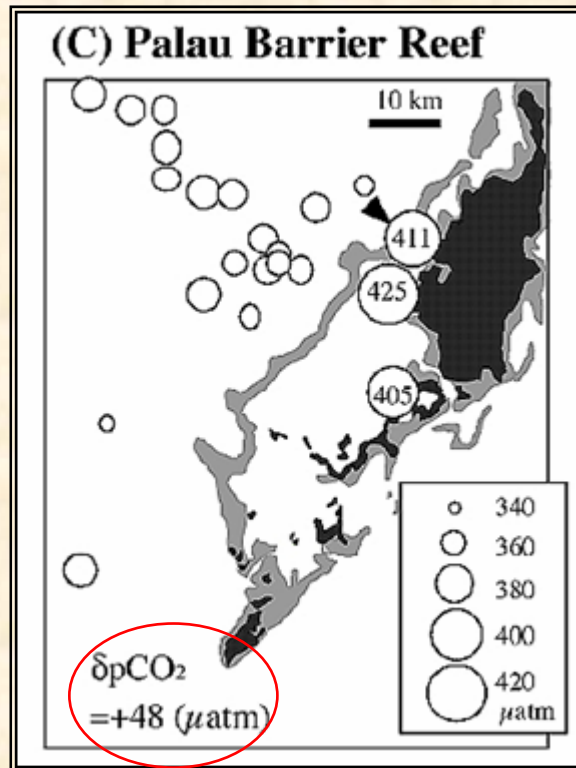


Kawahata, 2000

Reef Calcification Index (R.C.I.)



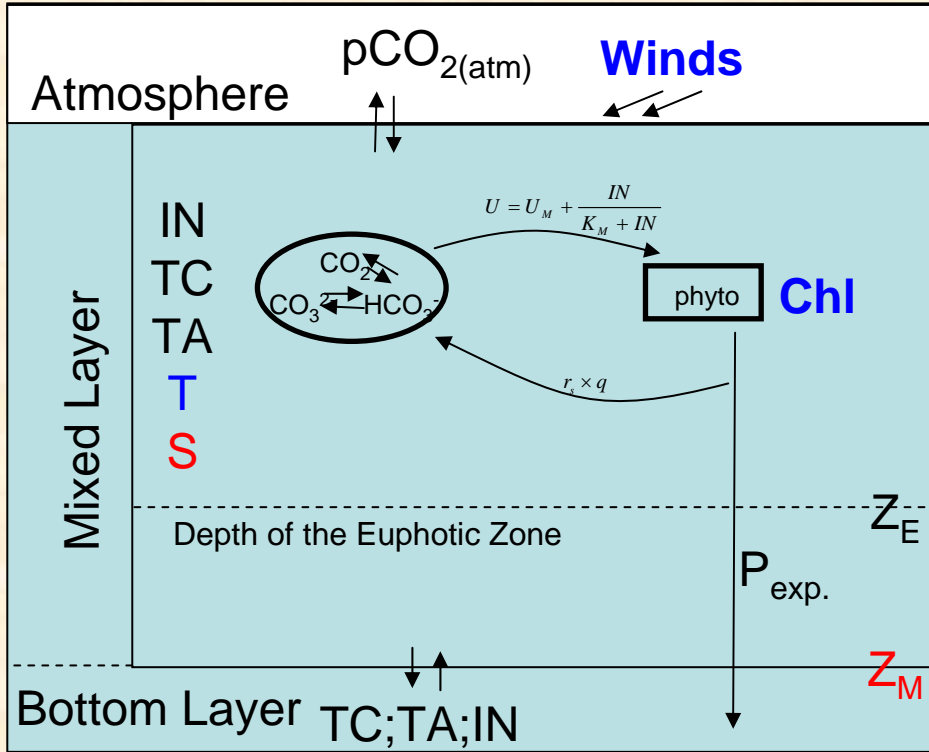
$$\delta pCO_2 = \underbrace{pCO_{2,L}}_{\text{Reef Water}} - \underbrace{pCO_{2,O}}_{\text{Offshore}}$$



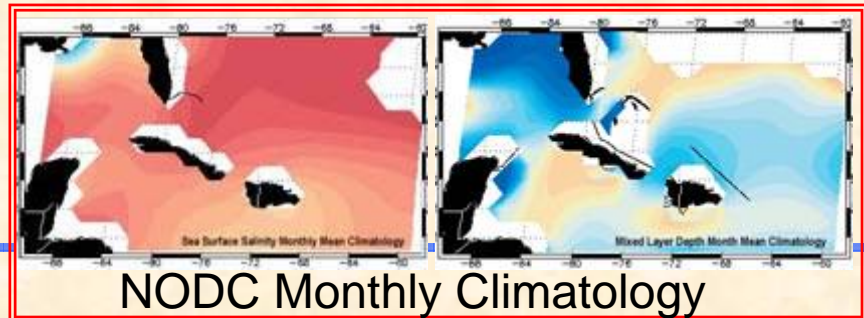
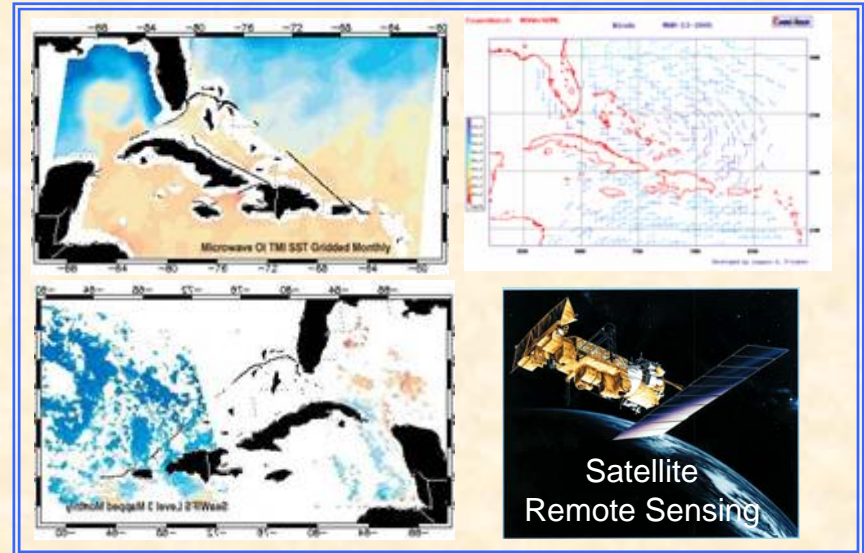
A positive R.C.I. indicates robust calcification

- Magnitude controlled:
 - Net primary productivity versus calcification (R_{OI})
 - Coral cover
 - Mean water depth
 - Hydrographic processes

Mechanistic pCO₂ Model

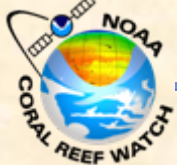


- Physical and biogeochemical processes constrained by monthly variations of:
 - Sea surface temperature
 - Chlorophyll concentration
 - Wind speed
 - Salinity
 - Mixed-layer depth

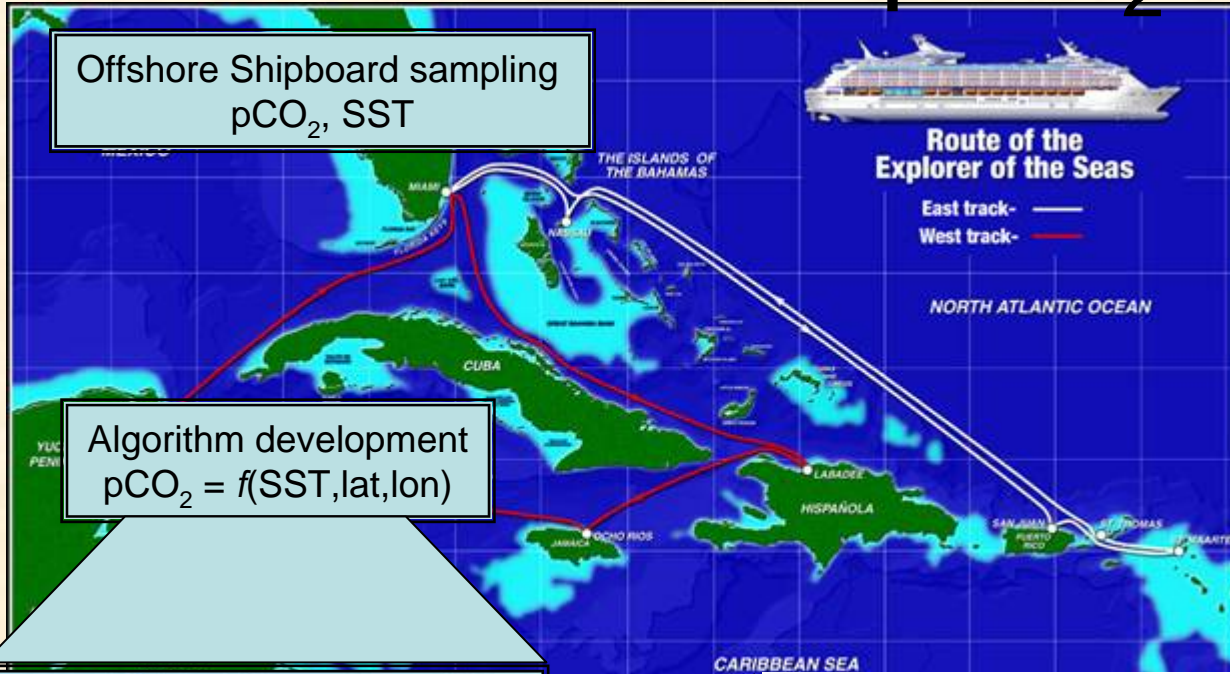


Louanchi, Metzl, Poisson (1996)

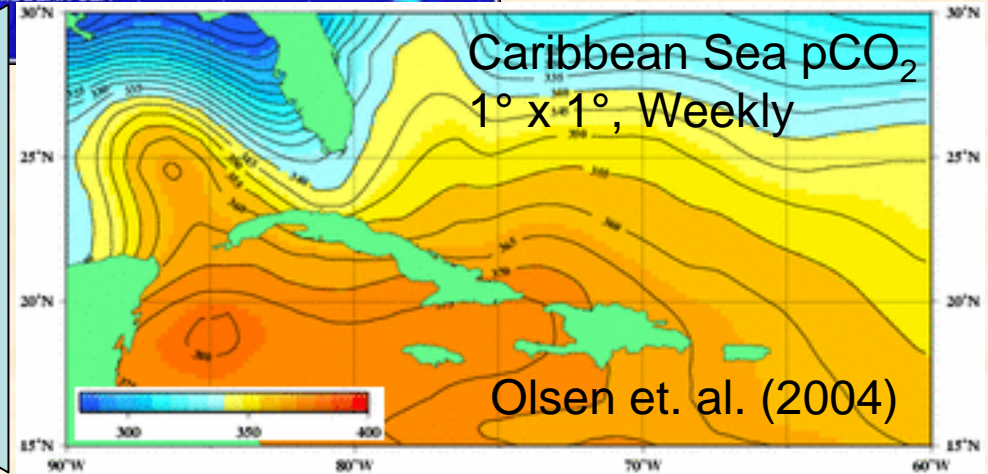
- Monthly 2°x 2° sea surface pCO₂ fields in the Indian Ocean where the model seeks to account for:
 - Air-sea exchange
 - Thermodynamic effects
 - Biological activity
 - Mixing processes



Statistical pCO₂ Model



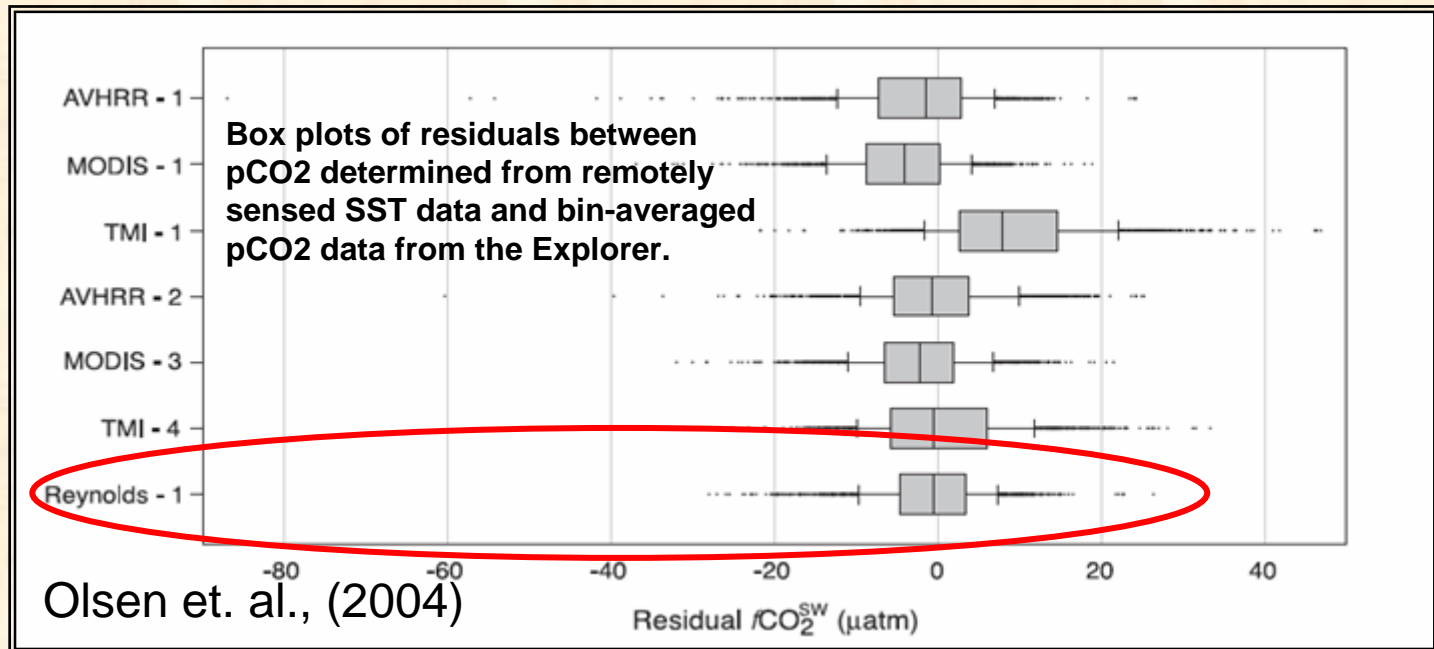
- 2002 – present
- East – West tracks
- Sea Keeper pCO₂ sys.
- Thermosalinograph



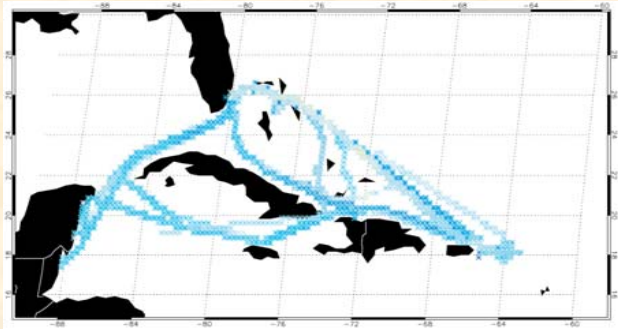
AOML Caribbean Sea pCO₂ Model

2002: pCO₂sw = 10.18 SST + 0.5249 lat - 0.2921 lon + 52.19,
n = 40204, rms = 5.7 μatm, r² = 0.87

- Low spatial resolution using Reynolds (1°x1°)
- Yearly drift in SST slope related to changes in atm. CO₂.
- Not provided NRT
- Lat & Lon dependence

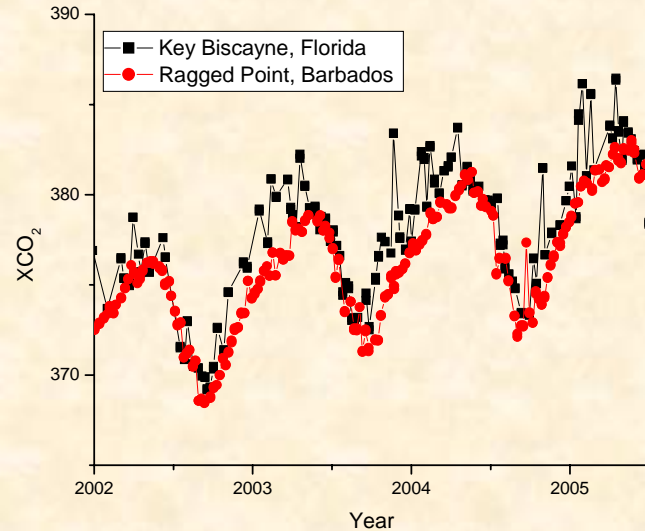


CRW Caribbean Sea pCO₂ Model



Ship observations of temperature and pCO₂ were assembled into weekly 0.25 degree binned averages from March 2002 through October 2005

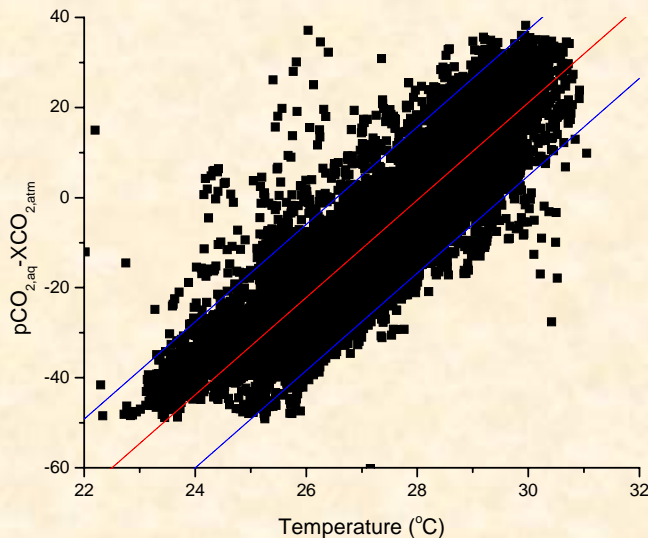
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Data for the dry atmospheric mole fraction of CO₂ (XCO₂) were provided by the NOAA/CMDL Carbon Cycle Greenhouse Gases (CCGG) Group flask sampling program. –T.J. Conway

Weekly mean values were linearly regressed to obtain the latitudinal XCO₂ gradient.

=



n	Adj-r ²	RMS
17582	0.81	8.27

CRW Caribbean Sea pCO₂ Model

- The offshore pCO₂ can be obtained from:

$$pCO_2 = -303.31 + 10.81 \times SST + xCO_{2,Key} + \frac{xCO_{2,KEY} - xCO_{2,RPB}}{12.5} \times (Lat - 25.6)$$

Sea Surface Temperature
- Satellite SST product

Local atmospheric CO₂ term
- NOAA/CMDL CCGG

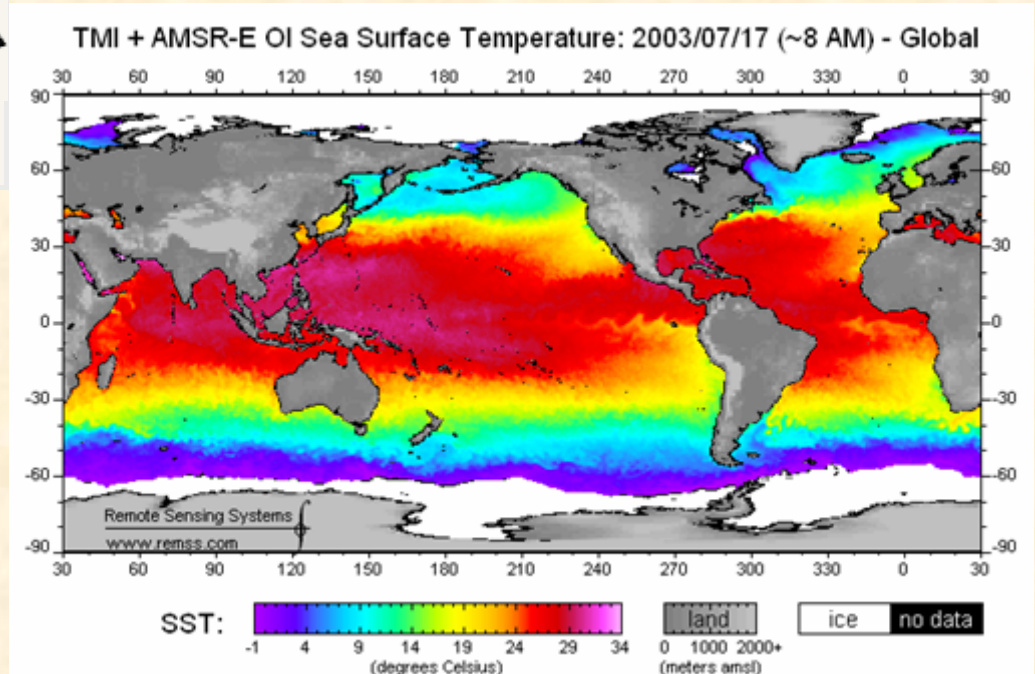
CRW Caribbean Sea pCO₂ Model

Remote Sensing Systems

Contact RSS

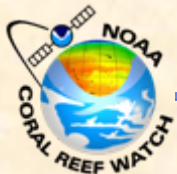


- Multi-satellite, multi-sensor
- Daily at ~25 km resolution
- Cloud penetrating
- Day & Night 'normalized' to daily minimum SST (~8 AM)
- NRT validated and bias corrected using *in situ* obs.
- Optimally Interpolated
 - Reynolds & Smith (1994)

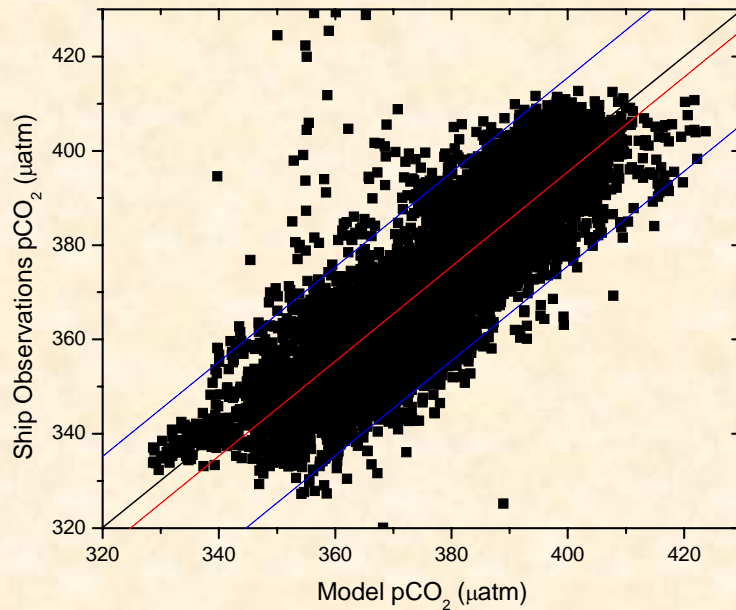


Microwave OI SST data are produced by Remote Sensing Systems and sponsored by the NASA Earth Science Physical Oceanography Program and the NASA REASoN DISCOVER Project. Data are available at www.remss.com.

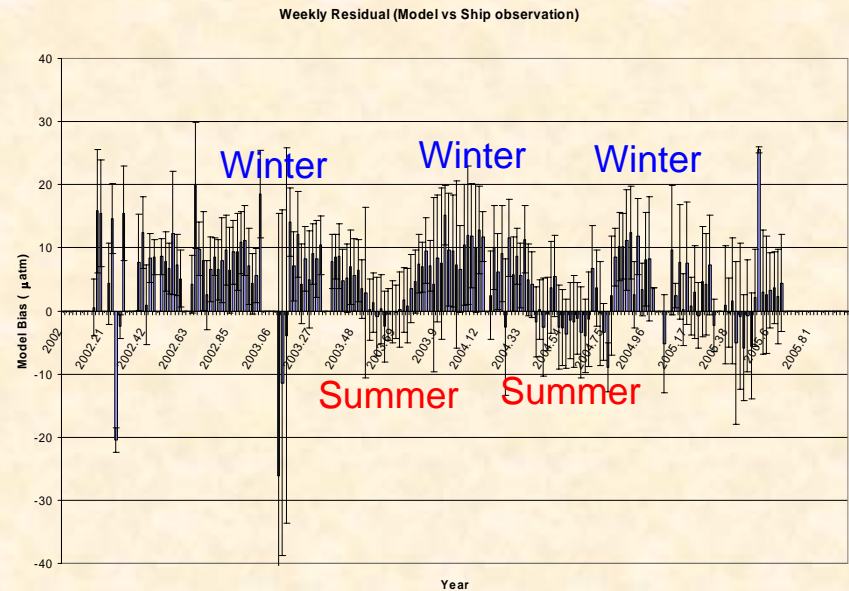
Instrument	Platform	Launched	Orbit	Coverage
TMI	TRMM	Nov 1997	Equatorial (35°)	40N to 40S
AMSR-E	Aqua	May 2002	Near Polar	Global



Evaluation of computed pCO₂ fields

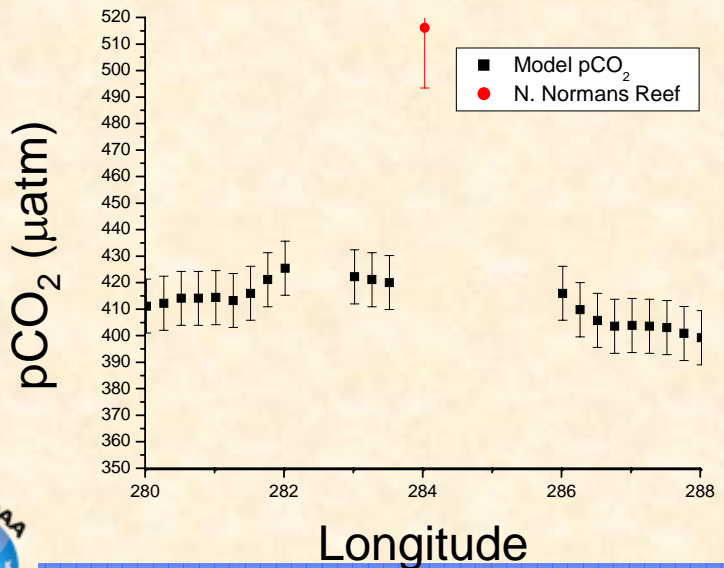
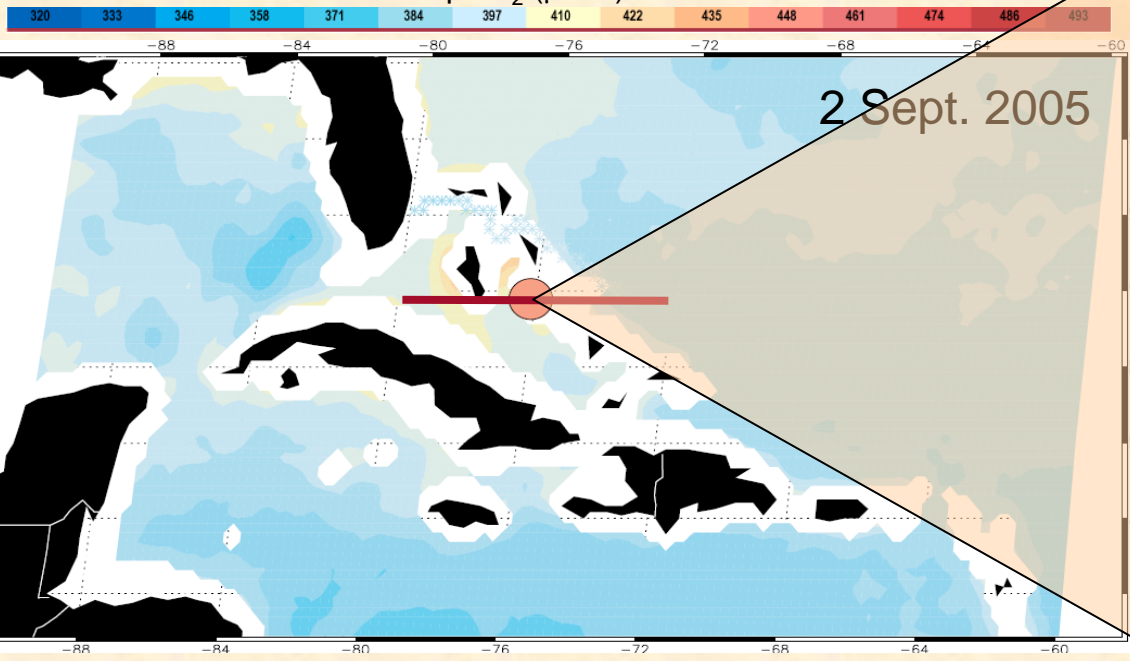


Slope	Adj-r ²	RMS
1.004±0.006	0.69	10.2

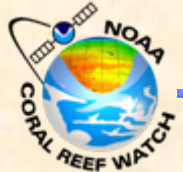


- Model performs best in summer months
- Consistent bias in winter

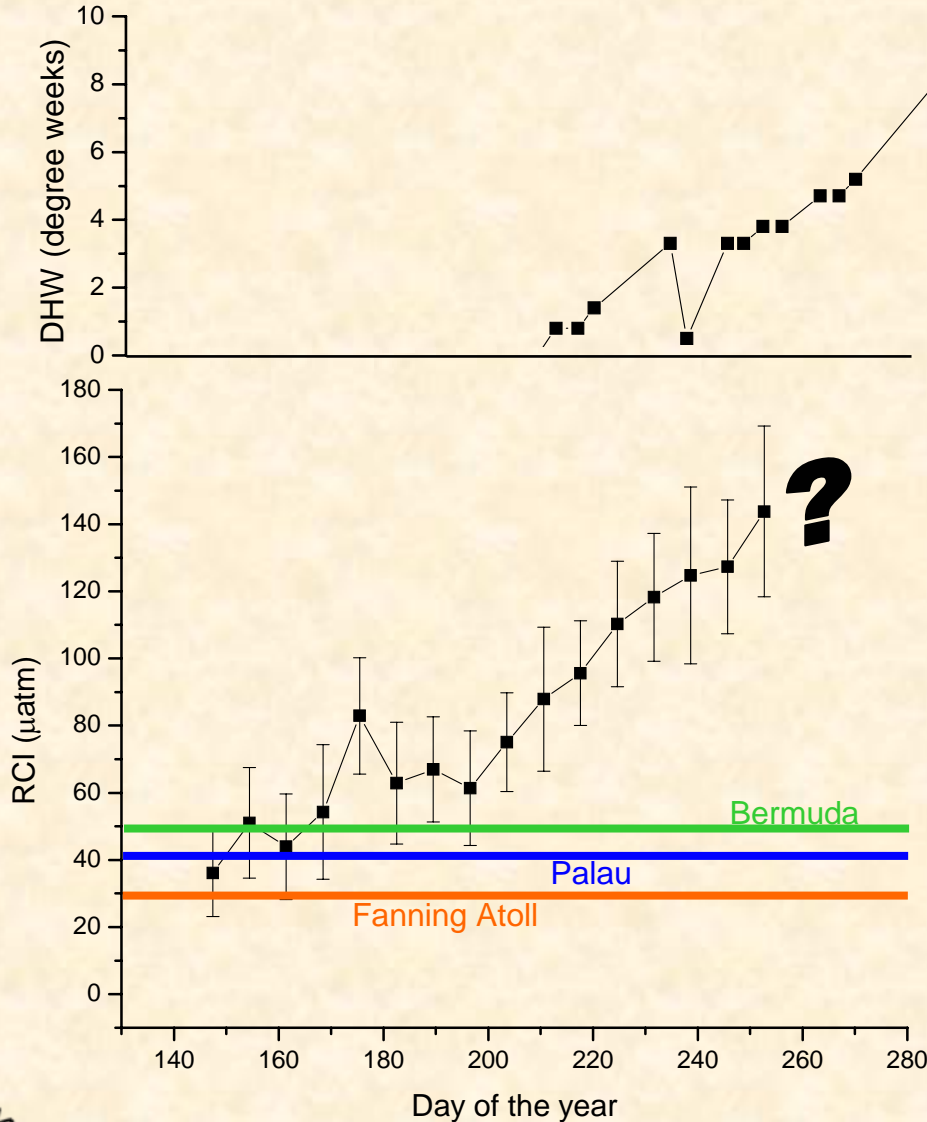
pCO₂ (μatm)



Proof of Concept:
N. Normans Reef, Bahamas
May – September 2005



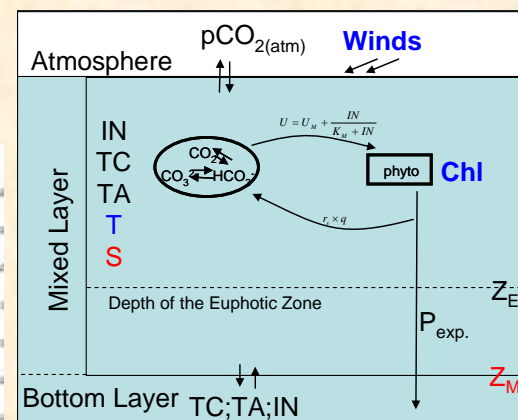
N. Normans Reef Prelim. Results



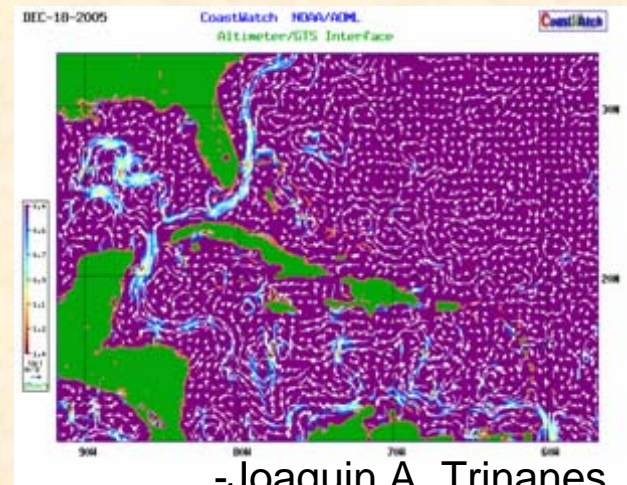
- Early summer
 - values similar to other previous studies.
- Mid-summer
 - DHW's begin accumulating
 - RCI values trend up
 - Similar increases were observed in Palau prior to '97-'98 bleaching event (Kayanne, 2005)
- Late summer
 - SAMI-pCO₂ fails
 - DHW's continue to climb
 - Coral bleaching evolves throughout the Caribbean

The Future of R.C.I.

- Improved Caribbean pCO₂ Model (FY06)
 - Air-sea exchange (QuickSCAT), Biological (Color)
- Additional Caribbean Sites (CREWS)(FY06)
- Hydrographic model (FY07)
- Expansion to Non-Caribbean Sites (FY08)
 - Commonwealth of Northern Mariana Islands (CNMI)
 - South shore of Oahu, HI
 - Palau
 - Bermuda



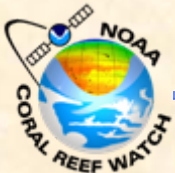
Louanchi, Metz, Poisson (1996)



-Joaquin A. Trinanes

Applications and Stakeholders

- Coral Reef Management
 - Long term monitoring of system level carbon budget
 - Real time monitoring overall reef health
- Academic
 - Hypothesis testing
 - Global carbon budget (source/sink)
- Government
 - Climate Observations and Services Program
 - Global Carbon Cycle Program
 - Coral Reef Conservation Program



NOAA's Strategic Plan

Significance:

- NOAA's CRW and the newly formed Coral Reef Ecosystem Integrated Observing System (CREIOS) are at the forefront of truly integrated research observations, spanning domestic and international arenas.
- Development of an R.C.I. product can serve the mission of CRW and can be used by managers, academics and government agencies to monitor environmental stresses to coral reefs.

NOAA Mission Goals:

- Protect, restore and manage the use of coastal and ocean resources through ecosystem-based management.
- Understand climate variability and change to enhance society's ability to plan and respond. Serve society's needs for weather and water information.

NOAA Cross-Cutting Priorities

- Integrated global environmental observation and data management
- Sound, state-of-the art research

Matrix and Collaboration Opportunities

- NOAA/OAR/AOML
- National Center for Caribbean Coral Reef Research (NCORE), RSMAS
- NGO's (Conservation International)
- NOAA/OAR/PMEL



Summary & Final Remarks

- In response to growing concerns over 'ocean acidification', NOAA CRW is developing a Reef Calcification Index (RCI).
- The RCI can serve as a feasible and low cost monitoring tool and compliment the suite of current NOAA CRW products.
- Sustained monitoring of the RCI at select reef communities should yield insight into changes in reef community structure.
- Short term variability in the RCI may prove an important bioindicator of acute coral stress (e.g. bleaching).
- Further improvements to the $p\text{CO}_2$ model are actively being investigated (air-sea exchange, biological activity)
- Expansion to other sites within the Caribbean could be achieved with little additional cost.
- With refinement and additional *in situ* resources the RCI can be expanded outside the Caribbean

