

Coral Reef Early Warning System (CREWS)

Program Report

Third Annual Coral Reef Program Review Meeting
March 22 – 25, 2005
Ft. Lauderdale, Florida

Sponsored by the
National Coral Reef Institute



National Oceanic and Atmospheric Administration (NOAA)

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The Coral Reef Early Warning System (CREWS) Network:

marine environmental monitoring to support research and marine sanctuary management

A CREWS Station is a "smart" meteorological and oceanographic monitoring platform installed near coral reef areas, software-configured to ensure the gathering of high quality data and the eliciting of automated alerts when specified environmental conditions occur (e.g., those thought to be conducive to coral bleaching)

Response to Coral Reef Task Force Monitoring Group's recommendation for a network of up to 18 stations at all major U.S. coral reef areas by 2010

CREWS stations provide hourly *in situ* data...

Air temperature, wind speed and direction, barometric pressure, PAR and UVR above and below the water, sea temperature and salinity (near-surface, near-bottom)

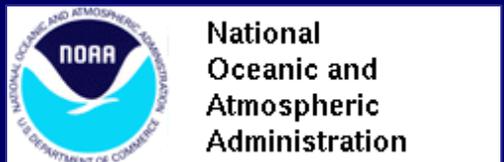
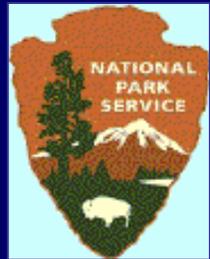
* (optional: pCO₂, fluorometry, tide level, PAM-fluorometry, transmissometry, nutrients, acoustic monitoring, Web cam, etc.)

...and information synthesis products

Surface-truth for satellite products, coral bleaching alerts, data quality alerts; and matching patterns as proscribed by biologists, oceanographers and the public (fish & invertebrate spawning, migration, bloom conditions, good fishing and/or diving conditions, etc.)



A true interagency, international collaborative effort!

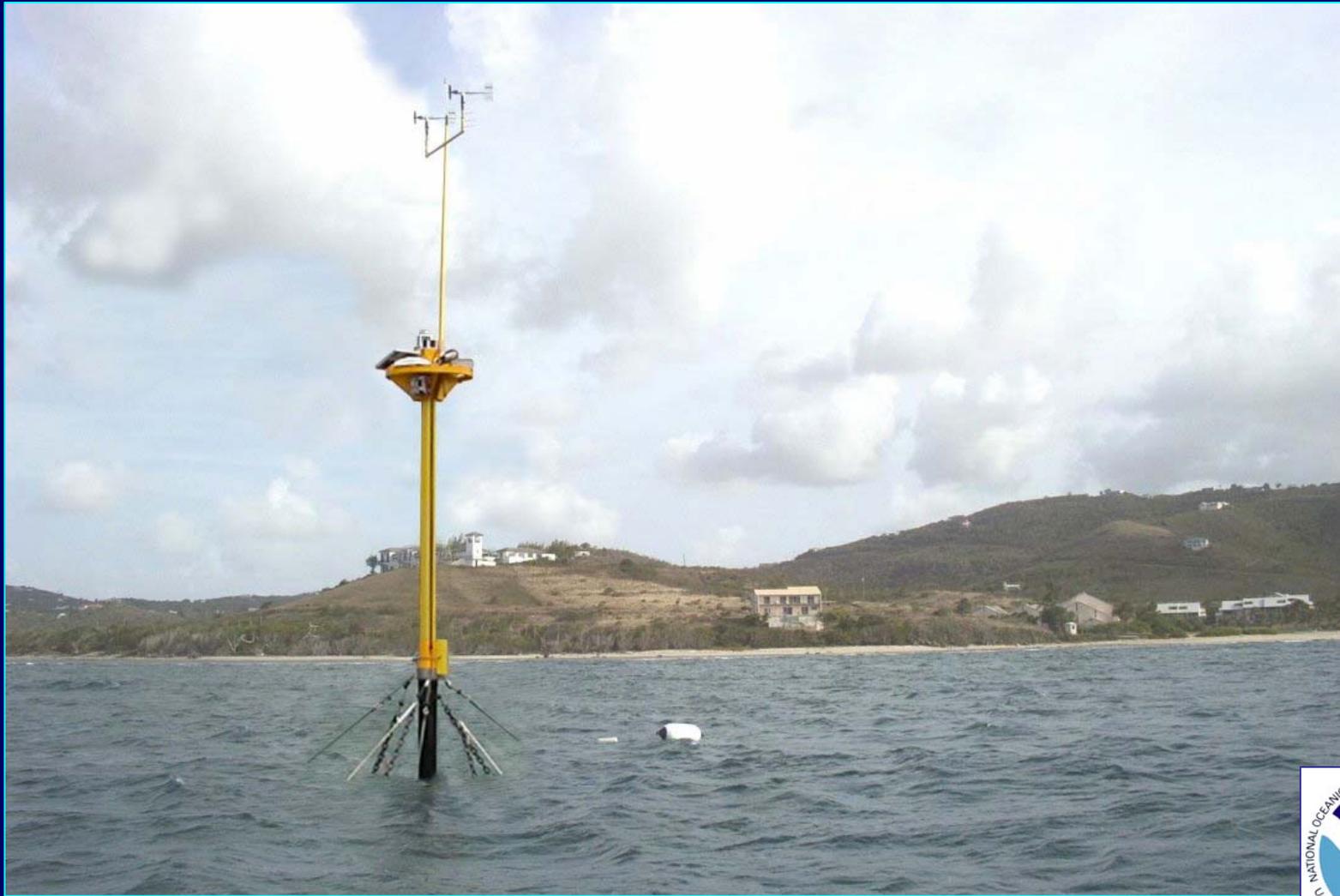


(your logo goes here)

CREWS Stations: Lee Stocking Island, Bahamas, and...



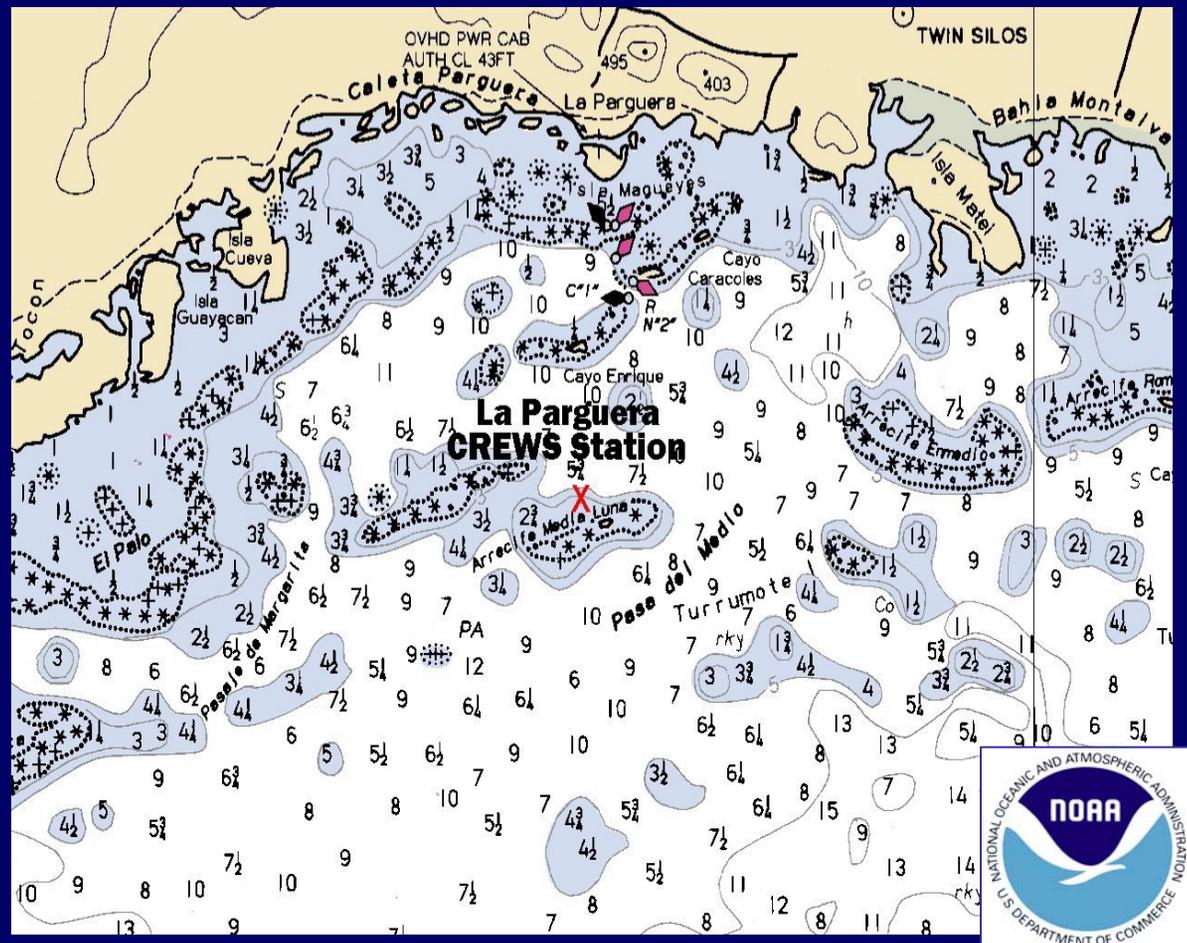
Salt River Bay National Historical Park and Ecological Preserve, St. Croix; US Virgin Islands



Logistics are now being arranged for installation of a CREWS station in SW Puerto Rico, near La Parguera, during late February or early March, 2005.

- Dr. Roy Armstrong of University of Puerto Rico will be chief collaborator.
- Part of the new Caribbean Coral Reef Institute effort (NOAA/UPR collaboration).

Instrumentation will include the basic suite, but will within a year include a special acoustic modem platform for monitoring remotely from the station.



Non-CRTF CREWS Stations

CARICOM/GEF/NOAA

Mainstreaming Adaptation to Climate Change (MACC) Project
Jamaica, Barbados, Bahamas, etc.

World Bank/GEF

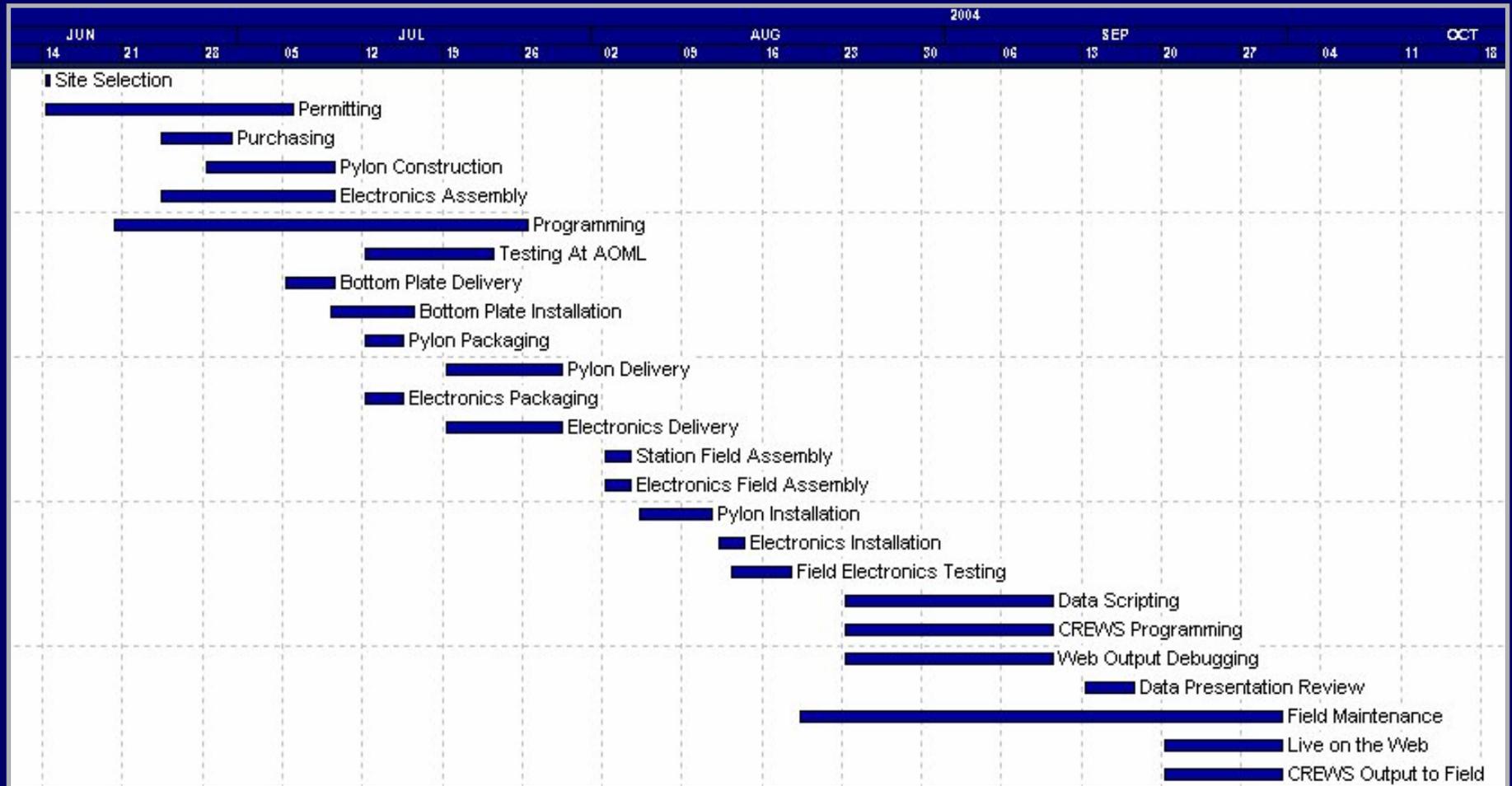
Mesoamerican Barrier Reef System (MBRS) project
Belize

Targeted Research Initiative

Heron Island, Palau, Philippines, Puerto Morelos, Zanzibar



Idealized Gantt chart shows the many phases involved in a CREWS station installation



The CREWS software has three principal components:

- * Raw data parser--makes columnar data report from raw data stream
- * Environmental Information Synthesizer for Expert Systems (**EISES**)
- * Expert system (type of Knowledge Based System) for coral bleaching

EISES/CREWS is a unique expert system deployment for marine ecosystem monitoring, a type of *Environmental Decision Support Systems*



Quality-controlled data are placed on the Integrated Monitoring Network Oracle database server for retrieval at a later time.

This effort requires:

- Data QC Specialist
- Database Administrator
- WebMaster



CHAMP >> CREWS Database Query Form :: NOAA's Coral Health and Monitoring Program :: - Mozilla Firebird

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http://www.coral.noaa.gov/imn/IMNQuery

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Integrated Monitoring Network Database Query^{1,2}

This release version of the database contains data from the Florida Institute of Oceanography's SEAKEYS project, and the NOAA/AOML's CREWS network of stations. [more»](#)

Integrated Monitoring Network Query Form

Station Name: select desired station ...

Year 2002

FROM: Month 01-January Day 01 Hour 0000

TO: Month 01-January Day 01 Hour 0000

Check all desired parameters below to be displayed.

<input type="checkbox"/> Air Temp	<input type="checkbox"/> Sea Temp NDBC
<input type="checkbox"/> Barometer	<input type="checkbox"/> Tide
<input type="checkbox"/> Conductivity	<input type="checkbox"/> Transmissometry
<input type="checkbox"/> Conductivity 1m	<input type="checkbox"/> UVB 1m Radiation
<input type="checkbox"/> Conductivity 2m	<input type="checkbox"/> UVB Surface Radiation
<input type="checkbox"/> Dew Point	<input type="checkbox"/> Voltage
<input type="checkbox"/> Fluorometry	<input type="checkbox"/> Voltage 2m
<input type="checkbox"/> Max Wind Speed	<input type="checkbox"/> Wind Dir
<input type="checkbox"/> Panel Temp	<input type="checkbox"/> Wind Dir 1
<input type="checkbox"/> PAR 1m	<input type="checkbox"/> Wind Dir 2
<input type="checkbox"/> PAR 3m	<input type="checkbox"/> Wind Gust
<input type="checkbox"/> PAR Surface	<input type="checkbox"/> Wind Gust 1
<input type="checkbox"/> Salinity	<input type="checkbox"/> Wind Gust 2
<input type="checkbox"/> Salinity 1m	<input type="checkbox"/> Wind Speed
<input type="checkbox"/> Salinity 2m	<input type="checkbox"/> Wind Speed 1
<input type="checkbox"/> Sea Temp FIO	<input type="checkbox"/> Wind Speed 2
<input type="checkbox"/> Sea Temp FIO 2m	

Submit Reset

The users choose a station name, year and date range, and parameters of interest. To retrieve the data, the user presses the Submit button at the bottom of the page.



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This release version of the database contains data from the Florida Institute of Oceanography's SEAKEYS project, and the NOAA/AOML's CREWS network of stations. [more>](#)

Integrated Monitoring Network Query Form

Station Name:

Year: Available range : 27-JUL-1992 to 31-DEC-2002

FROM:

Month: Day: Hour:

TO:

Month: Day: Hour:

Check all desired parameters below to be displayed.

- | | |
|--|--|
| <input checked="" type="checkbox"/> Air Temp | <input type="checkbox"/> Sea Temp NDBC |
| <input type="checkbox"/> Barometer | <input type="checkbox"/> Tide |
| <input type="checkbox"/> Conductivity | <input type="checkbox"/> Transmissometry |
| <input type="checkbox"/> Conductivity 1m | <input type="checkbox"/> UVB 1m Radiation |
| <input type="checkbox"/> Conductivity 2m | <input type="checkbox"/> UVB Surface Radiation |
| <input type="checkbox"/> Dew Point | <input type="checkbox"/> Voltage |
| <input type="checkbox"/> Fluorometry | <input type="checkbox"/> Voltage 2m |
| <input type="checkbox"/> Max Wind Speed | <input type="checkbox"/> Wind Dir |
| <input type="checkbox"/> Panel Temp | <input type="checkbox"/> Wind Dir 1 |
| <input type="checkbox"/> PAR 1m | <input type="checkbox"/> Wind Dir 2 |
| <input type="checkbox"/> PAR 3m | <input type="checkbox"/> Wind Gust |
| <input type="checkbox"/> PAR Surface | <input type="checkbox"/> Wind Gust 1 |
| <input checked="" type="checkbox"/> Salinity | <input type="checkbox"/> Wind Gust 2 |
| <input type="checkbox"/> Salinity 1m | <input type="checkbox"/> Wind Speed |
| <input type="checkbox"/> Salinity 2m | <input type="checkbox"/> Wind Speed 1 |
| <input checked="" type="checkbox"/> Sea Temp FIO | <input type="checkbox"/> Wind Speed 2 |
| <input type="checkbox"/> Sea Temp FIO 2m | |



The data are returned in a separate Web page. Instructions are given at the bottom of the page for saving in various formats.

Example:

To save the data for use in Microsoft Excel spreadsheet program, save this page results as follows:

Microsoft Internet Explorer Select 'File', then 'Save as' option. When file dialog appears, select save as type to be 'Web Page, HTML only'. Enter file name as appropriate. Once file is done saving Open Microsoft Excel and select 'File', 'Open' option and locate the file you just saved. Finally, save the file in Excel as an '.xls' type.



CHAMP >> CREWS Database Query Form << NOAA's Coral Health and Monitoring Program :: Mozilla Firebird

File Edit View Go Bookmarks Tools Help

http://www.coral.noaa.gov/imm/IMNQuery?StationName=SMKF1&FromYear=2002&FromMonth=3&FromDay=1&FromHour=08

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Station: Sombrero Reef
Station ID: SMKF1
Network: SEAKEYS
Location: 24.63N,81.11W
Requested Date Range: Fri Mar 01 00:00:00 GMT 2002 to Mon Apr 01 00:00:00 GMT 2002.
 Querying following Instruments: Air Temp, Salinity, Sea Temp FIO

Station	Date	jyear	jday	hour	Air Temp	Salinity	Sea Temp FIO
SMKF1	3/1/02	2002	60	0	16.6	34.9	21.34
SMKF1	3/1/02	2002	60	1	17.1	35.3	21.72
SMKF1	3/1/02	2002	60	2	17.6	35.3	21.8
SMKF1	3/1/02	2002	60	3	18.0	35.1	21.49
SMKF1	3/1/02	2002	60	4	18.2	35.1	21.49
SMKF1	3/1/02	2002	60	5	18.2	35.4	22.03
SMKF1	3/1/02	2002	60	6	18.8	35.6	22.51
SMKF1	3/1/02	2002	60	7	19.2	34.8	21.46
SMKF1	3/1/02	2002	60	8	21.3	34.6	21.35
SMKF1	3/1/02	2002	60	9	21.5	24.4	21.33
SMKF1	3/1/02	2002	60	10	21.9	34.3	21.35
SMKF1	3/1/02	2002	60	11	22.0	34.7	21.34
SMKF1	3/1/02	2002	60	12	22.1	34.9	21.48
SMKF1	3/1/02	2002	60	13	22.1	35.2	21.91
SMKF1	3/1/02	2002	60	14	22.4	35.5	22.4
SMKF1	3/1/02	2002	60	15	22.4	35.5	22.5
SMKF1	3/1/02	2002	60	16	22.7	35.5	22.56
SMKF1	3/1/02	2002	60	17	22.9	35.5	22.55
SMKF1	3/1/02	2002	60	18	22.7	35.4	22.16
SMKF1	3/1/02	2002	60	19	22.6	35.4	22.34
SMKF1	3/1/02	2002	60	20	22.8	35.4	22.49
SMKF1	3/1/02	2002	60	21	22.9	16.0	22.51
SMKF1	3/1/02	2002	60	22	23.0	32.7	22.65
SMKF1	3/1/02	2002	60	23	22.8	21.3	22.39
SMKF1	3/1/02	2002	60	24	22.7	35.5	22.52

Done

Data Grouping in CREWS

Subjective Data Ranges:

ul	unbelievably low	av	average
dl	drastically low	sh	somewhat high
vl	very low	hi	high
lo	low	vh	very high
sl	somewhat low	dh	drastically high
		uh	unbelievably high

Subjective Periods of the Day:

Abbrev	Period	GMT Time	Local (5 hours)	Local (4 hours)

(Basic Periods)				
midn	midnight	0300 - 0600	2200 - 0100	2300 - 0200
pdaw	pre-dawn	0600 - 0900	0100 - 0400	0200 - 0500
dawn	dawn	0900 - 1200	0400 - 0700	0500 - 0700
morn	morning	1200 - 1500	0700 - 1000	0800 - 1100
midd	mid-day	1500 - 1800	1000 - 1300	1100 - 1400
psun	pre-sunset	1800 - 2100	1300 - 1600	1400 - 1700
suns	sunset	2100 - 2400	1600 - 1900	1700 - 2000
even	evening	0000 - 0300	1900 - 2200	2000 - 2300
(Large Groupings)				
all	all-day	0300 - 0300	2200 - 2200	2300 - 2300
dayl	daylight-hours	0900 - 2400	0400 - 1900	0500 - 2000
nite	night-hours	0000 - 0900	1900 - 0400	2000 - 0500
dayb	dawn-morning	0900 - 1500	0400 - 1000	0500 - 1100
aftn	afternoon	1800 - 2400	1300 - 1900	1400 - 2000



**Rule: High Sea Temp + High Noon Irradiance + Low Winds
(Julian Day: 172 to 264...Season: Summer)**

	<u>ul</u>	<u>dl</u>	<u>vl</u>	<u>lo</u>	<u>sl</u>	<u>av</u>	<u>sh</u>	<u>hi</u>	<u>vh</u>	<u>dh</u>	<u>uh</u>
IF											
sea temp									all (24)	all (48)	
									dayl (15)	dayl (30)	
									nite (9)	nite (18)	
									dayb (6)	dayb (12)	
									aft (6)	aft (12)	
									basic (3)	basic (6)	
and: irradiance									mid (6)	mid (12)	
and: wind speed											
			all (24)	all (24)							
			dayl (15)	dayl (15)							
			nite (9)	nite (9)							
			dayb (6)	dayb (6)							
			aft (6)	aft (6)							
			basic (3)	basic (3)							

THEN

Conditions are [probably/possibly] conducive to mass coral bleaching.

Software Actions:

Add up all the points in parentheses for conditions that hold and output in an "alert" which shows totals for each parameter, as well as combined total. Total points act as an environmental index for stress, in this case, coral bleaching probability.

See key for day-period designations (e.g., "dayl" means daylight hours)
"Basic" refers to any of the 3-hour periods, except (in this case) any during night time.

~~~~ Coral Bleaching Alert for Sombrero Key, 08/12/1998 ~~~~

**Rule-T4 (9)**

Conditions possibly favorable for bleaching night-hours on 08/12/1998, because FIO sea temperature was very high (about 31.2).

**Rule-TWT1 (48)**

Conditions favorable for bleaching on 08/11/1998, because FIO sea temperature was very high (about 31.2) during mid-day, wind speed was very low (about 5.9), during mid-day, and tide was very low (about -4.40) during mid-day.

**Rule-T5 (6)**

Conditions possibly favorable for bleaching afternoon on 08/11/1998, because FIO sea temperature was very high (about 31.5).

**Rule-T8 (3)**

Conditions possibly favorable for bleaching evening on 08/11/1998, because FIO sea temperature was very high (about 31.0).

**Rule-T8 (3)**

Conditions possibly favorable for bleaching morning on 08/11/1998, because FIO sea temperature was very high (about 31.0).

**Rule-T5 (6)**

Conditions possibly favorable for bleaching afternoon on 08/10/1998, because FIO sea temperature was very high (about 31.3).

... [etc.] ...

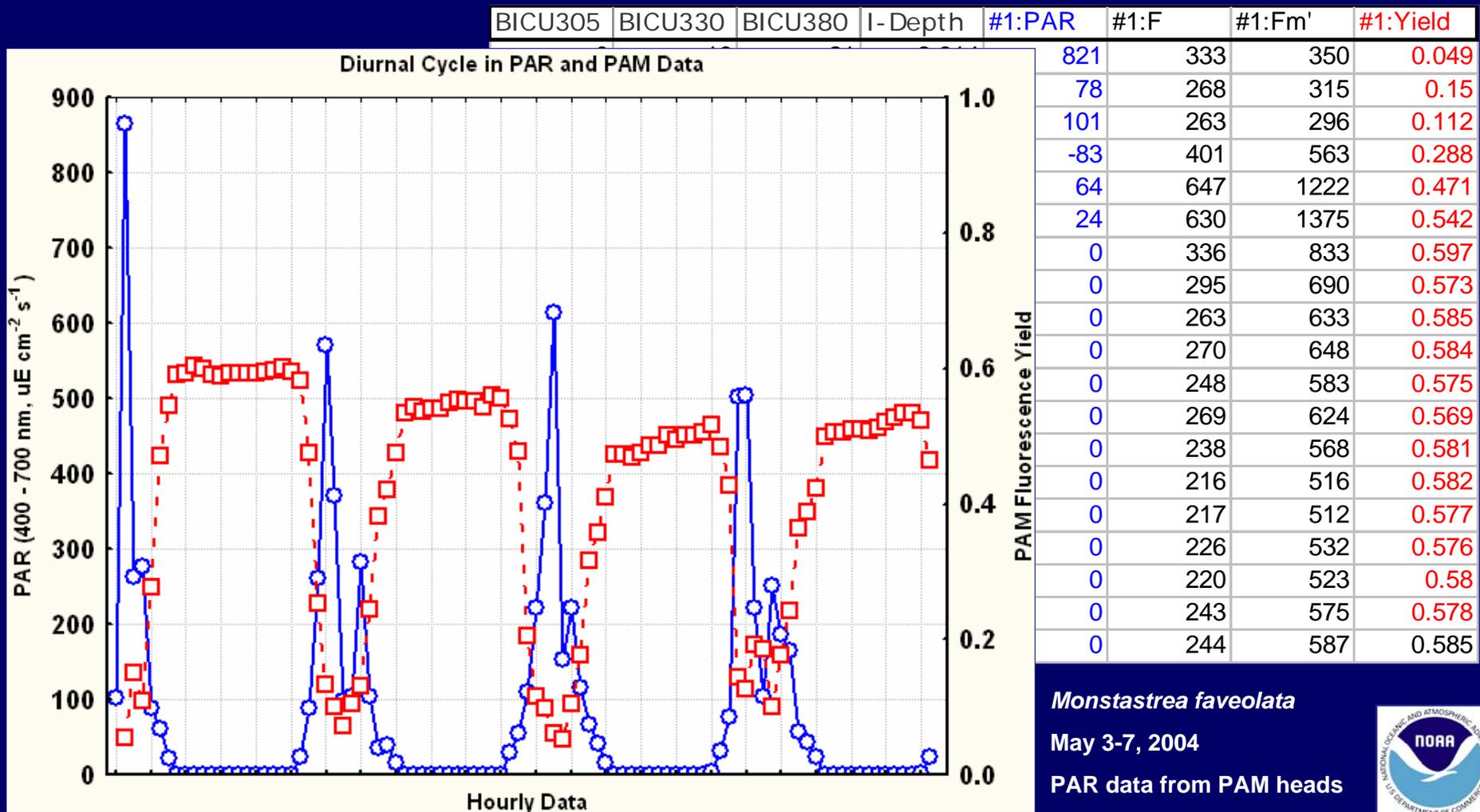
~~~~~

High temperature points:	138
High temperature, low wind points:	0
High temperature, low wind, low tide points:	48
Number of rules triggered:	18



Pulse Amplitude Modulation (PAM) Fluorometry

- PAM-fluorometry data provide a measure of coral PSII health
- Provides early indication of coral bleaching prior to visible paling
- Usually measured with submersible diving PAM





1. Power comes from station to central canister.
2. Divers position PAM-fluoro stand.
3. Diver positions PAM-fluoro head precisely.



LSI CREWS station PAM-flurometry data

Meteorological and Insolation data...

Date & Time				Meteorological Data				Surface Light Sensor				Underwater Light Sensor			
Date	jyear	jday	Hour	Baro	Air Temp	Wnd Spd	Wnd Dir.	BICS305	BICS330	BICS380	PAR-S	305 nm	330 nm	380 nm	PAR
1/28/2005	5	28	900	1018	21.7	19.5	62	0	0	0	0	0	0	0	0
1/28/2005	5	28	800	1018	21.7	20.4	58	0	0	0	0	0	0	0	0
1/28/2005	5	28	700	1019	21.8	20.5	64	0	0	0	0	0	0	0	0
1/28/2005	5	28	600	1019	21.9	20.5	60	0	0	0	0	0	0	0	0
1/28/2005	5	28	500	1019	21.8	19.2	75	0	0	0	0	0	0	0	0
1/28/2005	5	28	400	1019	21.8	20.6	64	0	0	0	0	0	0	0	0
1/28/2005	5	28	300	1019	21.6	21	63	0	0	0	0	0	0	0	0
1/28/2005	5	28	200	1019	21.6	20.8	59	0	0	0	0	0	0	0	0
1/28/2005	5	28	100	1018	21.5	20.7	57	0	0	0	0	0	0	0	0
1/28/2005	5	28	0	1018	21.5	19.5	34	0	0	0	0	0	0	0	0
1/27/2005	5	27	2300	1017	22.6	17.3	23	0	2	3	112	0	1	2	57

... as well as continuous oceanographic conditions and continuous PAM data on three different species...

Upper CTD			Lower CTD		<i>Agaricia spp.</i>			<i>Porites asteroides</i>			<i>Sidastrea siderea</i>		
Depth (m)	SeaT3m	Sal	Depth (m)	Sal3m	PAM1_Fo	PAM1_Fm	PAM1Yield	PAM2_Fo	PAM2_Fm	PAM2Yield	PAM4_Fo	PAM4_Fm	PAM4Yield
1.273	23.3	36.99	5.143	37.07	442	954	0.537	587	1362	0.569	510	1145	0.555
1.309	23.8	36.95	5.176	36.96	462	1003	0.539	574	1333	0.569	513	1152	0.555
1.411	23.9	36.98	5.283	36.98	471	1021	0.539	611	1419	0.569	529	1169	0.547
1.55	24	36.96	5.417	36.98	465	1007	0.538	610	1419	0.57	519	1144	0.546
1.688	24.1	36.94	5.556	36.96	471	1022	0.539	616	1446	0.574	535	1172	0.544
1.788	24.1	36.97	5.659	36.98	477	1024	0.534	591	1380	0.572	544	1184	0.541
1.833	24.2	36.89	5.684	36.91	471	1014	0.536	583	1361	0.572	542	1174	0.538
1.765	24.2	36.97	5.628	36.9	471	1008	0.533	612	1488	0.589	533	1148	0.536
1.66	24.1	36.97	5.522	36.97	470	1002	0.531	604	1441	0.581	539	1152	0.532
1.53	23.5	37.06	5.391	37.07	479	993	0.518	676	1507	0.551	583	1209	0.518
1.429	23.1	37.11	5.274	37.16	509	916	0.444	826	1604	0.485	651	1162	0.44

Rule: High Sea Temp + Low Fluoro Yield (night) + High Noon Irradiance + Low Winds
 (Julian Day: 172 to 264...Season: Summer)

	<u>ul</u>	<u>dl</u>	<u>vl</u>	<u>lo</u>	<u>sl</u>	<u>av</u>	<u>sh</u>	<u>hi</u>	<u>vh</u>	<u>dh</u>	<u>uh</u>
IF											
sea temp									all (24) dayl (15) nite (9) dayb (6) aft (6) basic (3)	all (48) dayl (30) nite (18) dayb (12) aft (12) basic (6)	
and: fluor yield		nite (18)	nite (9)	nite (6)							
and: irradiance									mid (6)	mid (12)	
and: wind speed		all (24) dayl (15) nite (9) dayb (6) aft (6) basic (3)	all (24) dayl (15) nite (9) dayb (6) aft (6) basic (3)								

THEN

Conditions are [probably/possibly] conducive to mass coral bleaching.

Software Actions:

Add up all the points in parentheses for conditions that hold and output in an "alert" which shows totals for each parameter, as well as combined total. Total points act as an environmental index for stress, in this case, coral bleaching probability.

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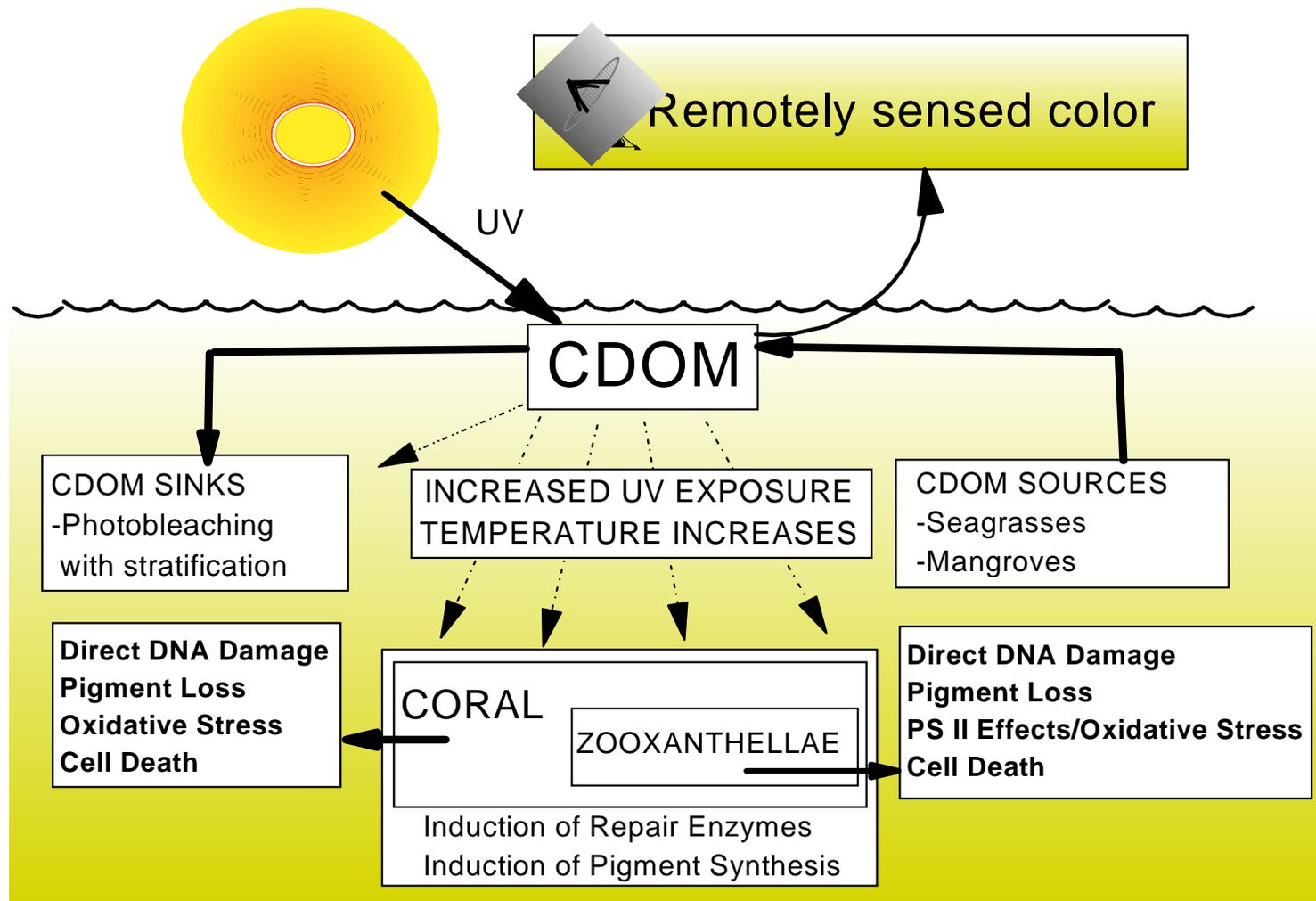
KEY: Subjective assignments for fluorescence yield and maximum noon insolation.
 (Note: These are starting levels to be verified through lab and field experimentation.)

	Fv		Ed
dl	.30 - .40	uh	> 1000
vl	.40 - .55	dh	800 - 1000
lo	.55 - .65	vh	600 - 800
uh	> .80		



...however, we also know that Chromophoric Dissolved Organic Matter (CDOM) is important in thermal/solar-induced coral bleaching...

(Richard Zepp, 2003)



**Rule: High Sea Temp + Low Fluoro Yield (night) + High Noon Irradiance
 + Low Winds + Low CDOM**
 (Julian Day: 172 to 264...Season: Summer)

	<u>ul</u>	<u>dl</u>	<u>vl</u>	<u>lo</u>	<u>sl</u>	<u>av</u>	<u>sh</u>	<u>hi</u>	<u>vh</u>	<u>dh</u>	<u>uh</u>
IF											
sea temp									all (24)	all (48)	
									dayl (15)	dayl (30)	
									nite (9)	nite (18)	
									dayb (6)	dayb (12)	
									aft (6)	aft (12)	
									basic (3)	basic (6)	
and: irradiance										mid (6)	mid (12)
and: fluor yield		nite (18)	nite (9)	nite (6)							
and: CDOM conc.		dayl (30)	dayl (15)								
		dayb (12)	dayb (6)								
		aft (12)	aft (6)								
		mid (12)	mid (6)								
and: wind speed		all (24)	all (24)								
		dayl (15)	dayl (15)								
		nite (9)	nite (9)								
		dayb (6)	dayb (6)								
		aft (6)	aft (6)								
		basic (3)	basic (3)								

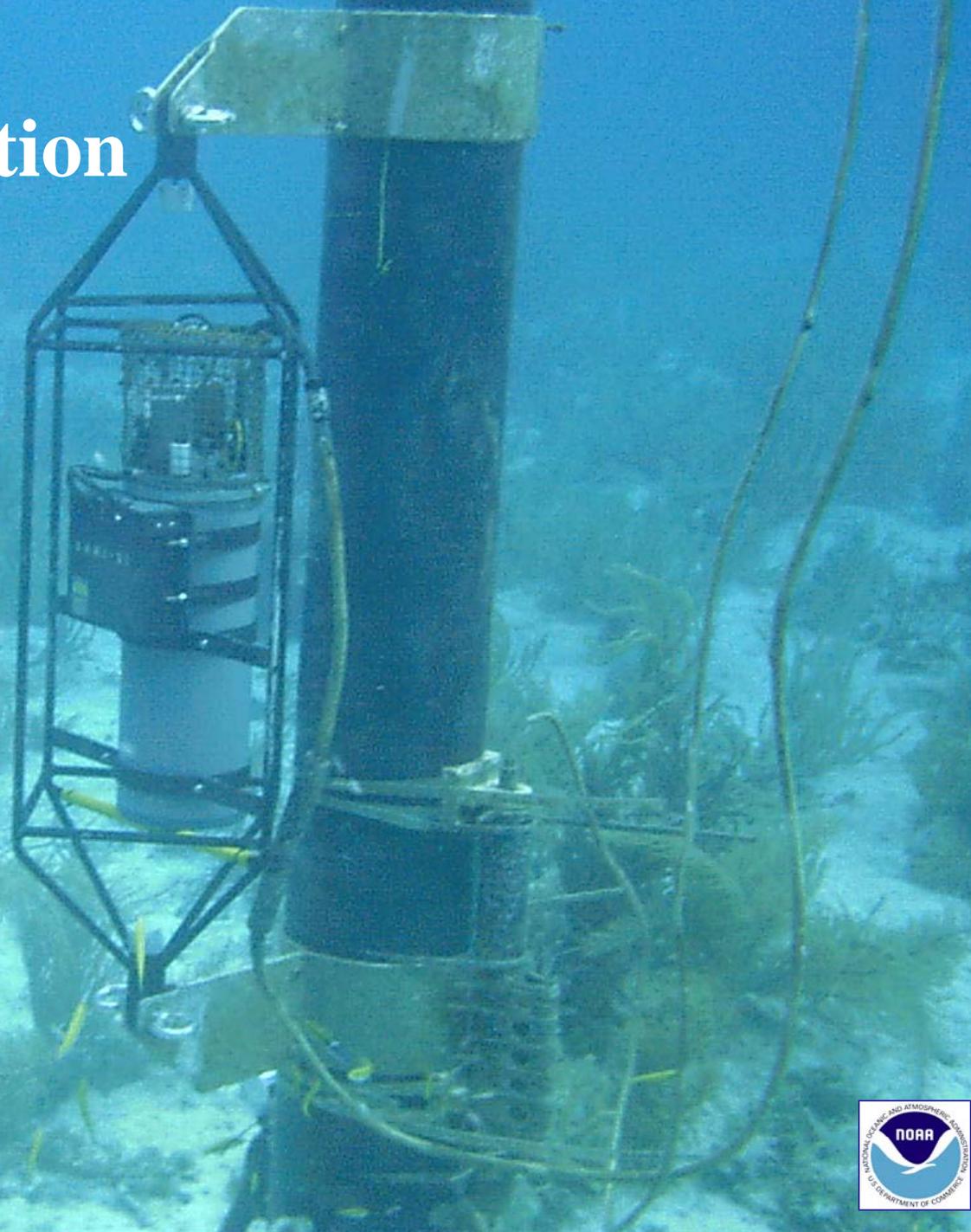
→ Better understanding of the biological mechanisms, better predictability of coral bleaching, good satellite surface-truthing, and better decision support.

THEN
 Conditions are [probably/possibly] conducive to mass coral bleaching.

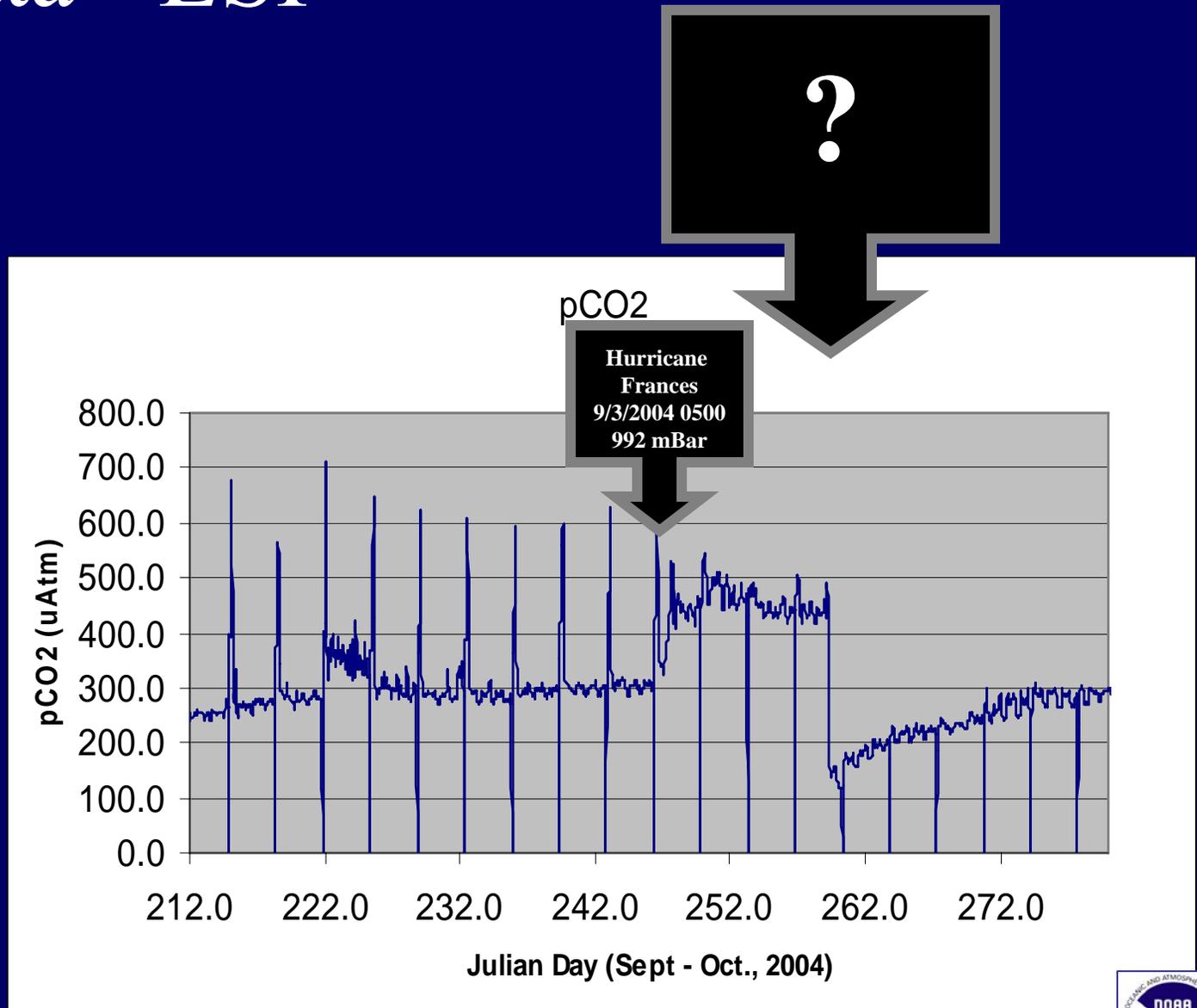


pCO₂ Data Collection

- Deployed July, 2004
- pCO₂ sensor (Sunburst Sensors)
 - Hourly pCO₂ (μ atm)
 - Water tight
 - Internal logging



pCO₂ data - LSI



Integrating Coral Data for Research and Decision Support

- Data integration is an important direction for NOAA's Coral Reef Conservation Program, under the aegis of the Coral Reef Ecosystem Integrated Observing System (CREIOS) project
- Integration of coral data is one of the recommendations by the U.S. Commission on Ocean Policy.

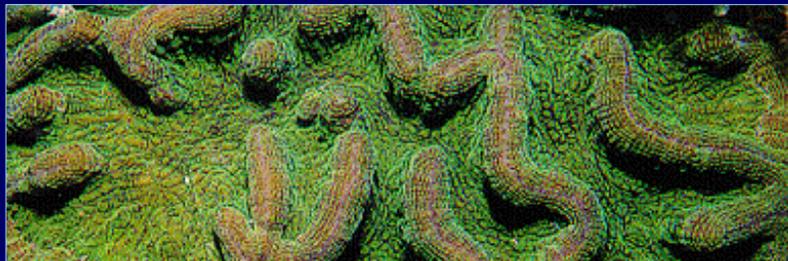


Integration, timeliness and information products are key concerns of the U.S. Commission on Ocean Policy:

Recommendation 26–9. Congress should fund the *Integrated Ocean Observing System (IOOS)* as a line item in the National Oceanic and Atmospheric Administration (NOAA) budget, to be spent subject to National Ocean Council direction and approval. IOOS funds should be appropriated without fiscal year limitation. NOAA should develop a streamlined process for distributing IOOS funds to other federal and nonfederal partners.

Recommendation 15-4. The National Oceanic and Atmospheric Administration, U.S. Geological Survey, and U.S. Environmental Protection Agency, working with other appropriate entities, should *ensure that water quality monitoring data are translated into timely and useful information products* that are easily accessible to the public and *linked to* output from the *Integrated Ocean Observing System*.

Recommendation 21–4. The *U.S. Coral Reef Task Force* should identify *critical research and data needs* related to coral reef ecosystems. These needs should guide agency research funding and be incorporated into the design and implementation of the *Integrated Ocean Observing System*.



The new generation of CREWS will utilize a new data integration and inferencing tool called G2 (by Gensym Corp.), used by...

- **NASA**
- **CIA**
- **FBI**
- **NSA**
- **NRO**
- **DOD**
- **FAA**
- **USAF**
- **USN**
- **DOE**
- **Biosphere II**
- **the Army's Knowledge Engineering Group**
- **the Joint Chiefs Decision Support Group**
- **the Defense Information Systems Agency**
- **the Joint Intelligence Center**
- **Boeing**
- **European Space Agency**
- **Inmarsat**
- **Intellsat**
- **Lockheed**
- **SatComm**
- **Iridium, and others**



- The G2 architecture will integrate data, images and documents from all *in situ*, biological and satellite stations, as well as from historical data (e.g., paleoecological data).
- Data will be served on the Web via custom application developed at AOML, *and* (more importantly) can be developed and manipulated remotely (e.g., at NASA, the Florida Keys National Marine Sanctuary, NOAA HQ, etc.) to provide for *custom* views of the data pool.
- Predictions, reports, alerts, etc. can be made using expert system inferencing and/or neural network within this architecture, in real-time, or not, as necessary.
- Backward chaining is an important and powerful feature.



New Web interface will integrate data from CREWS, CRED, AIMS, and SEAKEYS stations, satellite data, and other resources, using G2, and will still issue alerts as before, providing for greatly increased *modeling* power.

G2 can also be used for scheduling (good for logistics), and *disaster management*, which will make it of use to AOML's Hurricane Research Division, and hopefully other organizations.

The screenshot shows a Mozilla Firefox browser window displaying the NOAA's Coral Reef Early Warning System (CREWS)/G2 website. The browser's address bar shows the URL <http://www.coral.noaa.gov/crews-g2>. The website header features the NOAA Research logo and the title "Coral Reef Early Warning System (CREWS)/G2". Below the header, a blue banner contains the text: "Integrating and inferencing near real-time coral reef data for coral researchers and Marine Protected Area personnel." A paragraph follows, starting with "Aloha!" and describing the site's purpose: "This site provides a central location for integrated near real-time or recent (only) data relating to coral reefs, and also provides 'alerts' (through artificial intelligence technology) as to the occurrence of specified environmental conditions, as proscribed by modelers, oceanographers and marine biologists. Click on one of the coral reef areas in orange on the map to see what near real-time data and alerts are available for the area of your interest." Below this text is a world map with several orange-colored regions indicating coral reef areas. Underneath the map, a section titled "Some of our data integration partners..." lists various organizations: NOAA Research, National Environmental Satellite, Data and Information Service, National Marine Fisheries Service, National Ocean Service, National Aeronautics and Space Administration, Australian Institute of Marine Science, Florida Institute of Oceanography, Louisiana State University, University of California at Santa Cruz, University of Puerto Rico, Shoals Marine Laboratory, United States Geological Survey, Rosensteiel School of Marine and Atmospheric Sciences, University of South Florida, and University of the Virgin Islands. A banner for the NOAA's Coral Reef Information System (CoRIS) is also visible. At the bottom, a logo for the NOAA Coral Reef Conservation Program is shown next to the text: "The CREWS/G2 Program is another Coral Health and Monitoring Program (CHAMP) Project, supported by NOAA's Coral Reef Conservation Program, the High-Performance Computing and Communications Office, and operating at the Atlantic Oceanographic and Meteorological Laboratory." The browser's status bar at the bottom shows "Done".

Example page for Sombrero Key data request, to obtain integrated “raw” near real-time *in situ* and satellite data, as well as biota data.

- User clicks on data type and date range for the data, then clicks the Submit button at the bottom of the page.
- Data are returned in tabular format, and spreadsheet ready (as in IMN).
- User clicks on image to obtain biological data, and station images (above, below).

CREWS/G2 Data Request - Mozilla Firefox
http://www.coral.noaa.gov/crews-g2/data-int/smkf1/

noaa research Coral Reef Early Warning System (CREWS)/G2

Choose a date and time range, and the parameters of interest, then press the Submit button below.

Available Year: 2005

FROM:
Month 01-January Day 01 Hour 0000
TO:
Month 01-January Day 01 Hour 0000

Station Data

- Air Temperature
- Wind Speed
- Wind Gust
- Wind Direction
- Barometric Pressure
- Photosynthetically Available Radiation, Surface
- Ultraviolet, Surface (305 nm)
- Ultraviolet, Surface (330 nm)
- Ultraviolet, Surface (380 nm)
- Sea Temperature, Shallow
- Salinity, Shallow
- Pressure Sensor, Shallow
- Sea Temperature, Near Bottom
- Salinity, Near Bottom
- Pressure Sensor, Near Bottom
- Photosynthetically Available Radiation, UW
- Ultraviolet, UW (305 nm)
- Ultraviolet, UW (330 nm)
- Ultraviolet, UW (380 nm)

Satellite Data

- Sea Surface Temperature (MODIS/Aqua Terra)
- Photosynthetically Available Radiation (MODIS/Aqua)
- Wind Speed and Direction (SeaWinds/QUICKScat)
- Chromophoric Dissolved Organic Matter (MODIS/Aqua)
- Chlorophyll Concentration (MODIS/Aqua)
- Oceanic Rainfall (PR & TMI/TRMM)
- Sea Surface Height Anomaly (Altimetry/Jason-1)
- Surface Reflectance (Aster)
- Sea Surface Salinity (Aquarius)
- Ocean Color (VIIRS)

Click on the map to open another browser window with a larger image showing satellite pixel locations, and links to biological data.

Submit Reset

Example page for G2 products, and station and satellite information updates.

User Login: different access privileges for other menu choices.

Station: Details, info updates, links to maps, Landsat and other images.

Sensors: Metadata, calibration info, updates.

Biota: Latest monitoring data, links to more info.

Graphs: Wealth of x/y, scatter and other plots, of all variables.

Alerts: Latest bleaching and other alerts (next slide).

Rules: For Knowledge Engineers, and the curious.



The **Sombbrero Key** station is part of the [SEAKEYS Network](#) of meteorological and oceanographic monitoring stations located within the [Florida Keys National Marine Sanctuary](#), maintained by the [Florida Institute of Oceanography's](#) Keys Marine Laboratory on Long Key, Florida.

Many Permutations → Alert ≈ Threshold Environmental Indices ≈ Model Output

- Environmental stress-induced coral bleaching: high sea temp, light, CDOM, etc.
- Harmful (or other) Algal Bloom: sea temp, phytoplankton pigment(s), wave height, currents, nutrients, automated DNA sensor (e.g., Dr. Kelly Goodwin of AOML) etc.
- Coral growth: optical micrometer (Dr. Chris Langdon), pCO₂, pH, Talk, and/or O₂ kinetics, light, clouds, sea temp.
- Disease possibility/probability: sea temp, nutrients, currents, suspended sediments.
- Critical period concept (fishery success, ala Lasker, Feder, Theilacker and May [1971]): extended low winds + high light => concentrated phytoplankton bloom => concentrated zooplankton swarm => successfully feeding larval fish within CP.
- Larval drift predictions: need knowledge of larval life, currents, survival curves via temp/salinity combinations (e.g., Belize supplies larvae for spiny lobster).
- Migration cues: day length plus currents plus temperature clues, plus lunar period, plus...whatever.



Theoretically possible model outputs (continued)...

- Ship intrusion into Sanctuary: Automatic Identification System Rule
- High effluvial input to reef: high sedimentation, lowered salinity, offshore transport.
- Seismic measuring devices: tsunami early warning [TSEWS?]
- Change in bottom topography (lots of “training” of neural network required), habitat change.
- Backward chaining: not predictive, but after something happens, automated look up for “chained” rules that may indicate cause(s).
- “Blackwater” and low-salinity lens intrusion (e.g., from Everglades).

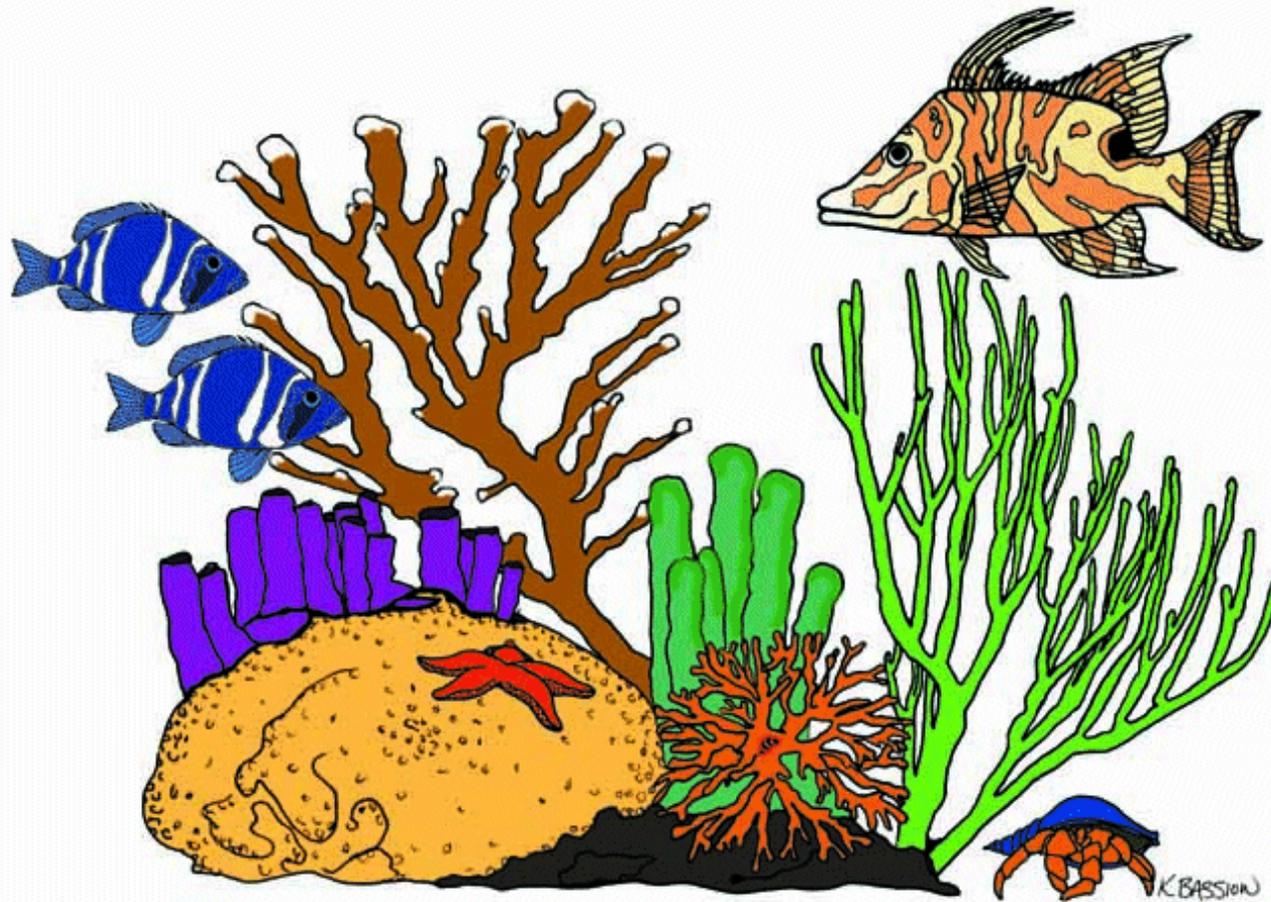


So, we have one approach for integration--into a single user interface and information pool--for any number of data sources. What we *don't have* are the questions, and the basic knowledge from field and laboratory-based research.

Knowledge Engineering (the encoding of knowledge into an expert system) requires:

- the proper questions to ask
- the answers or models for the questions, based on research
- domain expert guidance and continuing user feedback
- very clean data, updated often
- *research and integration partners!*





Coral Health And Monitoring Program

Coral Reef Early Warning System