NOAA Coral Reef Conservation Program, and the Integrated Coral Observing Network (ICON) project:
Current Capabilities and Vision for the Future

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A collaborative effort – interagency and international!
NOAA Goals
Coral Reef Conservation Program

PRODUCTS/ACTIVITIES

• Improved Understanding of Ecological Processes
  – Physical - biological linkages
  – Causes of Ecological Change

• Online Continuous and Integrated Data

• Baselines and Long-term Climate Trends

• Decision Support Tools
  – Near Real-Time Ecoforecasts for Coral Bleaching, Disease, Spawning, Larval Drift, Biological Productivity Changes, etc.
  – Predictive Numerical Models (bleaching, biology, chemistry)

• Local Action Strategy Support
  – Climate
  – Land-based Sources of Pollution
Key Threats to Coral Reef Ecosystems

Coral Reef Conservation Program

Key Threats Addressed

- Climate Change
  - Ocean Warming
  - Ocean Acidification
  - Sea-level Rise
  - Changing Ocean Circulation
- Impacts of Fishing
  - Biological Productivity
  - Larval Transport/Recruitment
- Land-based Sources of Pollution
  - Eutrophication
  - Near-shore Hydrodynamic Processes
- Alien/Invasive Species
- Coral Disease
- Recreational Overuse
NOAA Capabilities
Physical and Chemical Coral Reef Monitoring

CORE CAPABILITIES

Capability 1: *In Situ*, Fixed platform temporal oceanographic and water quality monitoring

Capability 2: Ship-based spatial oceanographic, water quality, and reef fish surveys

Capability 3: Satellite-based synoptic observations, climatologies, anomalies and related products

Capability 4: Regional Physical/Chemical Modeling
NOAA Capabilities

Capability 1: *In situ* Instrumentation

**Near Real-time Platforms**
- ICON/CREWS Pylons
- Ocean Acidification Moorings
- NDBC Buoys

**Subsurface Instrumentation**
- Ocean Current Profiles (ADCP)
- Wave & Tide Recorders (WTR)
- Subsurface Temperature Recorders
- Acoustic Fish/Plankton Sensors
- PAM Fluorometers (coral health)
- Ocean Acidification (pH, PCO₂)
NOAA Capabilities

Capability 1: *In situ* Instrumentation

Variables measured:

- Temperature and Salinity
- Air Temperature, Pressure, Rain, Humidity, Winds
- Currents, Waves, Tides
- Light (PAR, UV, attenuation)
- pCO$_2$, pH
- Coral Photosynthetic Efficiency (active fluorom.)
- Nutrients
- Frequency Distribution of Fish and Plankton
NOAA Capabilities

Capability 1: *In situ* Instrumentation

ICON/CREWS Stations – the current view

Puerto Rico — US Virgin Islands — Little Cayman
NOAA Capabilities

Capability 1: *In situ* Instrumentation

ICON/CREWS Stations – the current view

Puerto Rico — US Virgin Islands — Little Cayman
NOAA Capabilities

Capability 1: *In situ* Instrumentation

ICON/CREWS Stations – the current view

Puerto Rico –– US Virgin Islands –– Little Cayman
NOAA Capabilities

Capability 1: *In situ* Instrumentation

ICON/CREWS Stations – the current view

Florida Keys (Molasses Reef)
NOAA Capabilities

Capability 1: *In situ* Instrumentation

ICON/CREWS Stations – the current view

- Sombrero Key
- Fowey Rocks
NOAA Capabilities

Capability 1: *In situ* Instrumentation

**ICON/CREWS Stations** – the current view

Autonomous hourly, reef-fish and plankton size-frequency distributions:
- BioSonics DT-X
- Echosounder

Florida Keys (Tennessee Reef)
NOAA Capabilities

Capability 1: *In situ* Instrumentation

ICON/CREWS Stations – the current view

Florida mainland (Port Everglades)
NOAA Capabilities

Capability 1: *In situ* Instrumentation

Caribbean ICON/CREWS Sites (current, proposed):
NOAA Capabilities
Capability 2: Ship-based Monitoring

Spatial Structure of:
- Sea Temperature
- Salinity
- Ocean Currents
- Nutrients
- Chlorophyll
- Carbon chemistry
- Turbidity / Attenuation
NOAA Capabilities

Capability 3: Satellite Monitoring

- SST
- Wind
- Ocean Productivity
- Sea Surface Height
- Light
- Coral-Specific
NOAA Capabilities

Capability 4: Physical/Chemical Modeling

NOAA Modeling: Synthesis and product development applications of prior capabilities

Modeling Products:

- Bleaching forecasts
- Ocean acidification
- Hydrodynamic Modeling
- Harmful Algal Blooms
- Upwelling / productivity changes
- Other Ecoforecasting
NOAA Capabilities
Capability 4: Modeling

Ocean Acidification:

- Monthly modeled environmental estimates of sea surface carbonate chemistry in the Greater Caribbean.

Modeled fields of annual mean aragonite saturation state, Gledhill et al. (in press)
NOAA Capabilities
Capability 4: Modeling

Ecoforecasting:
• ICON/G2 Expert System

NOAA ICON ecoforecasts use fuzzy logic to predict impacts of physical, chemical, biological, and human-induced change on reef ecosystems and their components.

http://ecoforecast.coral.noaa.gov
ICON approach to ecoforecasting

• Environmental sensors are monitored in near real-time
• Hourly data or time-series evaluated for ecological significance
• Subjective values assigned for each ecoforecast, each condition
  - “high”, “very high” or “drastic high” light for coral stress,
  - “conducive” sea temperature for coral spawning, etc.

• Ecoforecast alerts can be triggered by individual conditions…
• …or by multiple conditions that potentiate one another!
• Alerts describe the severity and duration of each condition
  - Stimulus/Response (or stress) index calculated
  - Links provide graphs and maps for key conditions
Ecological Forecasts daily via Web and email

Detailed explanations of environmental triggers, as well as impact
NOAA Capabilities
Capability 4: Ecoforecasting

Hourly sea temperature (°C)

$T_{\text{hourly}}$ reported via satellite

High-frequency T variance

$T_{\text{var}} = \sum_{3d} [\sigma_{1d} (T_{\text{hourly}})]$

Mean hourly wind (knots)

NB: $T_{\text{var}}$ spike preceded wind

What is the forcing mechanism?
Chlorophyll shows cyclonic circulation

June 4th, 2006
June 6th
June 7th
June 8th
Self-Organizing Maps (SOM)

- A non-linear statistical analysis technique
  - No assumptions about underlying distributions
  - Robust to outliers

- Unsupervised machine learning – an Artificial Neural Network trained to automatically characterize similarities between data vectors
  - Multiple “units” each of same dimension as a data vector; arranged on an (arbitrary-sized) NxM map; initialized at random, or by Principal Components
  - Training: presenting data, one vector at a time to all NxM units; gradually, the set of units organize themselves so similar patterns are adjacent

- Can compare data to SOM units quantitatively – a “Best Matching Unit” is found for each data vector
Extended SOM – non-linear covariability between forcing and response (physical, ecosystem)

SCM "Modes" SMKF1 1988-2008 Annual, 336H frames (N=157): sea_t_1_day_deviation_3_day_average (c) (>93%) (>0.597)

#3 (40 frames - 25.5%)

#4 (31 frames - 19.7%)

#9 (27 frames - 17.2%)

#8 (14 frames - 8.9%)

#1 (11 frames - 7.0%)

#2 (11 frames - 7.0%)

#7 (9 frames - 5.7%)

#5 (7 frames - 4.5%)

#6 (7 frames - 4.5%)

vs. air_t_1_day_deviation_3_day_average (r), wind1_u_3_day_deviation_sum_wind1_v (g), wind1_speed_3_day_average (b)
Spatial SOM of SST fields
NOAA Capabilities

Coral Reef Monitoring

**Challenges:**

- Better integrate data – regional and local; physical, chemical, biological, ecological
- Tailor products to management needs
- Improved access and more timely delivery
- Automate observations
- Better serve management
- New instruments to address known gaps
- Higher space/time-resolution data
- More tools for climate change impacts
- Model parameterization/validation
Integrated Coral Observing Network (ICON) project

For more information:
http://ecoforecast.coral.noaa.gov

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Integrated Coral Observing Network (ICON) project

Additional Slides
NOAA Capabilities

Capability 1: *In situ* Instrumentation

Caribbean ICON/CREWS Sites (current, proposed):
NOAA Capabilities

Capability 1: *In situ* Instrumentation

**Management Requests:**

- ✓ Near-real-time monitoring (FL) – CREWS/ICON
- ✓ Currents for larval transport and connectivity (Region) – Drifters/ODP/CM
- ✓ Ocean acidification – MAPCO2 (Region)
  - Regional Integration (Region) – CariCOOS and other Regional OOSes
  - Continue reef SST monitoring (FL) – FKNMS
  - Nearshore salinity (FL)
  - Currents and waves for LBSP (PR, USVI)

**Satellite and Model Initiation/Validation**
### NOAA Capabilities

**Capability 2: Ship-based Monitoring**

#### Atlantic/Caribbean Oceanographic Cruises

<table>
<thead>
<tr>
<th>Region</th>
<th>Project</th>
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<th>09</th>
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<tr>
<td>Caribbean</td>
<td>Reef fish/Larval Fish (NMFS)</td>
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<td>GOM</td>
<td>Reef fish survey (NMFS)</td>
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<td>GOM</td>
<td>Flower Garden Banks NMS (NOS)</td>
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<td>GOM</td>
<td>Deep coral (NMFS)</td>
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<td>FL</td>
<td>Pulley Ridge reef fish (NMFS)</td>
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<td>FL</td>
<td>Florida Keys NMS (NOS)</td>
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<td>Tortugas Ecological Reserve (NOS)</td>
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<td>Oculina Banks (NMFS)</td>
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<td>FL</td>
<td>FACE (OAR)</td>
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<td>FL</td>
<td>Benthic habitat mapping (NOS)</td>
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<td>PR/USVI</td>
<td>Benthic habitat mapping (NOS)</td>
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<td>(FL)</td>
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<td>PR/USVI</td>
<td>Ocean Obs/fish larvae (OAR, NMFS)</td>
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<td>PR/USVI</td>
<td>Reef fish recruitment (NMFS)</td>
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<td>PR</td>
<td>Vieques seagrass &amp; coral (NOS)</td>
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<td>Navassa</td>
<td>Navassa NWR (NMFS, NOS)</td>
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NOAA Capabilities

Capability 2: Ship-based Monitoring

Management Requests:

- Currents for connectivity (USVI)
- Currents and waves for LBSP (PR, USVI)
  - See *in situ* list

Larval drift around Caribbean

Caribbean $\text{CO}_2$
NOAA Capabilities
Capability 3: Satellite Monitoring

SST-Based Products:
- Coral bleaching nowcasts
- Satellite Bleaching Alerts
- Virtual Stations
- Near-real-time data
- Long-term data
NOAA Capabilities
Capability 3: Satellite Monitoring

Management Requests:

- Circulation for:
  - Nearshore processes
  - Connectivity
- Coastal chlorophyll
- Bleaching prediction & follow-up
- Nearshore & higher resolution SST
- Ocean acidification
NOAA Capabilities
Capability 4: Modeling

Thermal Stress:
Bleaching and disease forecasts

- A tropical coral bleaching outlook system
- NOAA ESRL SST model
- Forecast regions of potential thermal stress from one-week to four months
- SST-based Disease outbreak potential
NOAA Capabilities

Capability 4: Modeling

Hydrodynamic Modeling:

- Multiple scales: bay to basin
- Existing examples: S FL HYCOM, PR/USVI ROMS, RTOFS

NOAA Environmental Modeling Center
Real-Time Ocean Forecast System (Atlantic)
NOAA Capabilities

Capability 4: Modeling

Management Requests:

- Bleaching event prediction (Region) - CRW
- Ocean acidification (Region) – CRW/AOML/UPRM
- HAB/Black water events (FL) – NCCOS
  - Larval transport/recruitment (USVI)
  - Sea level rise (PR,FL) – Climate & Coastal Program
  - Near-shore currents for LBSP (PR, USVI)
NOAA Capabilities

Physical and Chemical Monitoring

**Future Directions – Underway:**
- Light and temperature from satellites
- Bleaching and disease prediction
- Higher resolution data
- Standard systems for data access/analysis
- Training for data use and application
- Atlantic OA Test-bed, La Parguera, PR

**Future Directions – Down the Road:**
- Quantitative water quality and turbidity from satellites
- Ocean Acidification Monitoring Network
SME “street” – 2005 083
2005 129
Magnificent – 2005 244
2005 361
In situ data – $T_{\text{air}}$, $T_{\text{sea}}$ seasonal

Fowey Rocks

Molasses Reef

Sombrero Key
In situ wind - seasonal $W_U$, $W_V$

- Fowey Rocks
- Molasses Reef
- Sombrero Key
In situ cycles (Sombrero Reef)
Time-dependent spectrum

WT: sea temperature time series (SMKF1, last 2 years)
Extended PCA – covariability between possible forcing and coastal ocean response

PCA(\(n\)) Modes SMKF1 1988-2008 Annual, 336H frames (85.5\% of \(\sigma^2\)): sea_t_1_day_deviation_3_day_average (c)

#1 (22.5\% \(\sigma^2\))

#2 (16.5\% \(\sigma^2\))

#3 (12.4\% \(\sigma^2\))

#4 (8.6\% \(\sigma^2\))

#5 (7.0\% \(\sigma^2\))

#6 (5.7\% \(\sigma^2\))

#7 (4.9\% \(\sigma^2\))

#8 (4.1\% \(\sigma^2\))

#9 (3.8\% \(\sigma^2\))

vs. air_t_1_day_deviation_3_day_average (r), wind1_u_3_day_deviation_sum_wind1_v (g), wind1_speed_3_day_average (b)