Physical oceanography of coral reefs and other shelf-break ecosystems

A Joint Effort of CIMAS, NOAA, and the Florida Keys Marine Lab (Florida Institute of Oceanography / USF)

Lew Gramer (CIMAS/FIO–KML)

Jim Hendee (NOAA–AOML)

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In Collaboration With:

A Soloviev and B Walker (NSU); C Hu and B Barnes (USF); J Stamates and T Carsey (NOAA-AOML); jurisdictional resource managers; and … you?

Three Collaboratively Funded Physically Oceanography Projects:

NOAA CORAL REEF CONSERVATION PROGRAM

STATE OF FLORIDA INSTITUTE OF OCEANOGRAPHY FIO

Turbidity – American Samoa, CNMI, and Florida – LBSP

Upwelling – SE Florida – LBSP

Resilient Habitats – Florida, Flower Garden Banks, USVI – Climate Change

Overarching Goals

- Improve scientific understanding of the marine environment (turbidity, upwelling, cross-shelf-dynamics, air-sea fluxes)…
- Of coastal ecosystems such as coral reefs, and their related fisheries…
- To enhance manager decision-making.

Satellite Turbidity Monitoring in American Samoa, CNMI, Florida

NOAA CRCP Project #881

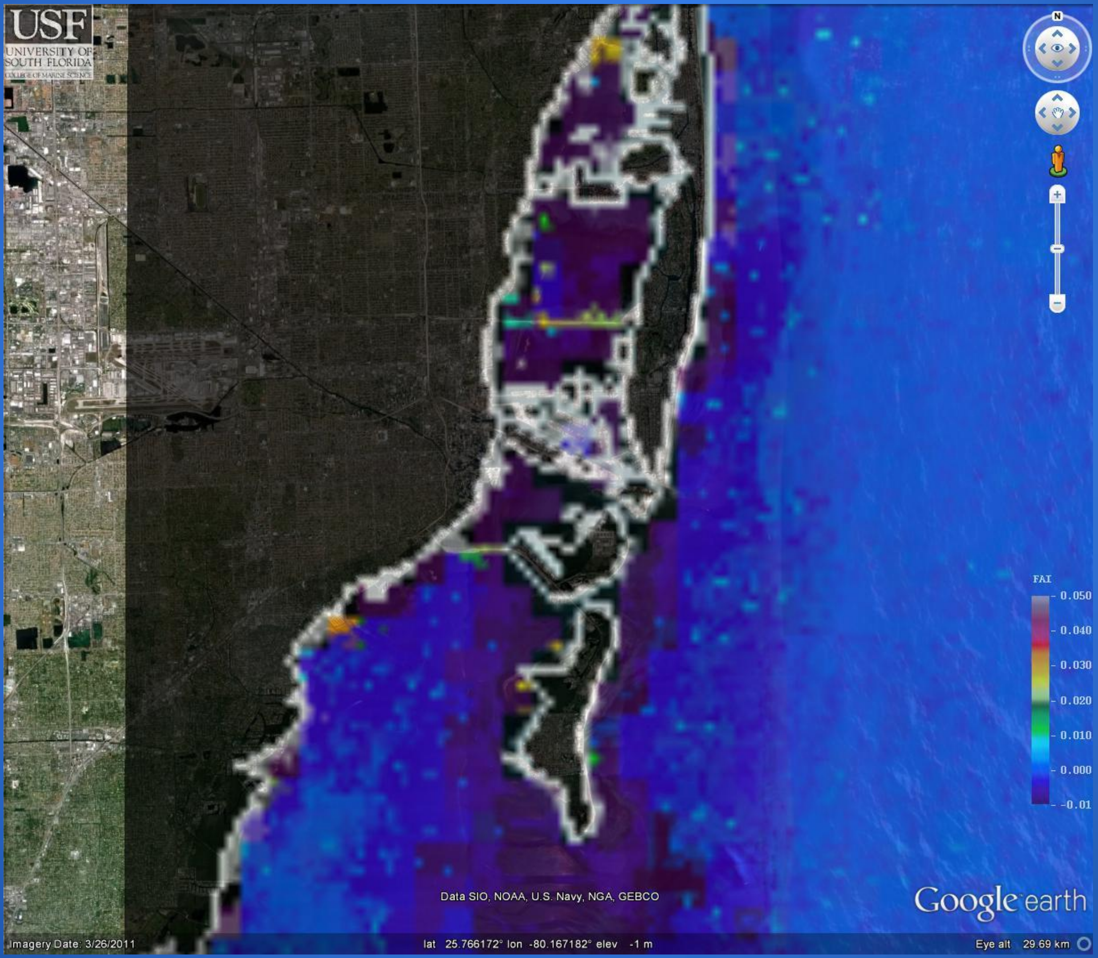
Drs. Brian Barnes, **Lew Gramer**, Jim Hendee, Chuanmin Hu

Coral Health And Monitoring Program

USF UNIVERSITY OF SOUTH FLORIDA

NOAA

250 m imagery



Satellite Turbidity - Facts

- Uses ***four*** color bands in MODIS (MOderate-Resolution Imaging Spectroradiometers)

- Two to four overpasses per day, 2002-present
- 250x250 meter pixels

- Uncalibrated: shows variation over time
  - Spatial coverage over 100s of km
- Site-calibrated: absolute NTU (smaller areas)

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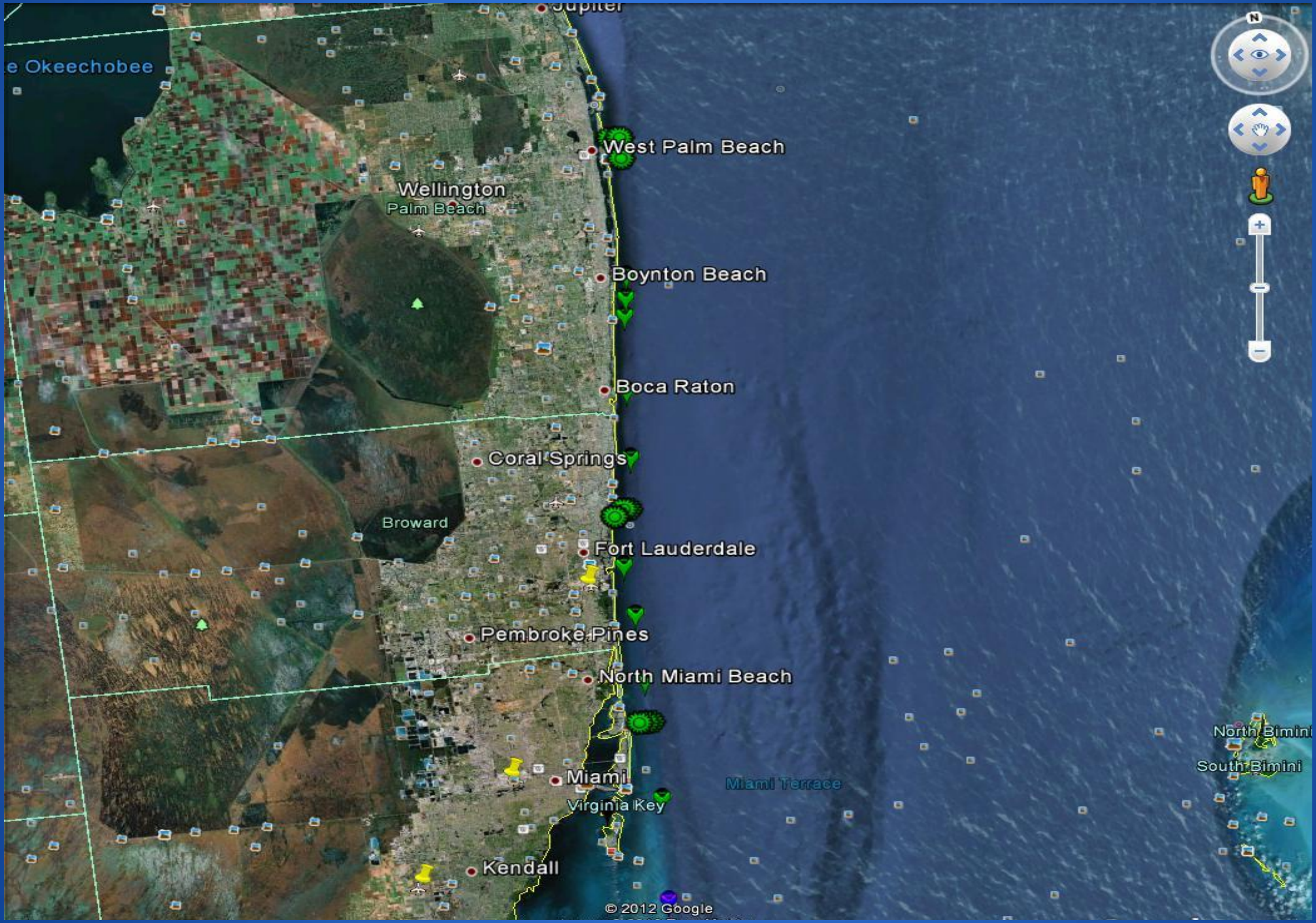
NOAA CRCP Project 789

Identifying LBSP management priorities: Quantifying the contribution of upwelling to LBSP and thermal stress on Florida reefs by sub-watershed

SE Florida shelf – observations

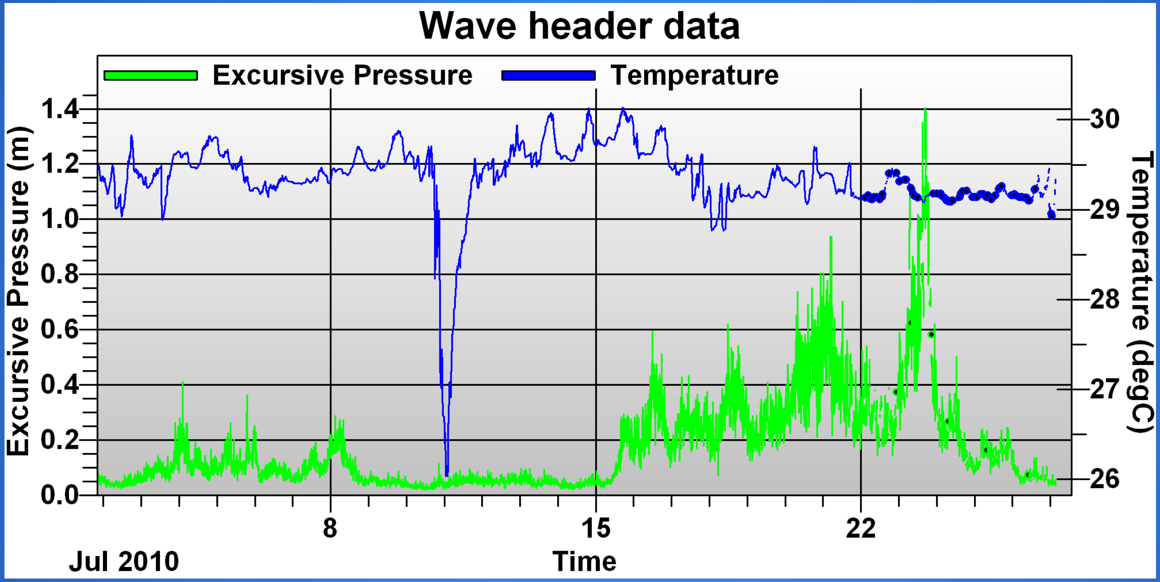


Sea temperature – above Palm Beach

Cold-water Events: Mechanisms

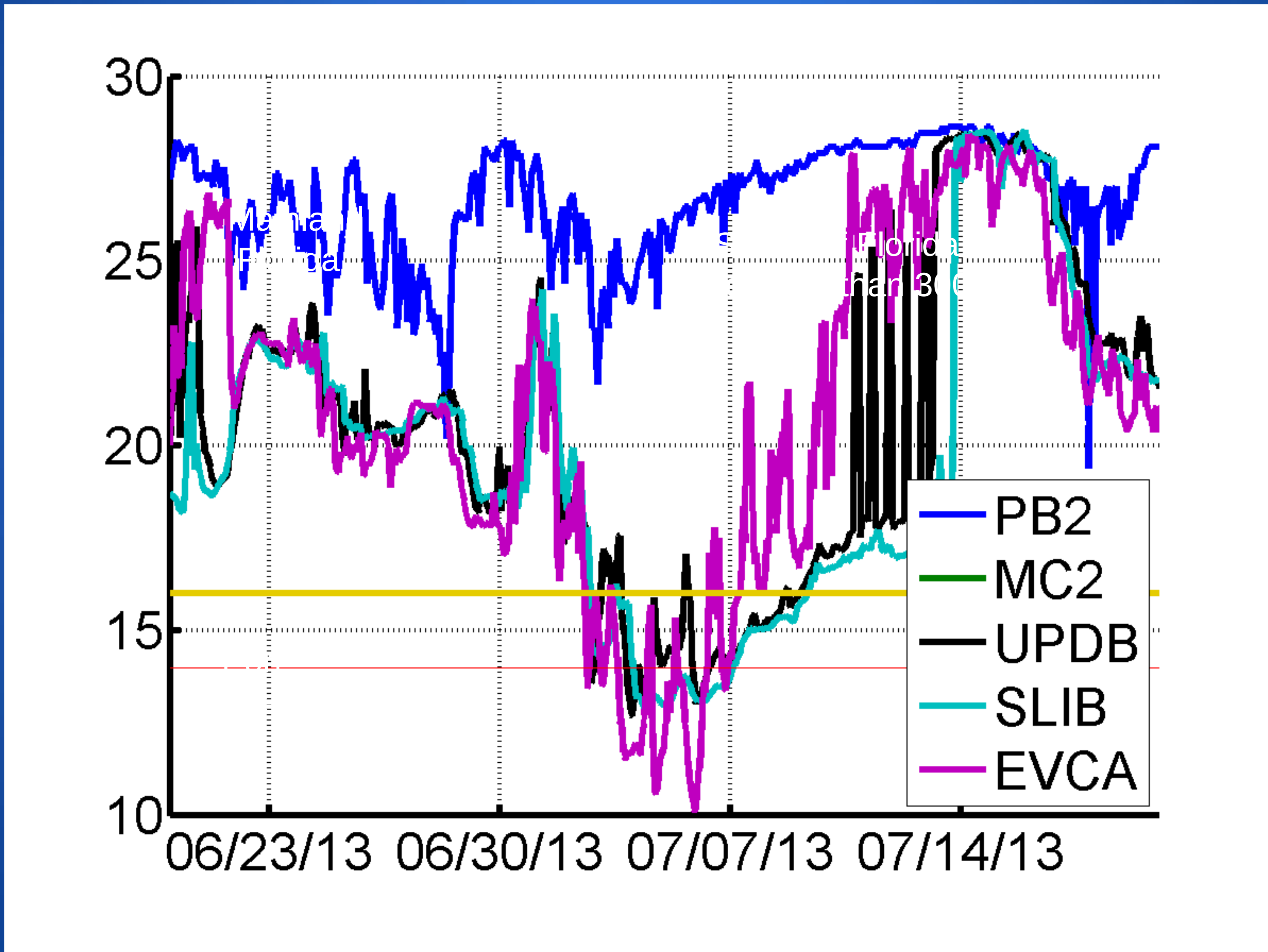
- Air-sea fluxes, advection, mixing
  - Heat Budget Model of Reef Heating (Gramer 2013)
- Submarine groundwater discharge
- “Upwelling” wind (coastal Ekman divergence)
- Seiches across the Straits of Florida (Soloviev)
- Eddies and current meanders (Lee, Hitchcock)
- Internal-wave *breaking* (Leichter, Monismith)
  - Internal waves excited by ***what mechanism***?

Unexplained Extreme Upwelling Event in July 2010



Upwelling event on the Dania Bach shelf. Data from the NSUOC bottom mooring deployed at 11 m isobath.

Summer Upwelling: Martin County



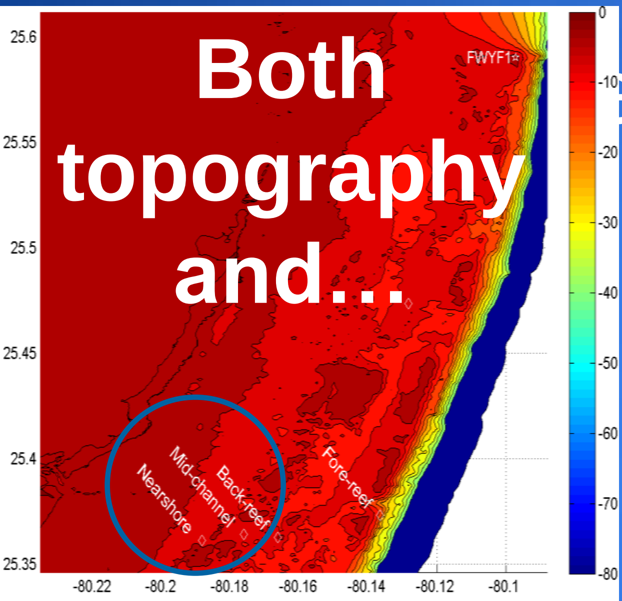
Model of Coastal-ocean Heating and Shelf-water Exchange (MoCHSE)

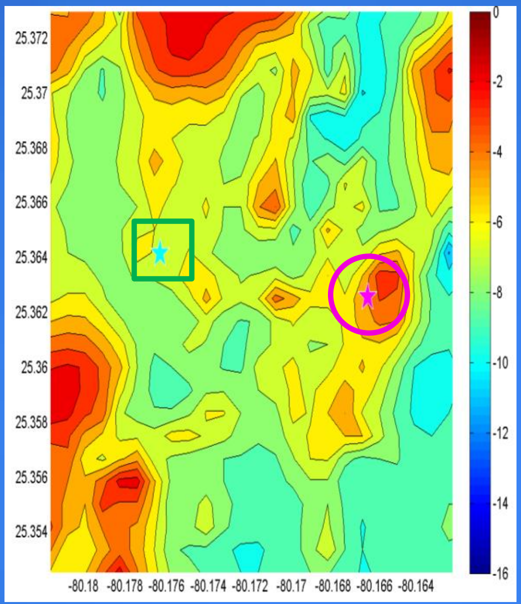
Mapping refugia and at-risk habitats within U.S. Coastal MPAs (FKNMS, SEFCRI, FGBNMS, USVI, others)

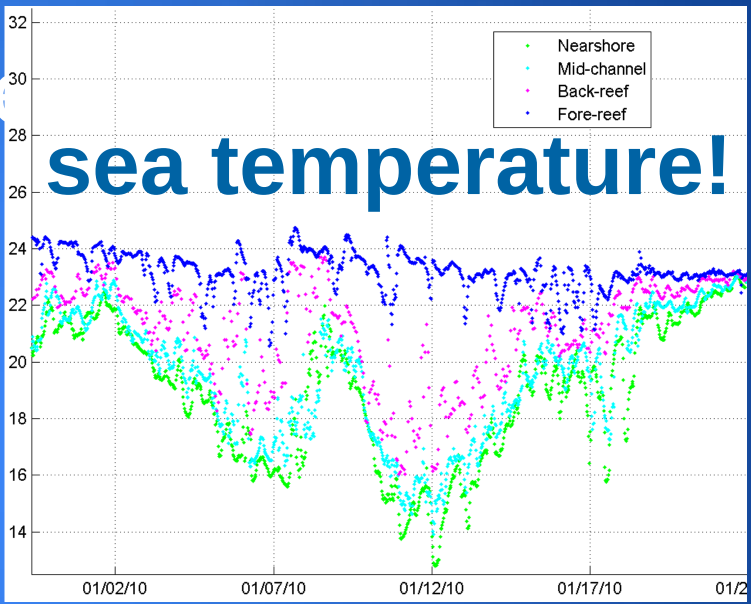
Thermal Stress: ***Small Scales***

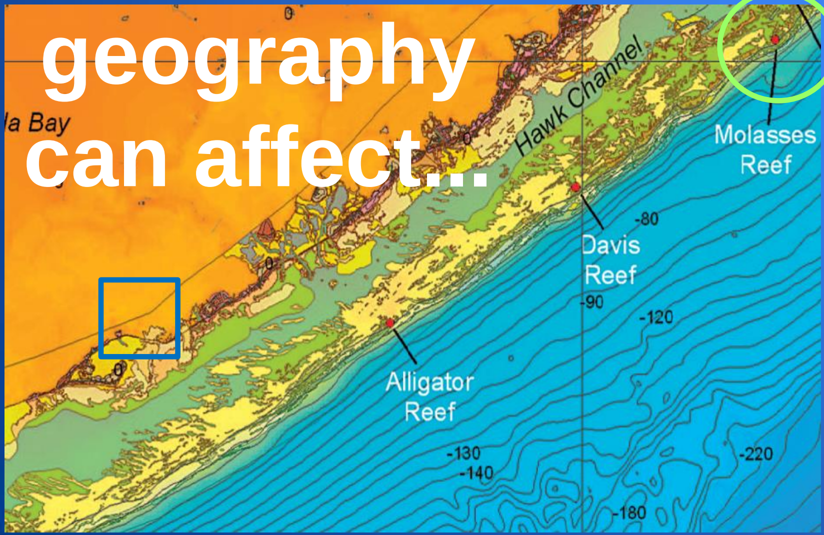
- Cross-reef variability
  – ***Topography and geography*** both condition thermal stress due to heating and cooling…
- Vertical structure in deeper water
  – Summer stratification, internal waves, eddies…
- ***Result? High-frequency variability…***

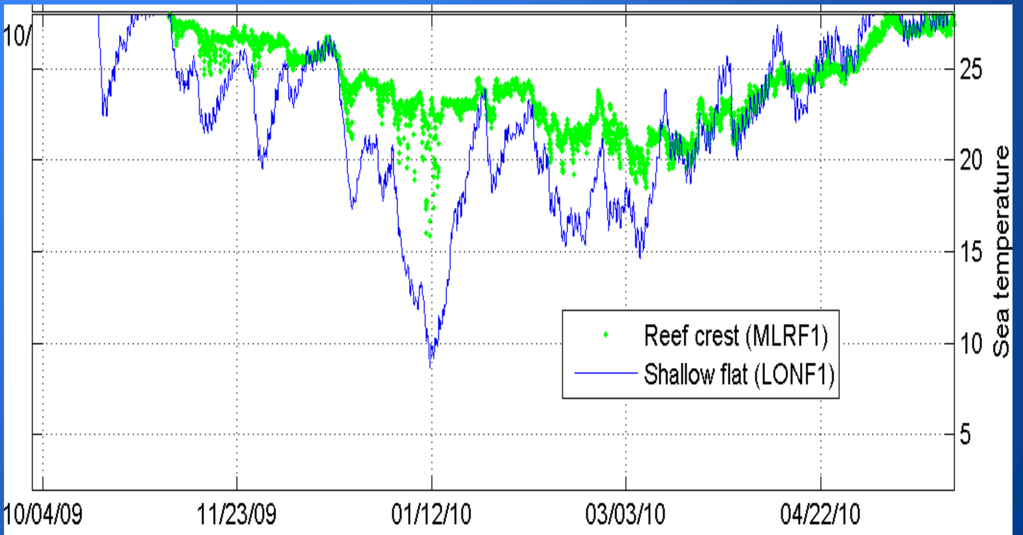
Thermal Stress: *Small Scales*











Heat Budget Equation

$$\partial_t T_S = \frac{Q}{\rho C_p h} + K\nabla^2 T_S - \vec{u} \bullet \nabla T_S - \vec{u}_{hc} \bullet \nabla_h T_{S,hc}(Q, h, \beta)$$

$Q = \gamma\, Q_{shortwave} + Q_{longwave} + Q_{sensible} + Q_{latent} + Q_{rain} + Q_{benthic}$

$Q_{shortwave}$, $Q_{longwave}$: downward from reanalysis, upward estimated from *in situ* and model (wave) data.

γ : Absorption factor for insolation: depends on attenuation rate "K_d" for visible and near-UV light with depth, time of day, and seabed reflectivity – $\gamma = 1 - P_{PEN} \cdot \tau[1 - A_b \cdot (1 - e^{-K_d . h . \sec(45^o)})]$.

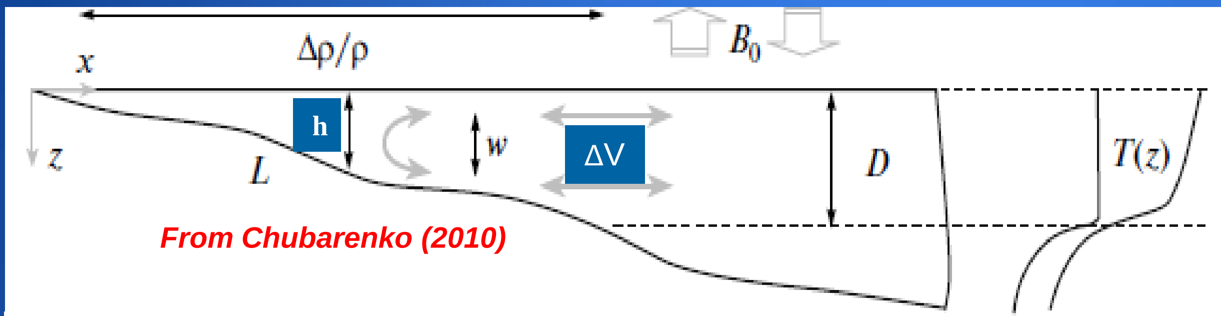
$Q_{sensible}$, Q_{latent}, Q_{rain} : estimated using TOGA-COARE 3.0a from *in situ* (temps. and wind) and reanalysis data.

$Q_{benthic}$: Benthic flux: model from %insolation reaching bottom, seabed reflectivity, substrate composition:

$$\rho_b C_{pb} h_b \cdot \partial_t T_b = Q_{bSW} + Q_{bLW} + Q_{bCD}^{I} + Q_{bCD}^{O} + Q_{bSH}$$

Sea temperature at shallow, high relief sites like coral reefs is a balance of: air-sea fluxes, sea-bottom fluxes, "passive" heat advection, and mixing processes ("horizontal convection", Fickian heat diffusion)

Horizontal Convection



From Chubarenko (2010)

TABLE 1. Possible scalings for ΔV.

Balance	Unsteady inertia	Stress divergence	Advective inertia
Steady temperature	$V_{US} \sim (u_f^3 T/D)^{1/2}$	$V_{VS} \sim (u_f^{3/2}/q^{1/2})$	$V_{NS} \sim \beta^{-1/3} u_f$
Unsteady temperature	$V_{UU} \sim (\beta u_f^3 T^2/D_0^2)$	$V_{VU} \sim (\beta u_f^3 T/qD)$	$V_{NU} \sim (u_f^3 T/D)^{1/2}$

Monismith et al. (2006)

$B_0 = g\alpha Q_{24hSMA}/\rho C_p$	Sea-surface buoyancy flux	$[m^2/s^3]$
$u_f = (h \cdot B_0)^{1/3}$	Characteristic conv. Velocity	[m/s]
$Q^V_{hc} \propto h \cdot \Delta V$	Volume discharge rate	$[m^2/s]$
T	Buoyancy forcing periodicity	[s]

$$\left|\vec{u}_{hc}\right| = \frac{Q^V{}_{hc}}{h}; \quad \left|\nabla_h T_{hc}\right| = Q_{24hSMA}\left(\frac{1}{h} - \frac{1}{(h+\beta x)}\right)/\rho C_p$$

Horizontal convection ***counteracts*** surface heating or cooling over sloping sea floor topography:

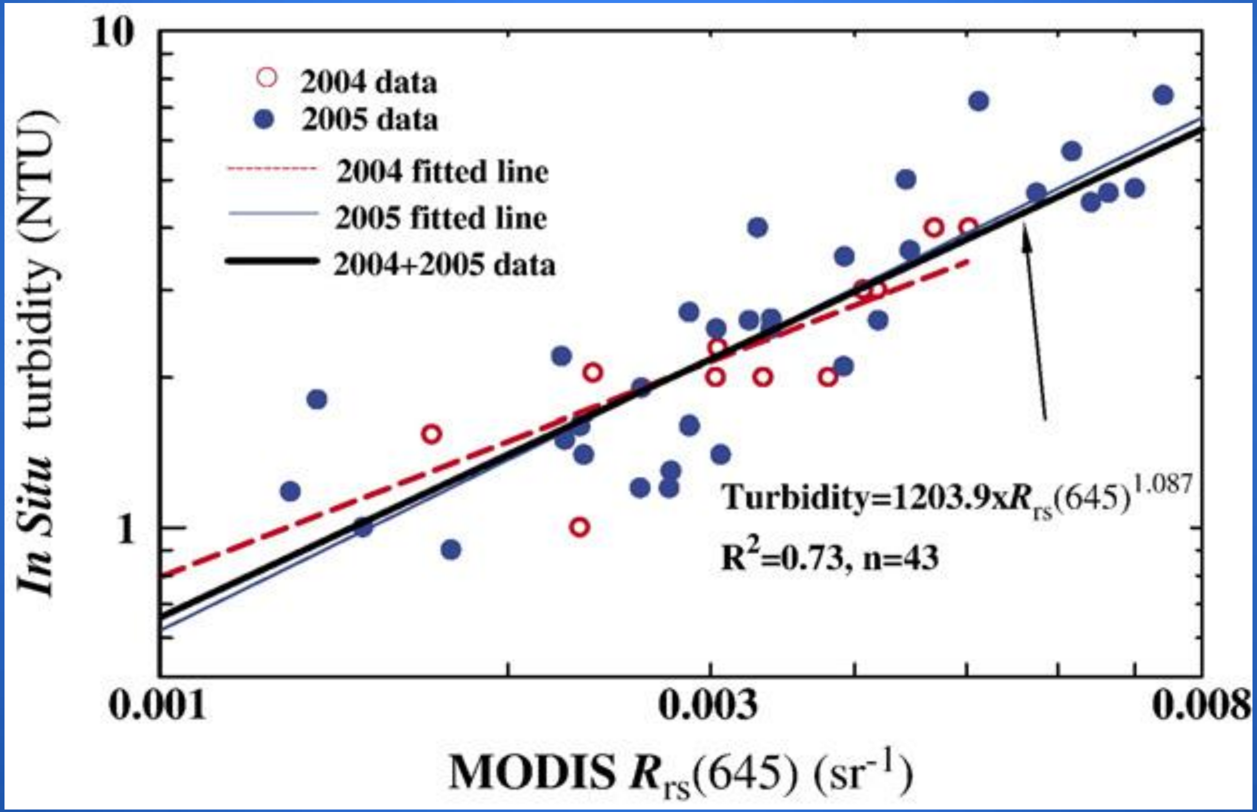
Thermal & momentum balances determine the convection rate, and mixing limits it.

Gramer et al. propose…

- MoCHSE system will serve as a basis for management and research strategies to enhance resilience and restoration of coral reefs and associated fisheries, and inform planning for extended protection boundaries

EXTRA SLIDES

Calibrated Turbidity (NTU)



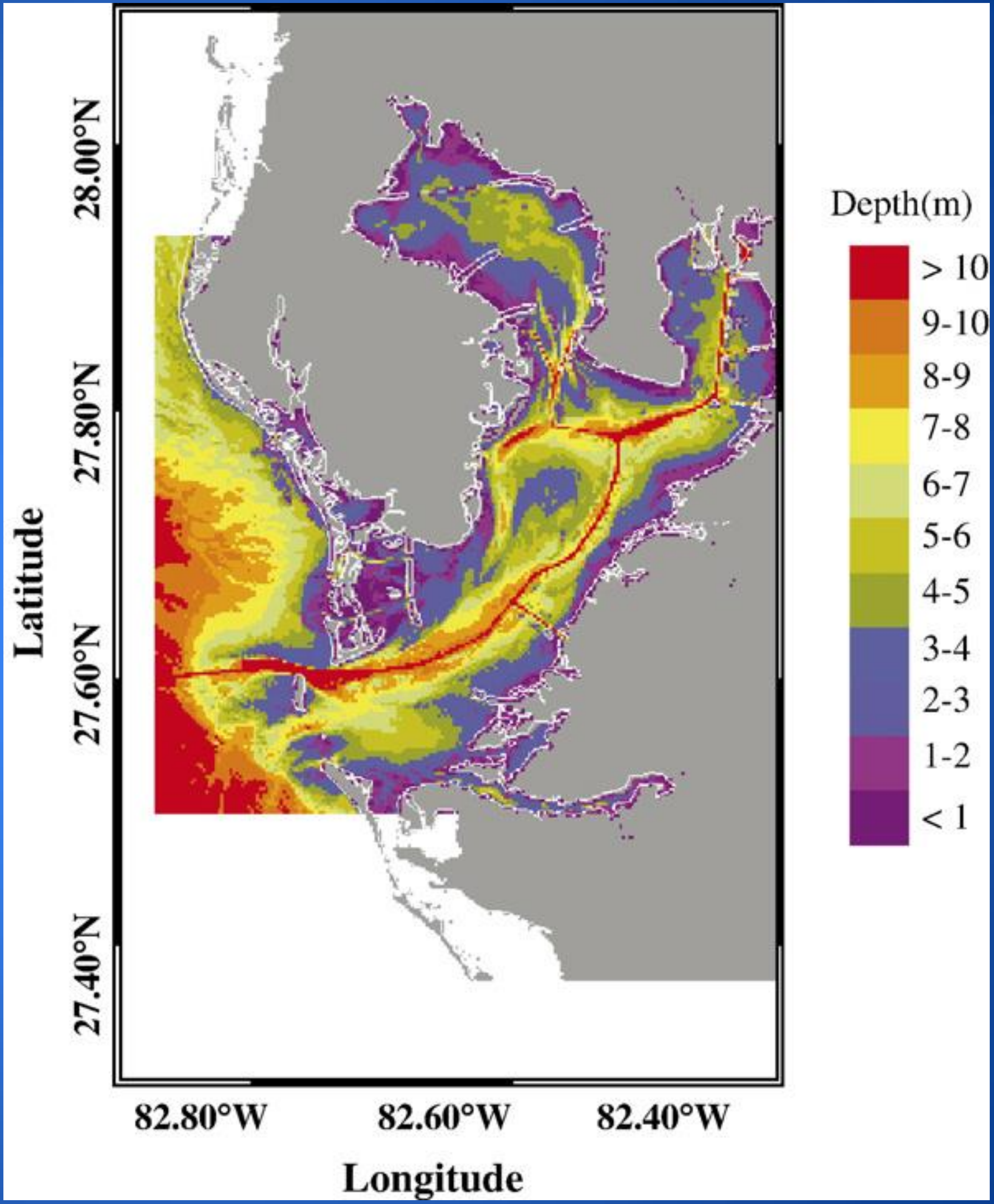
Chen et al., Remote Sensing of Environment 109 (2007) 207–220

Tampa Bay

Shallow

coastal

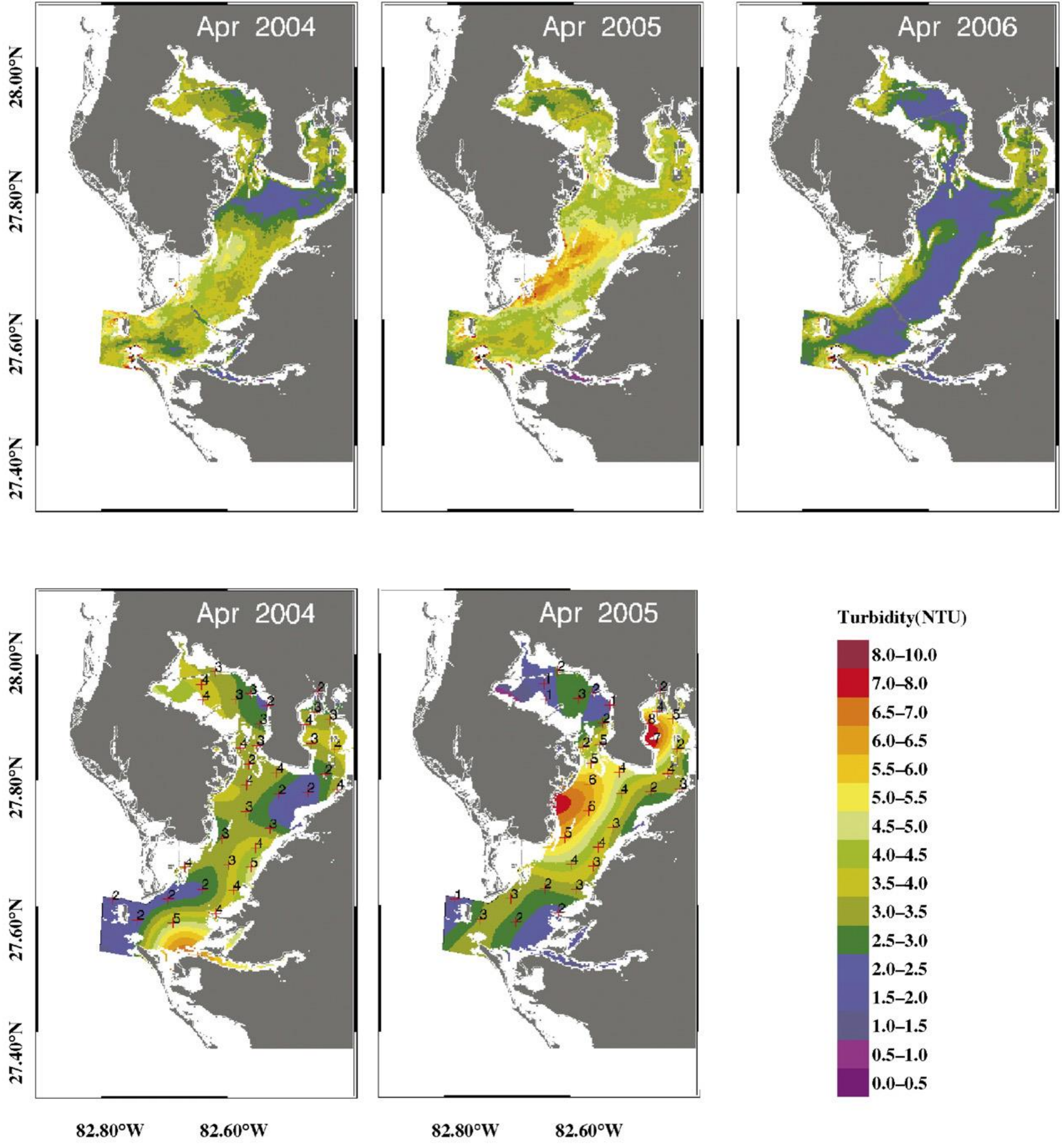
waters…



Chen et al., RSE 2007

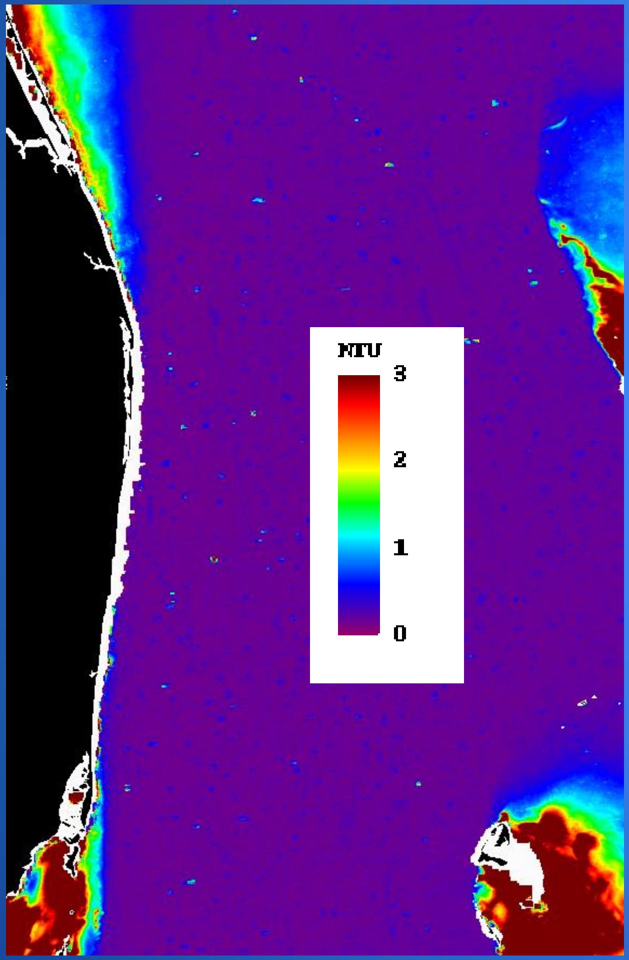
Post-Calibration:

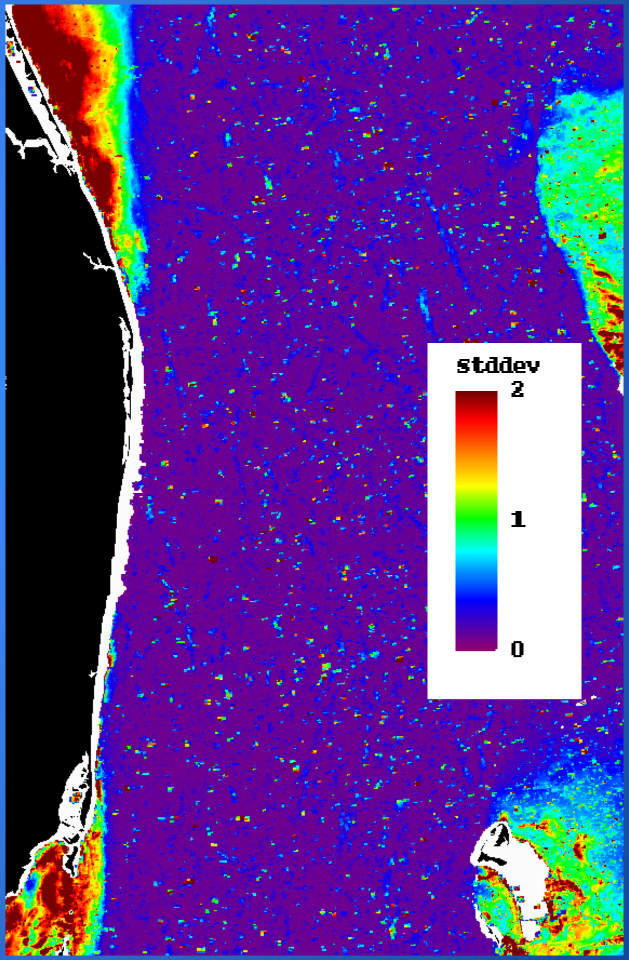
Comparing MODIS (top) with *in situ* (bottom)



Chen et al., RSE 2007

Climatology: 2002-2013





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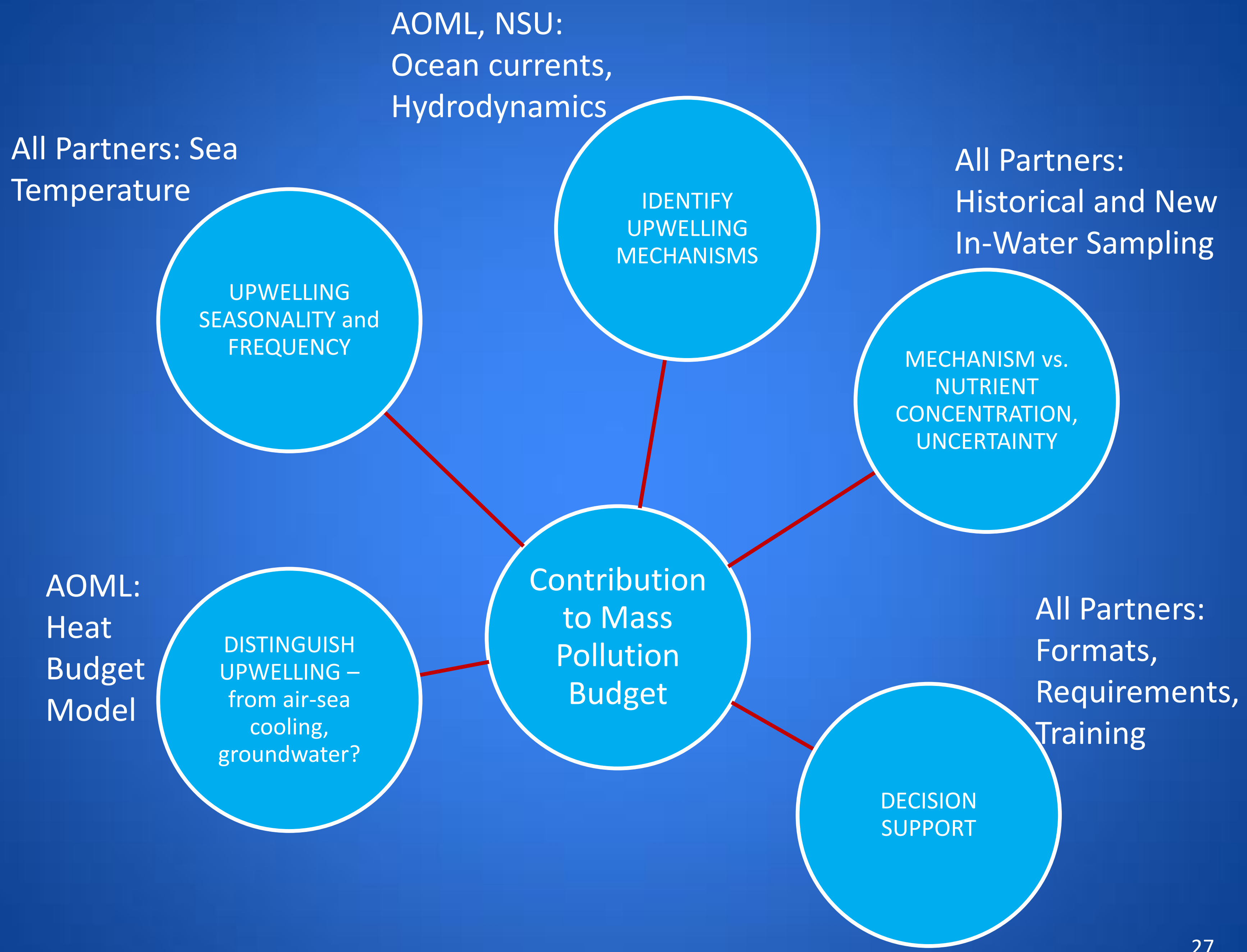
Mechanisms for Reef Cooling

- Rapid air-sea cooling – driven by *strong winds*
  - Can be modeled by a *reef heat budget*
- Vertical mixing – due to wind and/or waves
  - But only over colder waters – only at deeper reefs
- Or, ***upwelling***…

Partners…

- State Partners
    - Florida DEP CRCP – data, guidance on end-products
    - Florida FWC – data, field partnerships, end-users
    - Florida Institute of Oceanography and USF
- NOAA AOML/CIMAS – data, expertise
    - Sea temperatures, ocean currents
    - In-water nutrient sampling
    - Heat-budget model: telling upwelling from air-sea fluxes
- Nova Oceanographic Center
    - Sea temperature
    - Ocean currents data
    - Expertise in physical oceanography of SE Florida shelf


AOML, NSU:
Ocean currents,
Hydrodynamics
All Partners: Sea
Temperature
IDENTIFY
UPWELLING
MECHANISMS
All Partners:
Historical and New
In-Water Sampling
UPWELLING
SEASONALITY and
FREQUENCY
MECHANISM vs.
NUTRIENT
CONCENTRATION,
UNCERTAINTY
Contribution
to Mass
Pollution
Budget
AOML:
Heat
Budget
Model
DISTINGUISH
UPWELLING –
from air-sea
cooling,
groundwater?
All Partners:
Formats,
Requirements,
Training
DECISION
SUPPORT

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2014-2016:

Model of Coastal-ocean Heating and Shelf-water Exchange (MoCHSE) – Mapping refugia and at-risk habitats within MPAs of Florida

Thermal Stress: ***Small Scales***

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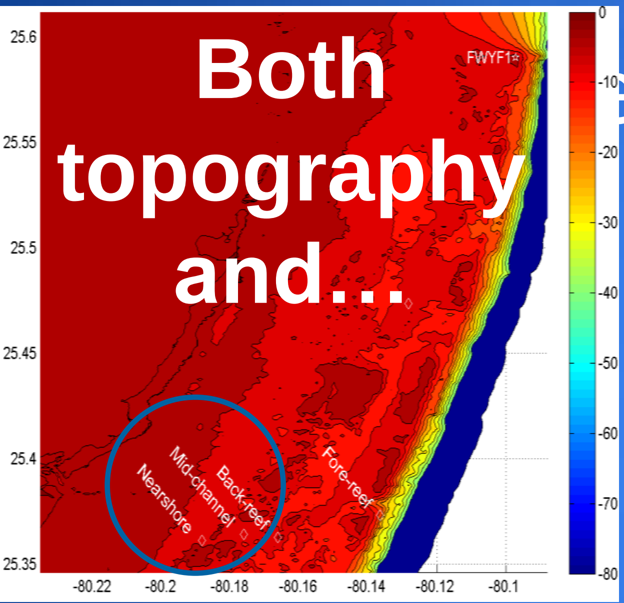
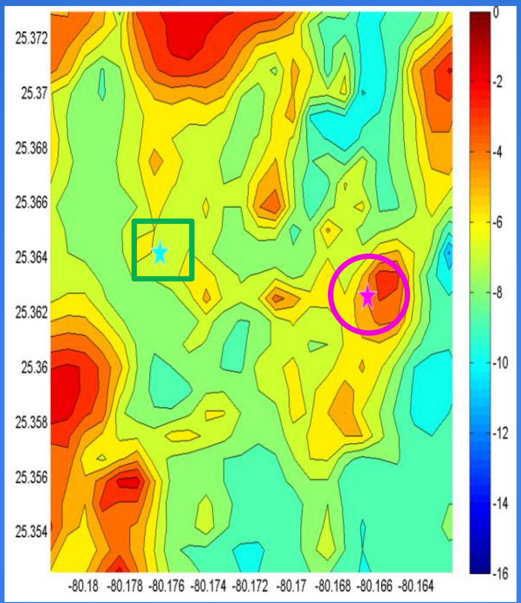
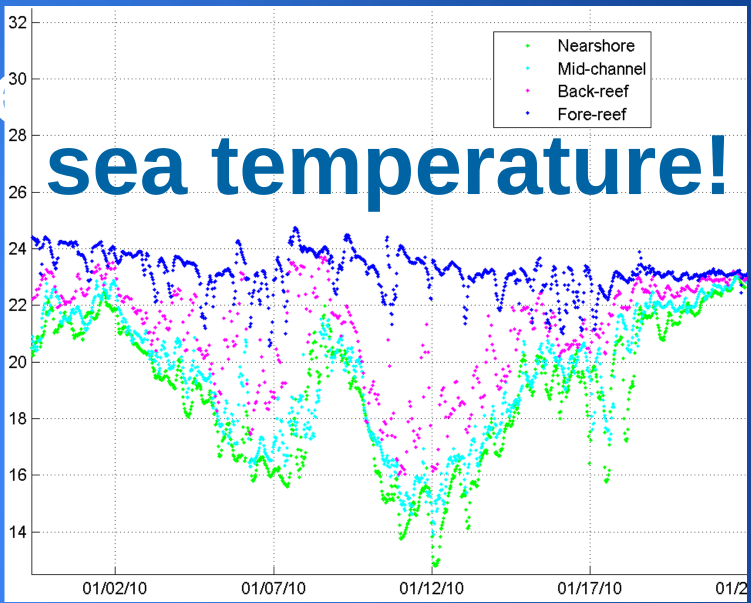
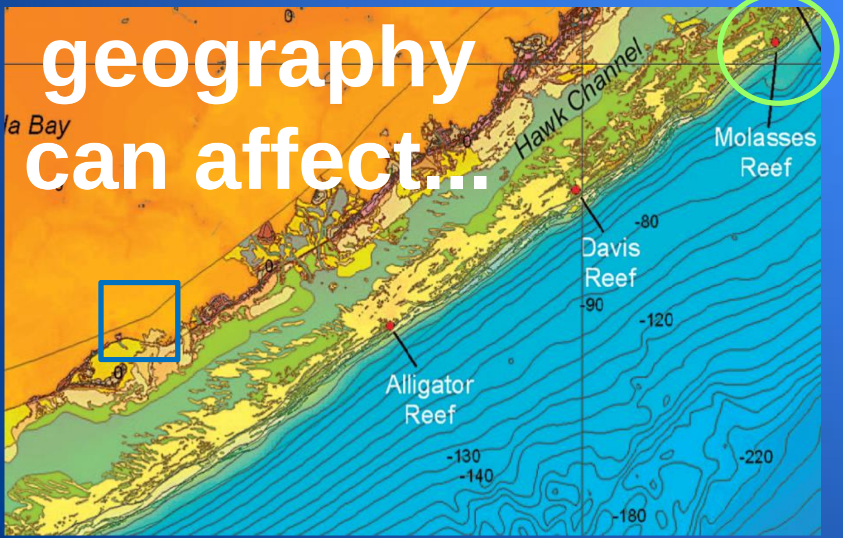
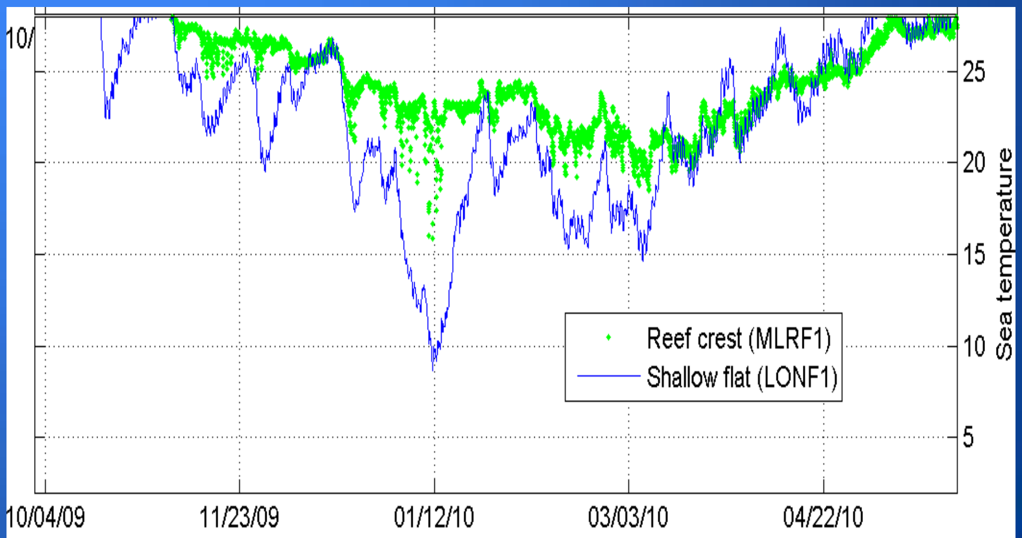
Both topography and… geography can affect… sea temperature!











Gramer et al. propose…

- MoCHSE system will serve as a basis for management and research strategies to enhance resilience and restoration of coral reefs and associated fisheries, and inform planning for extended protection boundaries

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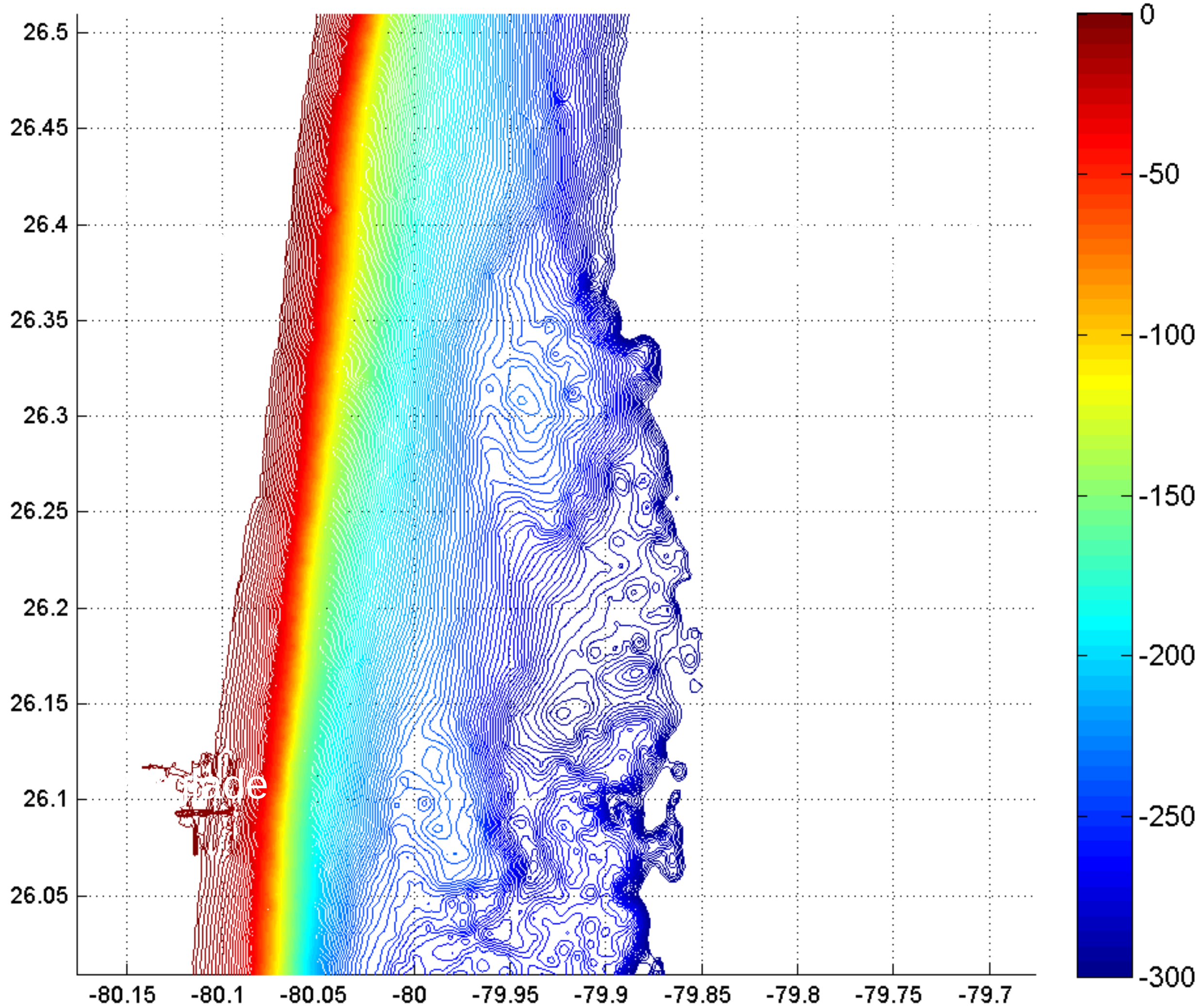
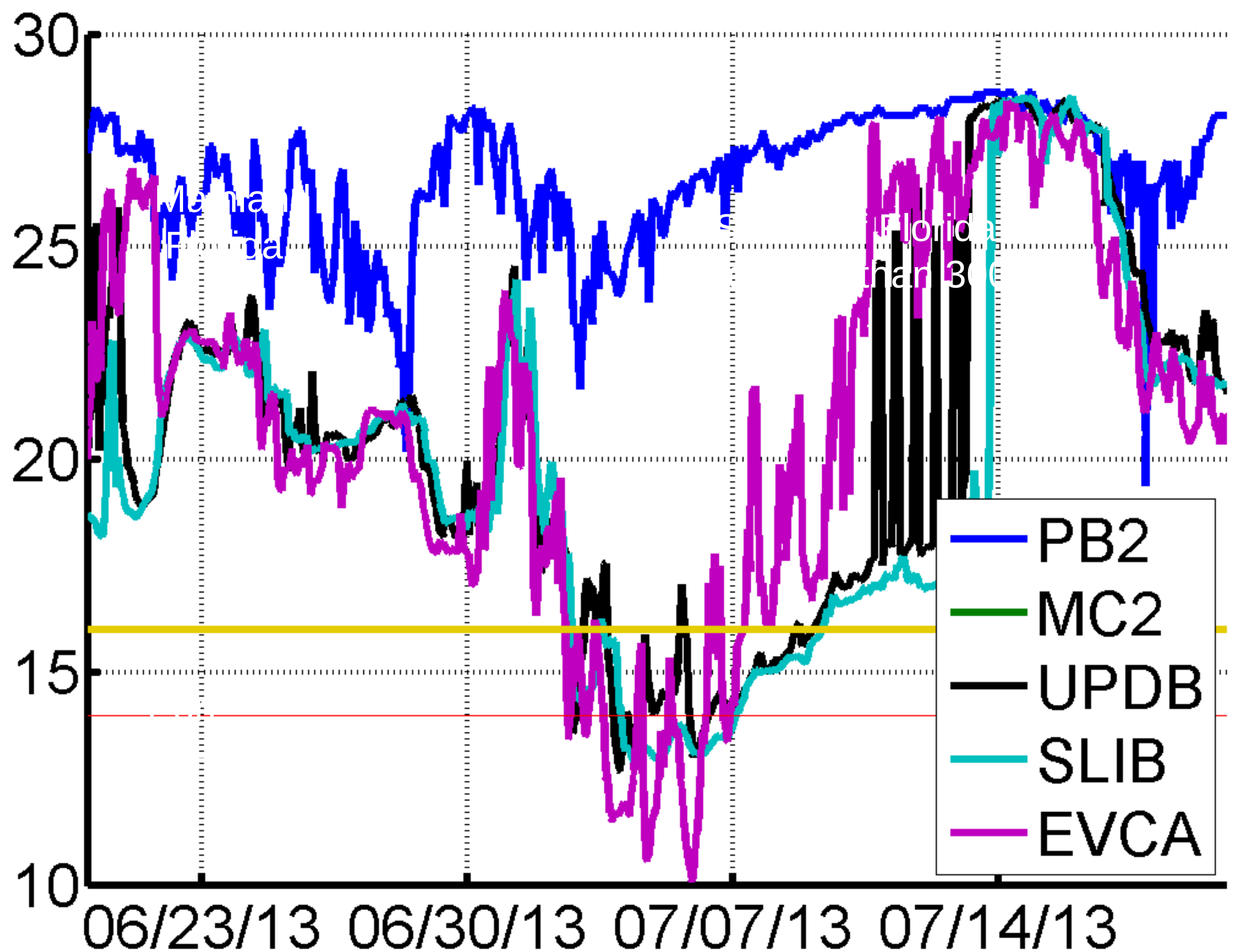
So that Managers can…

- Understand thermal stress on corals better…
- At time and space scales that allow them to manage for sub-jurisdictional impacts and…
- With more timely and reliable information, to manage for larger-scale impacts better as well!

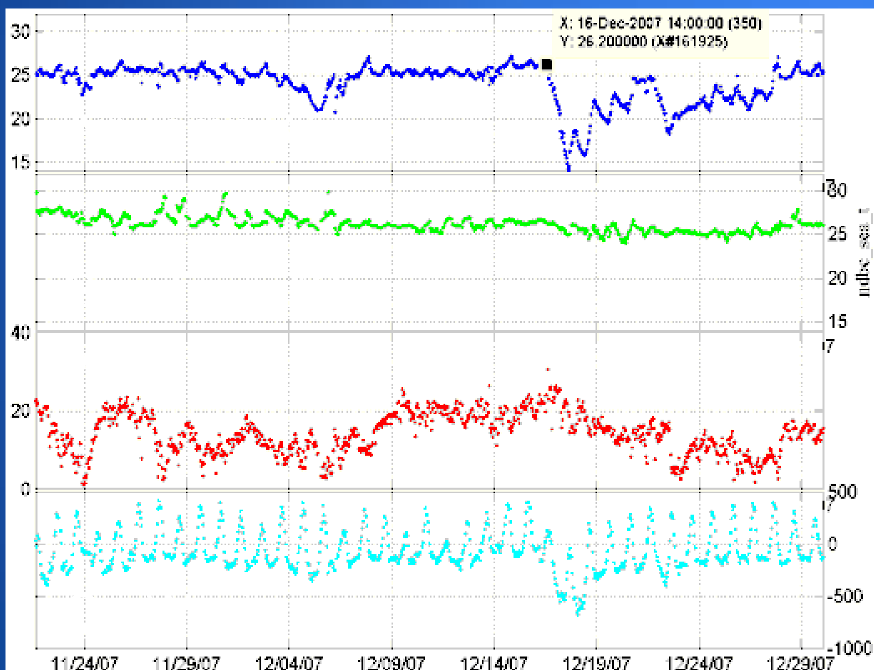
Bathymetry primer: SE Florida shelf



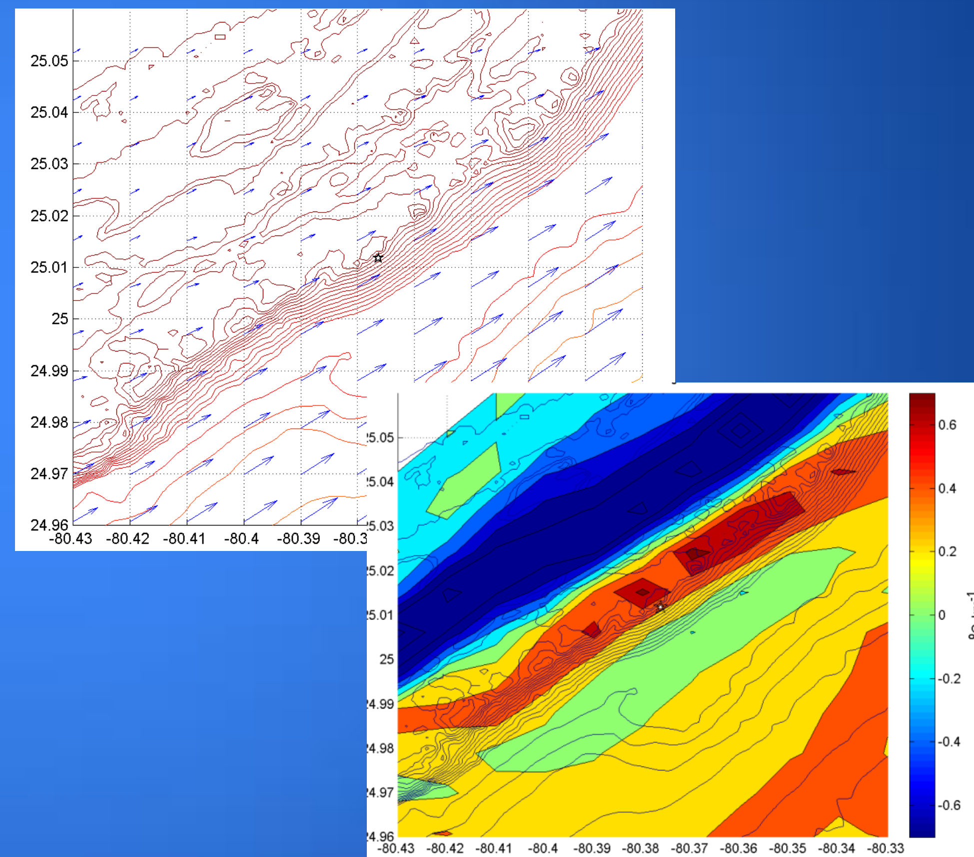
Summer Upwelling: Martin County



Large-scale Heat Budget – Issues

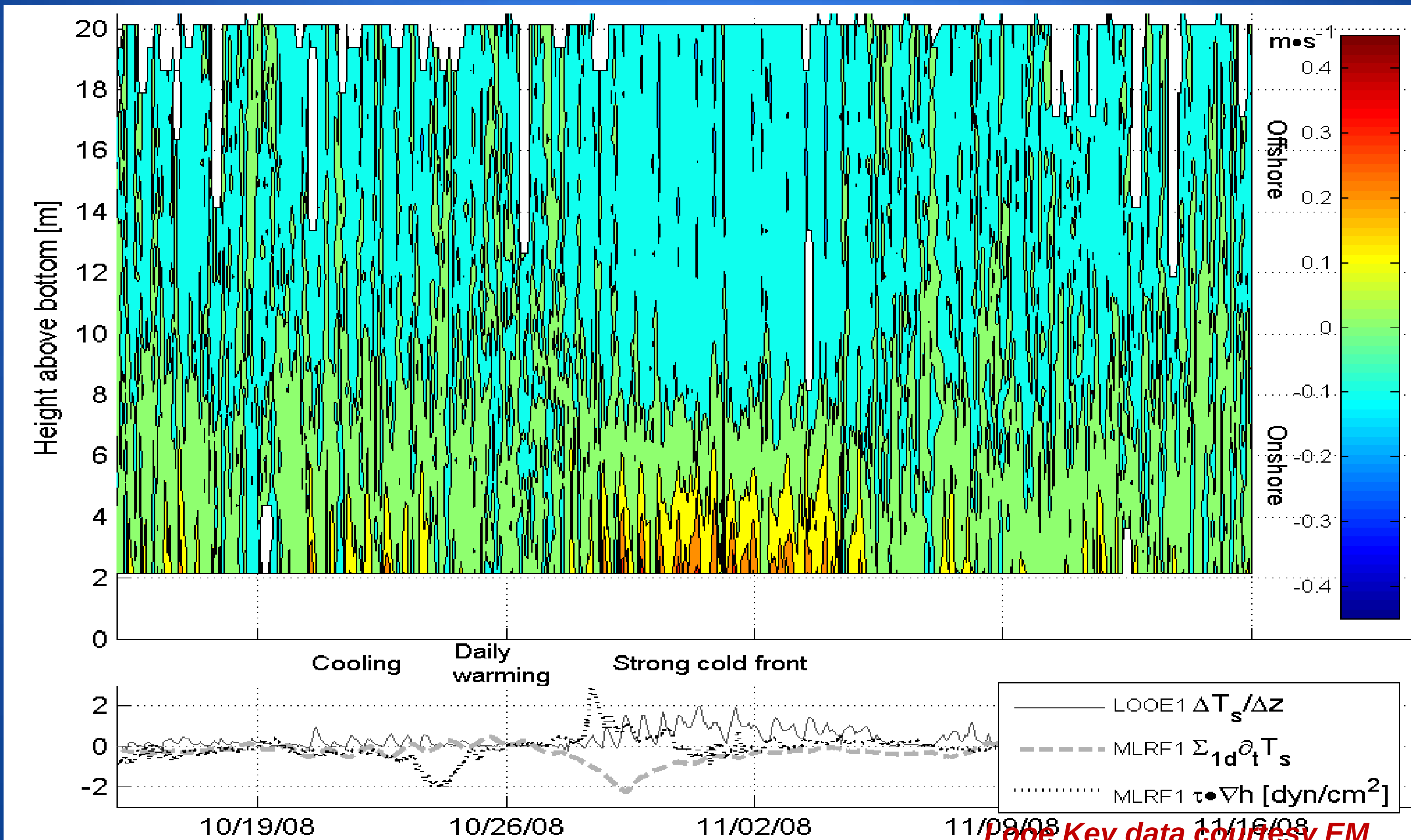


AIR-SEA: Air and sea temperature, wind speed, *net heat flux* (Q_0 per TOGA-COARE; Fairall et al. 2003)



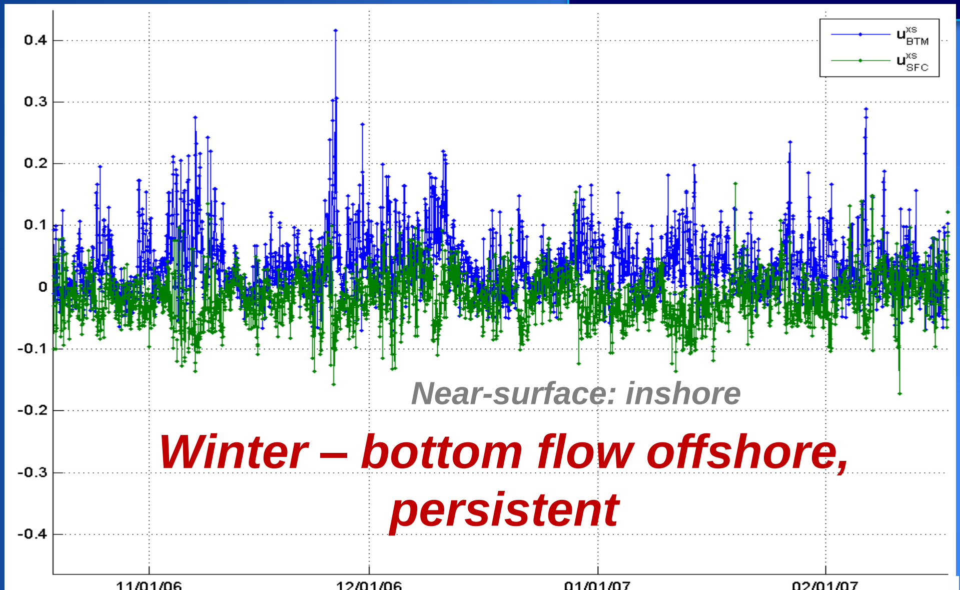
ADVECTION: Hydrodynamic model (FKEYS 900m HYCOM: T, u, v)

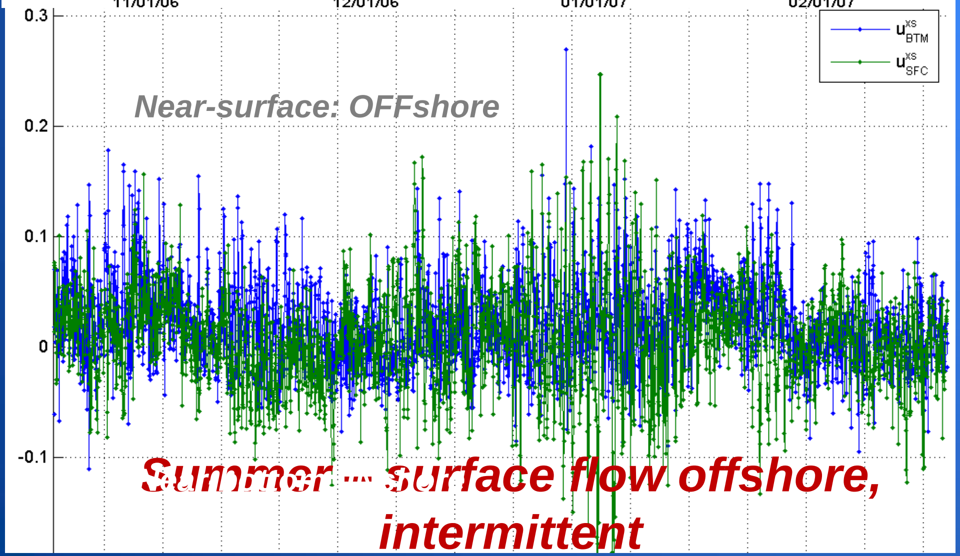
Evidence for Operation of Horizontal Convection on Florida Reefs

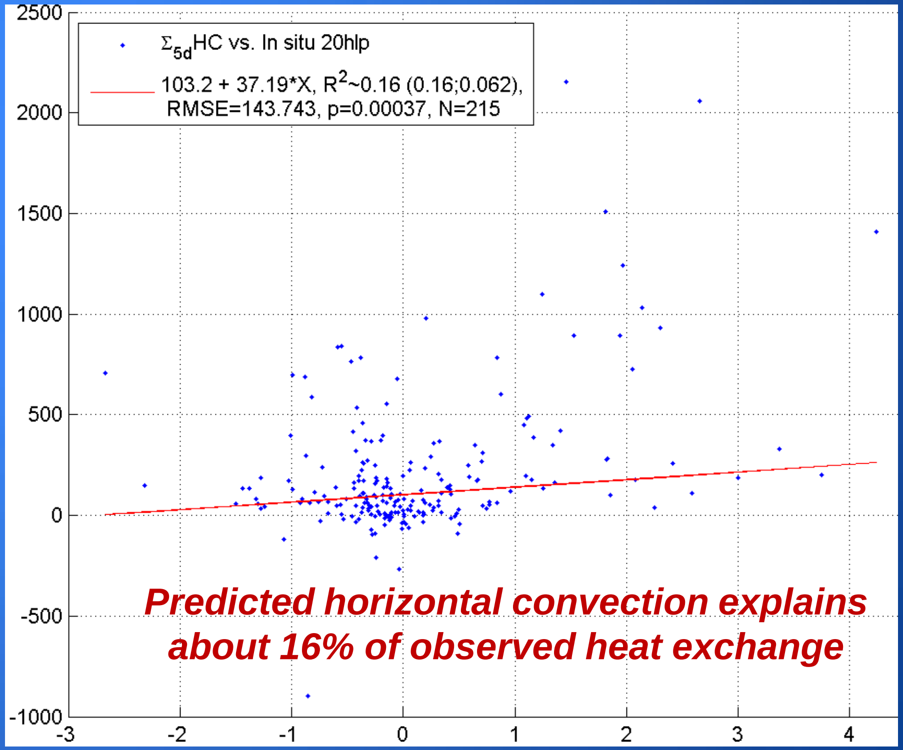


Looe Key data courtesy EM Johns

Evidence for Operation of Horizontal Convection on Florida Reefs







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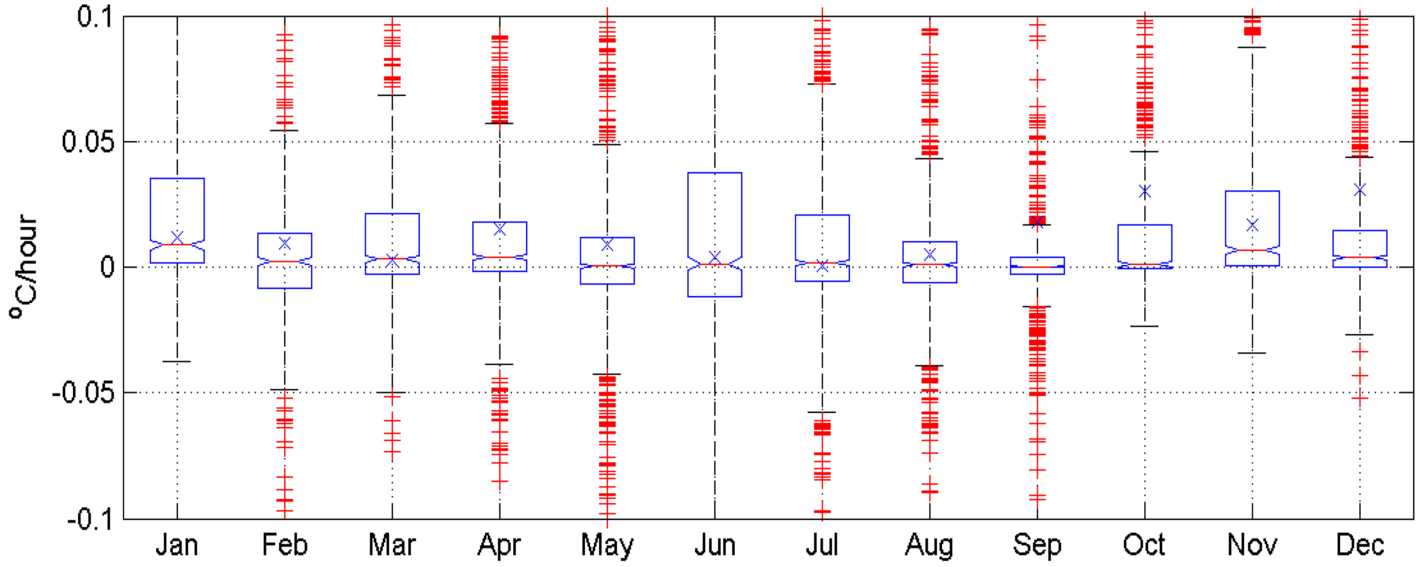
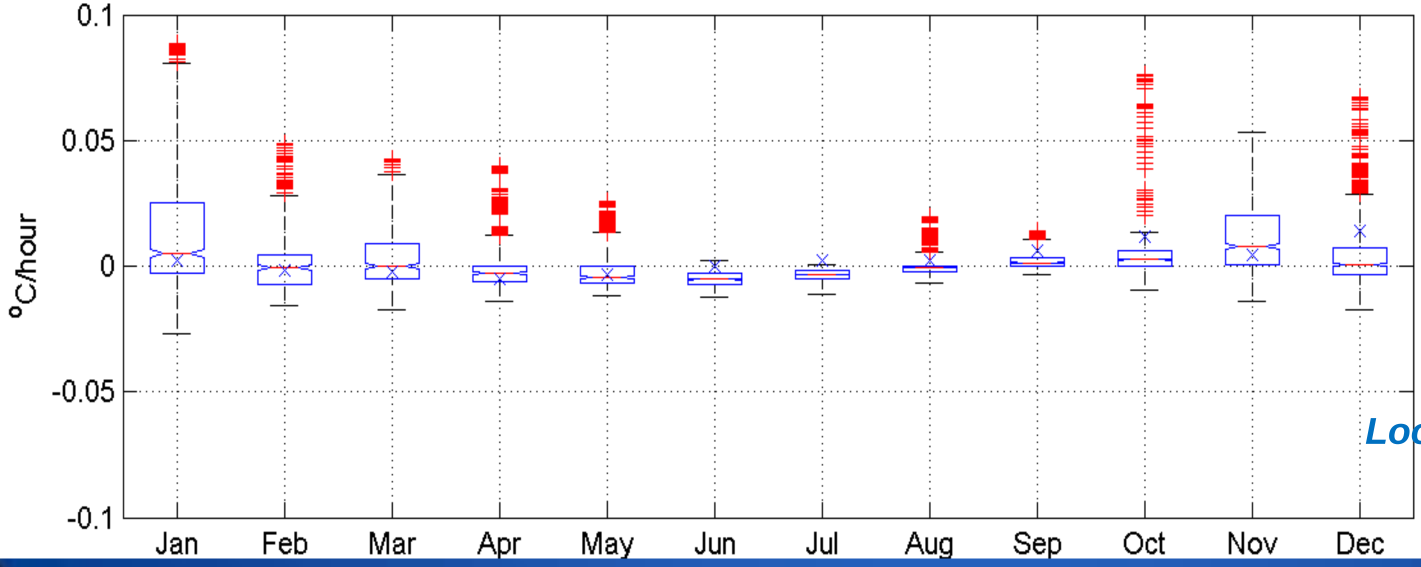


Observed heat exchange at Looe Key
(estimated from $\Delta T/\Delta z$, $\Delta u/\Delta z$)



Predicted heat exchange from Horizontal Convection

Looe Key data courtesy EM Johns