Upper-Ocean Thermal Structure Variability during Hurricanes Ernesto and Isaac (2012)

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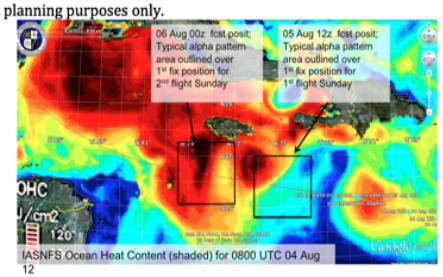
MODIS Image: Hurricane Isaac 1130 CDT (1630 UTC) 28 August 2012 Courtesy: http://earthobservatory.nasa.gov/IOTD/view.php?id=79008

Background / Purpose

- AXBT Demonstration Project
  - Goal: Increase hurricane forecast accuracy by assimilating ocean observations from beneath tropical cyclones into coupled numerical models in near-real time
  - *Incremental objective (#1): Collect, process, and transmit AXBT data to coupled modeling centers in near-real time*
- Sensing strategy development critical to "smart" collection, effectively employing limited resources
  - Challenge: optimize collection of upper-ocean temperature observations within an operational context
  - Currently: flight track and ocean-feature dependent (see Ernesto mission 0605A details from 05 August 2012 below)
  - Strategy: continue to improve initial conditions in the ocean component of coupled models
    - NRL MRY: Data denial study underway to identify optimal horizontal and vertical observation spacing (COAMPS-TC)
    - HERE: Climatology and variance in upper-ocean thermal structure are investigated and compared to observational data to determine potential areas where the use of climatology-based initial conditions may result in errant upper-ocean temperatures
- Focus for today
  - Comparison of Isaac and Ernesto AXBT observation data to climatological temperatures, OHC, and variance

3. OHC quicklook:
Objective over next few flights is to sample all quadrants around the TC, but the focus will be on the forecast track region as well as the OHC boundaries where feasible. Alpha pattern boxes are purely notional and are included as situational awareness tools for AXBT deployment planning purposes only.



OHC as of 0800z 03 Aug (shaded, IASNFS courtesy D.S. Ko); green line to east is the TC track (courtesy NRL MRY); teal line NHC OFCL track forecast current as of 0000z 04 Aug (overlay courtesy of Tropical Atlantic). Black boxes outline standard alpha pattern dimensions, and are only notional for planning purposes.

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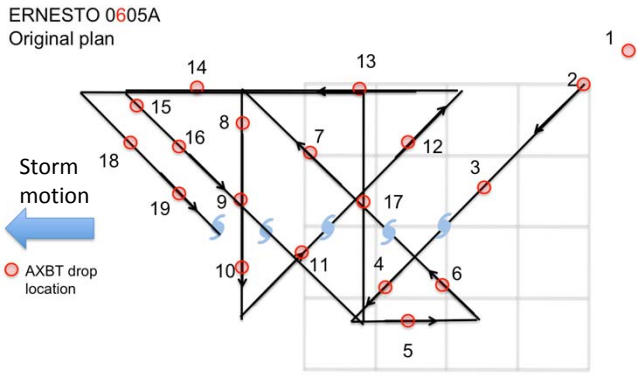
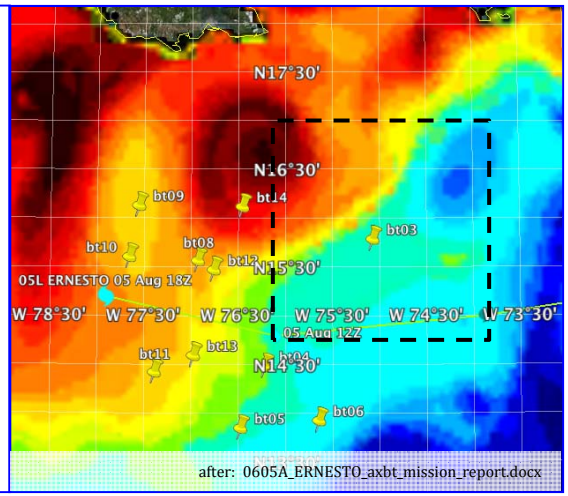
Mission Planning

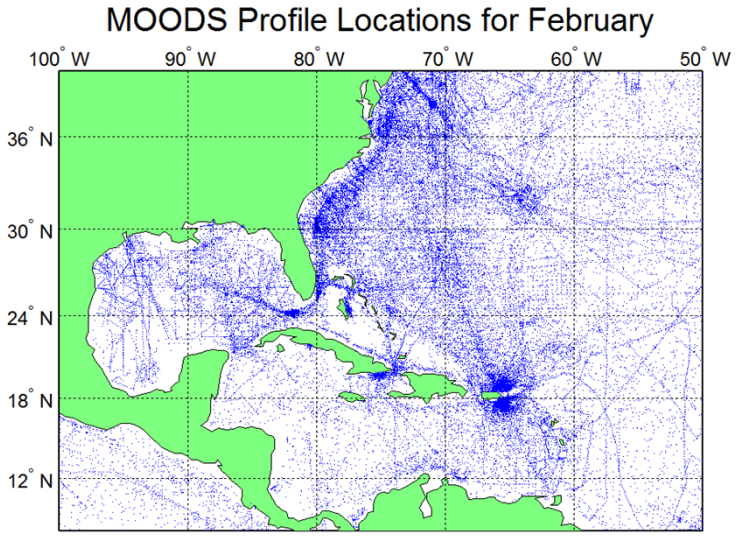




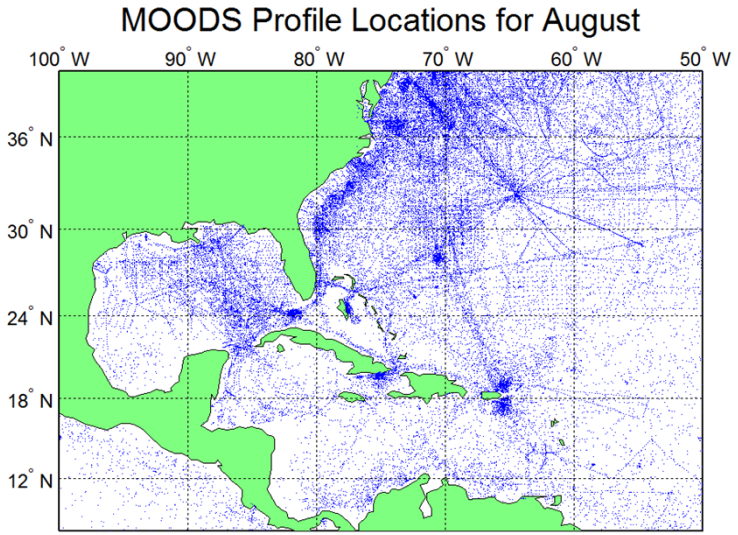
after: 0605A_ERNESTO_axbt_mission_report.docx

Data and Methods

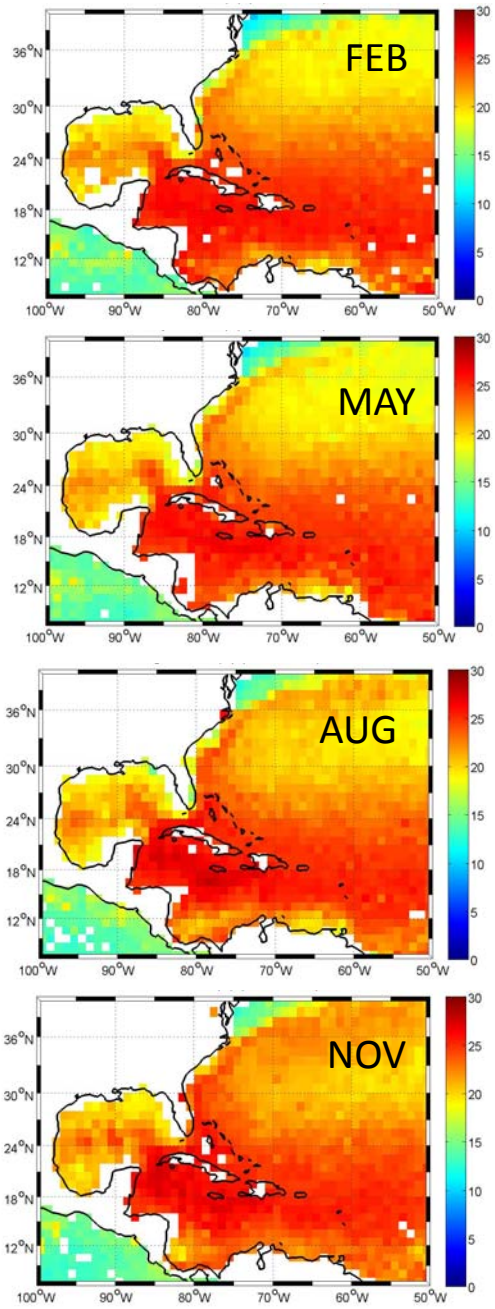
- Data
  - Master Oceanographic Observation Data Set (MOODS)
    - 50-yr subset (1960-2009) provided by NAVO
    - Included more than 752,000 observations from XBTs, AXBTs, CTD probes, and Nansen casts
    - Heavily concentrated along shipping routes
  - AXBT Demonstration Project
    - Included 212 quality-controlled AXBT observations
    - Collected during Hurricanes Ernesto and Isaac in August 2012



- Methods
  - Developed monthly climatology temperature vs. depth profiles
    - MOODS profiles interpolated to 1-m vertical resolution
    - Averaged profiles in 1° x 1° grid boxes by month
    - Technique varied from other climatologies (e.g. Levitus, GDEM, MODAS, SMARTS)
  - Analyzed TC-relevant ocean characteristics and variance of those characteristics
  - Compared to Isaac and Ernesto AXBT data



Mean Temp (°C)
at 100-m depth



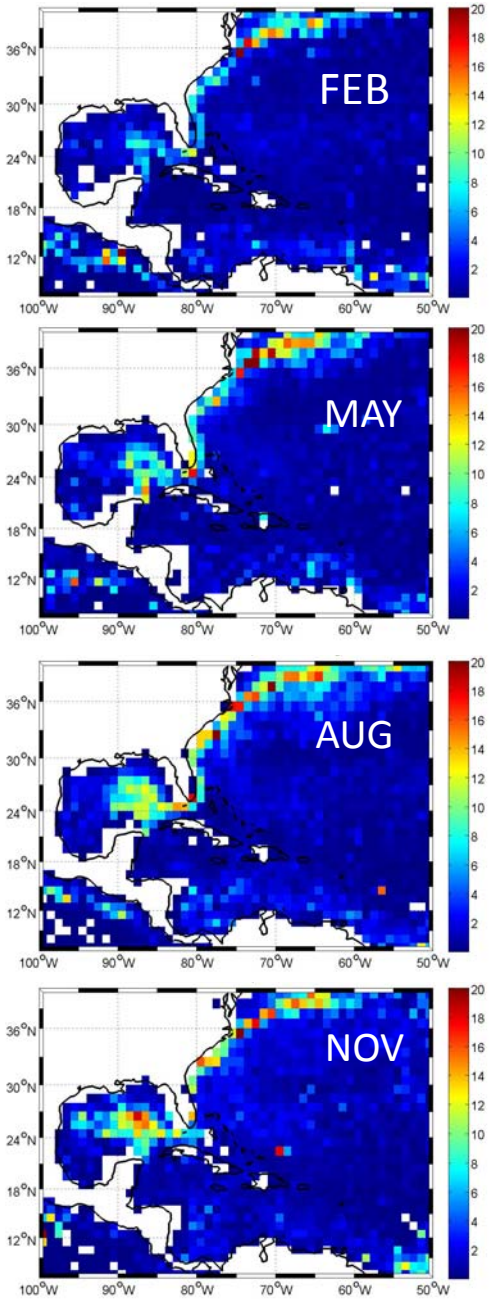
Monthly MOODS Climatology

- TC-relevant characteristics
  - Focus: upper-ocean thermal structure
  - Variables: SST, 50-, 100-, 150-, and 300-m temperatures, depth of the 26˚C isotherm, OHC
- 100-m temperatures
  - Evolution of dynamic features
    - Loop Current
    - Gulf Stream
  - Mean temperatures and positions
- Variance of 100-m temperatures
  - Formula:

$$Variance = \frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}$$

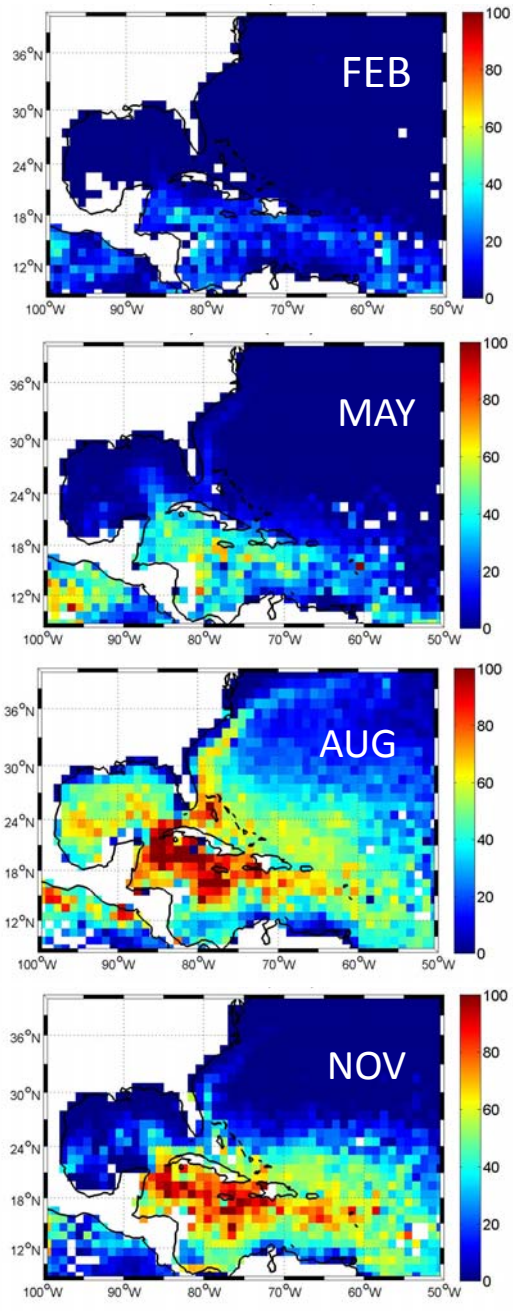
  - High variance noted near dynamic features

Variance of Temp (°C) ^{2}
at 100-m depth



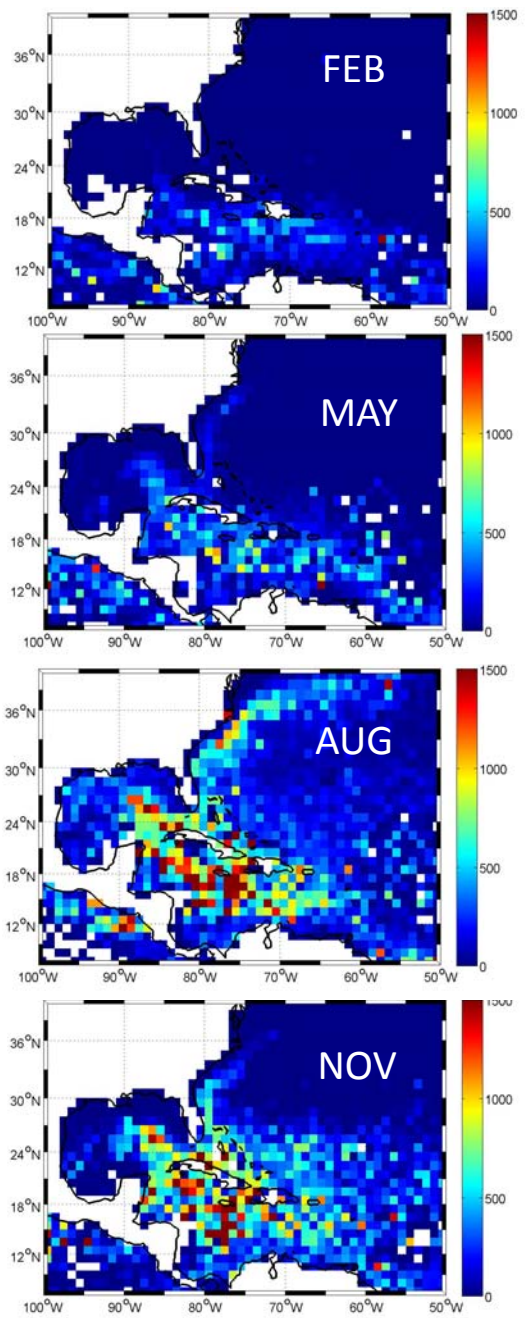
Monthly MOODS Climatology

Mean OHC (kJ/cm^2)



- OHC mean
  - Highest values
    - AUG: western Caribbean and Gulf of Mexico
    - NOV: western Caribbean
  - More seasonality in OHC than T100
  - Climatological zonal and meridional gradients in OHC in the central Caribbean
- OHC variance
  - Noisier than T100 variance
  - High variance areas
    - Coincided with well sampled areas and primary ocean features (e.g. Gulf of Mexico, Gulf Stream)
    - Coincided with with regions of few profiles in the MOODS database (e.g. western Caribbean)

OHC Variance (kJ/cm^2) ^{2}

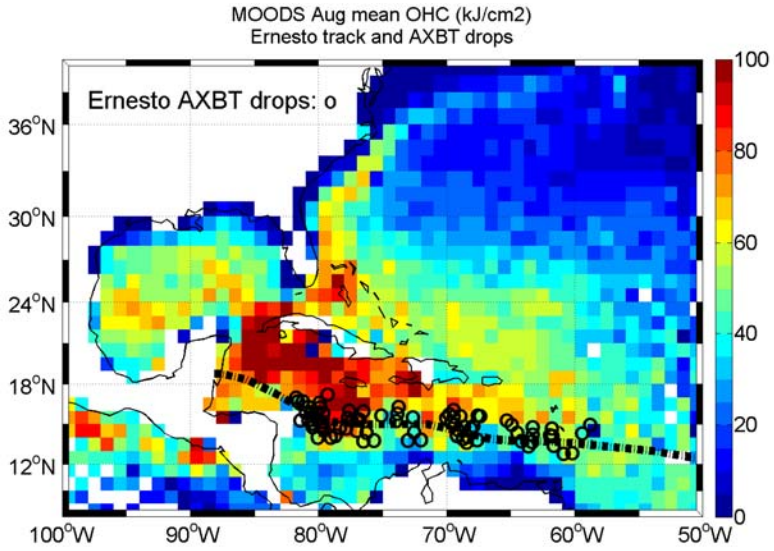


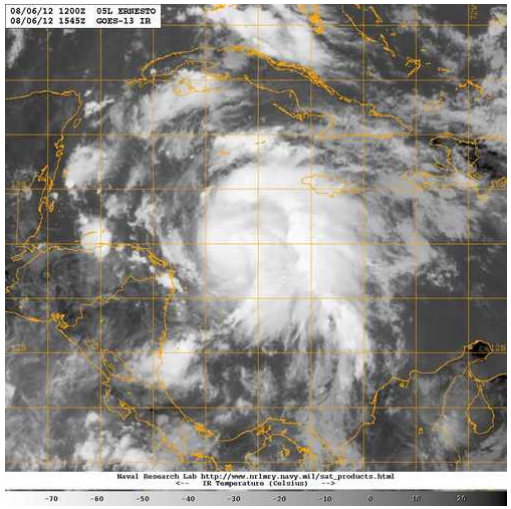
AXBT deployments during Ernesto and Isaac (2012)

Ernesto

QC'd AXBT obs: 80
Missions: 7
Dates: 3-6 August 2012
Wind speeds: 40-55 kts

- Tracked westward, transiting OHC gradients in the Caribbean.
- Achieved hurricane intensity prior to landfall over the Yucatan.

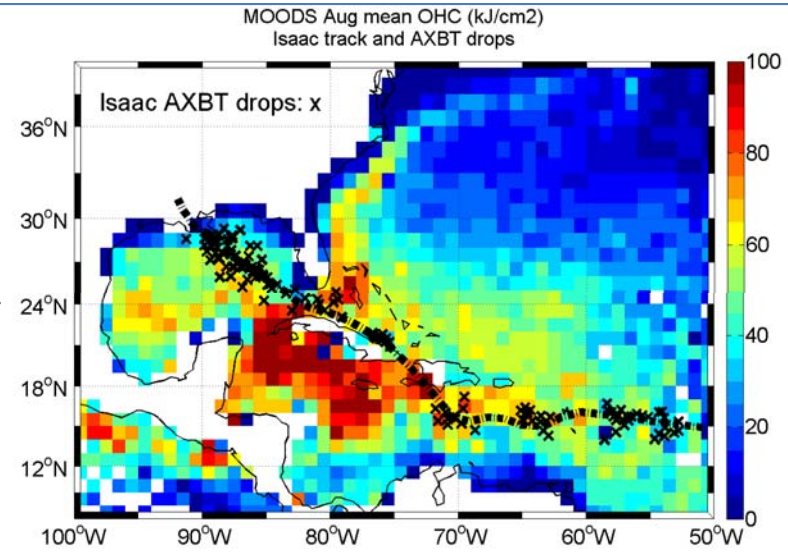


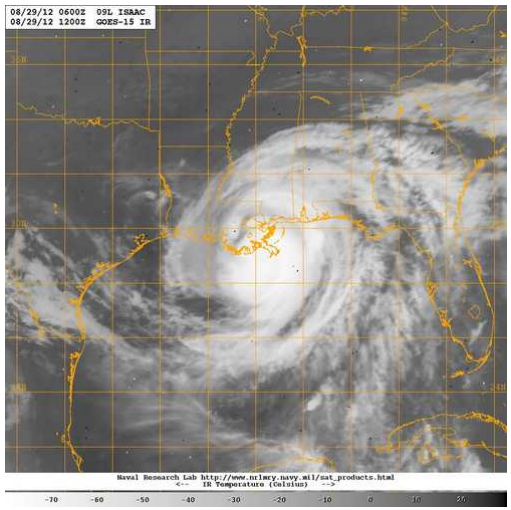


Isaac

QC'd AXBT obs: 132
Missions: 12
Dates: 21–30 August 2012
Wind speeds: 30-70 kts

- Transited the eastern edge of the climatological mean position of the warm core eddy.
- The loop current was retracted and the WCE was west of its usual position



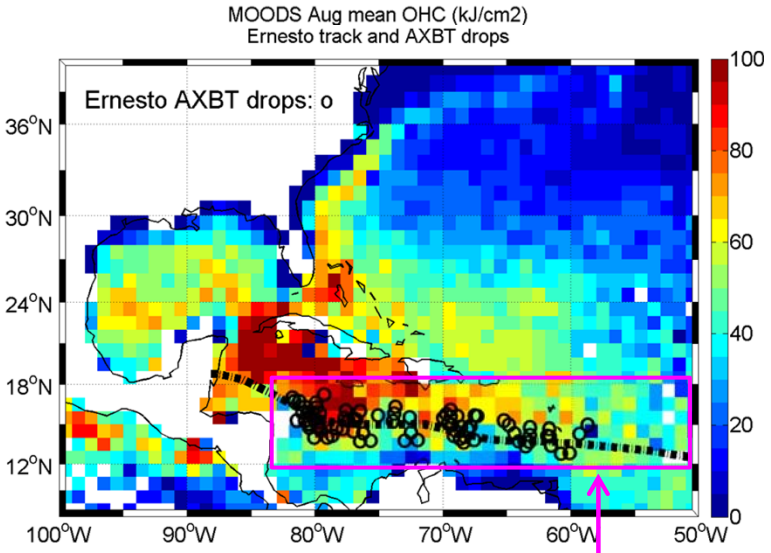


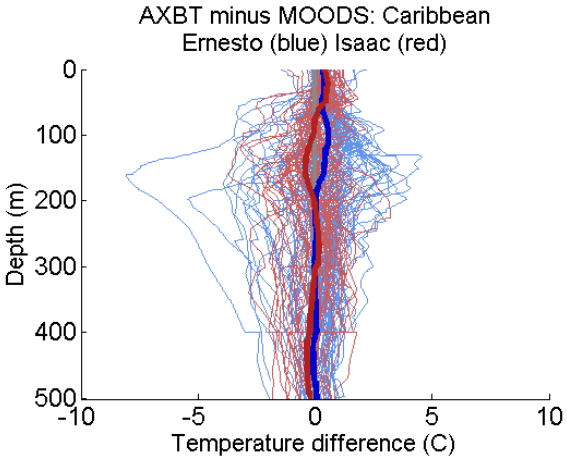
Caribbean Sea and Gulf of Mexico Analysis

Caribbean Sea

QC'd AXBT obs: 129 (80-E + 49-I)
Missions: 11 (7-E + 4-I)
Dates: 3-6, 21–24 August 2012
Wind speeds: 30-55 kts

- Right: Profiles of observed (AXBT) minus Climatology (MOODS) temperature differences
  - Storms: Ernesto and Isaac
  - Depth: 0-500m

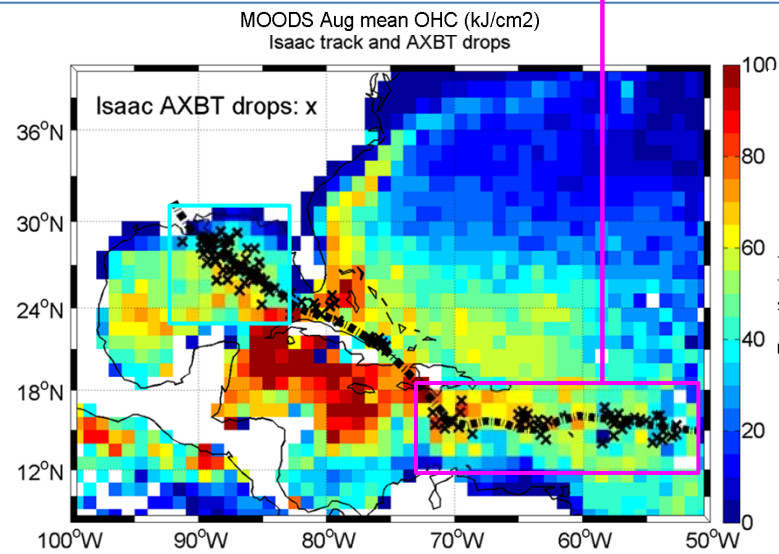


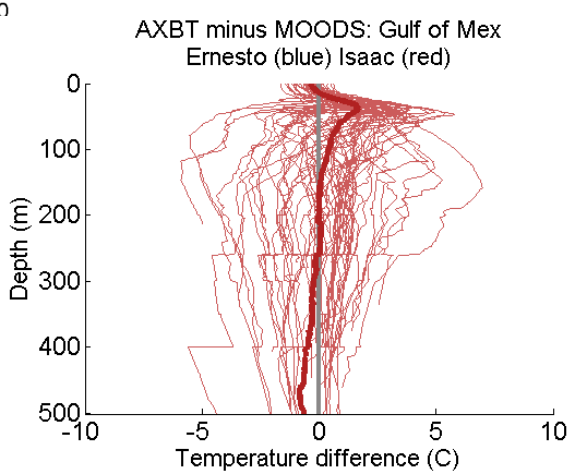


Gulf of Mexico

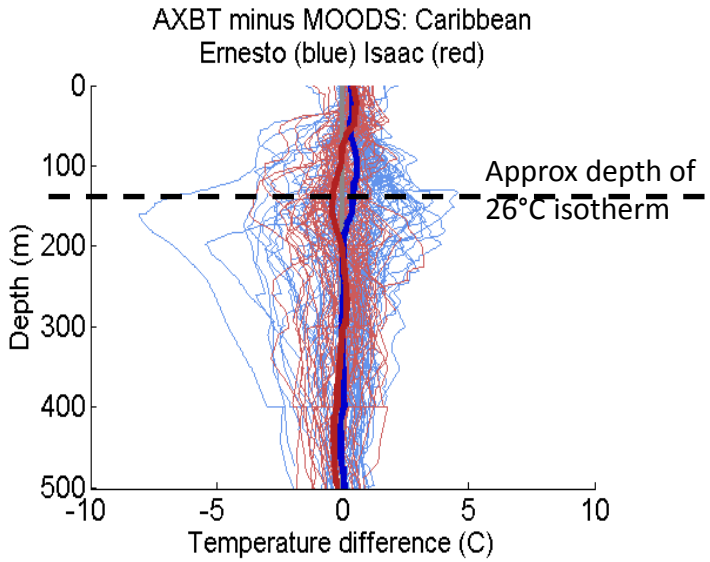
QC'd AXBT obs: 65 (Isaac)
Missions: 6 (Isaac)
Dates: 27–30 August 2012
Wind speeds: 45-70 kts

- Right: Mean AXBT-MOODS difference profiles are depicted with thick vertical lines



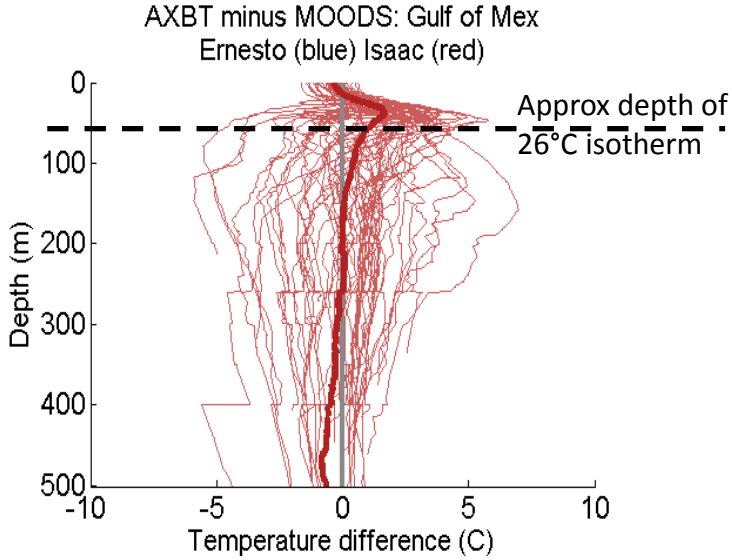


Temperature Differences: AXBT minus MOODS



Caribbean Sea (129 profiles)

- Upper 50m:
  - Observed temperatures were slightly *warmer* than climatology
- 50-200m:
  - Ernesto: observed temperatures were slightly *warmer* than climatology and the observations were distributed across the Caribbean
  - Isaac: observed temperatures were slightly *colder* than climatology, and the observations were confined to the eastern Caribbean Sea and western Atlantic Ocean
- 200-500m:
  - Observed temperatures resemble climatology

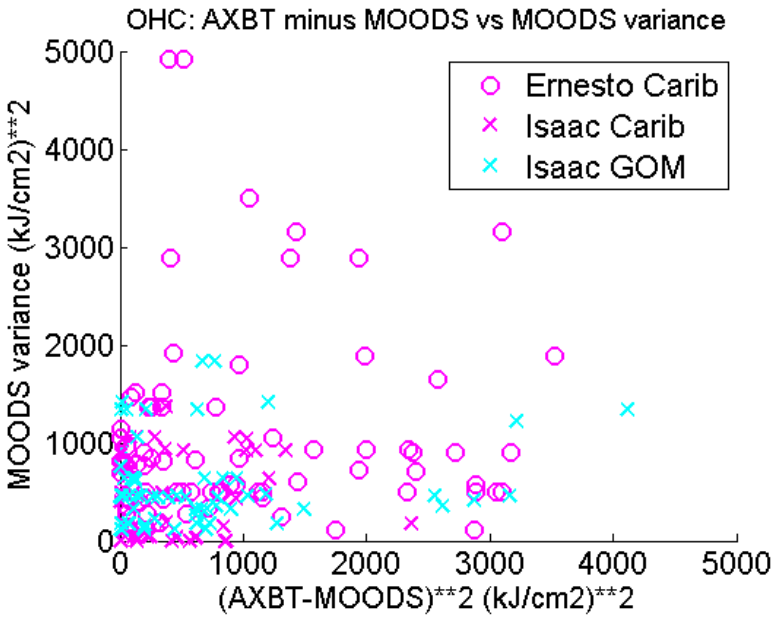


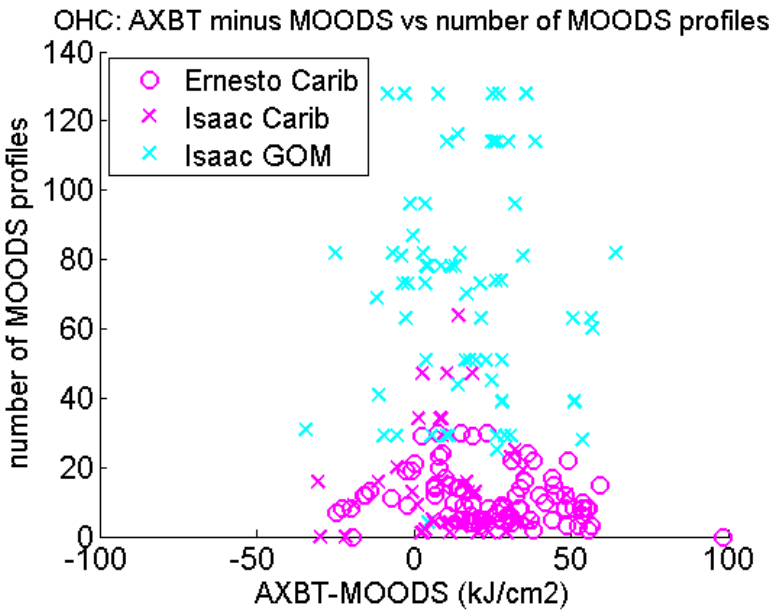
Gulf of Mexico (65 profiles)

- Surface:
  - Observed temperatures were slightly *colder* than climatology
- 5-150m:
  - Observed temperatures *averaged 2°C warmer* than climatology
  - Consistent with results found in initial COAMPS-TC study
- 150-500m:
  - Close to climatology, slight *cooling* between 350-500m
- Not all climatological profiles extended to 500m
  - Resulted in discontinuity in deeper profiles

Targeting AXBT Observations based on Climatology

- Departure from climatology was not well explained by
  - OHC Variance
    - Temperature differences were not correlated to climatological OHC variance
    - Departures from climatology were found in regions of both high and low variance
  - Number of profiles in the climatology
    - Temperature differences were not correlated to number of observations
    - High departures from climatology were found throughout the range of observation density
- Based on these two cases, climatology alone appears insufficient for targeting AXBT deployment locations





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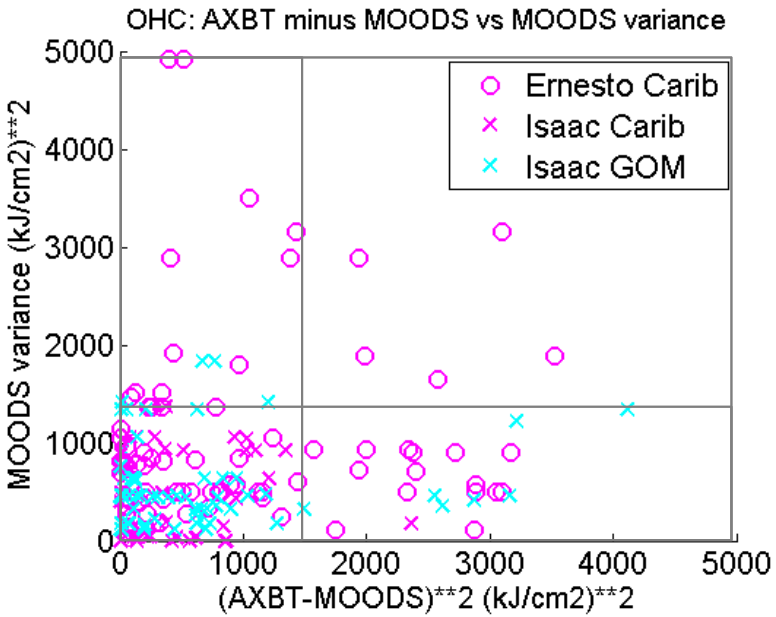

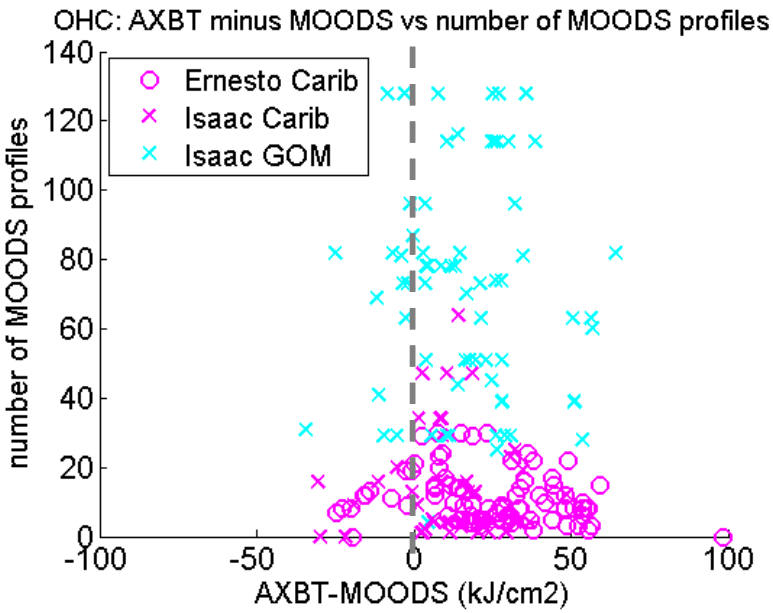

Summary and Future Work

Summary

- A climatology was created to aid in developing an AXBT Demonstration Project sensing strategy
  - Captured important dynamical features (e.g., Loop Current, Gulf Stream, WCE, and CCE)
  - **AXBT observations from Hurricanes Ernesto and Isaac in 2012 revealed important sub-surface temperature departures from climatology**
  - Differences between AXBT observations and climatology during Hurricanes Ernesto and Isaac in 2012 were unrelated to climatological variance and to the number of profiles in the climatology
- Climatology alone appears insufficient for targeting AXBT deployment locations and may also result in errant upper-ocean temperatures if used to initialize coupled models

Future Work

- Climatology
  - Conduct Principal Component Analysis to identify patterns in dynamical ocean features which may drive variance

- AXBT Demonstration Project Sensing Strategy
  - NRL MRY data denial study to identify optimal horizontal and vertical AXBT observation spacing
  - Detect sensitivity in coupled models through targeting techniques parallel to atmospheric techniques
  - Compare sensitive regions in coupled models to climatological variance, including other existing temperature climatologies