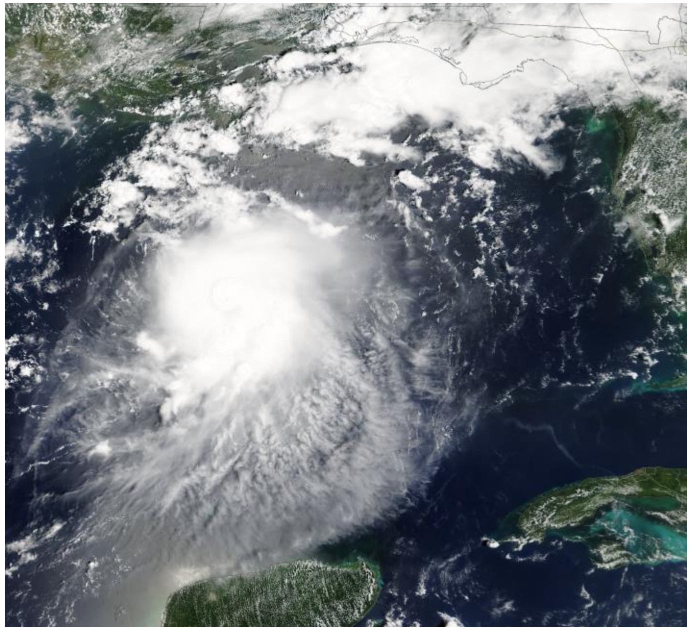
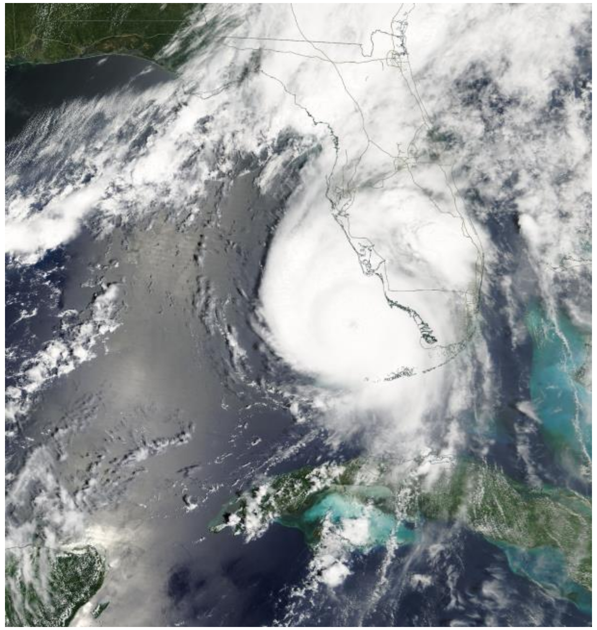
How Do Oceanic Factors Influence Tropical Cyclone Intensity Change?

A Case Study on Bonnie, Charley, and Ivan of the 2004 Atlantic Hurricane Season

Research by: Samuel H. Robles, Oscar Guzman, Dr. Haiyan Jiang





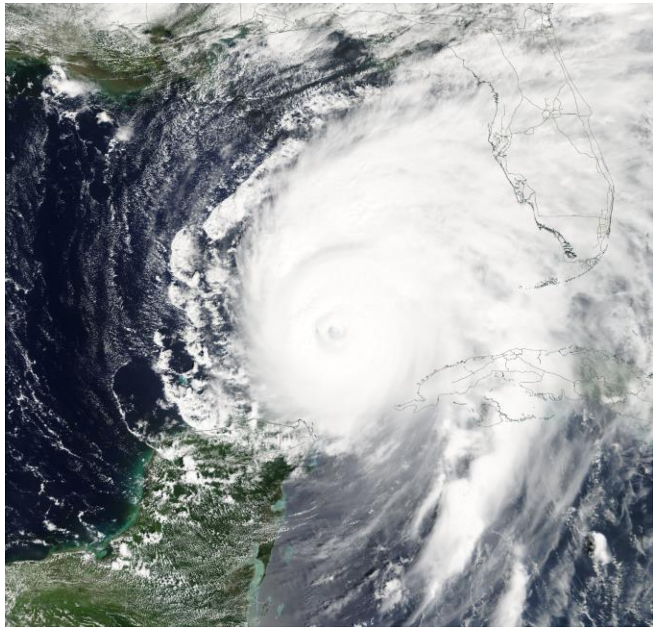
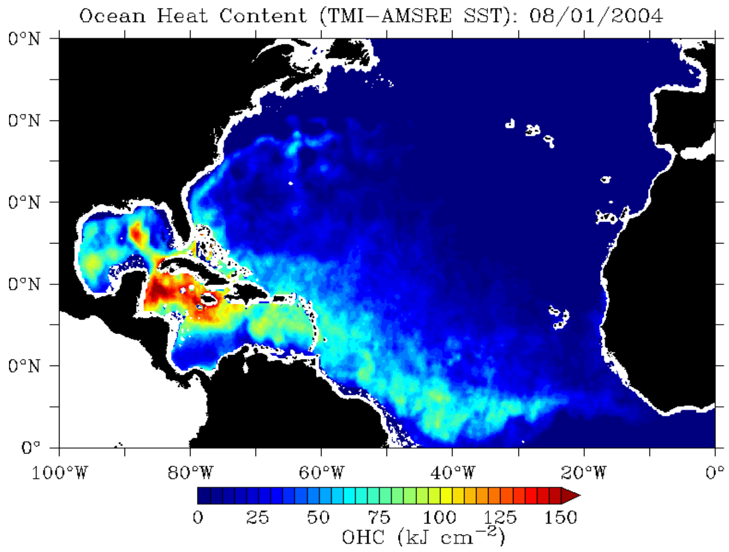
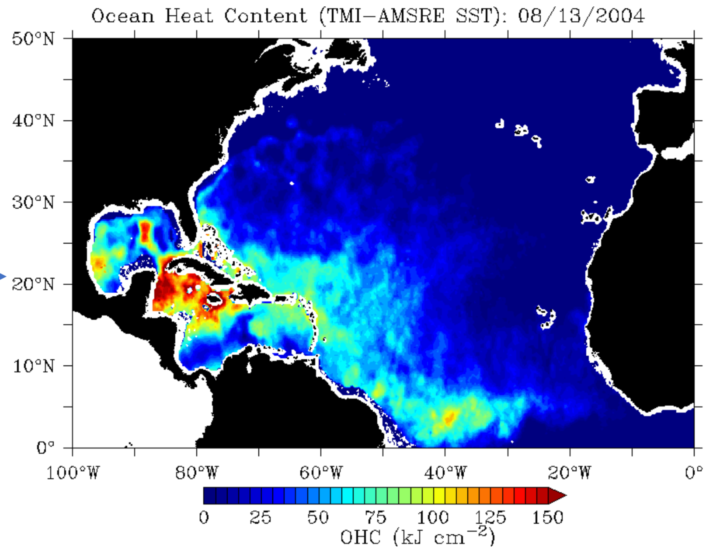


Image Source: NASA EOSDIS Worldview
https://worldview.earthdata.nasa.gov/

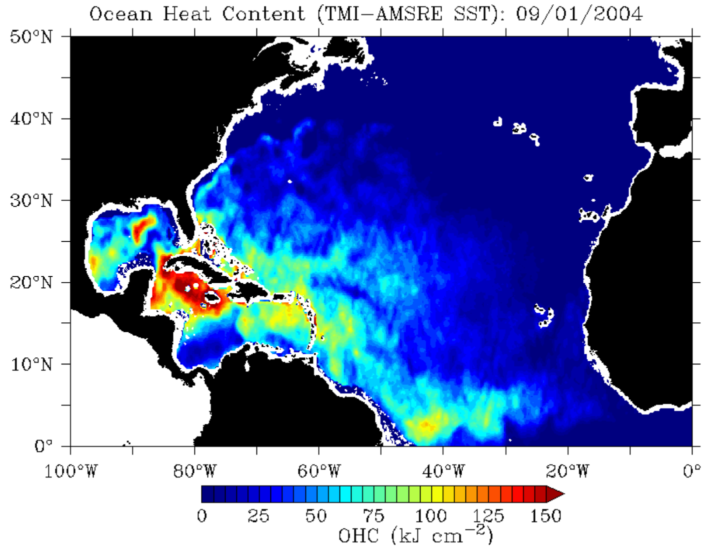
Background

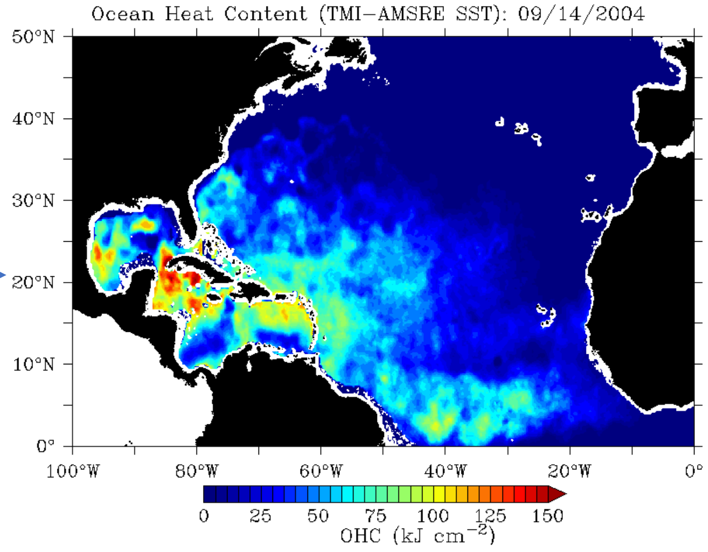
- 14 of top 20 costliest TCs to strike the US passed within Gulf of Mexico waters
  - 6 of those 14 storms experienced Rapid Intensification – 30+ knot (35+ mph) wind increase in 24 hours or less - after passing near to or over Gulf Stream/Loop Current system *[Blake et al. (2011)]*
- It has been shown that understanding the effect the ocean has on TCs can help to minimize forecast track error and better resolve storm intensity forecasts *[Oey et al. (2007); Jaimes & Shay (2009)]*
- Many case studies have been done on individually impressive storms, few seek to directly compare them to their less impressive counterparts





Images Source: Upper Ocean Dynamics Laboratory at the University of Miami Rosenstiel School of Marine and Atmospheric Sciences (http://www.rsmas.miami.edu/groups/upperocean-dynamics)

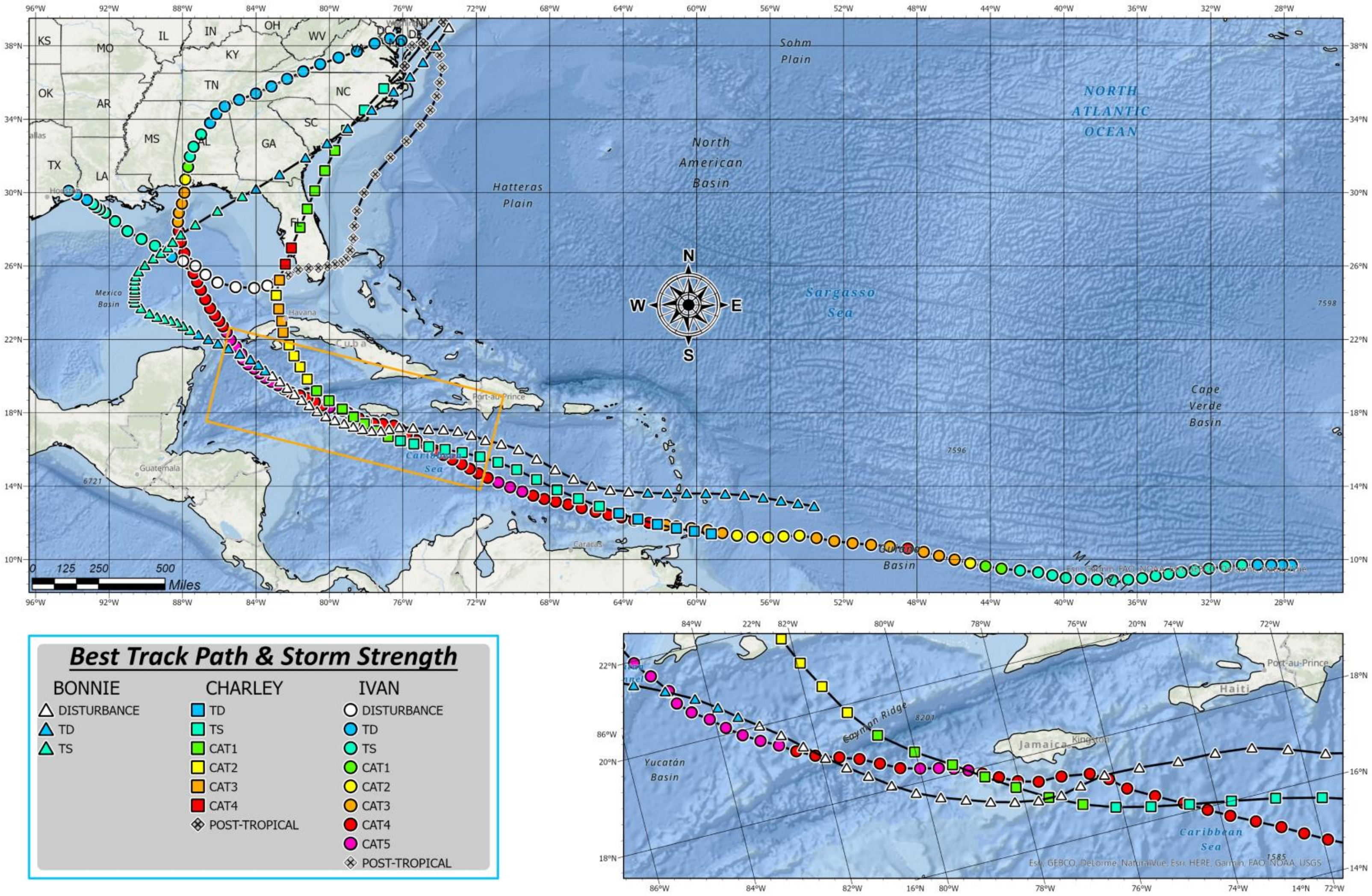




Research Motivation

1. Same season, same basin origination point
2. Short temporal scale (less than 6 weeks) – relatively similar oceanic conditions
3. Tracks begin similarly, diverge upon reaching Gulf of Mexico
4. Dissimilar strengthening trends with wildly varying outcomes

❖ *What caused BONNIE, CHARLEY, & IVAN to develop so differently?*



Methodology

1. Datas extracted from IBTrACS and SHIPS databases
   - Initial time (t=0) data used from SHIPS
     - Spline interpolated from 6 hourly to 3 hourly to match
   - Assimilated with 3 hourly IBTrACS dataset
   - Using Python scripts and ArcGIS Pro, plots were generated showcasing intensity changes due to individual oceanic parameters
     - Python scripts - Time Series Plot and Hovmöller Diagram
     - ArcGIS Pro – visual maps of satellite derived changes in Ocean Heat Content, the depth of the 26° Isotherm, and Sea surface temperatures
2. ECMWF: ERA Interim Analysis used to generate a multidimensional raster animation of daily sea surface temperature changes around each storm's track path

Data Sources

IBTrACS (v4) *[Knapp et al. 2010]*

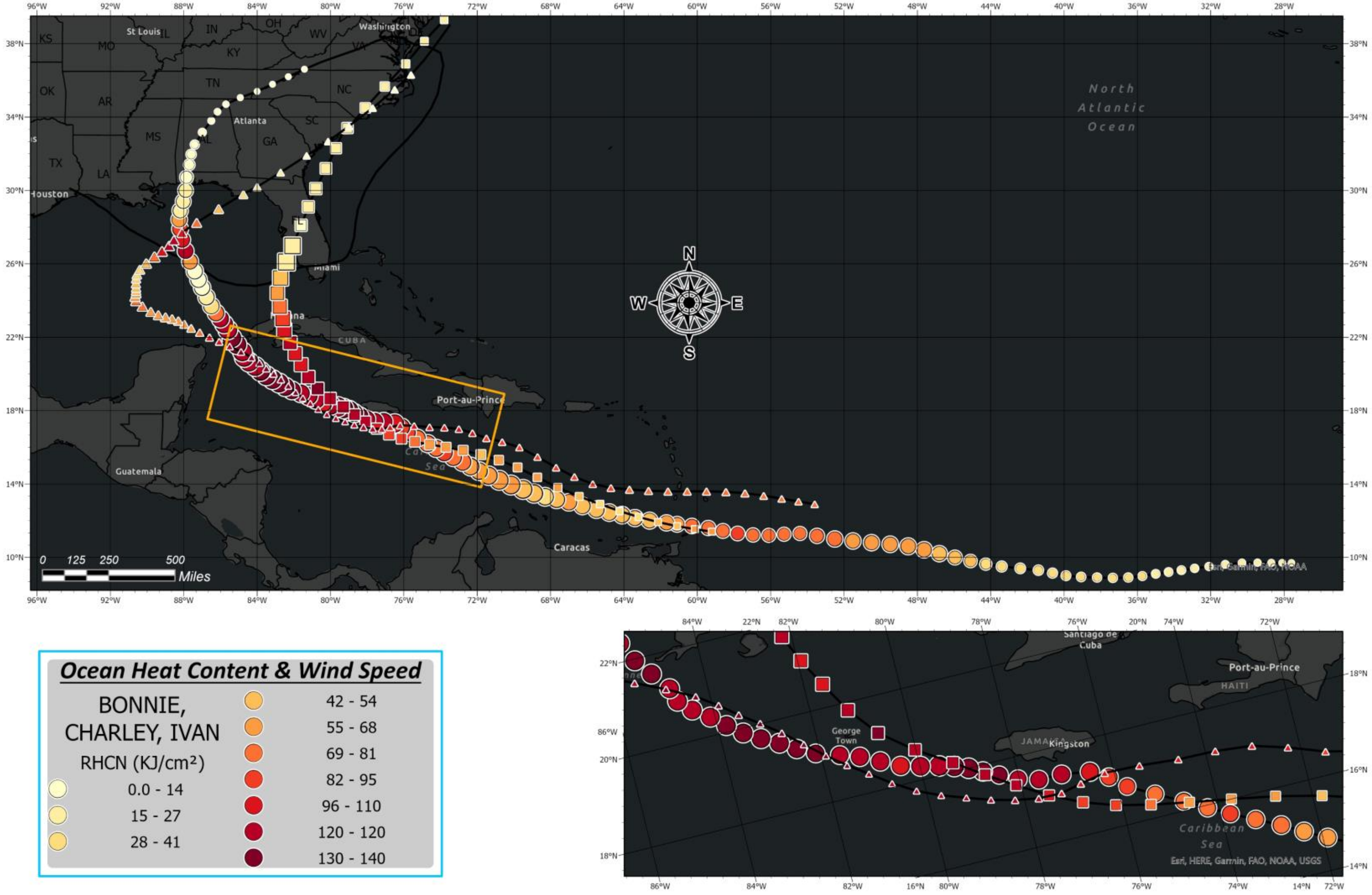
Table 1: International Best Track Archive for Climate Stewardship	
Variable	*Description*
SID	*Storm Identifier*
SEASON	*Year*
NAME	*Name provided by the agency.*
ISO_TIME	*ISO Time provided in Universal Time Coordinates (UTC). Format is YYYY-MM-DD HH:mm:ss.*
USA_LAT /LON	*Deg north/Deg east*
DIST2LAND (km)	*Distance to land from the current position. The land dataset includes all continents and any islands larger than 1400 km^2. The distance is the nearest at the present time in any direction.*
USA_WIND (knots)	*Maximum sustained wind speed in knots: 0 - 300 kts.*
USA_PRES (mb)	*Minimum sea level pressure, 850 - 1050 mb.*
USA_SSHS	*Saffir-Simpson Hurricane Scale information based on the wind speed provided by the US agency wind speed*
STORM_SPD (knots)	*Translation speed of the system as calculated from the positions in LAT and LON*
STORM_DIR (degrees)	*Translation direction of the system as calculated from the positions in LAT and LON. Direction is moving toward the vector pointing in degrees east of north [range = 0-360 deg]*

SHIPS (Aug 2018, Nov 2021) *[DeMaria and Kaplan 1994, 1999; DeMaria et al. 2005; Schumacher et al. 2013]*

Table 2: Statistical Hurricane Intensity Prediction Scheme	
Variable	*Description*
OAGE	*Ocean Age (hr*10), which is the amount of time the area within 100 km of the storm center has been occupied by the storm along its track up to this point in time*
RSST	*Reynolds sea surface temperature (deg C*10) vs time*
RHLO	*850-700 hPa relative humidity (%) vs time (200-800 km)*
RHMD	*relative humidity (%) vs time for 700-500 hPa*
RHHI	*relative humidity (%) vs time for 500-300 hPa*
SHDC	*Shear magnitude with vortex removed and averaged from 0-500 km relative to 850 hPa vortex center*
RD26	*Ocean depth of the 26 deg C isotherm (m), from satellite altimetry data*
RHCN	*Ocean heat content (KJ/cm^2) from satellite altimetry data*

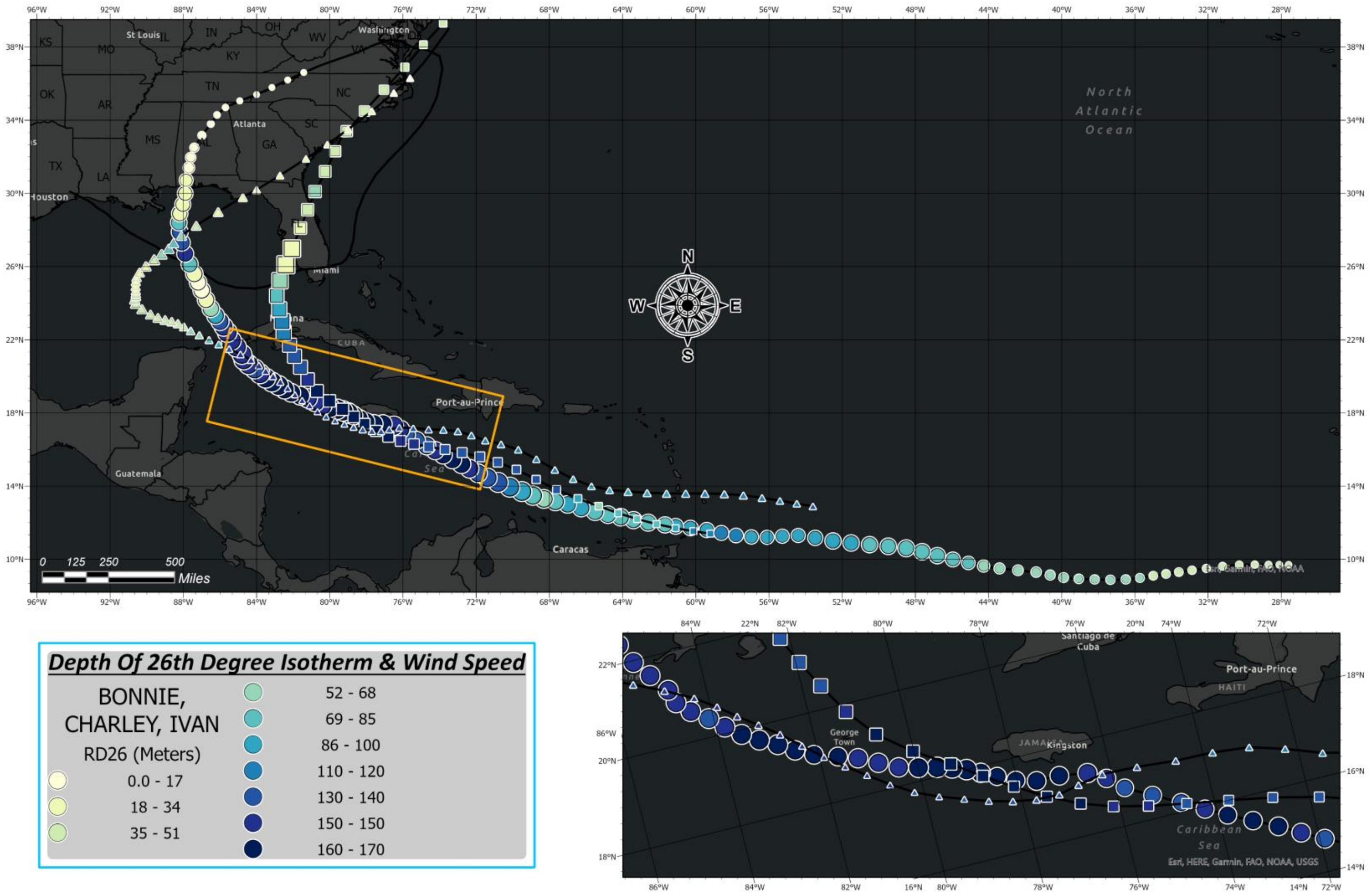
Ocean Heat Content

- Oey et al. (2007) defines areas over 60 KJ/cm^2 as conducive to TC strengthening
  - Areas over 90 KJ/cm^2 are conducive to Rapid Intensification
- The Caribbean provides the deepest OHC values of any 3 of the storm's paths
- All 3 storms experience reduced values in the Gulf
  - Perhaps due to upwelling with Bonnie
  - Due to shallow shelf water with Charley
  - Due to Cold Core Eddie with Ivan *[Walker et al. (2005)]*
    - Ivan also interacted with Warm Core Eddie afterwards

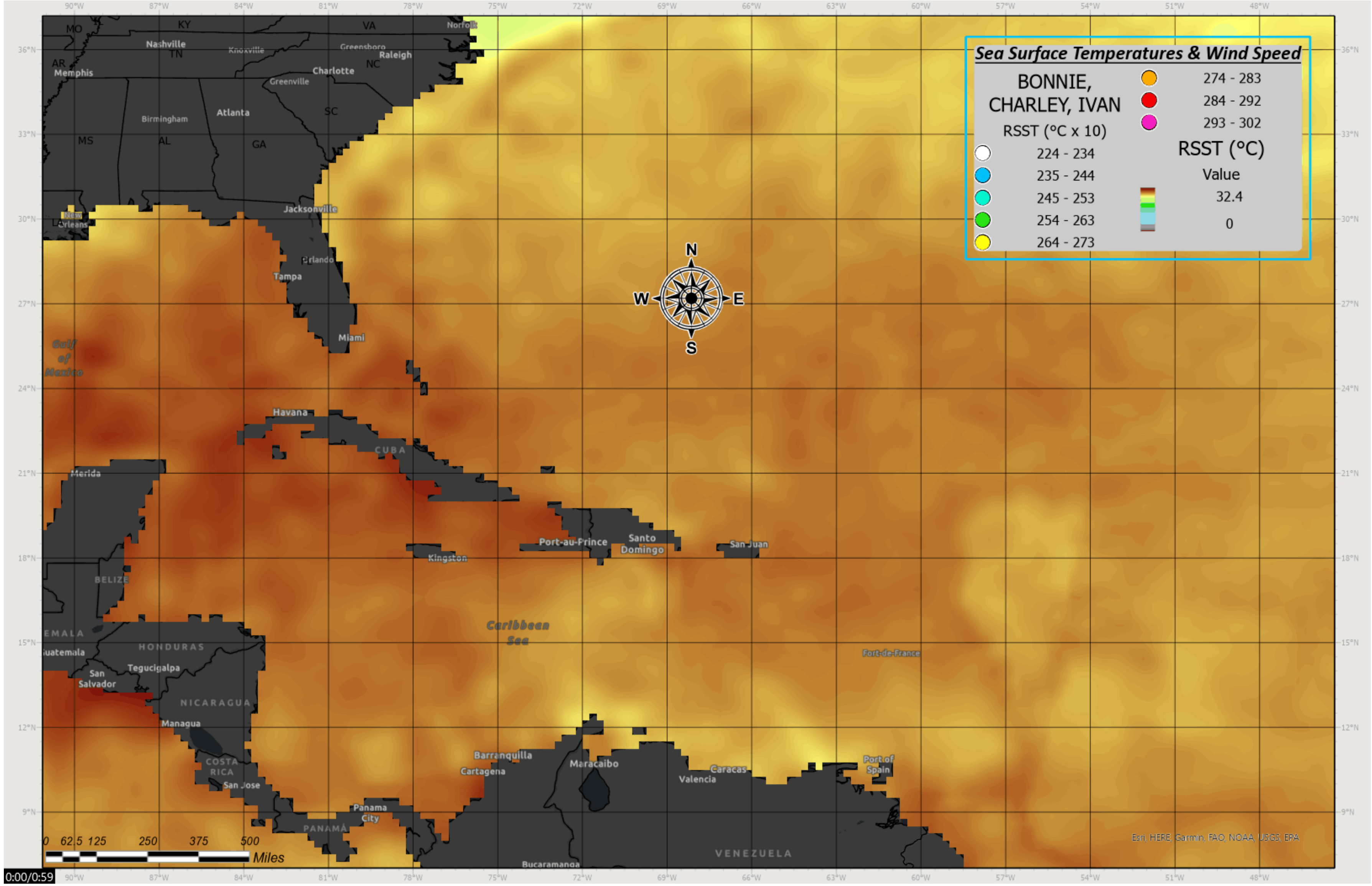


Depth of the 26° Isotherm

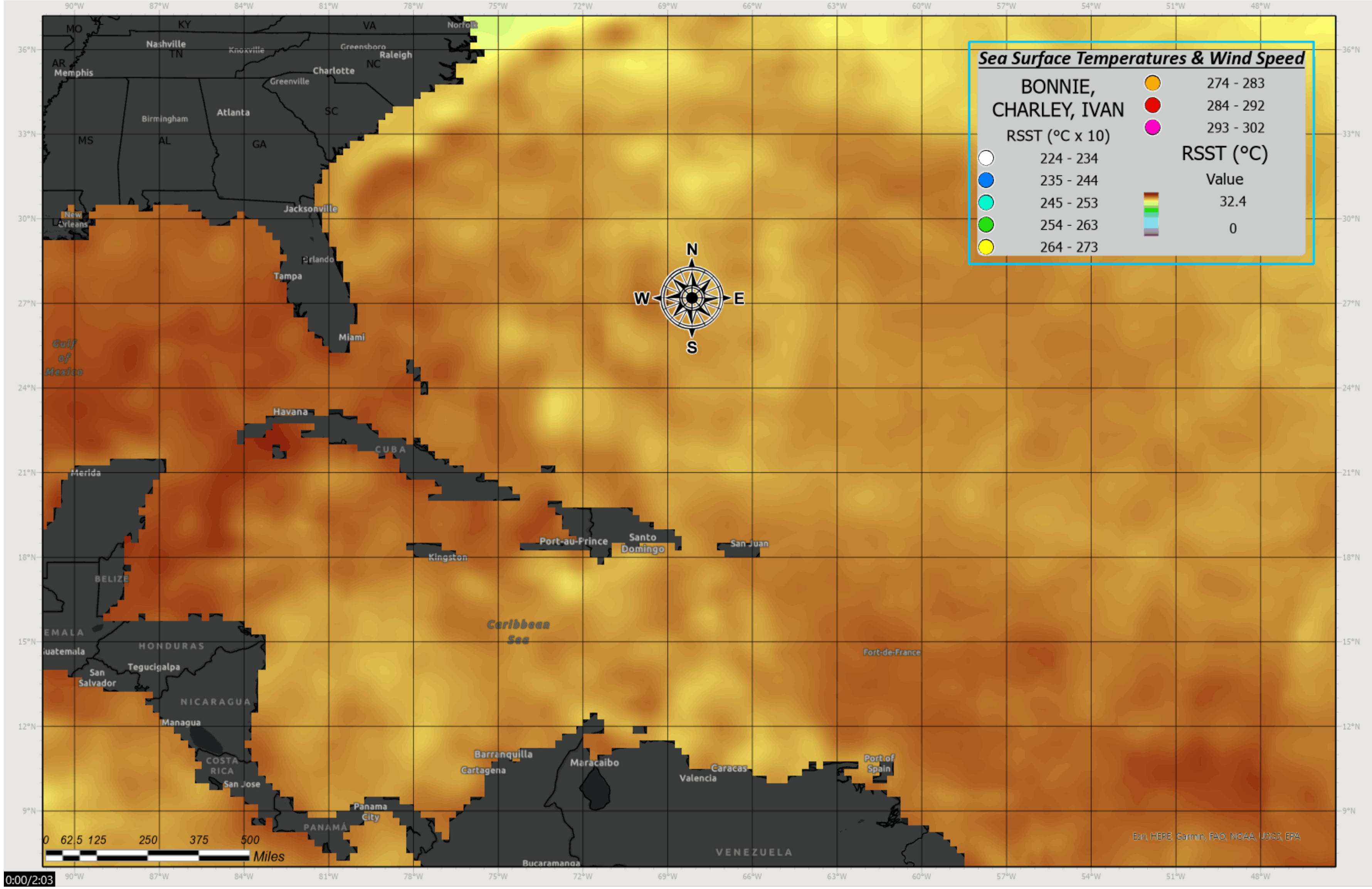
- Water level beneath ocean surface that defines Mixed Layer depth
- Necessary temperature level used to establish OHC in the Leipper & Volgenau (1972) formula
- Deeper Mixed Layer = Deeper uniform temperatures
  - Usually indicates greater Oceanic Heat Content present
  - Helps to reduce upwelling



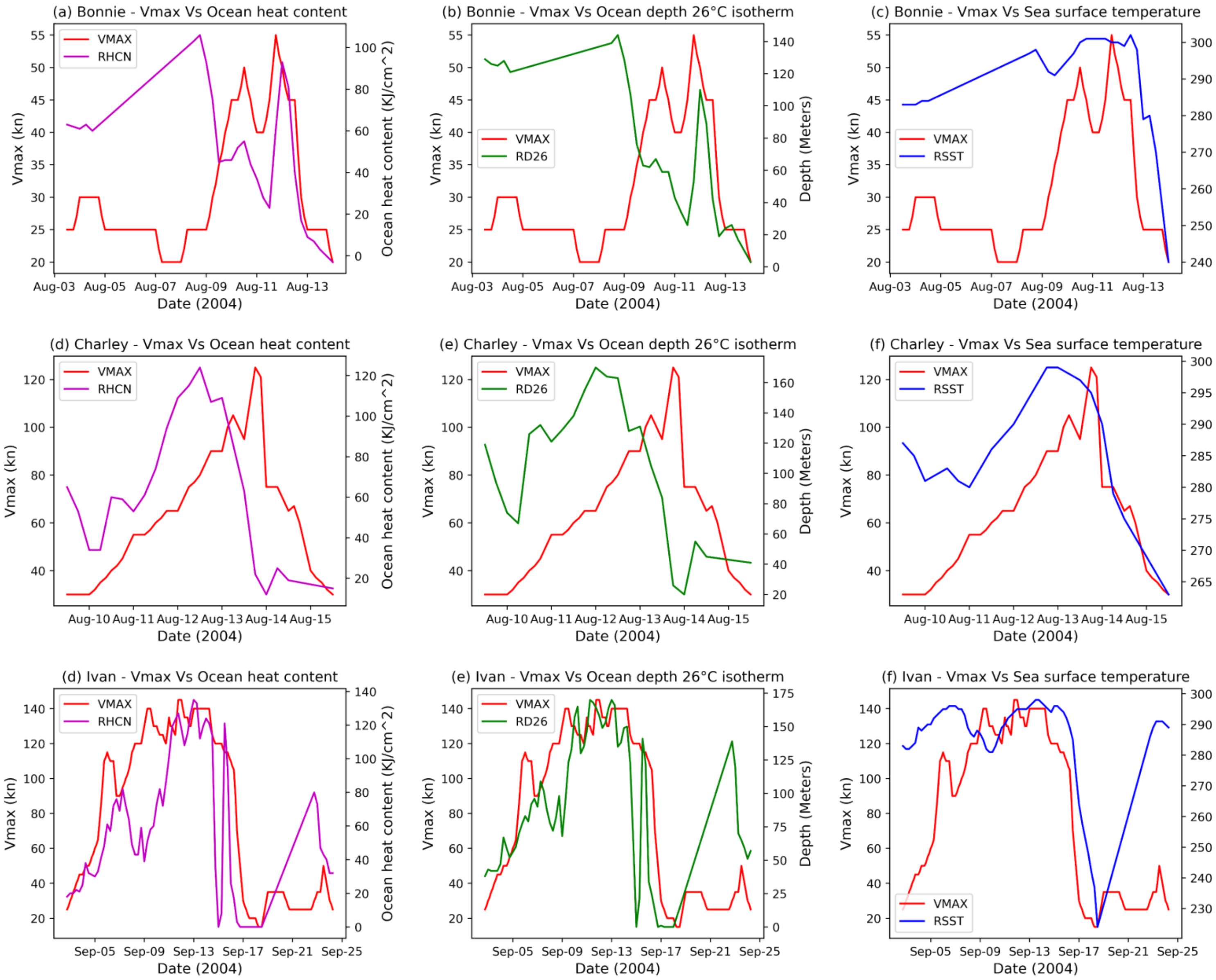
ECMWF – ERA Interim Analysis: Multidimensional Raster → BONNIE & CHARLEY



ECMWF – ERA Interim Analysis: Multidimensional Raster → IVAN

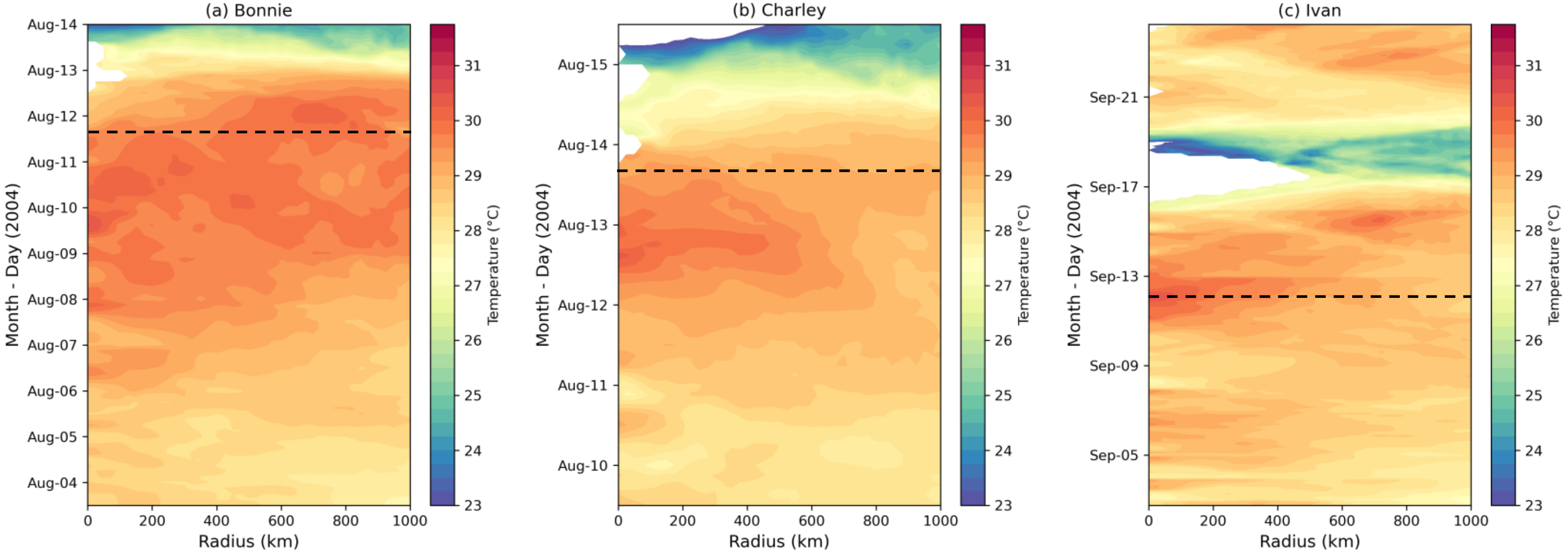


Time-Series Plots



Hovmöller Diagram

- Radial Decomposition analysis
  - Calculates azimuthal averages of sea surface temperatures in 40 increments, growing larger by 25km wide annuli out to 1,000km from storm center
- Dashed line denotes wind maxima over the storm's lifetime
- White areas indicate landfall



Concluding Remarks

- Bonnie showed a weak response to a conducive ocean environment
- Charley maintained steady strengthening in an even more favorable setting
- Ivan took full advantage of the copious available ocean energy
  - Advanced maturity upon entering Caribbean
- Caribbean Sea is primary area of warm ocean energy in Atlantic Basin
  - Largest OHC values
  - Deepest Mixed Layer
  - Warmest SSTs
- OHC is primary factor in strengthening trends
  - Strong association with increased Mixed Layer depth
- SSTs are good for providing an upper bound on TC intensification limits but do not scale linearly with strength or provide a good indication of intensity changes *[DeMaria & Kaplan (1994)]*
- Low OHC in Cold core eddies have the ability to provide negative feedback to storm intensity
- Oceanic parameters tell only part of the story with regards to TC intensification
  - Atmospheric conditions must be studied to provide full picture
    - Example: Solid structure and outflow, possible positive jet-trough-hurricane interaction and eyewall contraction/symmetry with Charley *[Lee & Bell (2007)]*