The FSU-COAPS Coupled Ocean-Atmosphere Model

The Impacts of an Evolving Ocean Boundary Condition on TC Structure and Intensity

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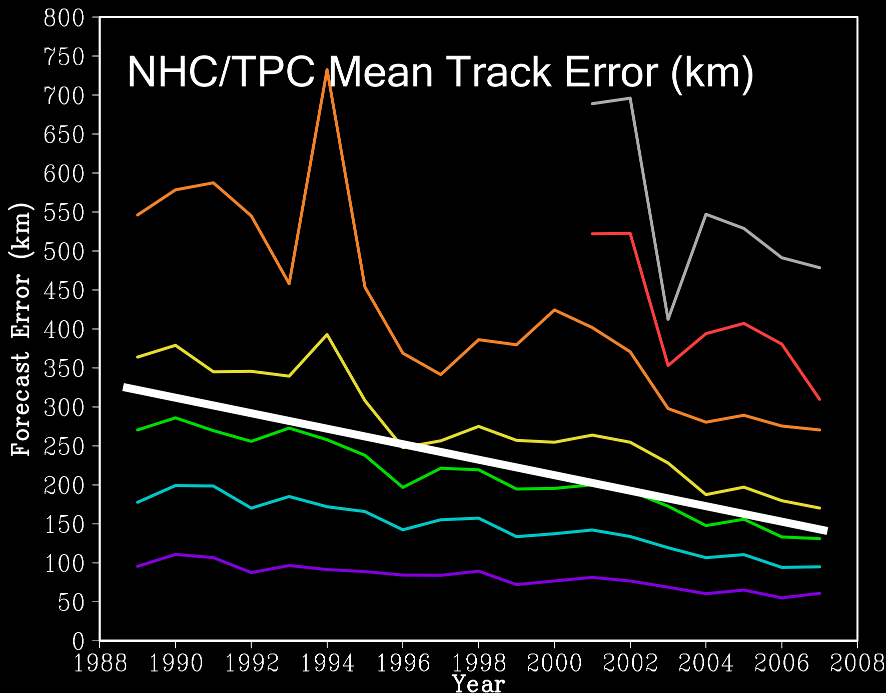
Introduction

Motivation and Scientific Importance

The application of NWP modeling to TCs has increased dramatically in recent decades; the **skill** in **track forecasting** has **improved** dramatically on average, while TC **intensity forecasting** remains **difficult** (Franklin, 2008)



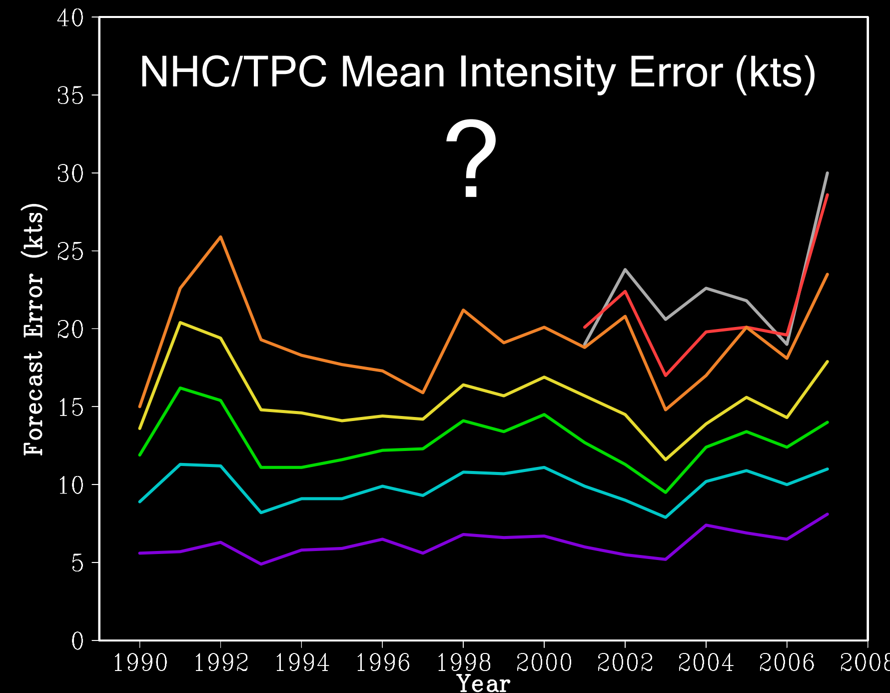


Image derived from *http://www.nhc.noaa.gov/verification/verify5.shtml*

Legend

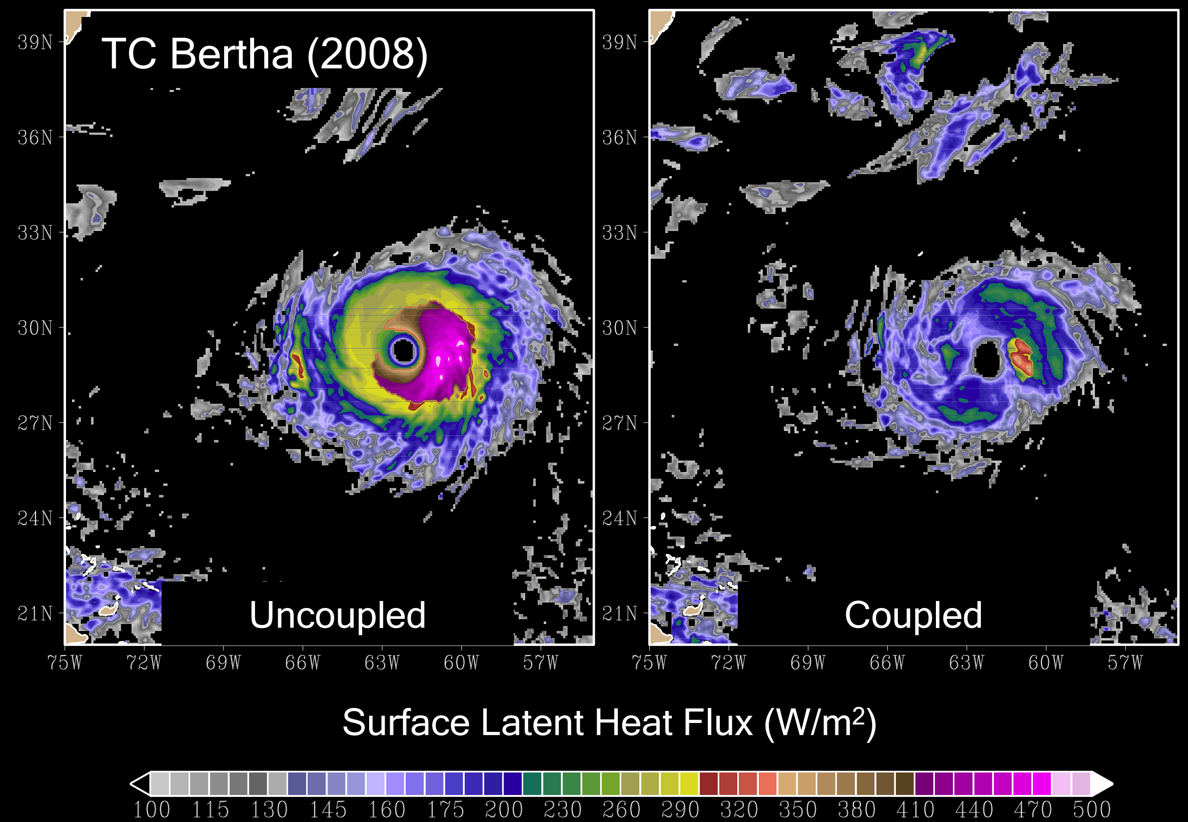
12-h 24-h 36-h 48-h 72-h 96-h 120-h

Introduction

Motivation and Scientific Importance

Several hypotheses have been proposed, as they pertain to NWP, for the inability to forecast TC intensity with any reasonable skill:

1. NWP models **without** an **evolving ocean boundary condition**, and subsequently forced by a TC, are subject to **incorrect** atmosphere-ocean **interactions** and **feedbacks** (Price, 1981; Price, 1983; Emanuel, 1986; Shay et al., 1992; Shay et al., 2000)

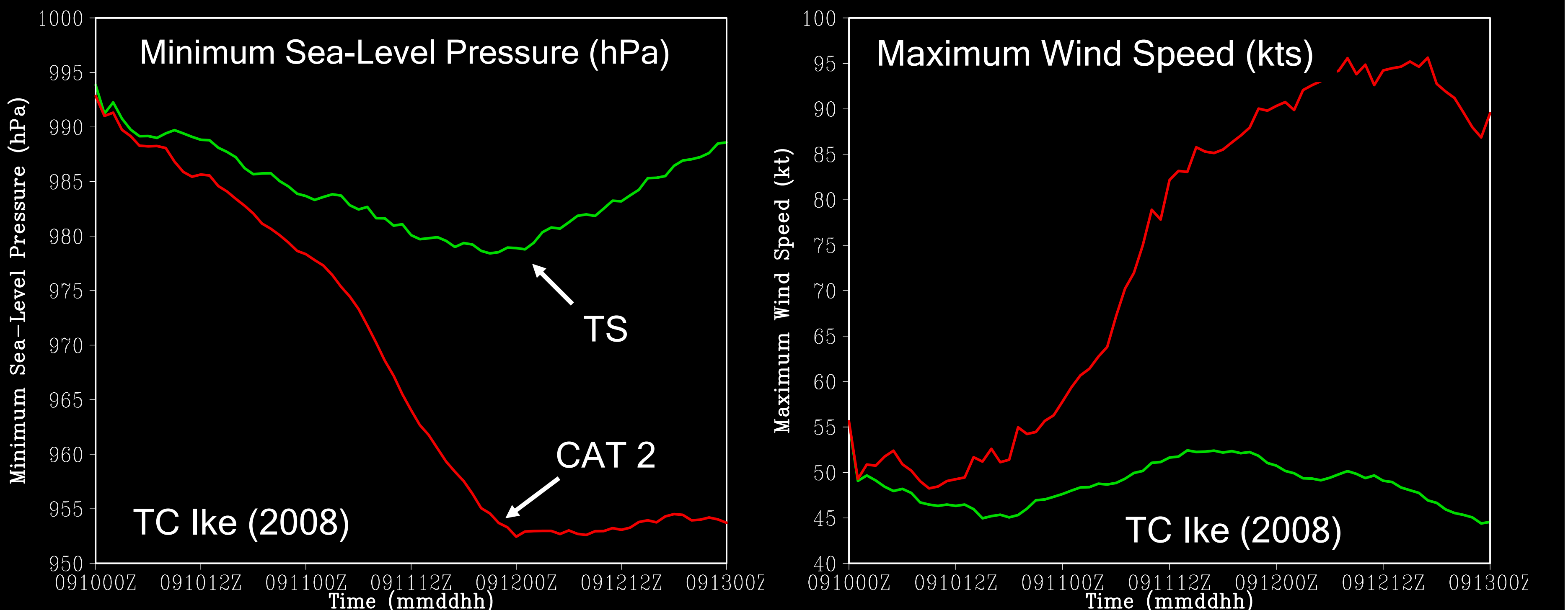


Introduction

Motivation and Scientific Importance

Several hypotheses have been proposed, as they pertain to NWP, for the inability to forecast TC intensity with any reasonable skill:

2. There is insufficient application of both **high-resolution grid-length resolutions** and in-situ **wind observations** for the **initial conditions** supplied to the NWP model (Anthes, 1974; Kurihara et al., 1993; Serrano and Unden, 1994; Kurihara et al., 1995)



Legend: 30.0-km 8.81-km

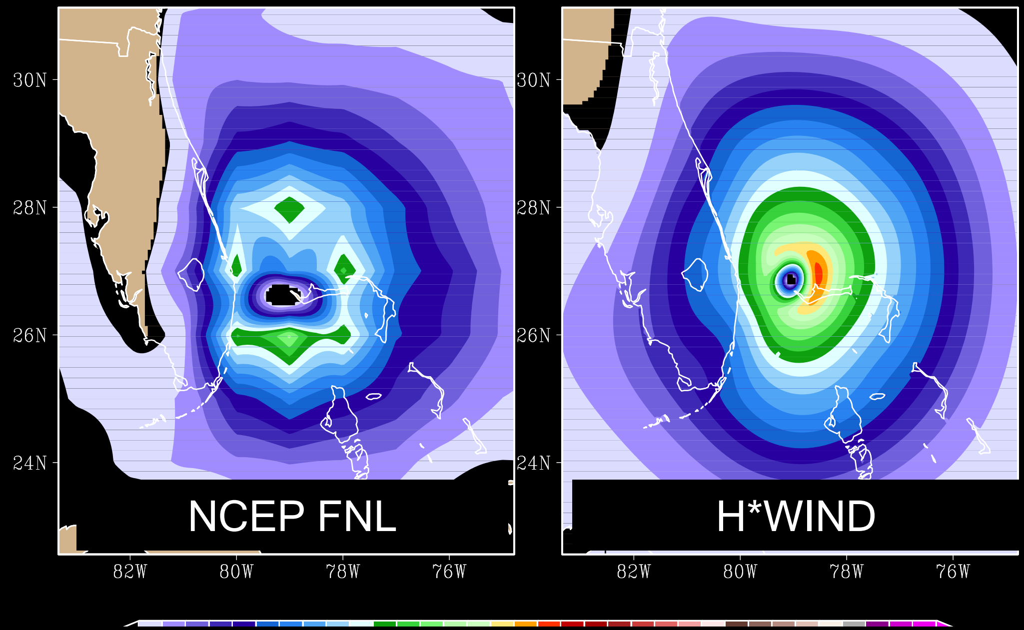
Introduction

Motivation and Scientific Importance

Several hypotheses have been proposed, as they pertain to NWP, for the inability to forecast TC intensity with any reasonable skill:

3. The TC initial vortex must be positioned correctly and of accurate intensity, while also physically balanced relative to the resolution and physics of the atmospheric model

TC Frances (2004) 04 September 1800 Z



The Impact of Initial Conditions

- Using improper initial conditions can result in errors related to the position, intensity, and the exchange of energy between the atmosphere and ocean (Mathur, 1991; Kurihara et al., 1993; Bender et al., 1993b; Kurihara et al., 1995; Bender and Ginis, 2000)
- The dynamic initialization of the TC vortex will minimize the imbalances related to the model resolution and physical parameterizations (Hoke and Anthes, 1978; Fiorino and

The respective contributions for each component, to the TC intensity problem, remains unknown!

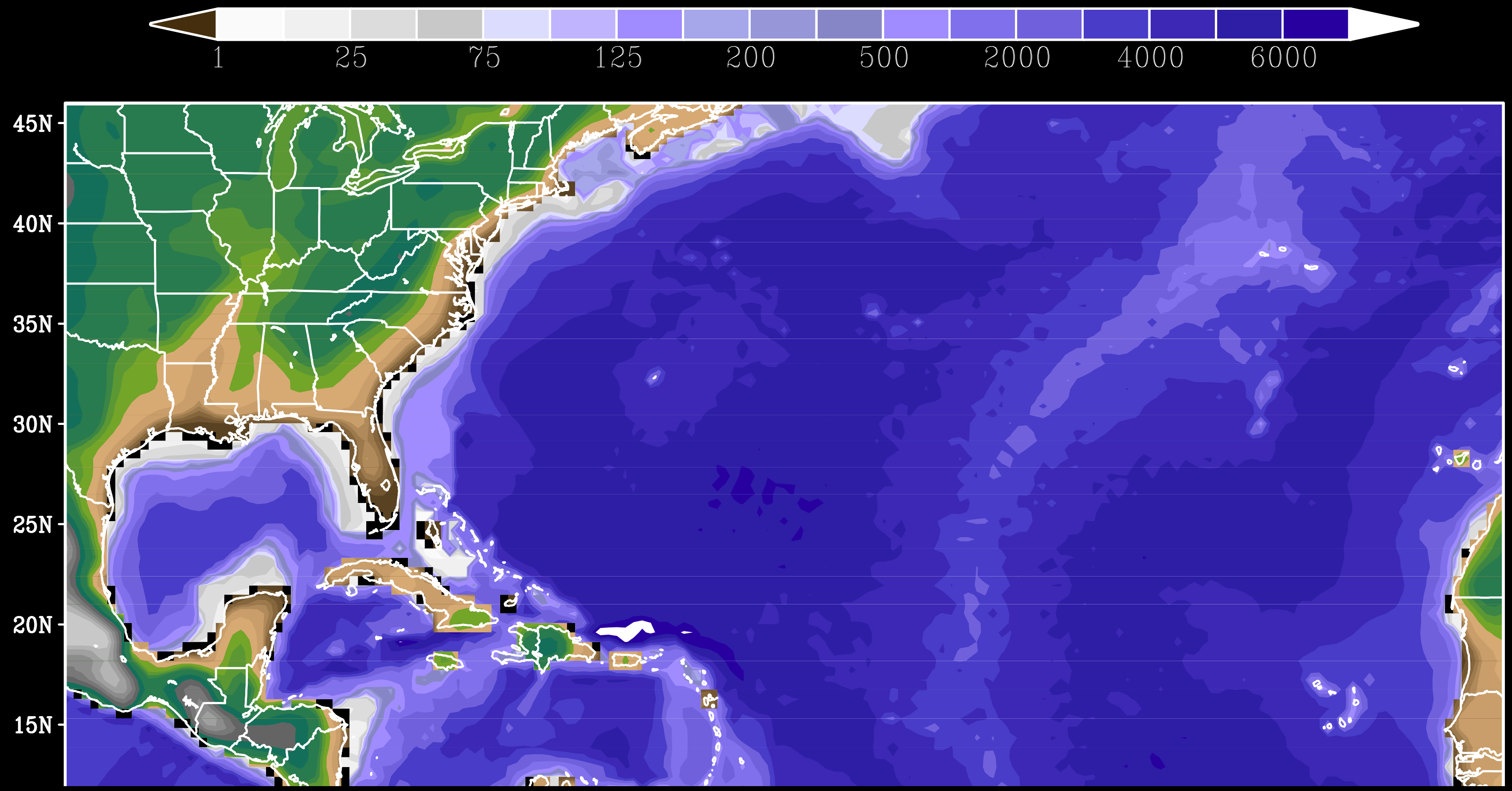
Coupled Atmosphere-Ocean Model

Atmosphere and Ocean Models

- **Atmosphere model:** Weather Research and Forecasting (WRF) Advanced Research WRF (ARW) v 2.2 (Skamarock et al., 2005)
    - WRF-ARW as demonstrated skill related to the forecasting of TCs:
        1. Davis et al., 2008 – Prediction of Landfalling Hurricanes with the Advanced Hurricane WRF model
        2. Xiao et al., 2008 – Experiments on WRF Hurricane Initialization (WRF-HI) – An Approach Based on WRF Variational Data Assimilation of Remote-Sensing and Synthetic Observations
        3. Wang et al., 2006 – Evaluation of WRF-ARW high resolution tropical storm forecasts in the 2005 season
- **Ocean model:** HYbrid Coordinate Ocean Model (HYCOM) (Bleck, 2002; Chassignet et al., 2003; Halliwell, 2004)
    - HYCOM has demonstrated skill related to TC forecasting
        1. Halliwell, 2008 – Improving the Ocean Model Response to Tropical Cyclones
        2. Halliwell, 2006 – Improving Ocean State Initialization in Coupled Tropical Cyclone Forecast Models
        3. Prasad and Hogan, 2007 – Upper ocean response to Hurricane Ivan in a 1/25 nested Gulf of Mexico HYCOM

Coupled Atmosphere-Ocean Model

Grid Configurations



HYCOM resolution: 1/12º x 1/12º at the equator

HYCOM grid dimension: 1063 x 545 x 32 (sub-region of Global HYCOM)

WRF-ARW resolution: 8.81-km at 8.05 N, -55.4 W

WRF-ARW grid dimension: 1083 x 565 x 35

To be determined

$SST1$: Sea-surface temperature

The Impacts of an Evolving Ocean Boundary Condition

Case Study Selection

TC Bertha (2008) – 03 July to 20 July

STABLE AIR IN ITS PATH. AFTER ABOUT 24 HR ON THE NHC TRACK...SSTS
THEREAFTER SSTS WARM SLIGHTLY AND MOST GLOBAL MODELS FORECAST AN
CHANGE IN BETWEEN WHILE THE SYSTEM IS OVER THE COOLEST SSTS. THE
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THEREAFTER SSTS WARM SLIGHTLY AND MOST GLOBAL MODELS FORECAST AN
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LIMIT INTENSIFICATION. SSTS ALONG THE TRACK ARE EXPECTED TO
LIMIT INTENSIFICATION. SSTS ALONG THE TRACK ARE EXPECTED TO
OVER SSTS OF 25 DEGREES C....WHICH IS THE MAIN LIMITING FACTOR FOR
THE NEXT COUPLE OF DAYS. THEREAFTER...THE SSTS ALONG THE TRACK ARE
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THE NEXT COUPLE OF DAYS. THEREAFTER...THE SSTS ALONG THE TRACK ARE
ATMOSPHERIC ENVIRONMENT BUT OVER MARGINALLY WARM SSTS. SUCH
ATMOSPHERIC ENVIRONMENT BUT OVER MARGINALLY WARM SSTS. SUCH
CONDUCIVE FOR GRADUAL STRENGTHENING AS SSTS INCREASE AND THE SHEAR
THEREAFTER...THE SSTS WILL INCREASE ALONG THE PROJECTED
FORECAST TO MOVE OVER MARGINALLY WARM SSTS DURING THE NEXT 24 HOURS
WHICH IS EXPECTED TO LIMIT INTENSIFICATION. THEREAFTER...SSTS
FOR STRENGTHENING AS SSTS ALONG THE PROJECTED PATH GRADUALLY
PROJECTED PATH. BERTHA IS CURRENTLY OVER SSTS OF ABOUT 25 DEGREES
CELSIUS...BUT THE SSTS WILL BE INCREASING BY ABOUT ONE DEGREE PER
CONVECTION WHICH MAY FORETELL AN INCREASE IN STRENGTH. SSTS UNDER
PERIOD...THE SHEAR COULD RELAX AND SSTS INCREASE SO THERE IS SOME
STRENGTH LATER IN THE FORECAST AS THE SHEAR RELAXES AND THE SSTS
SSTS SLOWLY FALL. THIS ENVIRONMENT IS EXPECTED TO RESULT IN A SLOW
DAYS 3 THROUGH 5 DUE TO COOLING SSTS AND THE POTENTIAL
INCREASING SSTS. SHEAR IS FORECAST TO INCREASE BY ALL MODELS IN A
IN STRENGTH IS FORECAST AS SSTS DIMINISH SLOWLY ALONG THE TRACK.
AS SSTS ALONG THE FORECAST TRACK COOL AND THE SHEAR INCREASES.
SHEAR AND WANING SSTS. THE EXTRATROPICAL TRANSITION PROCESS SHOULD
RAPIDLY DECREASING SSTS...AND BY 120 HR...THE REMNANTS OF BERTHA

SYSTEM COULD UPWELL COLDER WATER UNDERNEATH IT. THIS COULD
SO. DUE TO ITS SLOW MOTION...BERTHA IS PROBABLY CAUSING UPWELLING
TOO MANY HOURS IN THE SAME AREA PRODUCING UPWELLING. THE HURRICANE
FUTURE...GIVEN THE EFFECTS OF OCEAN UPWELLING UNDER A STATIONARY
UPWELLING COLDER WATER UNDERNEATH IT. THIS SHOULD CAUSE A

OCEAN HAS ACQUIRED ENOUGH ORGANIZED CONVECTION TO NOW BE CONSIDERED
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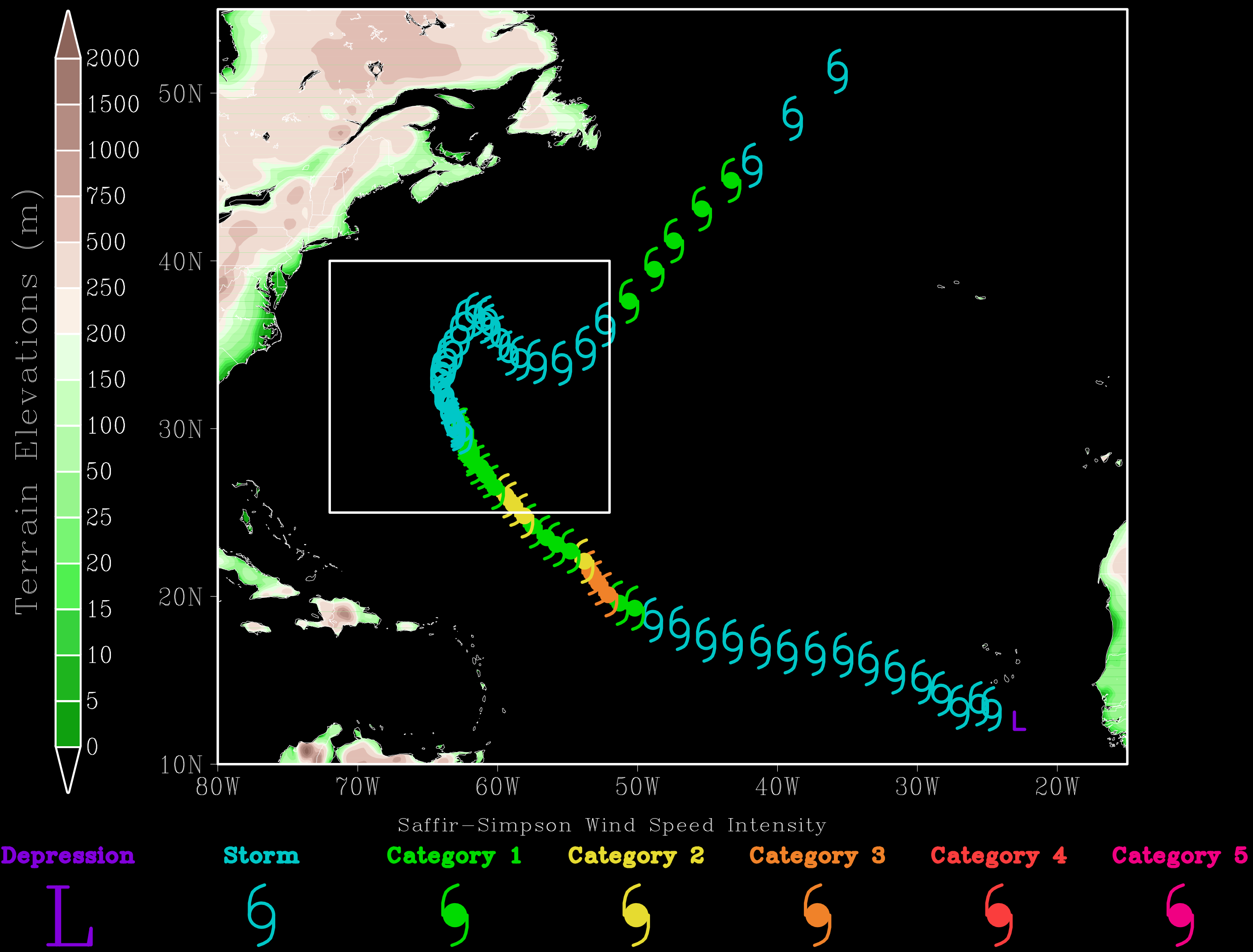
THE OCEAN IS PLENTY WARM AHEAD OF BERTHA SO THE SHEAR WILL BE THE
STRENGTHENING AND THE OCEAN IS PLENTY WARM. HOWEVER...THE VARIOUS
CHANGES...EVEN THOUGH THE OCEAN AND ATMOSPHERIC ENVIRONMENTS ARE NOT
TO WEAKEN. OCEAN ANALYSES FROM THE ATLANTIC OCEANOGRAPHIC AND
OCEAN. THEN...A GRADUAL WEAKENING IS INDICATED. ALTHOUGH IT APPEARS
FUTURE...GIVEN THE EFFECTS OF OCEAN UPWELLING UNDER A STATIONARY

Acquired from *http://www.nhc.noaa.gov/archive/2008/BERTHA.shtml*

The Impacts of an Evolving Ocean Boundary Condition

Case Study Selection

TC Bertha (2008) - 03 July to 20 July



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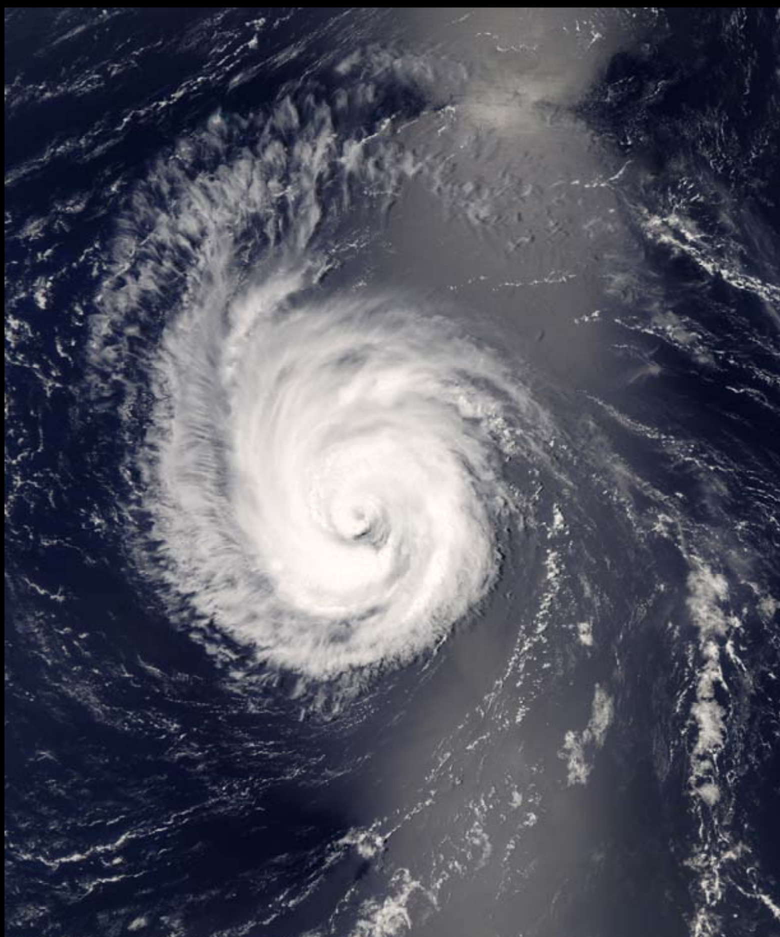
Observation Analysis

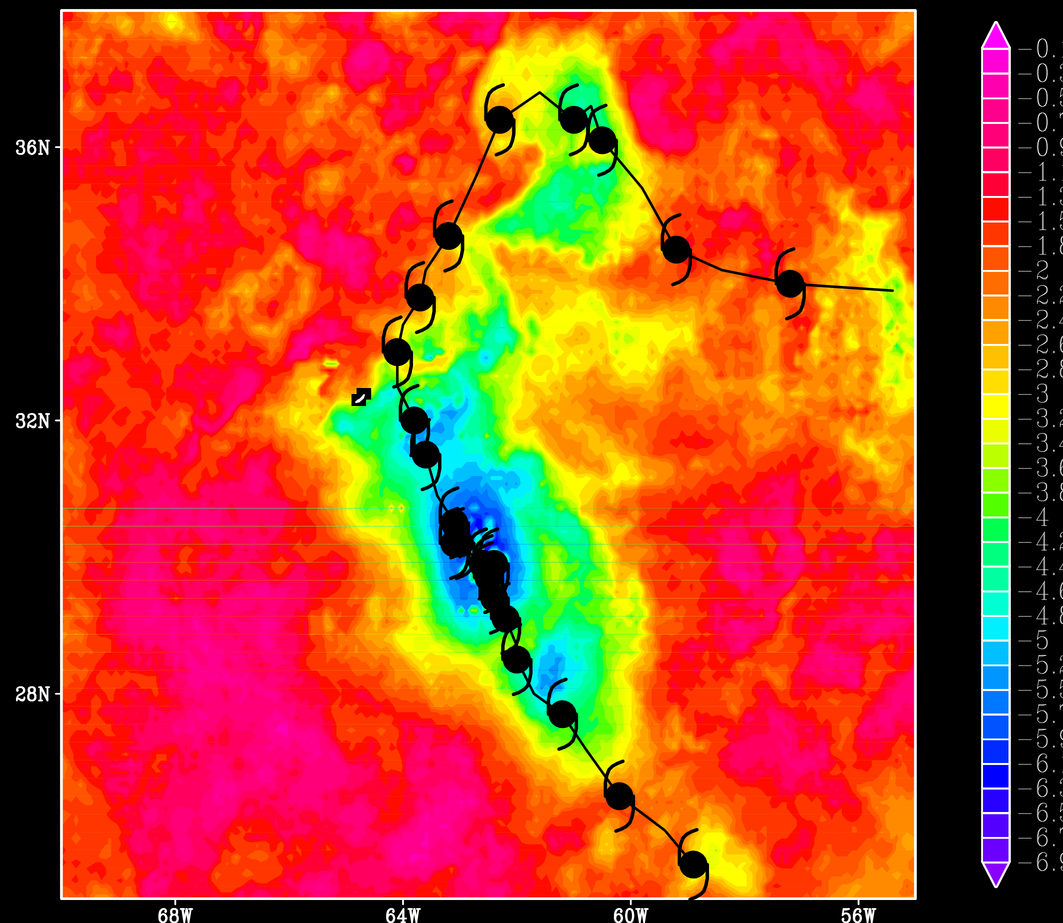
TC Bertha (2008) - 03 July to 20 July



TC Bertha (2008) 1705 UTC 10 July

Image acquired from http://rapidfire.sci.gsfc.nasa.giv/gallery/?2008192-0710

Daily Multi-sensor Improved Sea-Surface Temperature (MISST) TC Bertha (2008) Estimated Cold-Wake

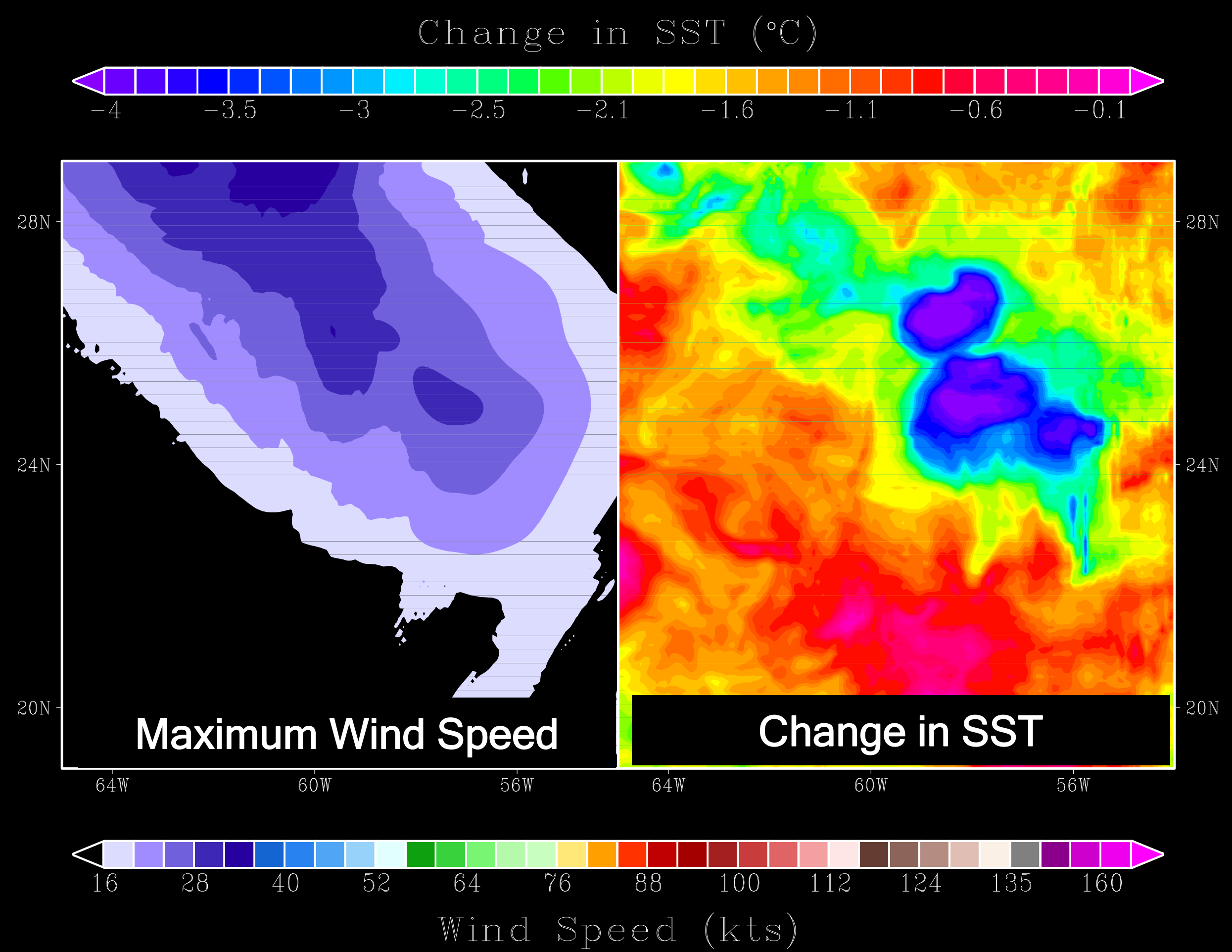


Track positions obtained from HURDAT (Jarvinen et al., 1984)

The Impacts of an Evolving Ocean Boundary Condition

Coupled-Model Atmosphere/Ocean Interactions

WRF-ARW Wind Swath and HYCOM SST Cold-Wake Analysis



SST (HYCOM) cooling response is greatest within region of maximum winds

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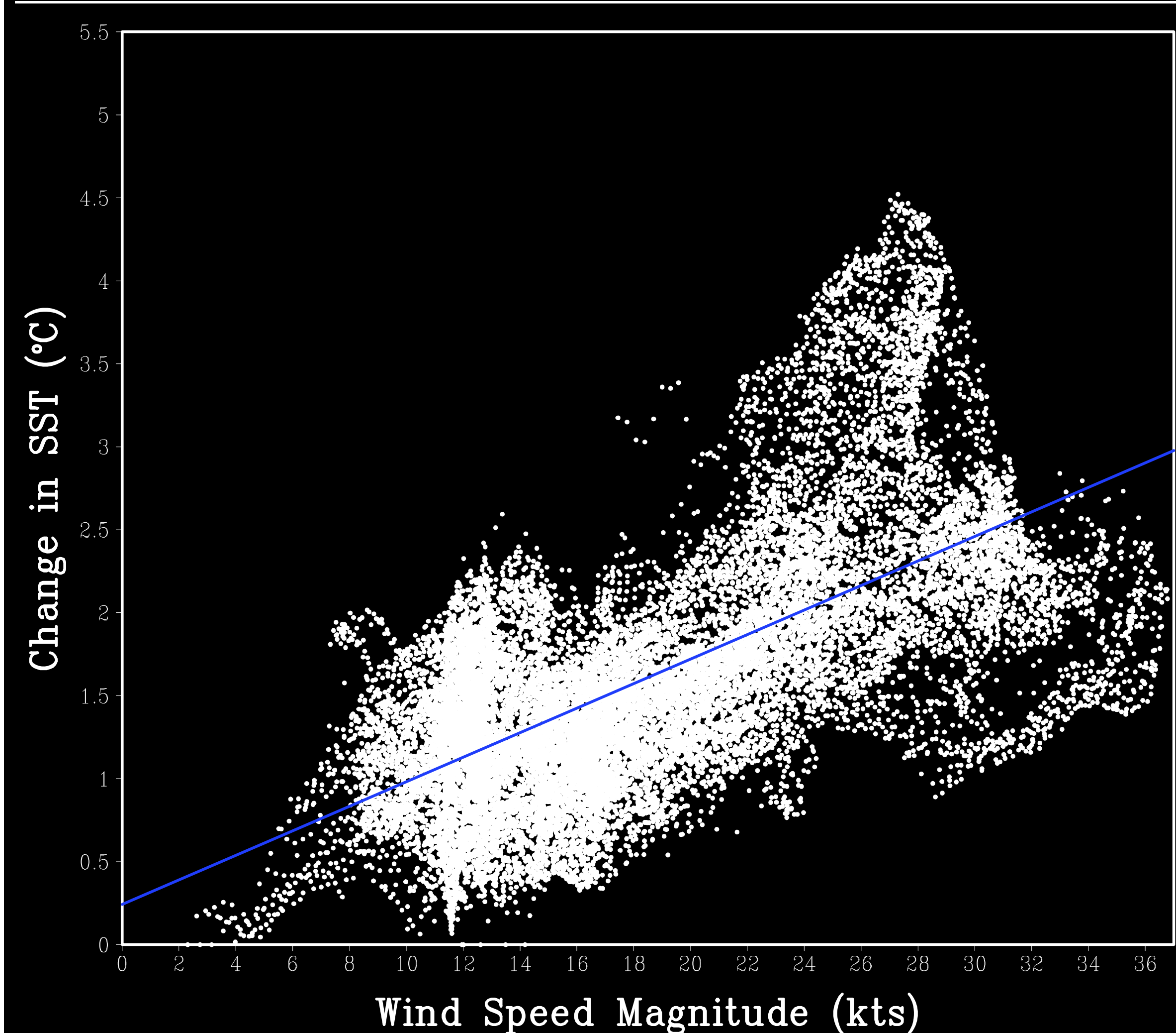
WRF-ARW Wind Swath and HYCOM SST Cold-Wake Analysis

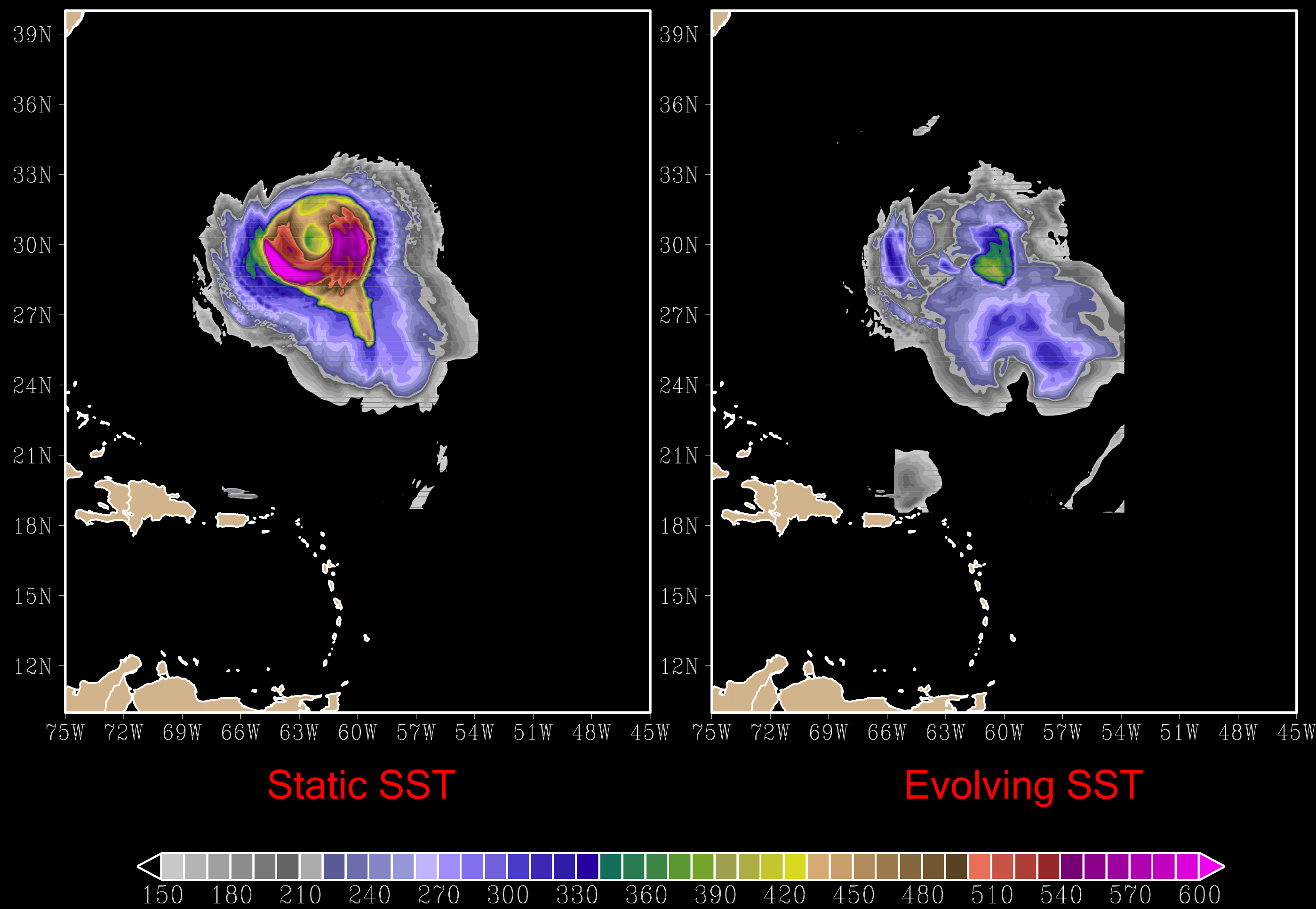


- **Maximum wind** speed and **change in SST** are spatially **correlated** at *r* = 0.69
- The **change in SST** is also dependent on the **translational speed** of TC vortex, the **size** of the TC vortex, temporal **duration of high-winds**, the **structure** of the **upper-ocean**, ocean and atmosphere **boundary-layer processes**, etc.
- In the case of TC Bertha (2008), the **slow translational speed** (stalling) and subsequent **long-duration high-winds** appear to be the mechanisms which induced the substantial **cold-wake** and eventual **weakening of TC**

The Impacts of an Evolving Ocean Boundary Condition

Static vs. Evolving Ocean Boundary Conditions

TC Bertha (2008) - 0000 UTC 10 July to 0000 UTC 13 July



Surface Latent Heat Flux (W/m^2)

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Static vs. Evolving Ocean Boundary Conditions

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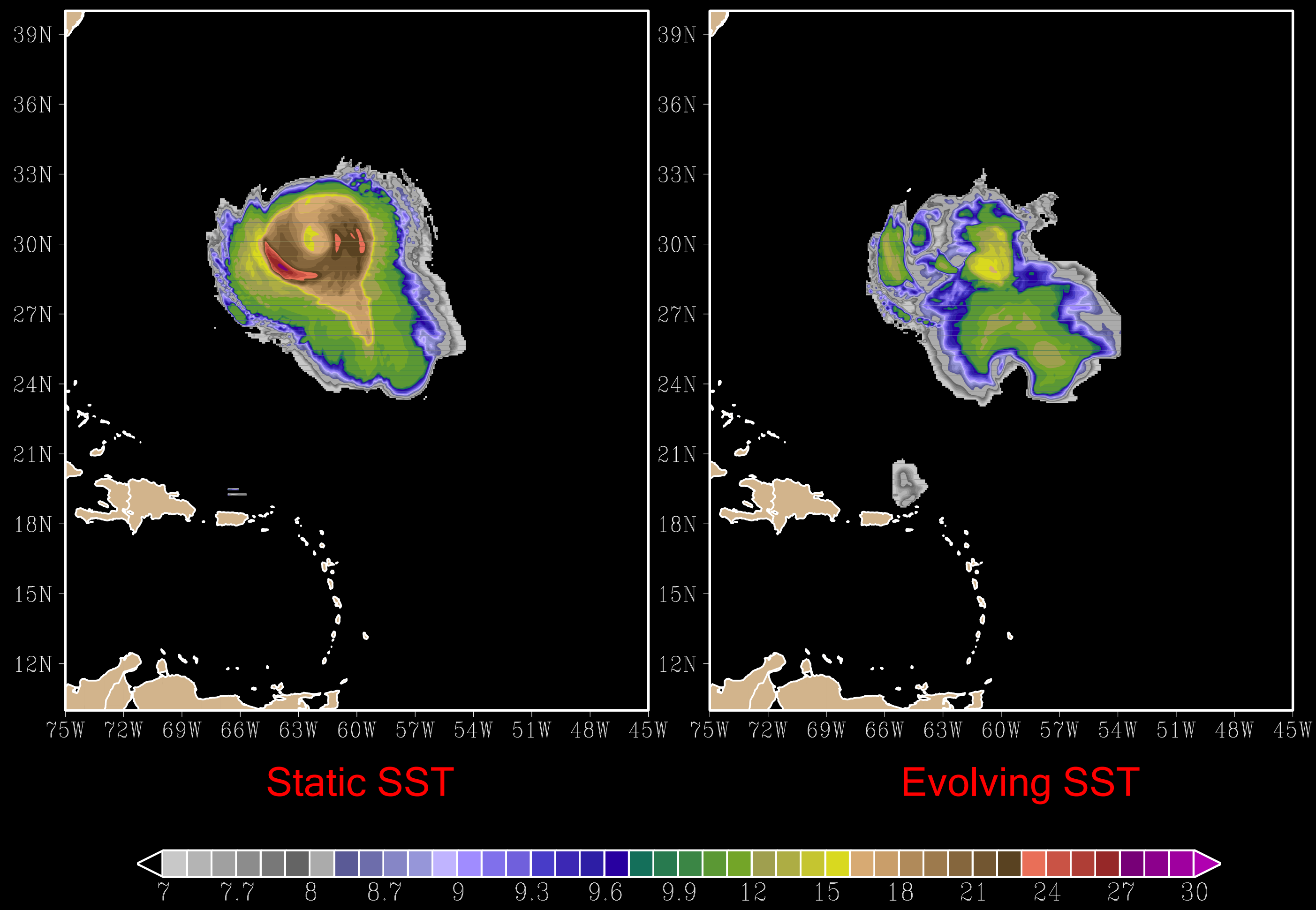

Surface Moisture Flux (kg m^{-2} s^{-1}) x 10^5

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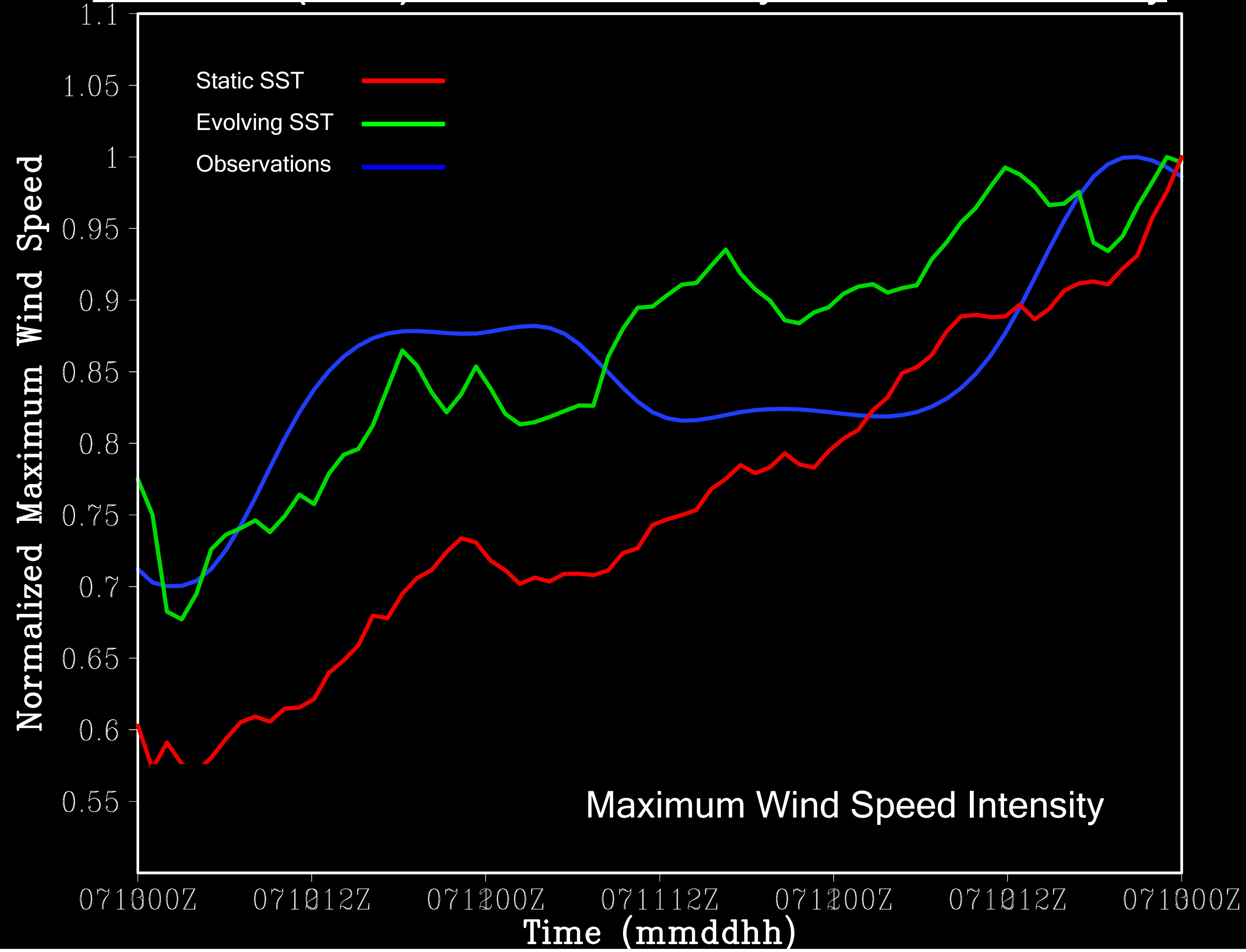

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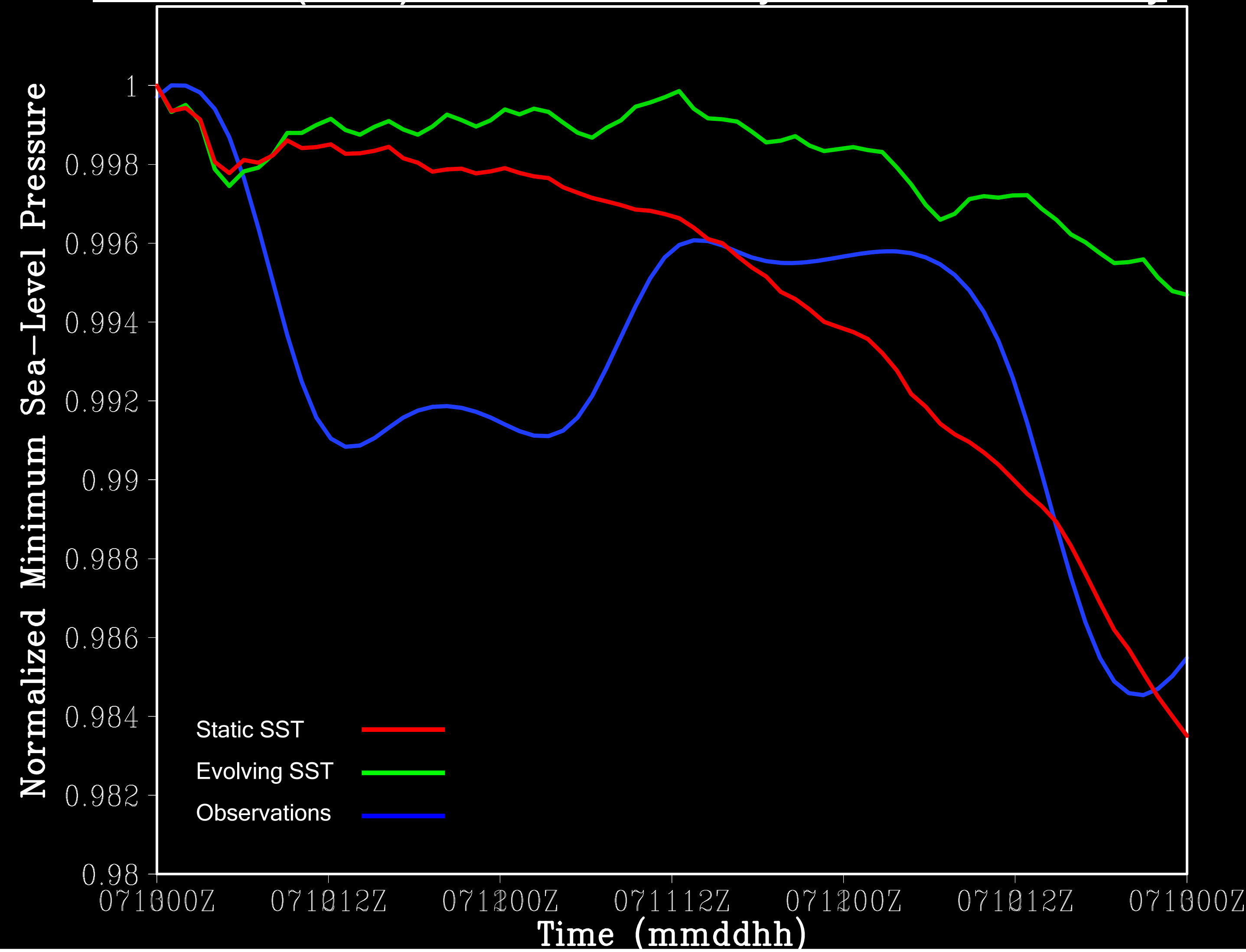

Coupled Atmosphere-Ocean Model

Conclusions and Future Work

- In the case of TC Bertha (2008), the greatest ocean (SST) response is largely correlated to the regions of maximum wind speed; D'Asaro et al., (2007) concluded similar things for TC Frances (2004)
- The use of an evolving SST more closely resembles the temporal modulations and trends for maximum wind speed and minimum sea-level pressure intensity depicted in the observations
- Actual model intensity measurements do not correlate with the intensity values seen in the observations
  1. Poor initial conditions for the structure and intensity of the TC vortex
  2. Grid-length resolutions which are too coarse to capture appropriate rates of intensification
  3. The impacts of waves and sea-spray have not been included
  4. The choice of atmosphere and ocean model physical parameterizations
- Ongoing and future work includes:
  1. Inclusion of a dynamic TC vortex initialization methodology (akin to GFDL)
  2. Wave-model and sea-state parameterizations (Bourassa, 2006)
  3. Assimilation of TC PBL wind profile, TC troposphere thermodynamic, and drag coefficient (Powell et al., 2003) observations