Targeted Ocean Sampling Guidance for Tropical Cyclones

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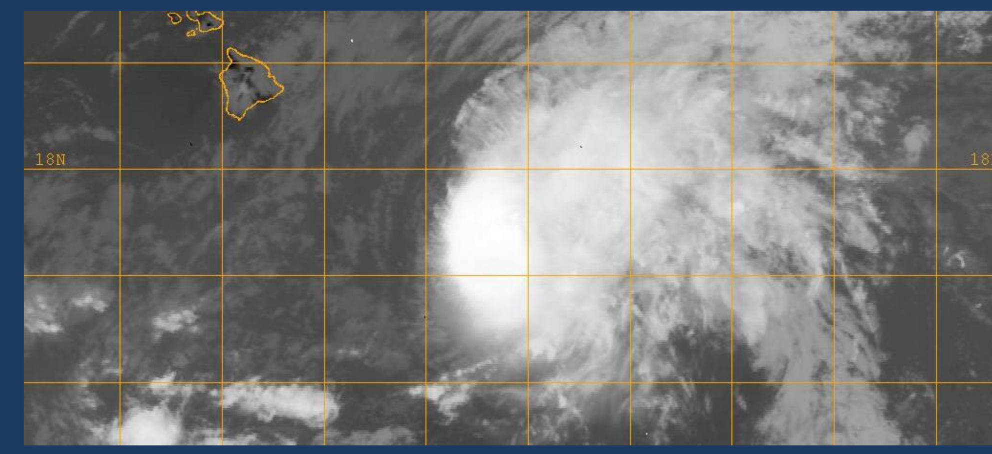


INTRODUCTION

To date, global observations of densely covered sea surface temperature (SST) made by infrared and microwave satellites are unable to provide reliable SST retrievals near the TC center due to cloud cover, rain, and sea state contamination [Gentemann et al., 2010]. Therefore, routinely deployed in situ ocean instruments that observe the vertical profile of ocean temperature, salinity, and currents near the storm are important additions to an effective measurement strategy. Such measurements can provide an improved representation of the ocean conditions in the path ahead of a moving TC, and improved initialization of both coupled and uncoupled TC models.

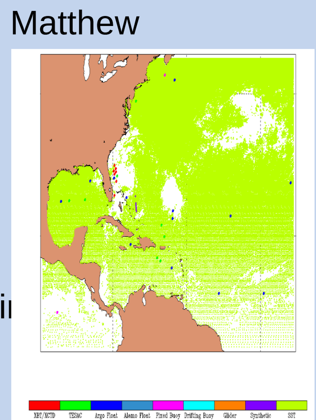
APPROACH

Recently, Cummings and Smedstad [2014] showed that an adjoint-based procedure based on a three-dimensional variational analysis is another accurate method to assess the impact of ocean observations. The advantage of using the analysis adjoint is that the data impact is solely due to assimilation of the observations at each update cycle time and not from the effect of air-sea coupling. To answer the question of where best to obtain the TC ocean observations that will positively benefit a given air-sea coupled TC model forecast, we examine the feasibility of applying a modified targeted observing form of the adjoint-based ocean data method used by Cummings and Smedstad [2014].

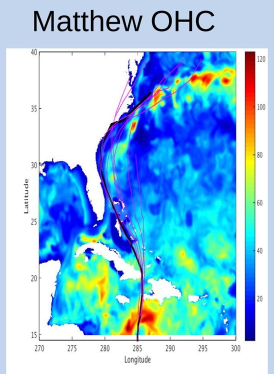
Table 1. Number of AXBT and ALAMO Profiles That Are Assimilated in NCODA

Tropical Cyclone	Isaac	Hilda	Matthew
AXBT	57	36	35
ALAMO	0	20	7

1200 UTC 7 October, 2016 for Hurricane Matthew

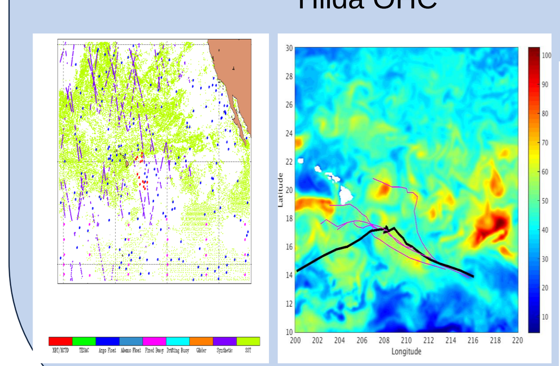


Matthew OHC

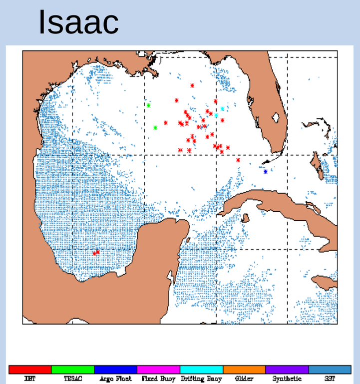


Composite map of different types of sea temperature observations used in NCODA analysis on 1200 UTC 10 August, 2015 for Hurricane Hilda & NCODA analyzed OHC (Jm^{-2})

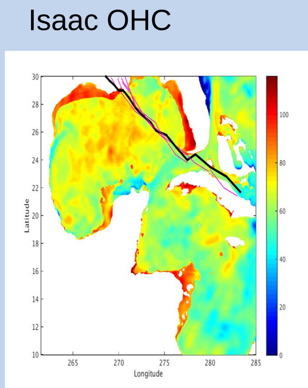
Hilda OHC



1200 UTC 28 August, 2011 for Hurricane Isaac

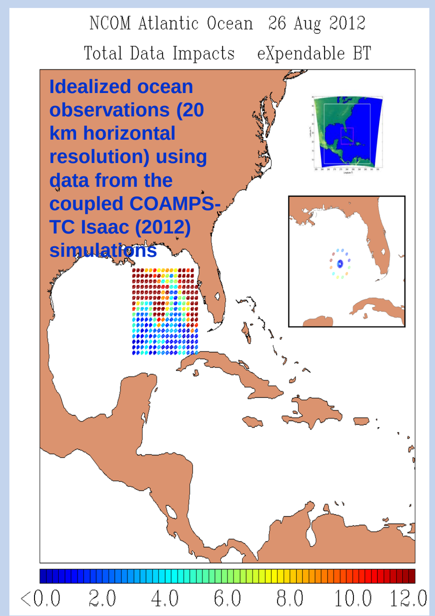


Isaac OHC



MODEL

COAMPS-TC, TC Isaac 10 m wind speed



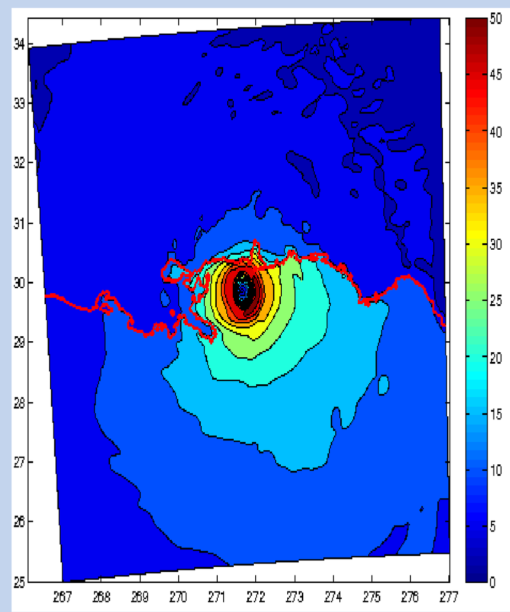


Table 2. Description of COAMPS-TC Experiments

Experiments	Isaac	Hilda	Matthew
Simulation Periods	25–29 August 2012	10–14 August 2015	3–9 October 2016
Assimilation	Atmos:12 × 4 km Ocean: 4 km With AXBT	Atmos: 45 × 15 × 5 km Ocean: 5 km With AXBT and ALAMO	Atmos: 45 × 15 × 5 km Ocean: 5 km With AXBT and ALAMO
Targeted	Atmos:12 × 4 km Ocean: 4 km Without AXBT	Atmos: 45 × 15 × 5 km Ocean: 5 km Without AXBT and ALAMO	Atmos: 45 × 15 × 5 km Ocean: 5 km Without AXBT and ALAMO

METHODOLOGY

The procedures for calculating the Impacts of observations on forecast error and for targeted observing are similar, but differ in two important ways. In both applications data impact (de24) is measured as the inner product of a 3-D adjoint sensitivity vector at the observation location J (∂J/∂y; output from the NCODA adjoint) and model-observation difference ($|y-x_b|$) expressed by the following data impact equation derived by Langland and Baker [2004a].

$$\delta e_{24} = \langle |(y - Hx_b)|, \partial J/\partial y \rangle, \quad (1)$$

where J is the forecast error sensitivity, y is the observation, H is the forward operator, and x_b is the model first guess field. For the forecast error problem, the adjoint sensitivity vector is computed from the gradient of the difference between COAMPS-TC 24 and 36 h forecasts valid at the same time relative to a verifying analysis:

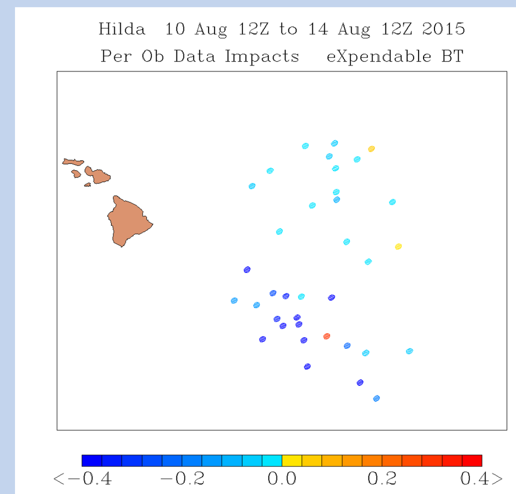
$$\Delta e_{24}^{36} = \langle (x_{24} - x_0)\cdot(x_{24} - x_0) \rangle - \langle (x_{36} - x_0)\cdot(x_{36} - x_0) \rangle, \quad (2)$$

where x_{24} and x_{36} are the forecast states at 24 and 36 h length, and x_0 is the verifying analysis. The outer brackets represent a scalar inner product. The forecast error gradients are projected from model space to observation space using the adjoint of the NCODA variational assimilation procedure according to:

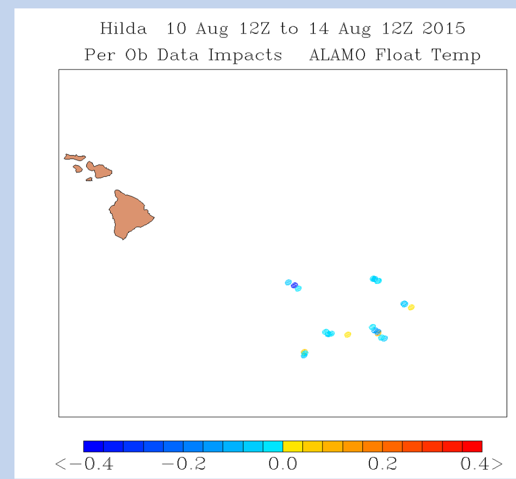
$$\partial J/\partial y = K^T \Delta e_{24}^{36}, \quad (3)$$

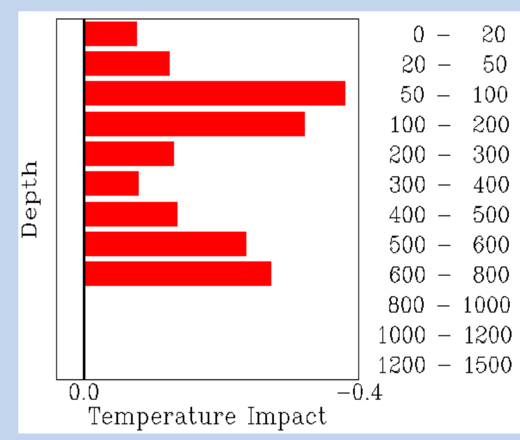
where K^T is the adjoint of the Kalman gain matrix $K^T=[HBH^T+R]^{-1}HB$, with B and R the background and observation error covariance. The observation sensitivity vector is the forecast error gradient in observation space; its elements exist at the observation locations.

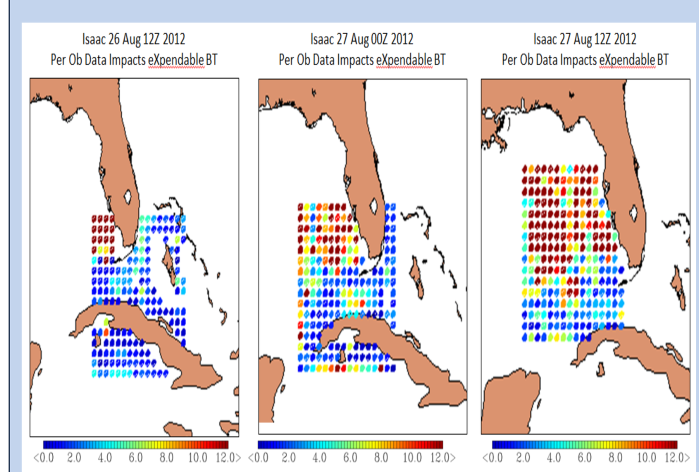
RESULTS



A composite per-observation AXBT (TOP) and ALAMO (BOTTOM) vertical impact during the period of 10-14 August 2015 for Hurricane Hilda. (b) Hurricane Hilda sea surface temperature observation impact normalized by the number of samples from AXBT, ARGO profiler, fixed buoys, , gliders (TESAC), altimeters, various sources of SST (satellite and in situ), and ALAMO.







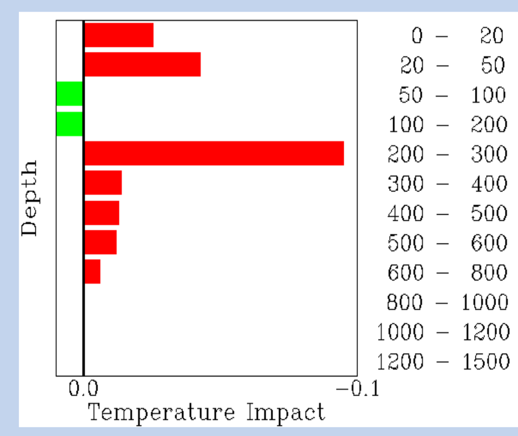
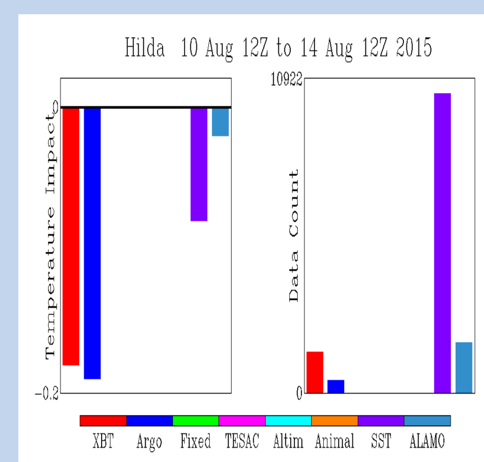


Table 3. Spatial Correlation of the Assimilation and Targeted Impact Factors

Depth Layer	Total Mean	Isaac	Hilda	Matthew
0–20 m	0.28	0.11	0.16	0.53
20–50 m	0.35	0.11	0.15	0.59
50–100 m	0.36	0.54	0.25	0.55
100–200 m	0.41	0.93	0.24	0.56
200–300 m	0.44	0.84	0.20	0.79
300–400 m	0.38	0.82	0.21	0.63
400–500 m	0.53	0.88	0.43	0.35



SUMMARY

A 3D variational ocean data assimilation adjoint approach is used to examine the impact of ocean observations on coupled tropical cyclone (TC) model forecast error for three recent hurricanes: Isaac (2012), Hilda (2015), and Matthew (2016). Targeted ocean observation regions from these three hurricanes, show that the largest positive impacts in reducing the TC model forecast errors are sensitive to the initial pre-storm ocean conditions such as the location and magnitude of pre-existing ocean eddies, storm-induced ocean cold wake, and model track errors. **We demonstrated that a new innovative adjoint-based targeted ocean sampling technique is capable of providing skillful guidance on where to deploy the ocean observations in order to reduce coupled model forecast biases.**

References

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