Combining altimetry with in situ data: quantitative impact assessment of operational ocean observation strategy in hurricane applications using Observing System Experiments and OSSEs

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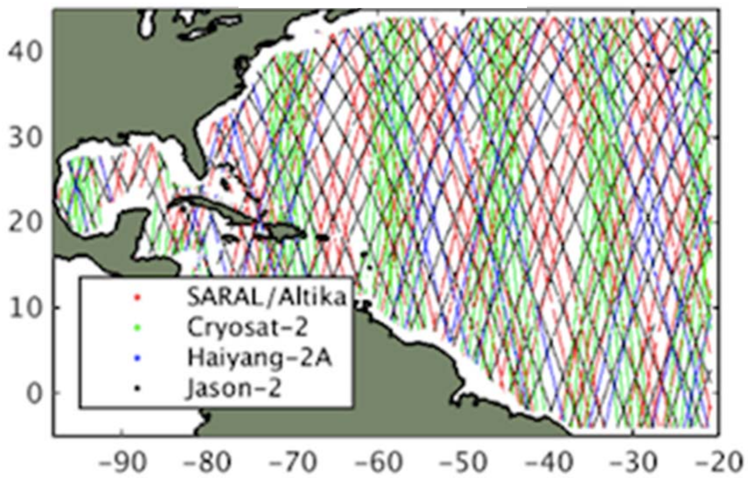
Components of the OSSE system

- **Nature Run (NR)**
  - Multi-year validated free run by an advanced ocean model (the "truth")
    - HYbrid Coordinate Ocean Model (HYCOM) run at 0.04^{o}
- **Ocean Nowcast-Forecast System**
  - **Forecast Model (FM)**
    - HYCOM with substantially different configuration and lower resolution compared to the NR **("fraternal twin" system)**
  - **Ocean Data Assimilation (DA) procedure**
    - In-house statistical interpolation system designed specifically for HYCOM Lagrangian vertical coordinates
- **Synthetic Observation Simulation Toolbox**
  - Addition of realistic errors
- **System fully validated** (Kourafalou et al., 2016; Androulidakis et al., 2016; Halliwell et al., 2017)

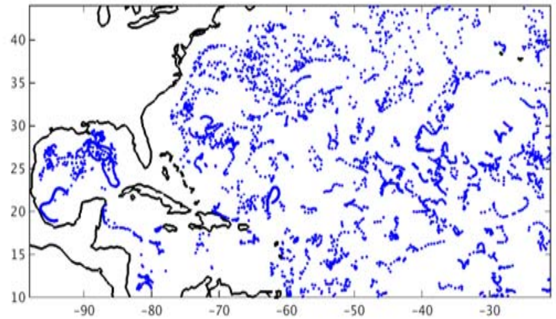
Observing System Simulation Experiments (OSSE) to evaluate operational ocean observing system components during the 2014 hurricane season

Altimetry
Argo floats
XBT transects
In-situ SST
Satellite SST (not shown)

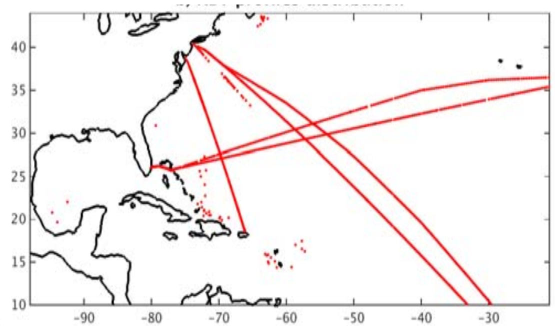
Altimetry



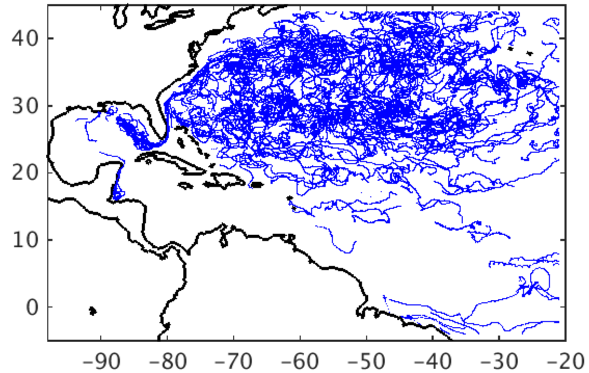
Argo floats



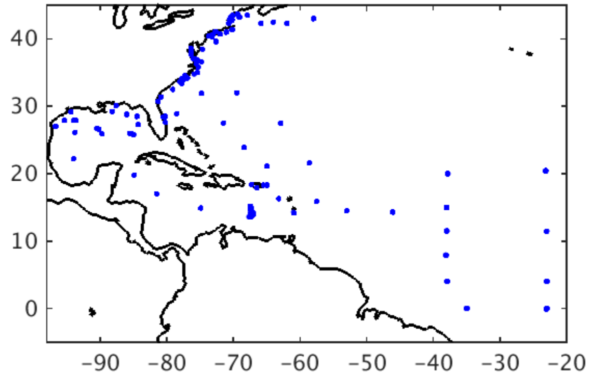
XBT



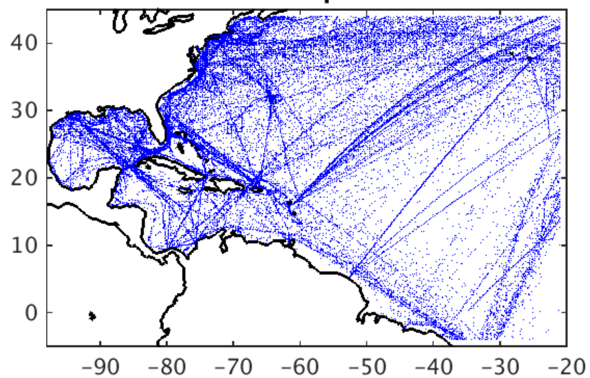
SST Drifters



SST Bouy



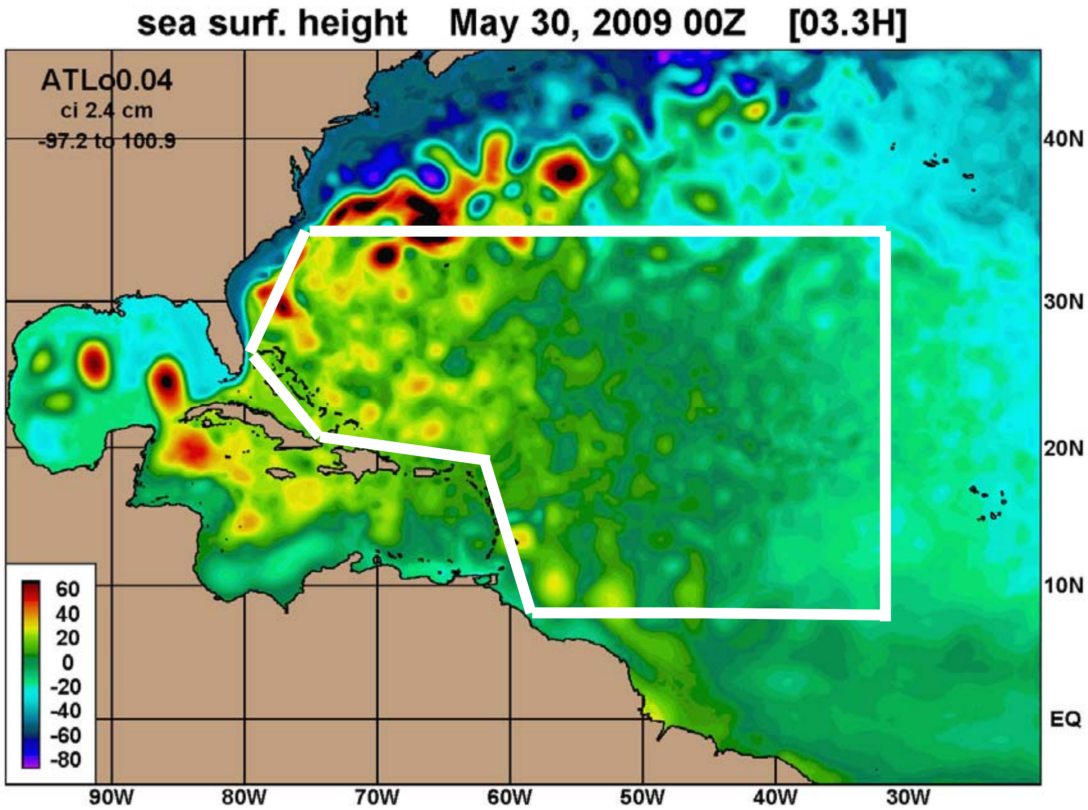
SST Shipobs



- **Altimetry** provides **large quantities of data** to constrain the ocean simulation

OSSE analysis domain

Analyses were conducted over the open North Atlantic domain outlined below



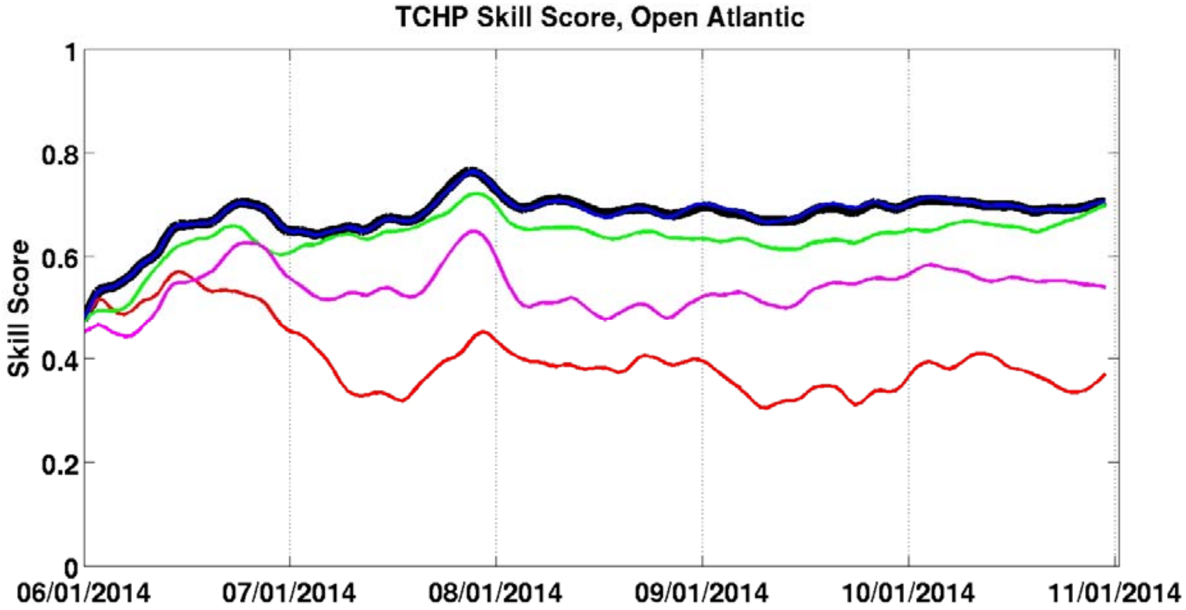
Impact on reducing errors with respect to the truth provided by the NR in **Tropical Cyclone Heat Potential** (TCHP):

$$\text{TCHP} = c_p \int_0^{H_{26}} \rho \left[T(z) - 26 \right] dz,$$

Time series of skill score over analysis domain

- Control (assimilates all observations)
- Deny altimetry
- Deny Argo floats
- Deny XBT
- Deny all SST

$$SK = 1 - \frac{\text{MSE}_{expt}}{\text{MSE}_{ref}}$$



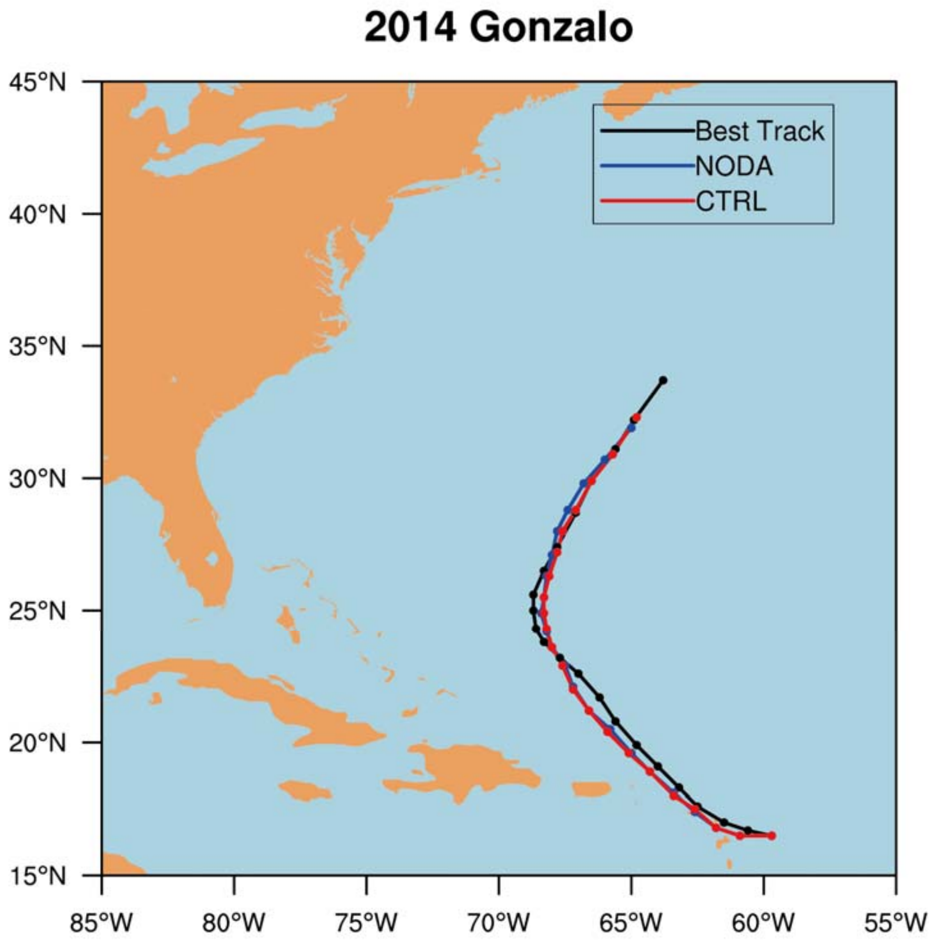
- **Altimetry** is the **most effective** of the existing observation networks for constraining the ocean TCHP: constrain on the mesoscale field

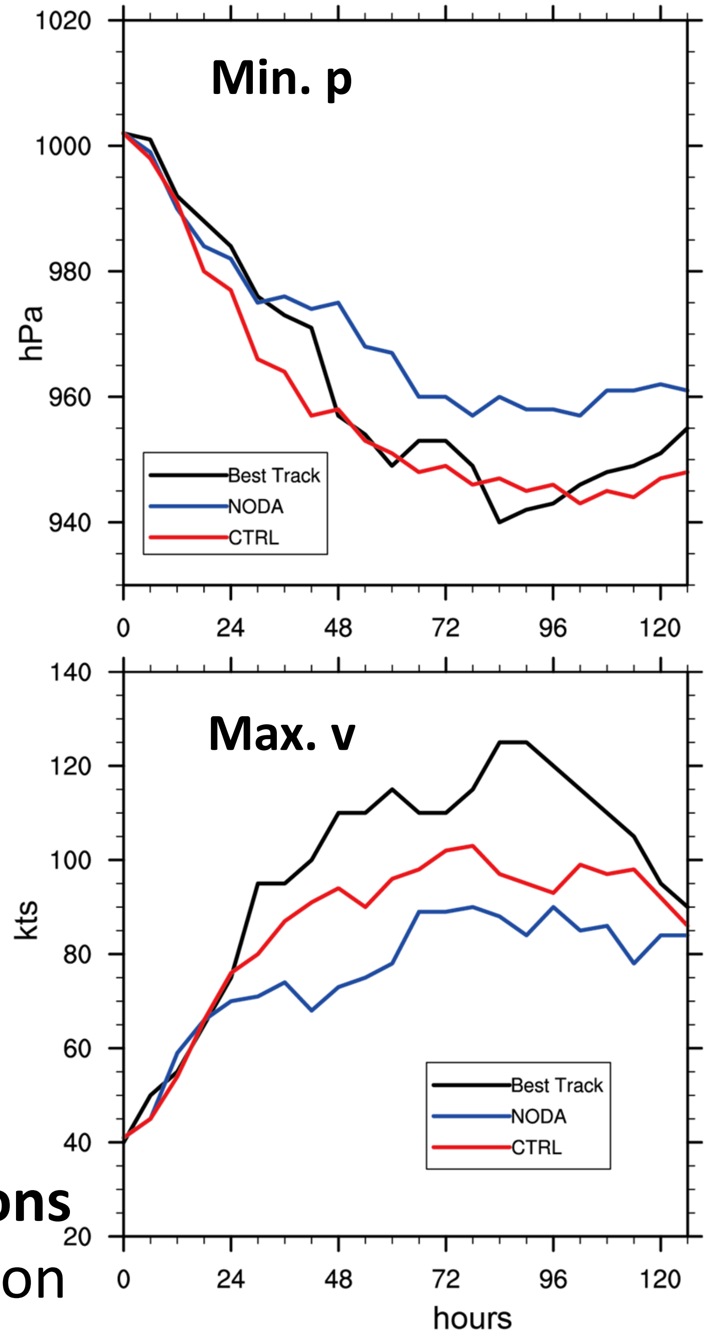
Observing System Experiments to demonstrate observing system impact on hurricane intensity prediction

- An ocean OSE (*i.e. assimilating real observations*) run during the 2014 hurricane season is used to evaluate the **impact of the existing operational ocean observing system** on **coupled model intensity forecasts** for Hurricane Gonzalo
  - **CTRL** – Control experiment that **assimilates all observations**
  - **NODA** – Experiment that **denies all observations**

- Ocean analyses from these two experiments are used to initialize the HYCOM-HWRF regional coupled TC prediction system to performs the forecasts

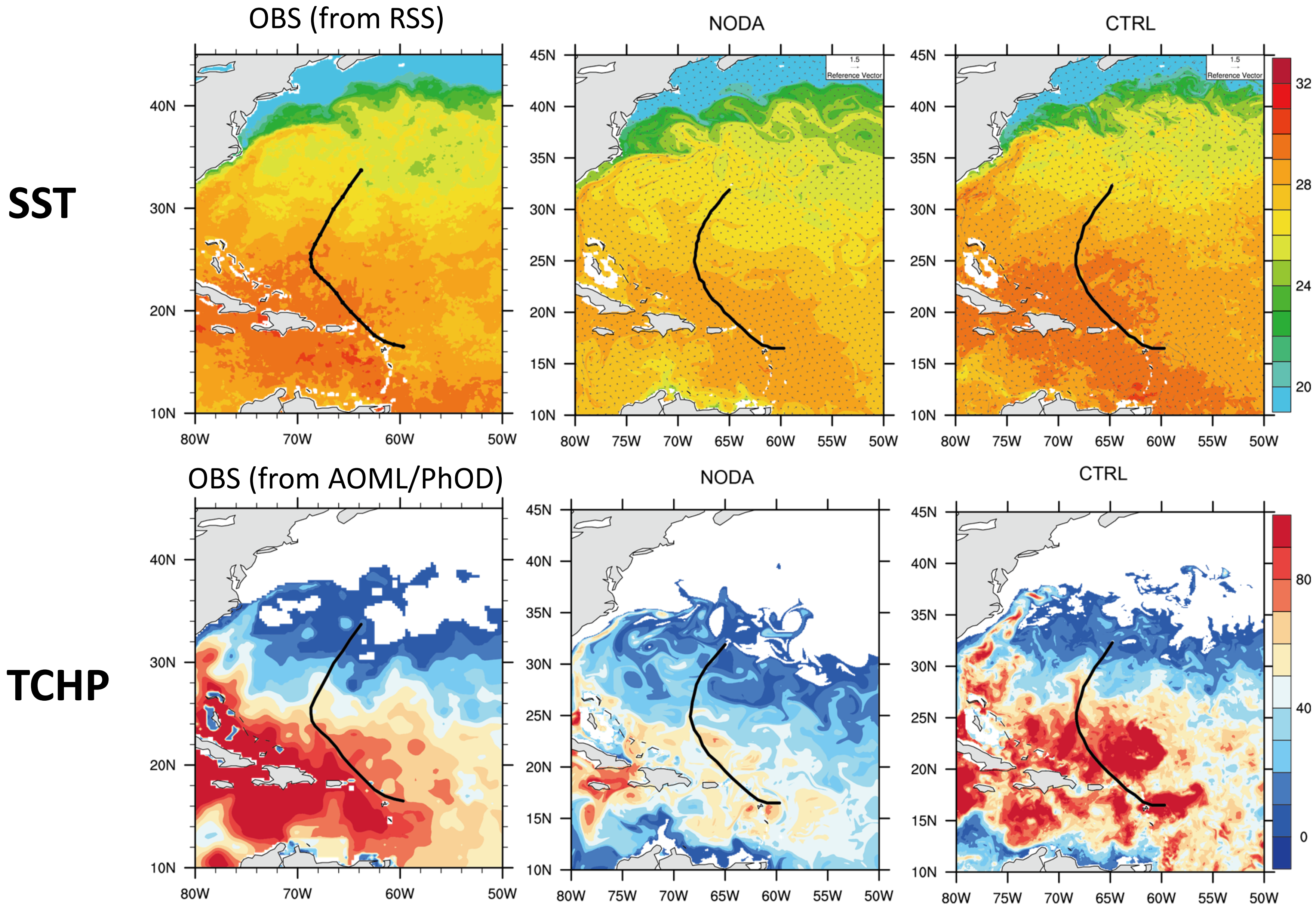
Hurricane Gonzalo forecasts compared to best track





- The **assimilation of ocean observations** improves the storm intensity prediction

Hurricane Gonzalo initial fields



- Largest improvement in ocean TCHP

OSSE quantitative assessment of synthetic airborne surveys conducted prior to Hurricane Gonzalo (2014)

Two types of surveys deploying synthetic profilers conducted for each storm:

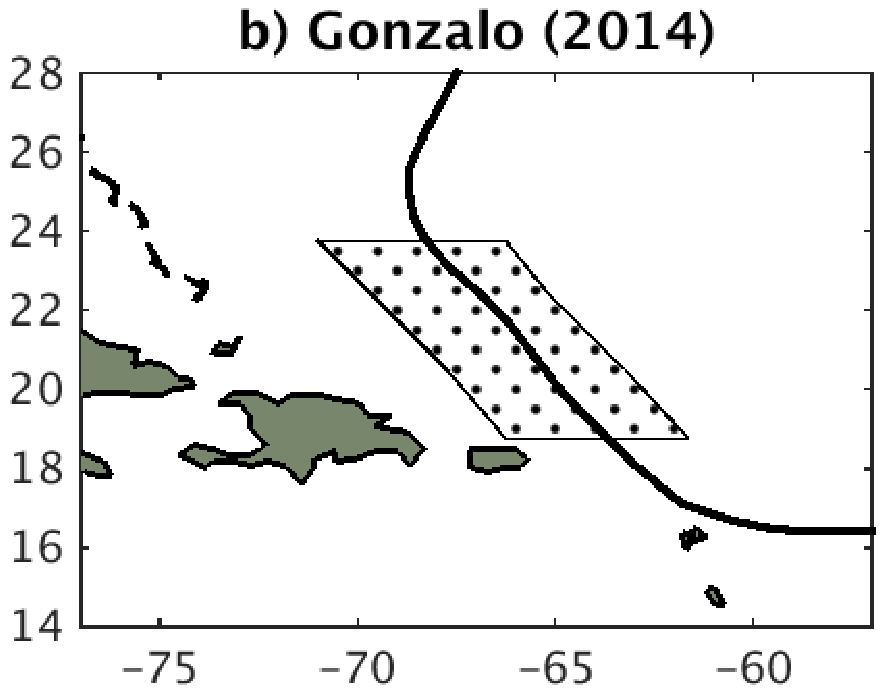
1. Deploy **AXBTs** to a depth of 400 m
2. Deploy **AXCTDs** to a depth of 1000 m

Surveys conducted about **two days before** storm arrival.

Profile assimilation was added to two experiments:

CONTROL – assimilates synthetic version of ocean observing system components (altimetry, Argo, ship XBT, satellite and in-situ SST)

NOALT – same as CONTROL but denies all 4 available altimeters

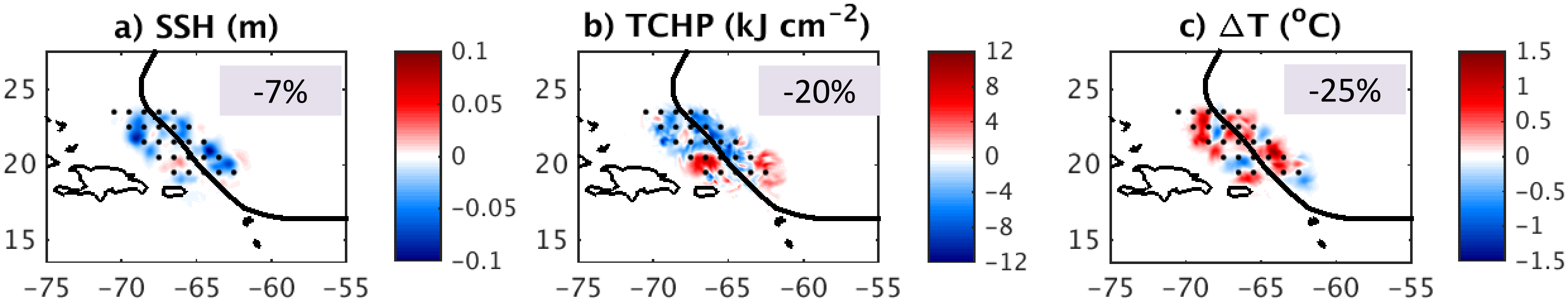


RMS error (RMSE) is analyzed within the parallelogram containing the profiles.

RMSE primarily represents errors in **mesoscale structure**

Correction resulting from synthetic AXCTD profiles

- **Additional corrections** resulting from adding **rapid-response profiles** to CONTROL are **confined to the immediate survey region**
  - Correlation scales are short [O(100 km)]
  - Little time for impacts to spread



Percentage RMSE reduction wrt control run resulting from profile assimilation for Sea Surface Height (SSH, left), TCHP (center), and Temperature difference (surface - T at 100m depth, right)

For maximum benefit, rapid-response pre-storm profile surveys should **cover as large an area as possible**.

RMSE reduction wrt the unconstrained simulation

(Without altimetry assimilation)

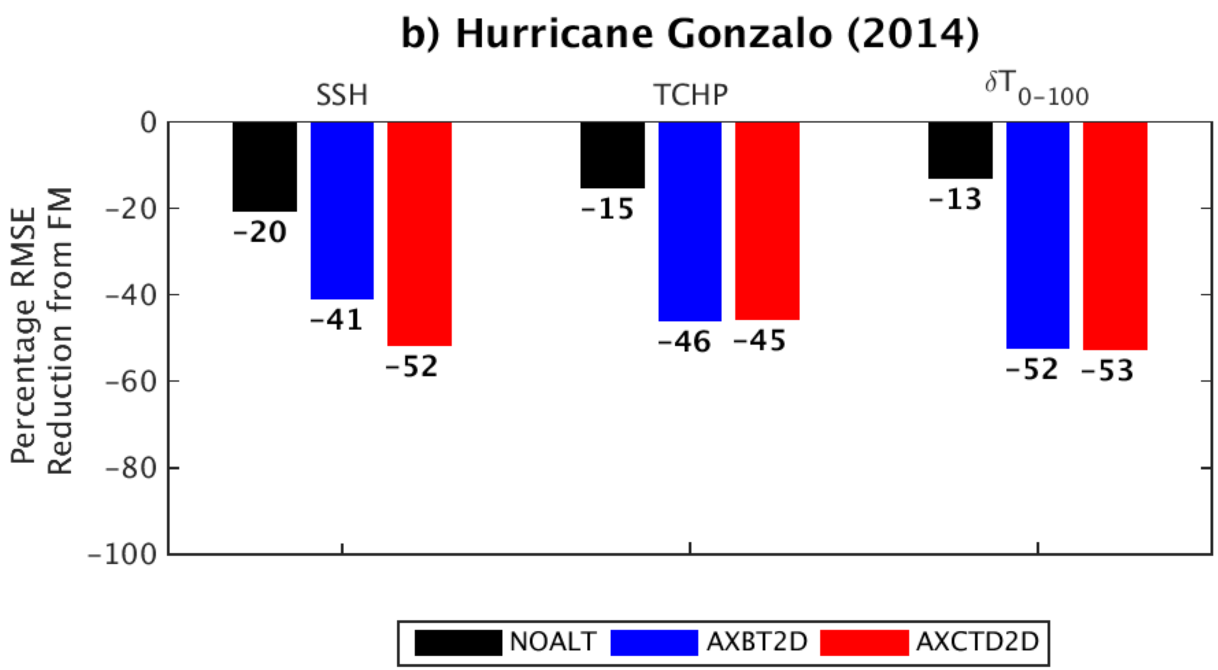
NOALT

add AXBT

add AXCTD

Large reduction in mesoscale errors in **both dynamical** (SSH) and **thermodynamical** (TCHP, $\delta T_{0\text{-}100}$) fields

Additional reduction in mesoscale errors for AXCTDs vs. AXBTs in SSH only.



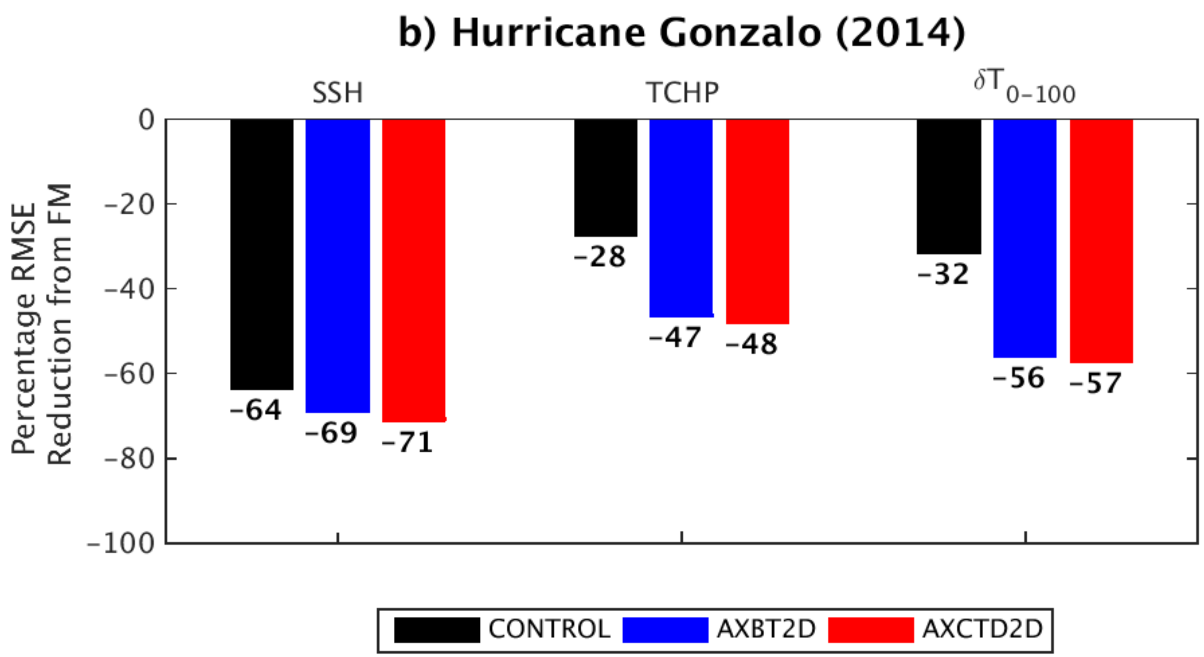
Error reduction (%) referenced to the error of the unconstrained FM assimilation

RMSE reduction wrt the unconstrained simulation

(With altimetry assimilation)

CONTROL
add AXBT
add AXCTD

Substantial reduction in mesoscale errors **in thermodynamical fields only**.

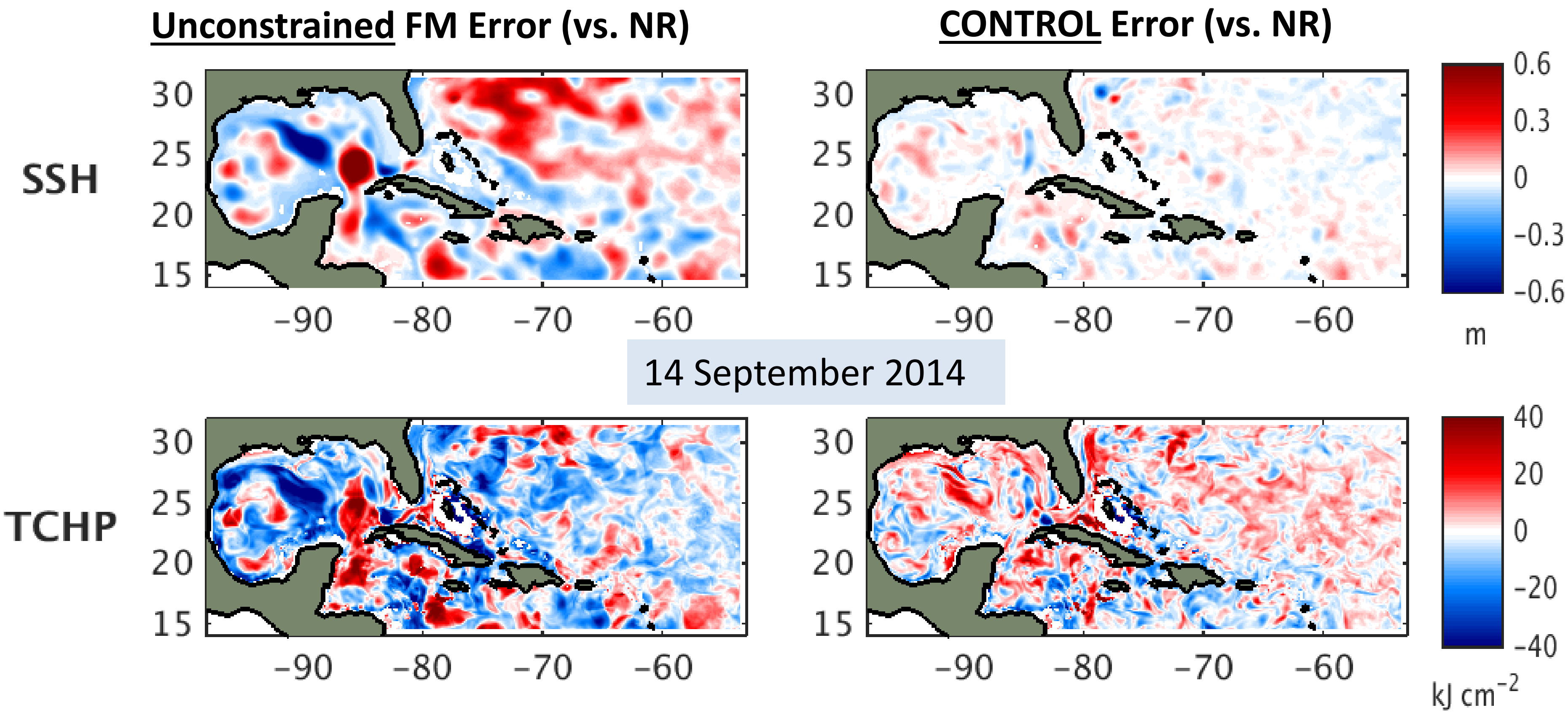


Error reduction (%) referenced to the error of the unconstrained FM assimilation

When altimetry data assimilated, little benefit in deploying AXCTD over AXBT

Ccl: Impact of existing ocean observing systems

- Large **mesoscale error reduction in SSH** –> **primarily from altimetry** assimilation
- **Smaller** mesoscale **error reduction in TCHP** and other thermodynamical fields
- Large regions of positive and negative bias remain in TCHP
- **Rapid-response surveys** have the **greatest impact** on model **thermodynamical fields** for these reasons



Conclusions and future plans

- **Altimetry** is currently the most important contributor to the **constrain of dynamical and thermodynamical fields** in the Atlantic hurricane region
- **Additional in situ profilers** deployed prior to a storm **locally improve TCHP estimates**, and thus have the potential to improve hurricane prediction (*see also poster APOP_001 by Goni et al – Thursday pm – on the impact of gliders*)
- Future plans: perform OSEs and OSSEs for the **2017 Atlantic hurricanes**
  - **Extensive ocean observations** collected in major storms
  - Estimate the **impact of the various components** of the existing observing system (including gliders) on coupled hurricane intensity prediction for **multiple storms** (Harvey, Irma, Jose, Maria)
  - Extend OSSEs to evaluate impacts of **additional components** to the observing system on storm intensity prediction
- Develop **global OSE-OSSE capabilities** (work in progress)
- Longer-term:
  - Extend OSSE system capabilities to the nearshore ocean and shallow seas
    - Present system designed for the deep ocean only
  - Perform OSEs and OSSEs that focus on other short-term forecast applications
  - Embed new data assimilation methods in the OSSE system
    - Validated and calibrated OSSE systems can be used to evaluate and compare different DA procedures