Applications Of UAS For High Impact Weather Prediction Through OSE/OSSE Studies

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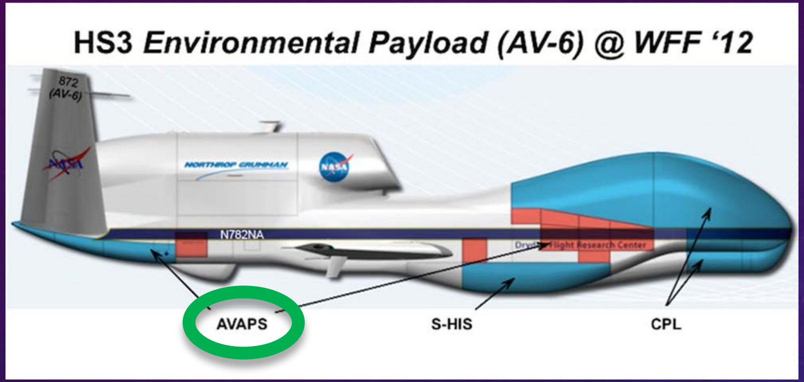
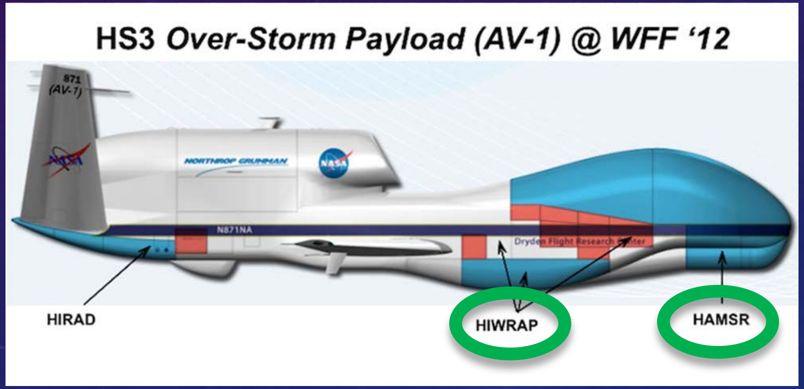
UAS workshop Oct 29 2019
Norman OK

Hurricane Observing Platform: Global Hawk



Scanning High-resolution Interferometer Sounder (SHIS)
Cloud Physics Lidar (CPL)



Hurricane Imaging Radiometer (HIRAD)
High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)
High Altitude MMIC Sounding Radiometer (HAMSR)

NOAA SHOUT Experiment: AVAPS, HIWRP, HAMSR

Unmanned aircraft

- Inner-core and over-the-storm sampling
- High altitude (~18 km, 60,000 ft) and long endurance (up to 24 h per flight)
- Provide 3-D wind, temperature and moisture structure (dropsondes, HIWRAP, HAMSR, SHIS), ocean surface wind speed and rain rate (HIRAD) along flight track, cloud top info (CPL, SHIS) profiles of temperature, wind and moisture at dropsonde locations
- Used for hurricane field campaign in the NASA Genesis and Rapid Intensification Processes (***GRIP***, 2010), NASA Hurricane Severe Storm Sentinel (***HS3***, 2012-14), NOAA Sensing Hazard with Operational Unmanned Technology (***SHOUT***, 2015-16), and NOAA the East Pacific Origins and Characteristics of Hurricanes (***EPOCH***, 2017)

Hurricane Observing Platform: NOAA P-3 and G-IV

Crewed aircraft

NOAA P-3

- Eye penetration to observe inner-core structure
- Typically fly at 3 km (~700 hPa, 10,000 ft)
- Provide 3-D wind structure (tail Doppler radar), surface wind speed (SFMR) along flight track, profiles of temperature, wind and moisture at dropsonde locations

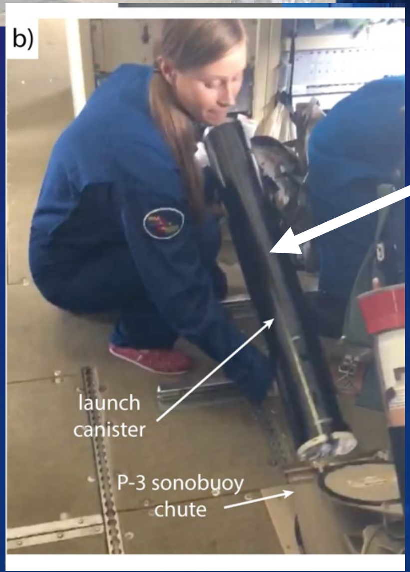
NOAA G-IV

- Synoptic surveillance to observe hurricane environment
- Typically fly at 14-15 km (~150 hPa, 45,000 ft)
- Provide 3-D wind structure (tail Doppler radar), surface wind speed (SFMR) along flight track, profiles of temperature, wind and moisture at dropsonde locations

Tail Doppler radar (TDR)
Stepped-Frequency Microwave Radiometer (SFMR)

Hurricane Observing Instrument: Coyote

Raytheon's Coyote sUAS:
Wingspan: 1.5 m
Length: 0.9 m
Weight: 6 kg

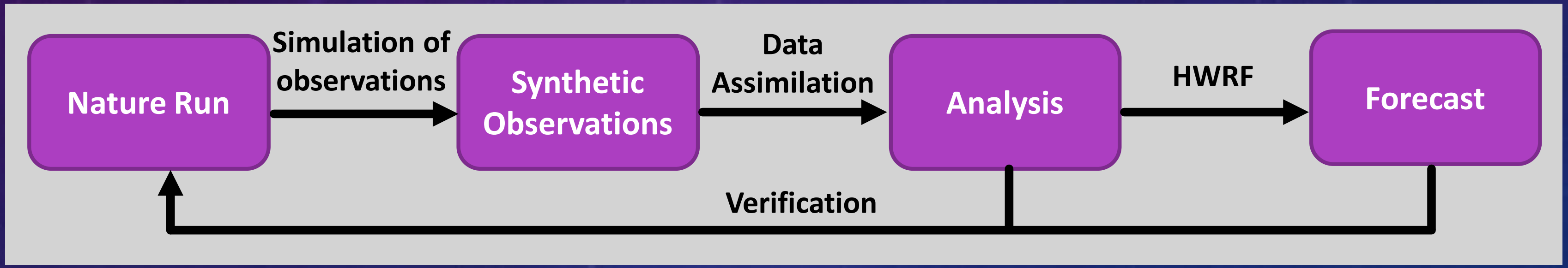


Coyote sUAS

- **Direct measurements at very low altitude**
  - Usually data void area
  - Manned aircraft impossible due to safety risks
- **Meteorological measurements:**
  - Wind speed and direction (up to 2-10 Hz)
  - Temperature, relative humidity, pressure
  - Sea surface temperature (SST) using infrared sensor

- **Observation System Experiment (OSE)**
  - Evaluate the impacts of a particular dataset through data denial experiment
    - one experiment including the dataset
    - one experiment *not* including the the dataset
  - Ensure the consistence of the ”control” datasets in both experiments

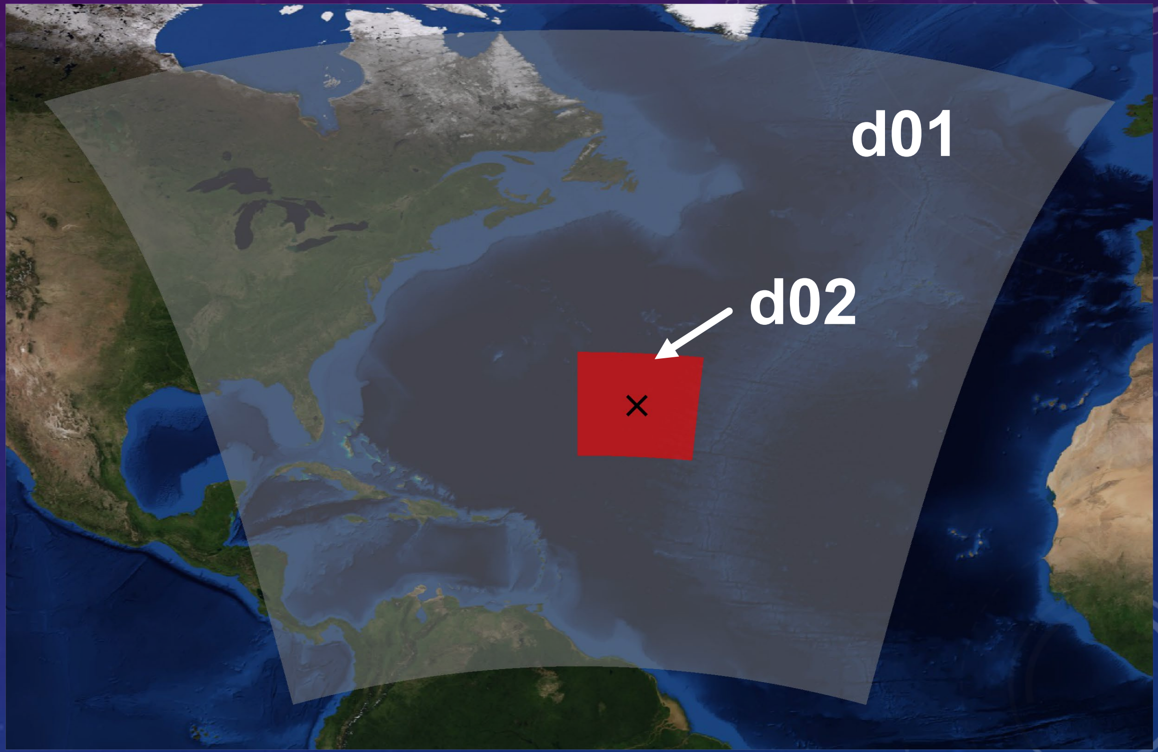
- **Observation Simulation System Experiment (OSSE)**



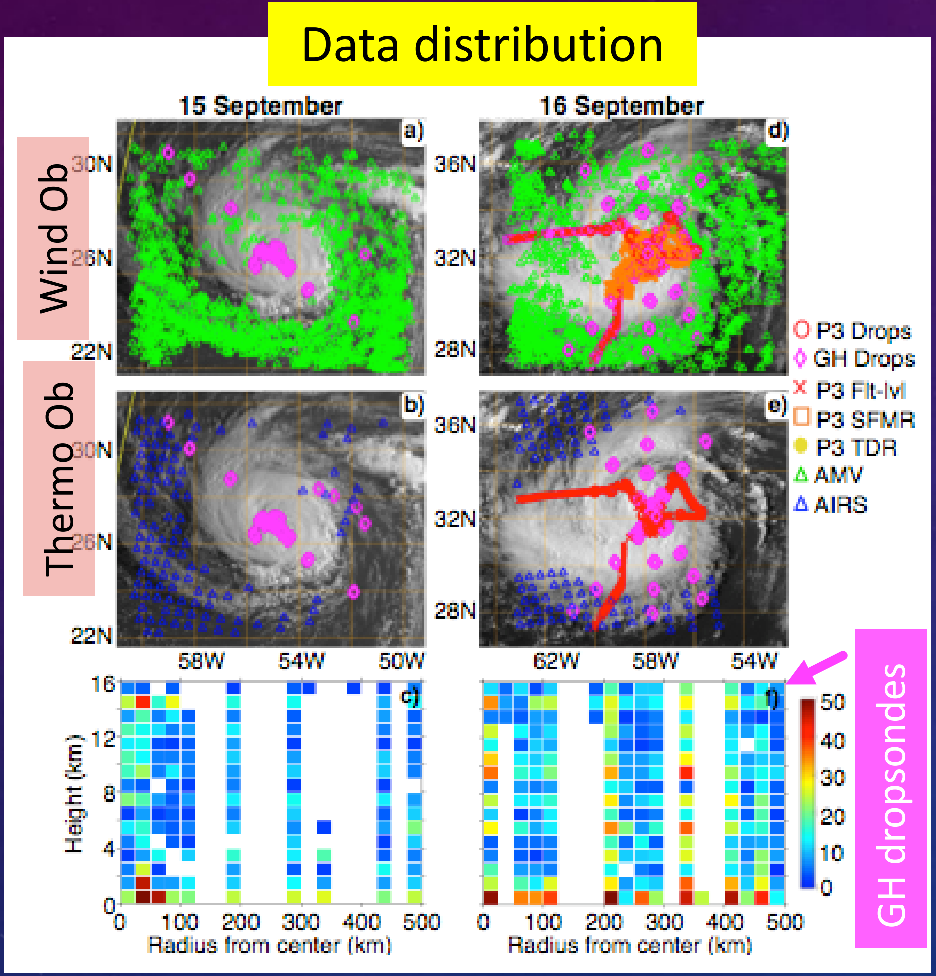
  - Quantify the potential impact of current/proposed observing systems on analyses and forecasts by assimilating synthetic observations simulated from a Nature run
  - Optimize different sampling strategy
  - Assess the limits of the data assimilation scheme

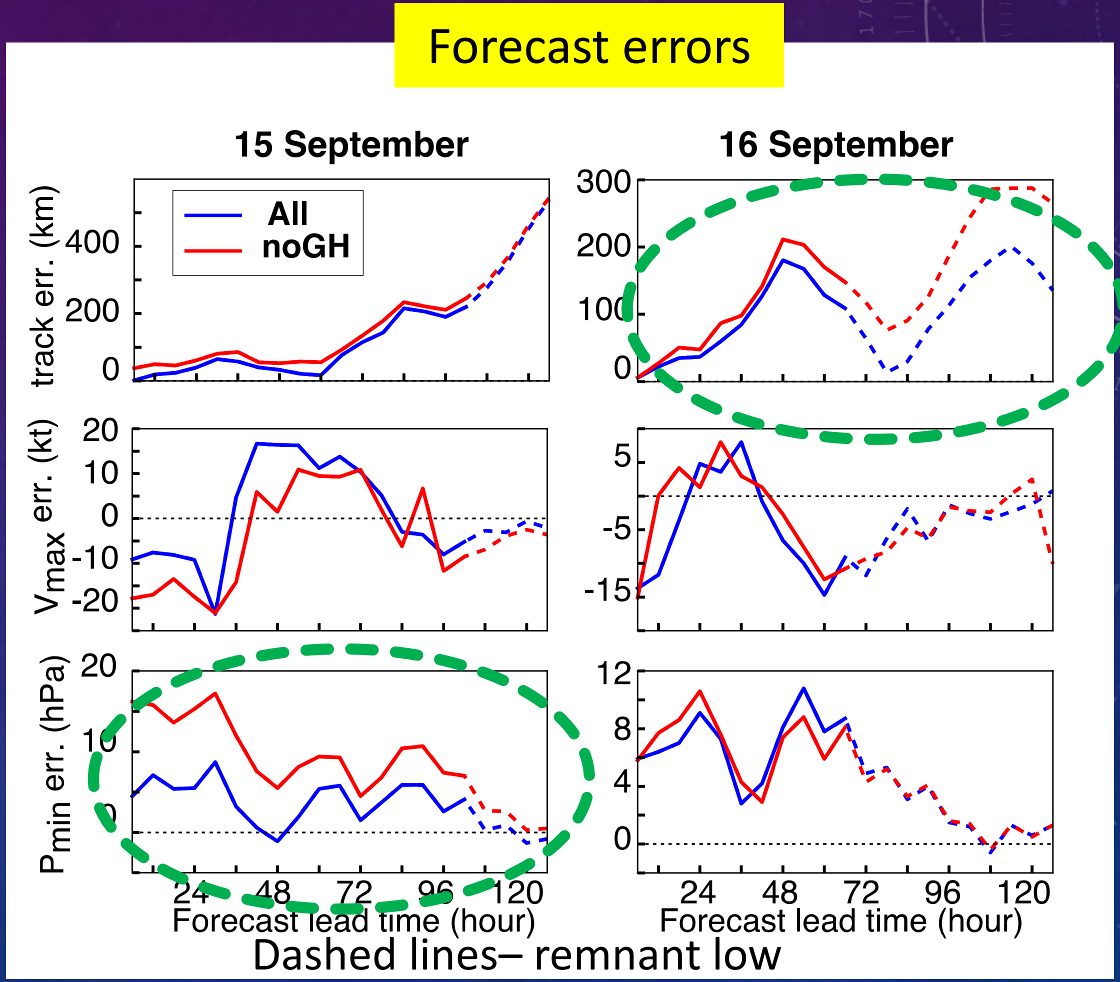
OSE/OSSE to Examine Impacts

- **Domain configuration**
  - **d01 – 9 km** outer domain (no DA)
  - **d02 – 3 km** resolution
    - **HEDAS** (hurricane ensemble data assimilation system, Whitaker and Hamill, 2002)
    - Assimilates conventional, satellite retrievals, GPS RO, TDR, TC vitals in storm relative (Aksoy 2013)
- **Forecast system**
  - HWRF (Gopalakrishnan et al. 2012)



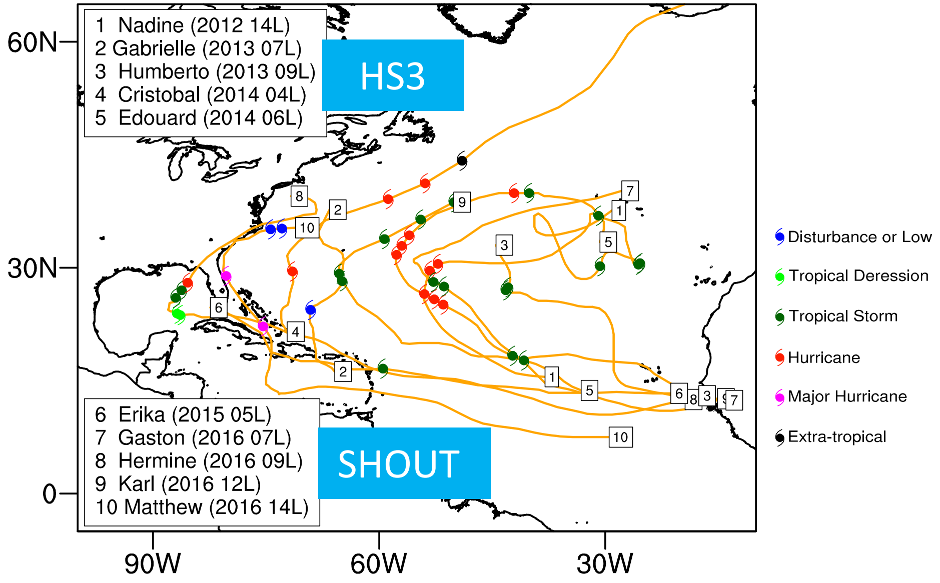
GH Dropsondes Case Studies: Edouard (2014)

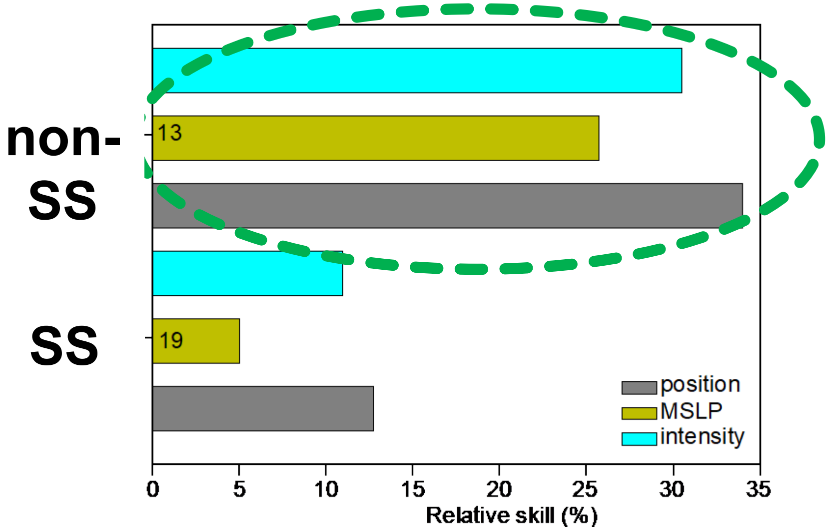


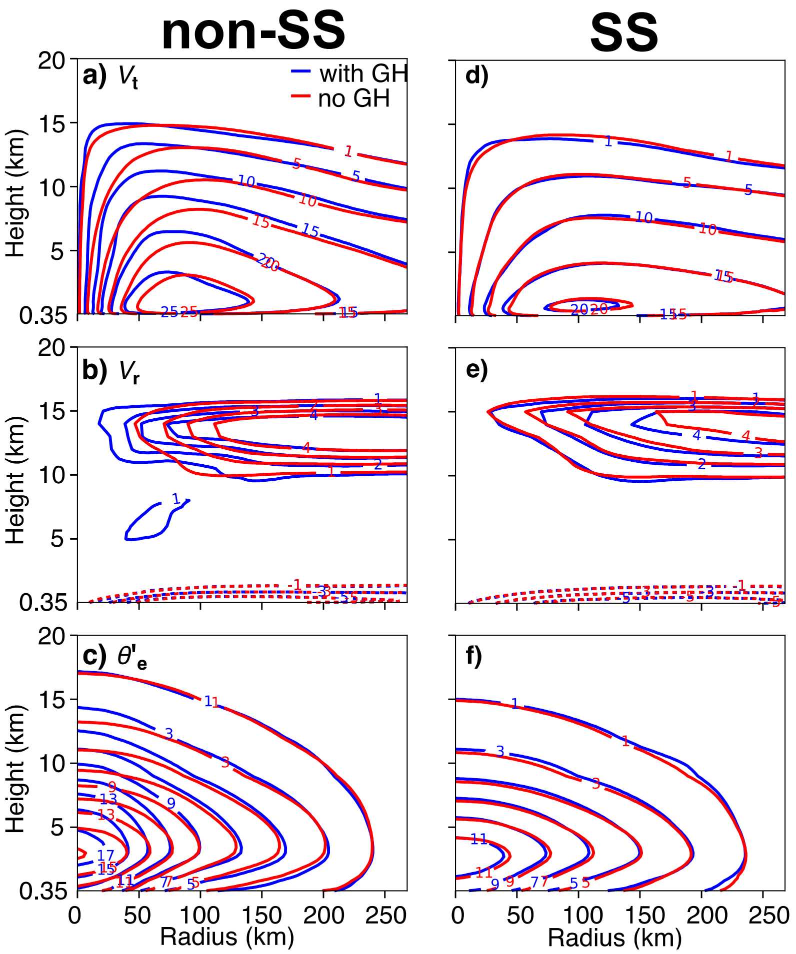


Christophersen et al. (2017)

GH Dropsondes Composite: Analysis







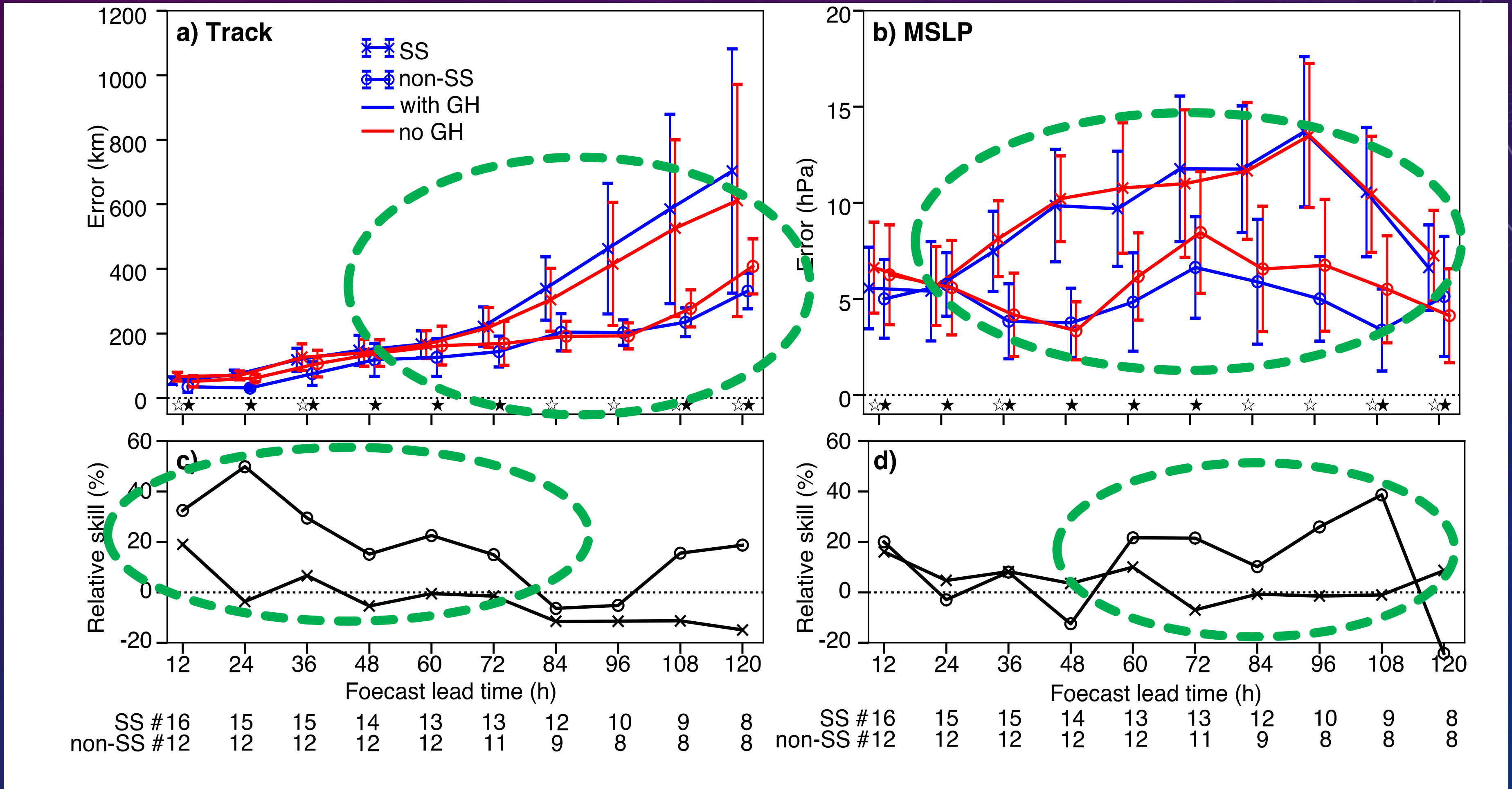
Non-SS: 24-h intensity change ≧ 20 kt

Cases with GH dropsondes

- Higher skills on initial position, intensity, and MSLP for non-SS cases than SS cases
- Noticeable impact on initial TC structure for non-SS

Christophersen et al. (2018a)

GH Dropsondes Composite: Forecasts

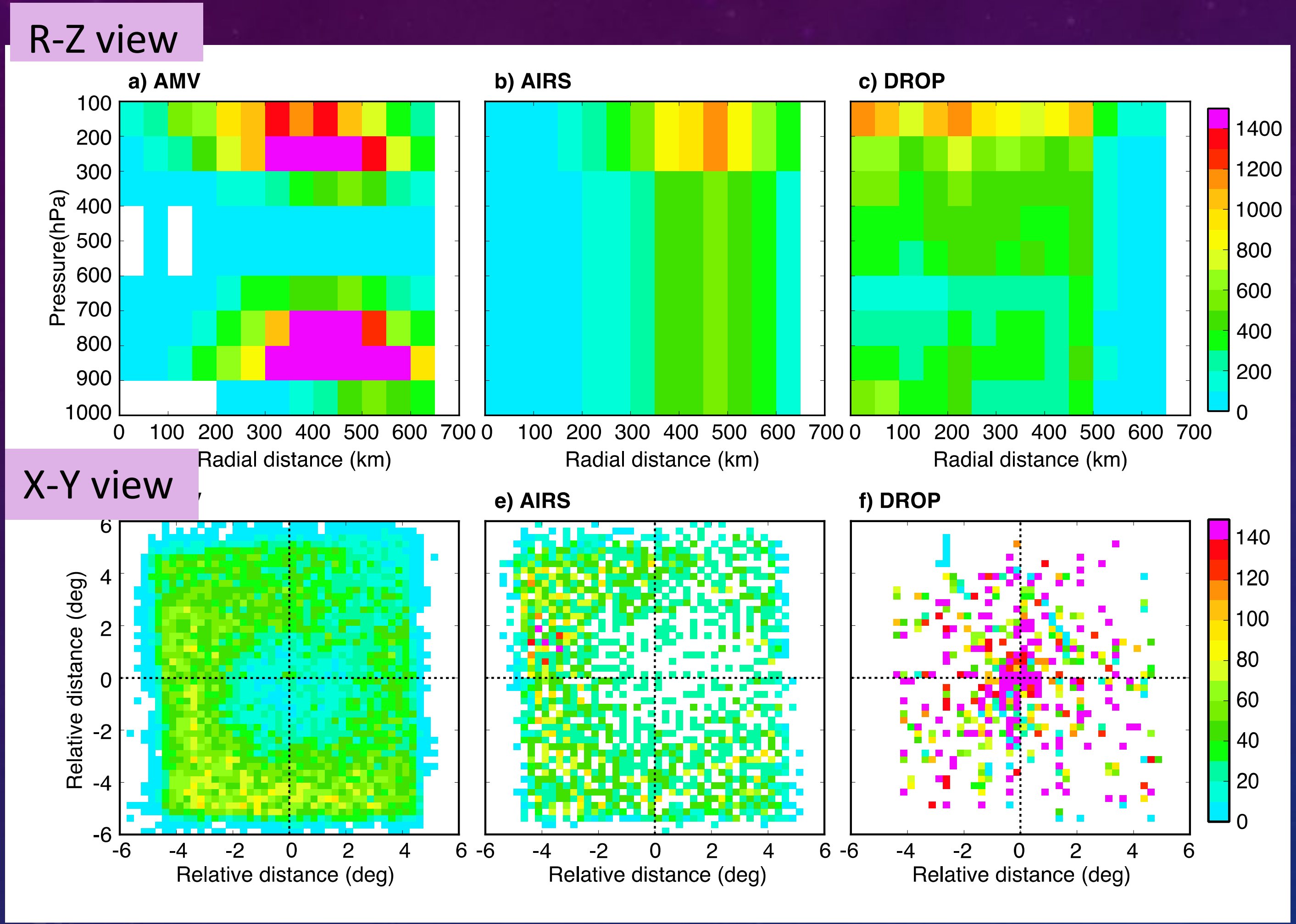


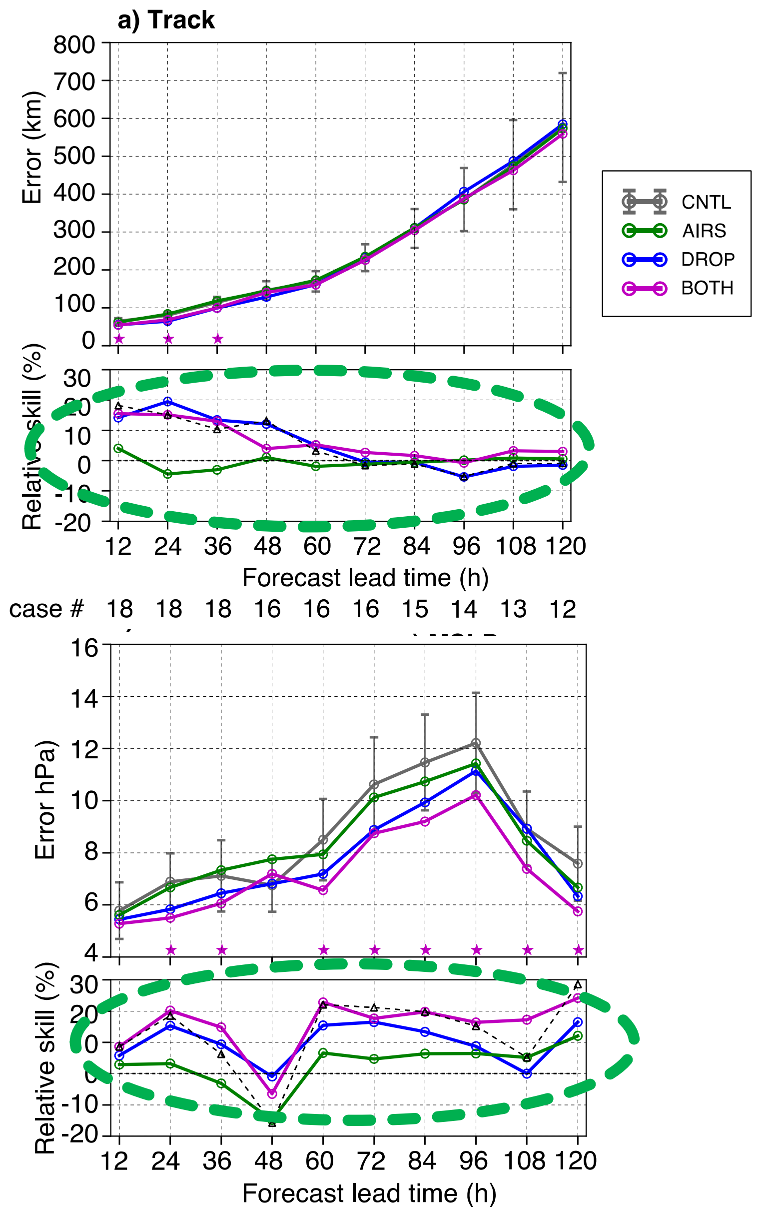
Cases with GH dropsondes

Christophersen et al. (2018a)

- Larger improvement of track forecasts for non-SS cases than SS cases
- MSLP improvement only see at 60-108 h lead time
  - Degradations at 24 h and 48 are outliers dominant->small sample limitations

GH Dropsondes & Satellite Composite



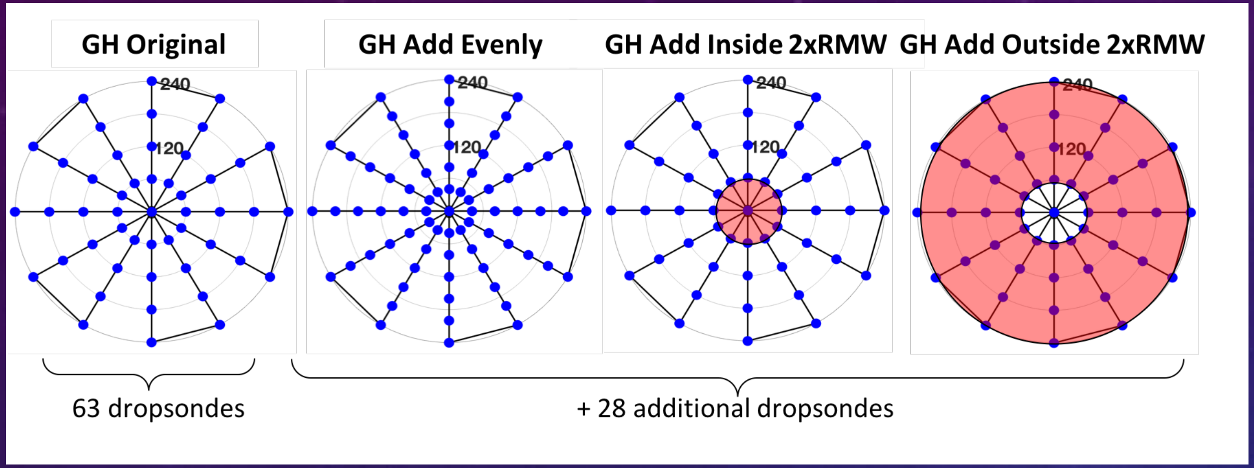


Christophersen et al. (2018b)

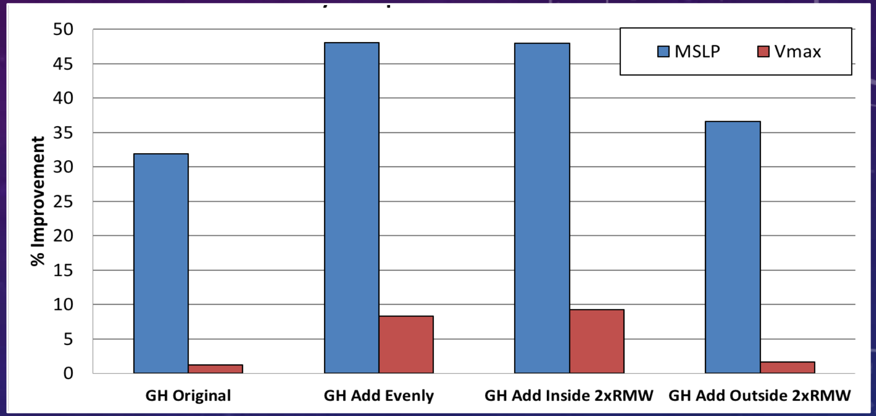
- GH dropsondes complements AIRS and AMV
- Combining both GH dropsondes and AIRS shows better predictions
  - An improvement on the track forecasts throughout the 5-day period
  - More-than-additive and significant intensity improvement

GH Dropsondes Impact in an OSSE

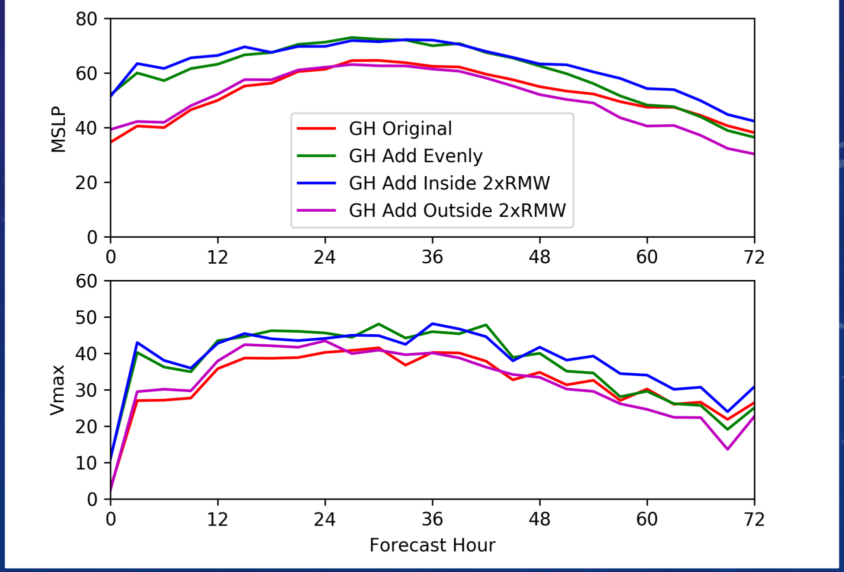
Storm-Relative Global Hawk Flight Pattern with Dropsonde Locations



Analysis Improvement vs. Control



Forecast % Error Improvement vs. Control



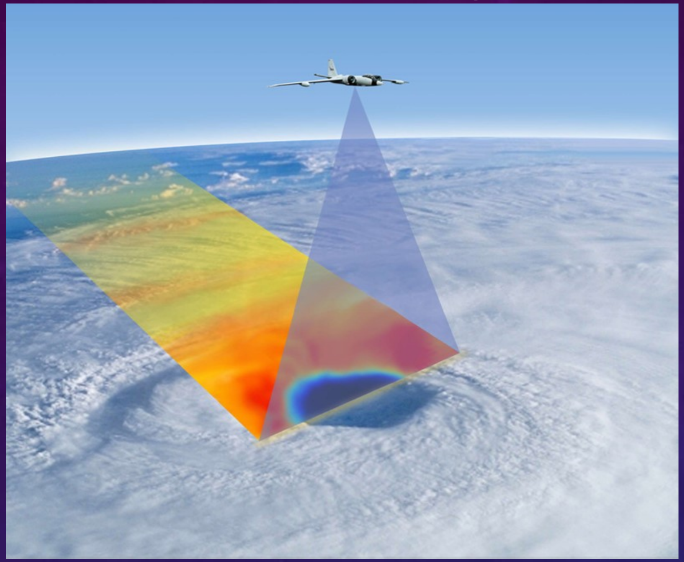
- Experiment setup
  - Control: Simulated P-3 dropsondes, flight level, TDR Vr, SFMR (no Global Hawk obs)
  - 24 cases for each GH dropsonde pattern

- Most overall improvement from **increasing data density within 2xRMW and evenly throughout storm**
  - Analysis inner core wind, moisture structure most similar to NR
  - Greatest reduction in MSLP, max wind forecast error

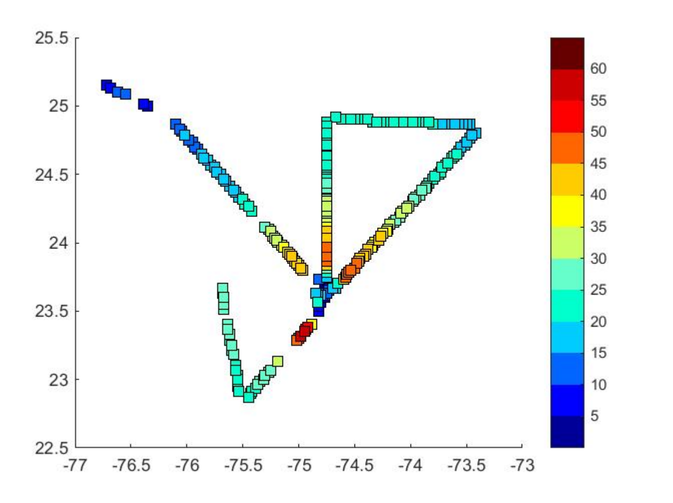
Dahl et al. 2018a

GH HIRAD Impacts on TC Forecasts

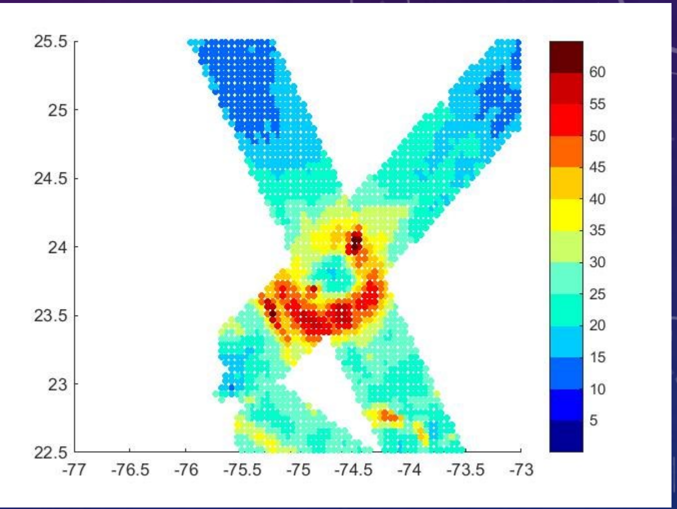
Instrument Coverage



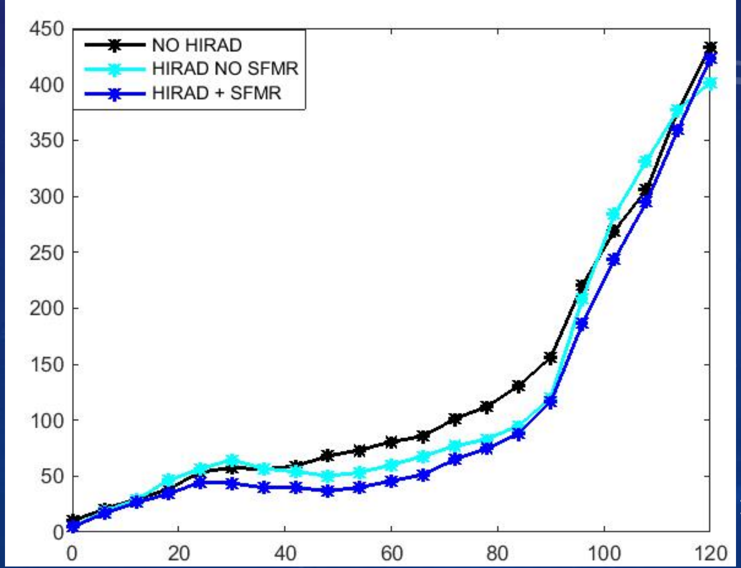
SFMR measured winds



HIRAD measured winds

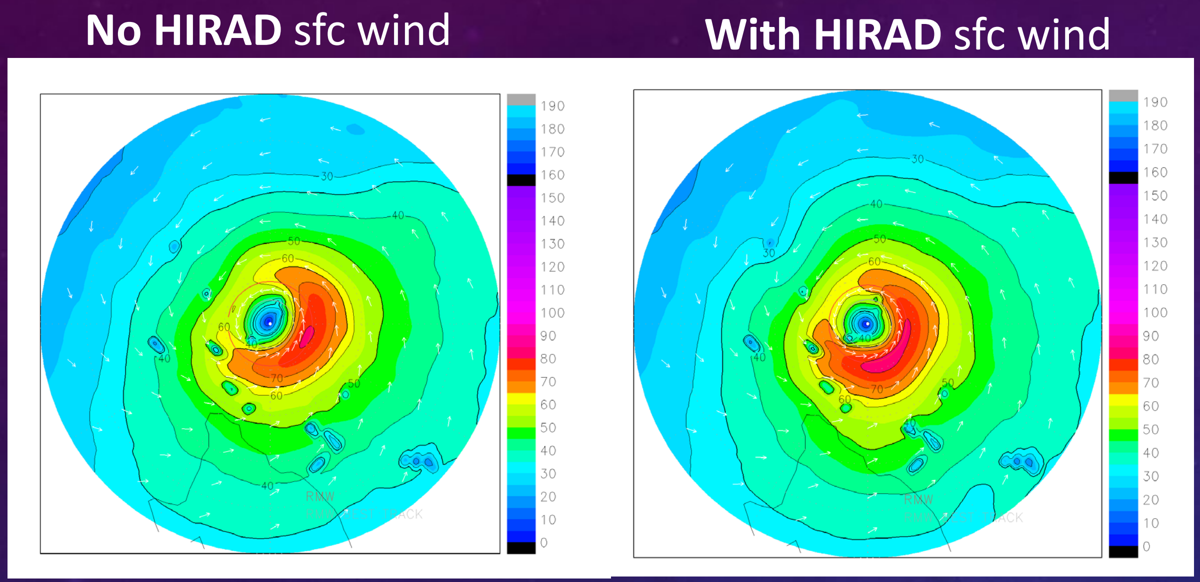


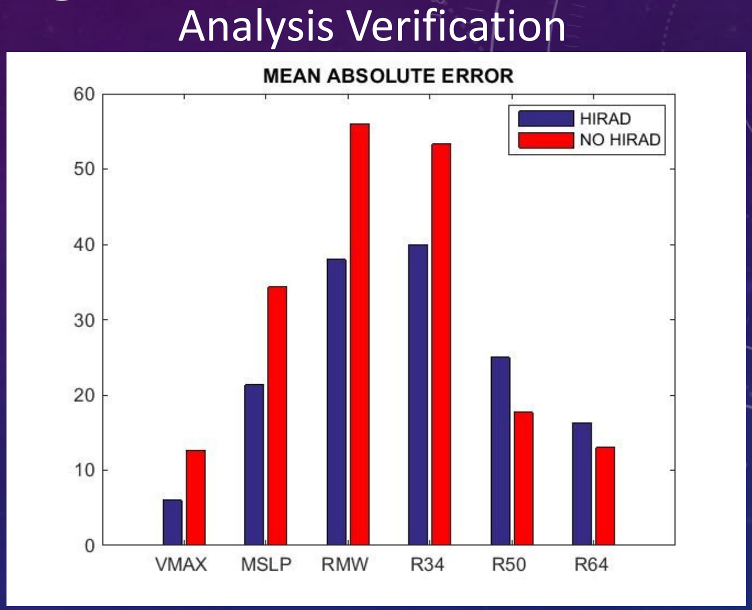
Track Forecast Errors



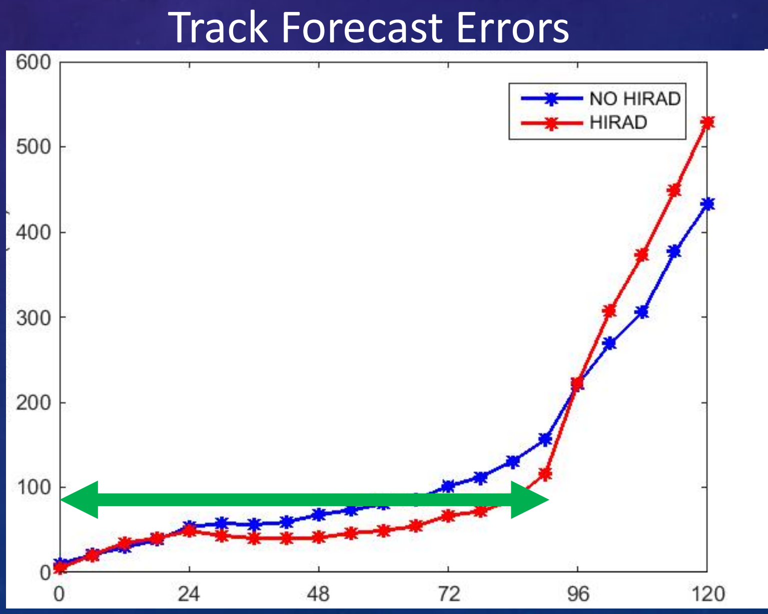
- Passive MW C-Band radiometer to retrieve ocean wind speed and rain rate
- Onboard during HS3 project (2012-14) and Tropical Cyclone Intensity (TCI, 2015)
- HIRAD swath (~ 60km) much wider than crewed aircraft obs (SFMR)
- Impact study tested for 2015 Hurricane Joaquin in an OSE
- Assimilation of both HIRAD and SFMR produces slight improvement in track forecast than just HIRAD alone

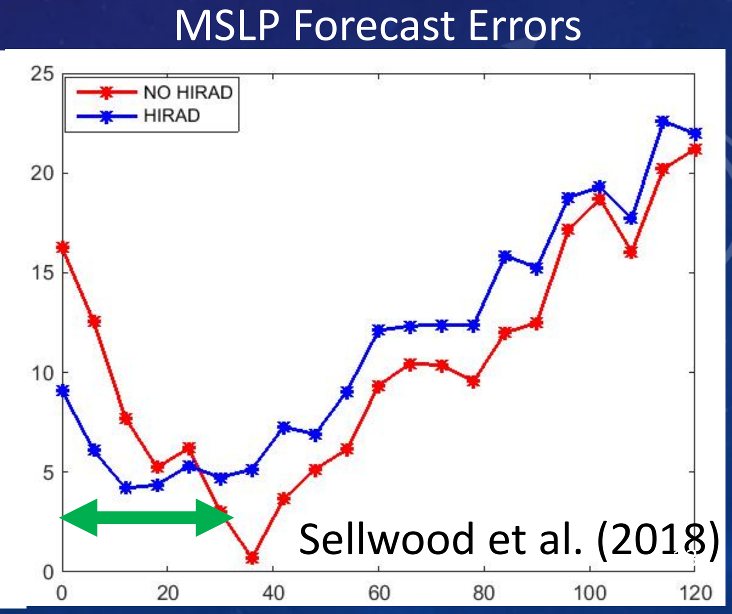
GH HIRAD Impacts on TC Prediction





- Superior analyses in terms of size and intensity result from assimilation of HIRAD surface winds
- Track improvement out to 96 hours
- MSLP improvement to 36 hours
- Greatest improvement using superob data, less frequent cycling and reduced vertical localization

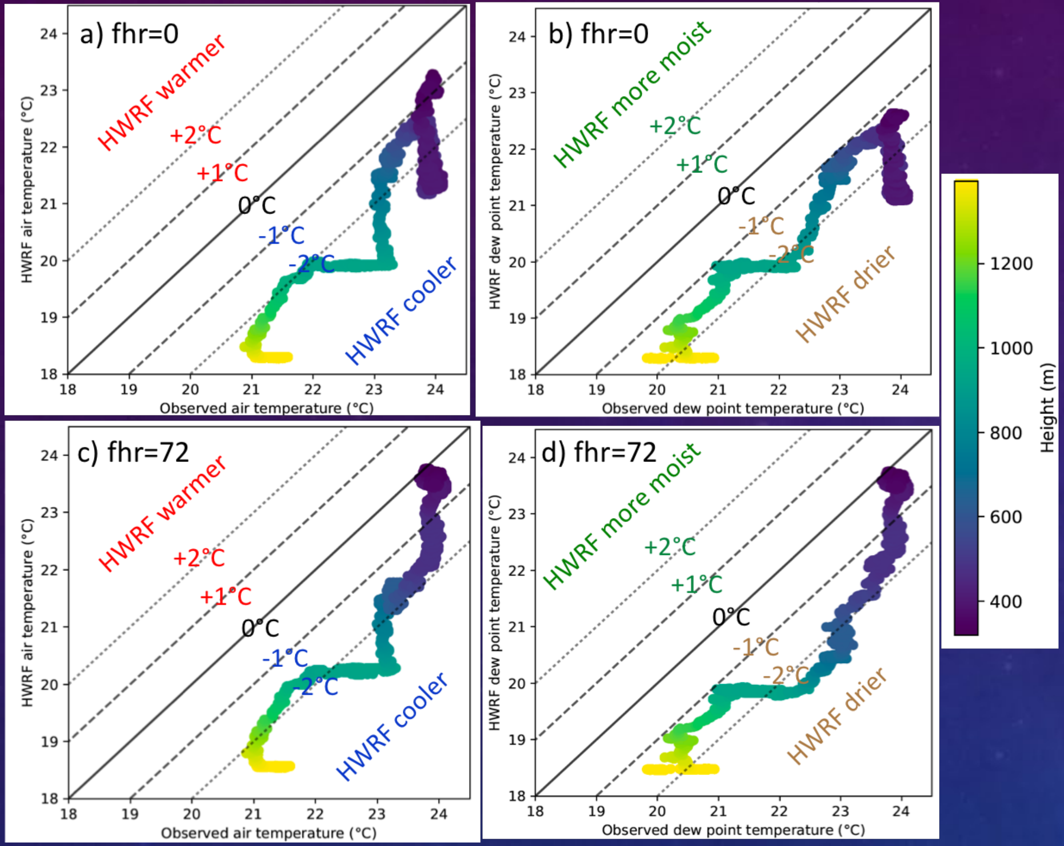




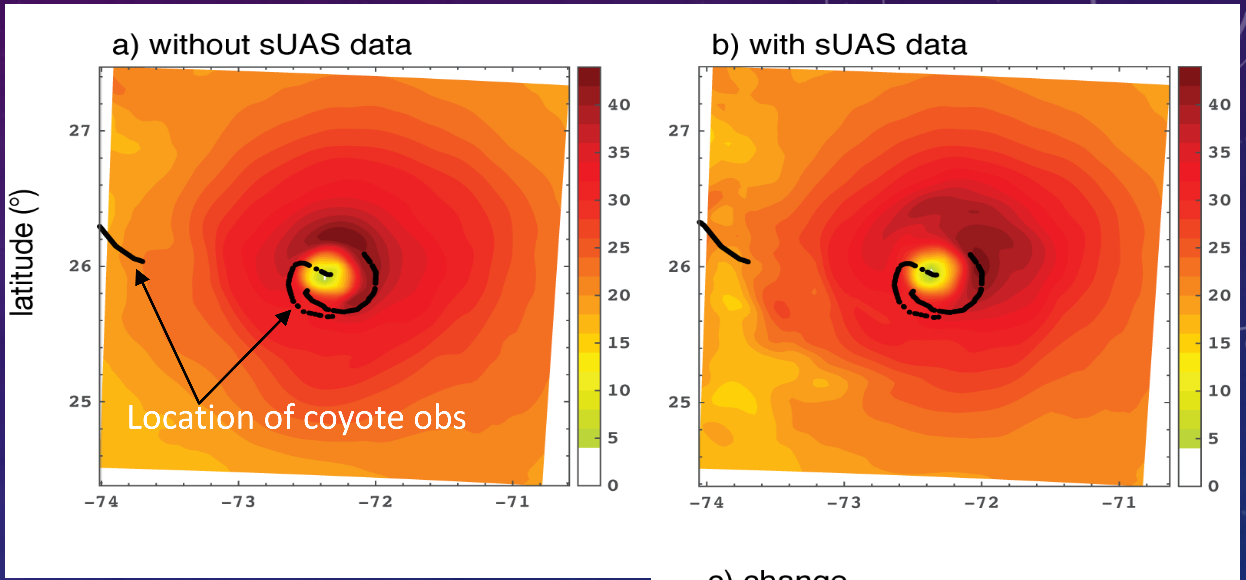
Sellwood et al. (2018)

Coyote Impact on Model Evaluation and Analysis

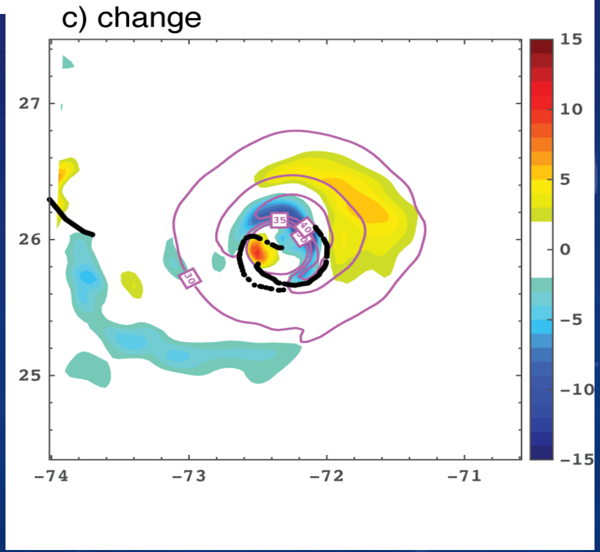
Hurricane Maria (2017)



- The Coyote data show that HWRF had a cool, dry and potentially unstable bias in the boundary layer

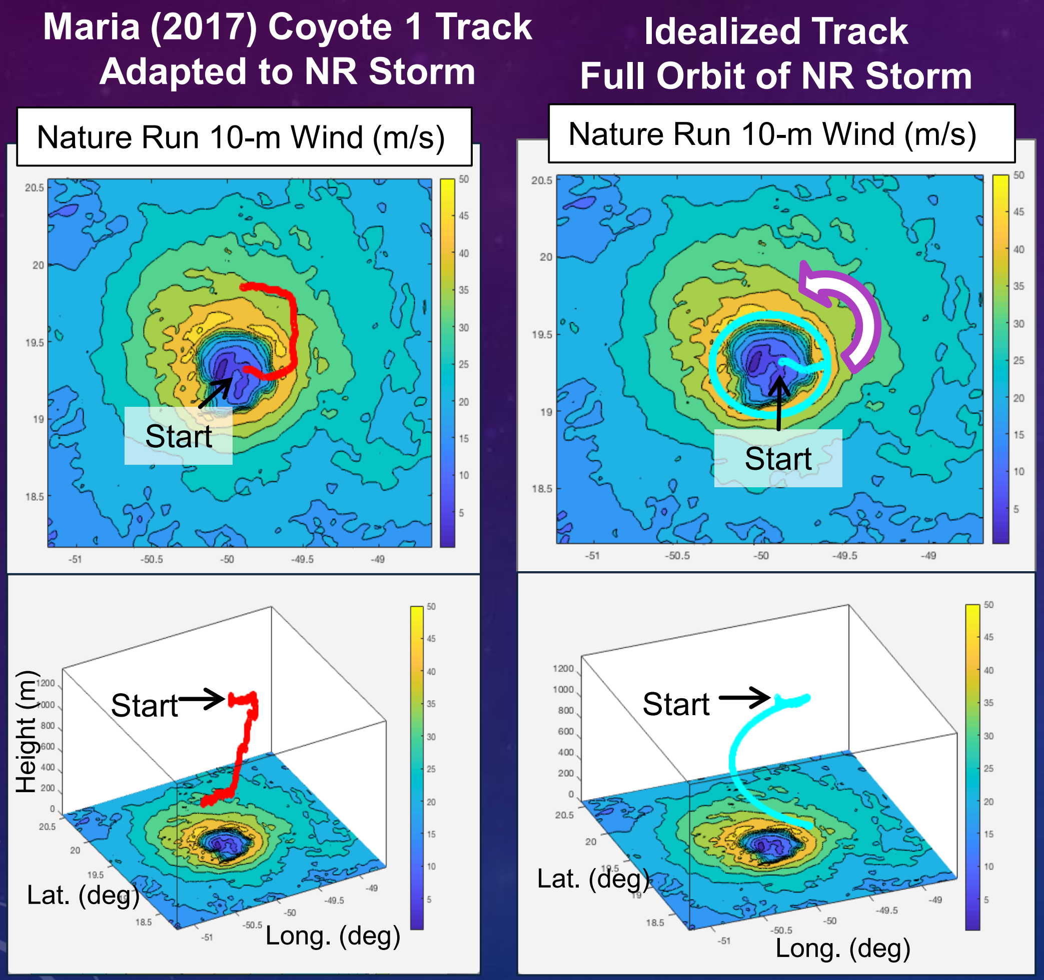


- After assimilating sUAS data, an outward shift of the eyewall in the northeast quadrant of the hurricane, and a decrease in wind speed in the southwest quadrant.



Cione et al. 2019a, accepted

Coyote Impact in an OSSE to Test Flight Trajectory



Dahl et al. 2018b

Control observations:

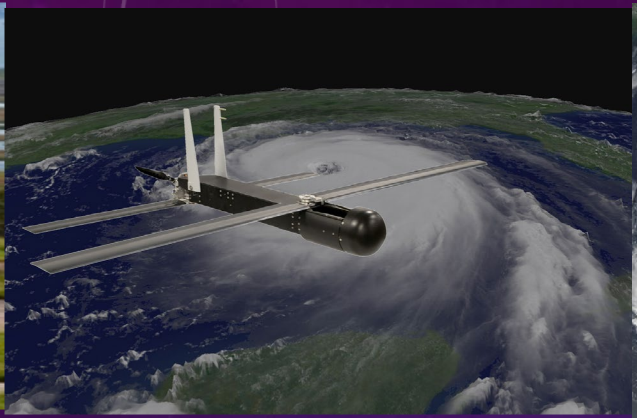
- Simulated P-3 dropsondes, flight level, TDR Vr, SFMR

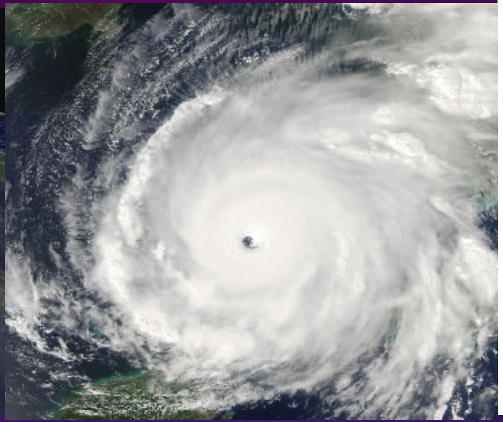
Main findings:

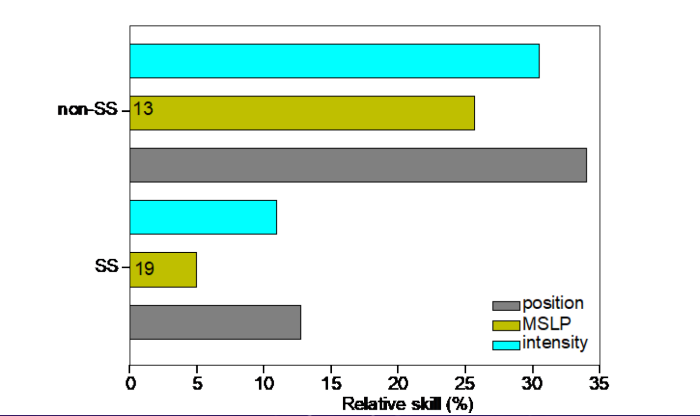
- Coyote obs along idealized full-orbit flight track improved analyzed upper BL storm structure beyond the partial orbit track, e.g.,
  - Stronger super-gradient flow above inflow layer
  - Reduced MSLP error
  - Reduced inner-core moisture error

Planned future work:

- Test flight strategies that incorporate expanded capabilities (e.g., longer endurance) of new sUAS platforms that are currently under development







Summary and Discussions

- GH dropsondes shows greater impacts for quick intensity changing TCs
- GH dropsondes combined with satellite shows more-than-additive improvements on both track and intensity forecasts
- In an OSSE, GH dropsondes achieves the most benefits when increasing data density within twice of the Radius of Maximum Wind (RMW) and evenly throughout storm
- Assimilation of GH HIRAD shows better initial TC intensity and structure representation, improvements on short-range intensity forecast and 4-day track forecast
- Coyote data has potential to validate model boundary layer physics as well as to improve TC initial-time intensity and low-level structure

What's next for NOAA on the Tropical Cyclone sUAS front?

AREA-I

ALTIUS-600

Overview

TC testing in 2020?

- Endurance: 4hrs
  - Includes 40W avionics and 3.5lb payload
  - Increased endurance attainable with more advanced battery chemistries
- Cruise speed: 55 KIAS
- Dash speed: 90 KIAS
- Cruise range: 220 Nm
  - Excludes launch descent glide distance
- Tube-stowed dimensions: 6”x42”
- Deployed wing span: 100”
- Deployed length: 42”
- Gross Weight: 23-25 lbs

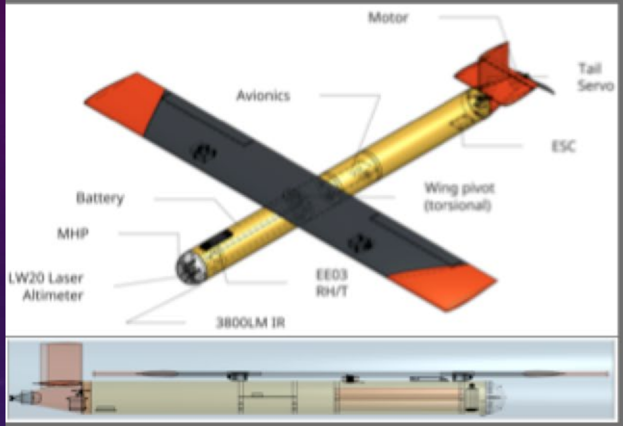
- TRL 8 (TRL 9 by FY2019)
- Fully integrated with the Air Force Common Launch Tube (CLT)
- Modular Payload:
  - Weight: 3-6lbs
  - Volume: 6” diameter by 7” length
  - ISR, Counter UAS, SIGINT, comm relay, kinetic, etc.
  - HoodTech EO, Trillium MWIR/EO, CloudCap/AES MWIR and Laser Designator gimbals available
- Successfully air launched from AC-130J, C-130A, UH-60M Blackhawk, Cessna Caravan, and Beech A36

Cione et al. 2019b

2018 SBIR subtopic: Developing a Cost Effective Air-Deployed UAS for use in Turbulent Environments

TC testing in 2021-22 ?

Black Swift
TECHNOLOGIES

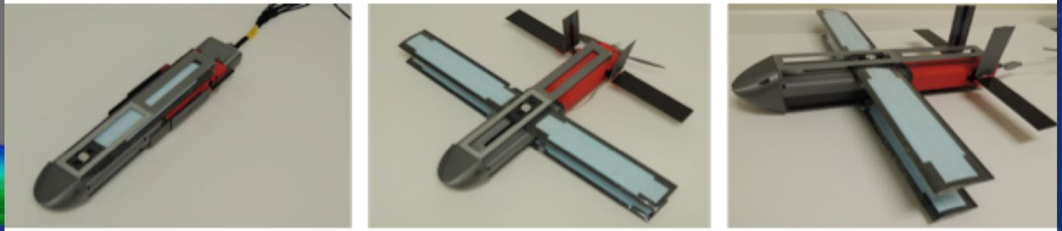


- **S0 Requirements:**
  - GTOW < 2.5 lbs
  - 1-2 hrs cruise endurance
  - Air deployed from tube
  - Routine flights in hurricane conditions
    - Up to 160 mph winds
    - Prec
  - Cost < $

BST PROPRIETARY

Develop from ground-up for NOAA expendable operations

- Target < $1K airframe, not including sensors
- Possible via small business partnership ⇒ flexibility & low overhead
- Barron Associates will build upon prior tube-deployed UAS development ⇒ emphasize 3D printed components
- Trade-off performance (reduced endurance) for cost
  - Compact printable surfaces
  - COTS hardware



Sonotube-UAS developed for NASA

NOAA

BARRON ASSOCIATES
Proprietary

BARRON WINGSONDE - Phase I Outcomes

1. Comprehensive design and functioning prototype of compact, tube-deployed UAS
2. Flight-test validation of aerodynamic configuration
3. Analysis of vehicle performance (endurance, maximum sustained winds, controllability) in a turbulent environment
4. Identification of a sensor suite and communication package
5. Wind estimation algorithms adapted for storm environment
6. Preliminary cost analysis for production system

Cione et al. 2019b

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