WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

8th WMO Workshop

on the Impact of Various Observing Systems on Numerical Weather Prediction and Earth System Prediction

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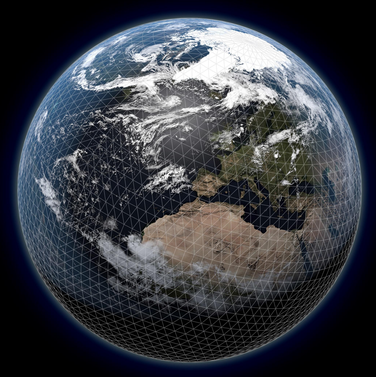
SMHI



IMPACT OF OCEAN OBSERVATIONS, FEATURES AND PROCESSES ON TROPICAL CYCLONE PREDICTION

P2.2

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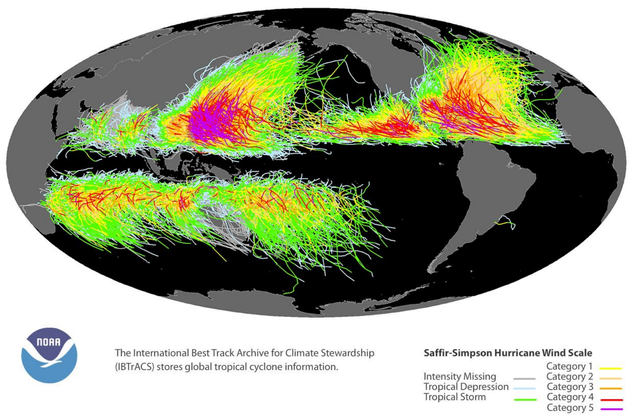
INTRODUCTION

- **Tropical Cyclones** (TCs) are among the most dangerous and destructive weather events worldwide, annually impacting >20M people with >$50B in losses.[1] – *Negative Societal Impacts*
- TC impacts are amplified by **rising sea levels, warming oceans,** and **heavier rainfall**, disportionately affecting small **developing states**.[2] – *Exasperated by Climate & Equity Trends*
- Improved TC **forecasts and warnings** will save lives & property, and promote equity & resiliency, across the globe. – *Response Value Chain*
- Modern **Earth System** forecast models require more **ocean data**, especially subsurface, to help improve forecast accuracy and extend forecast lead times. – *Reverse Flow of Requirements*



The International Best Track Archive for Climate Stewardship (IBTrACS) stores global tropical cyclone information.

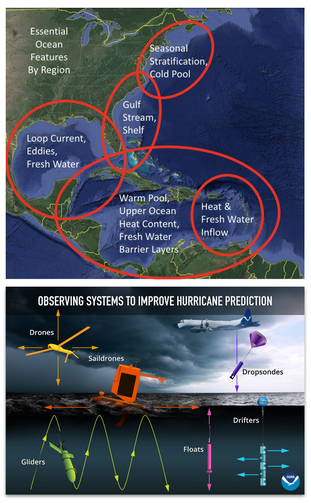
Saffir-Simpson Hurricane Wind Scale
Intensity Missing
Tropical Depression
Tropical Storm
Category 1
Category 2
Category 3
Category 4
Category 5

Requirements flow back through the Value Chain:

- **Emergency Managers** require accurate forecasts with longer lead times to make successful decisions such as evacuate vs. shelter in place.
- **Forecast Centers** require improved numerical model guidance to issue the most effective forecasts and warnings.
- **Modeling Centers** require atmospheric and ocean data for assimilation in Earth system models. Ocean data, especially subsurface, is limited.
- **Observing Systems Operators** require permissions to collect data in regions that cross national jurisdictions[3].

CASE STUDIES: OBSERVATIONAL IMPACTS

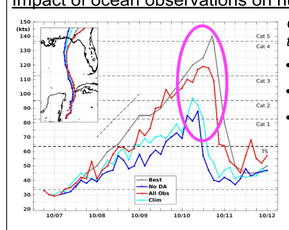
Tropical Americas & Caribbean (TAC)



- Essential Ocean Features & Observing Systems identified
- OSEs in Michael[4], Maria, Ida, Idalia demonstrate impact
- Hurricane Glider fleet deployed since 2018

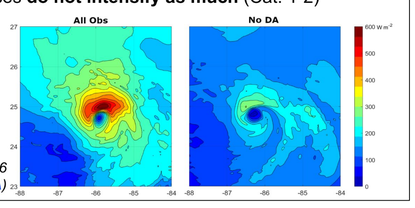
Hurricane Michael (2018)

Impact of ocean observations on hurricane forecasts: example of a 5-day cycle



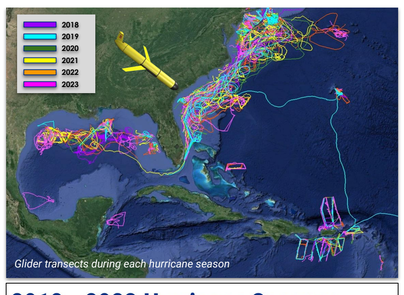
*Observed wind intensities (Best, grey), with simulated ones for the **All Obs**, **No DA**, **Clim** cases starting on 6 Oct., 18Z.*

- Hurricane **tracks close to observed**
- ***All Obs*: rapid intensification to Cat. 4**
- Unconstrained (***No DA***) and climatology (***Clim***) cases **do not intensify as much** (Cat. 1-2)



- **Ocean DA** leads to **higher energy fluxes** from the ocean toward the hurricane

*Surface enthalpy flux averaged over the 60-66 hour period (left: **All Obs**, right: **No DA**)*



Glider transects during each hurricane season

2018 - 2023 Hurricane Seasons

Keeping models on track:

420	Glider deployments
19,507	Glider days at sea
714,413	Glider temperature and salinity profiles

Contributing to intensity forecasts:

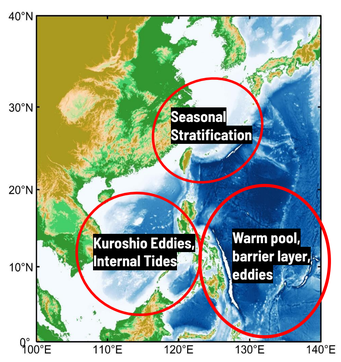
31 of 42 (74%)	Named storms aimed at U.S. waters had gliders in 5-day forecast cone
8 of 9 (90%)	Major hurricanes aimed at U.S. waters had gliders in 5-day forecast cone

Fortuitous data collection for research:

68 Glider-intercepts across *25* named storms

North Pacific Ocean & Marginal Seas (NPOMS)

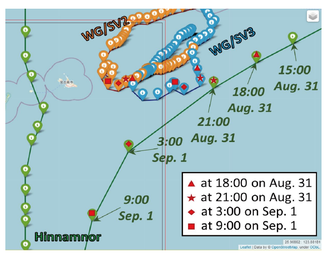
NPOMS Essential Ocean Features

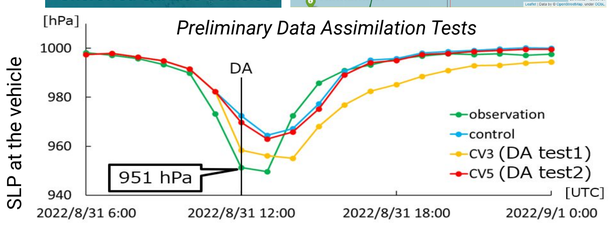


- **Yellow Sea** – coastal seasonal stratification
- **South China Sea** – deep Kuroshio eddies
- **Open Ocean** – warm pool, salinity barrier layers, mesoscale eddies

Credit: Dr. Shoude Guan

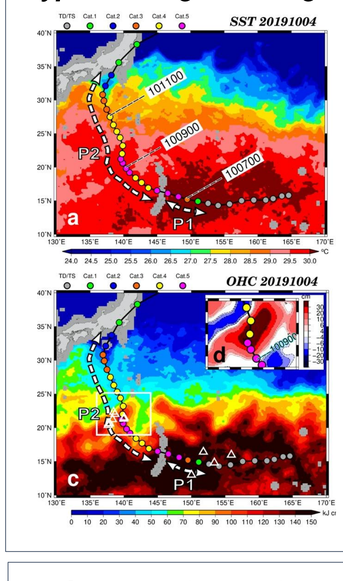
Typhoon Hinnamnor & Air-Sea Interactions[6]

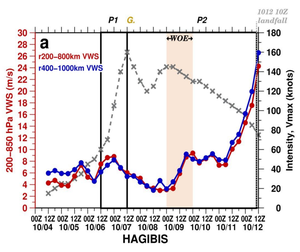




- **Super Typhoon** – passing south of Japan
- **Air-sea Interactions** – two uncrewed surface vehicles
- **Surface Pressure** – data assimilative models match observations

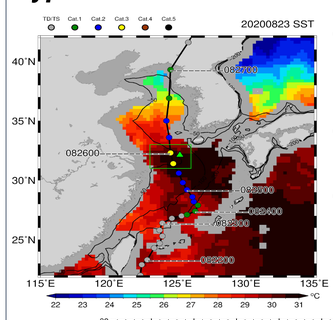
Typhoon Hagibis & High Ocean Temperatures[5]

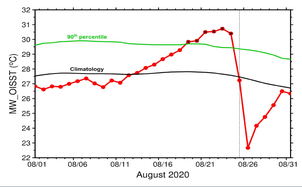


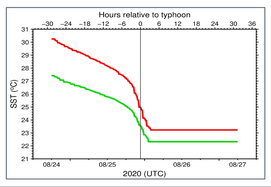


- **Fastest Intensification** – 3.3 x RI Threshold
- **High SST and OHC** —Argo profiles
- **Low Wind Shear** – RI over warm pool and intensification approaching warm eddy

Typhoon Bavi & Marine Heat Waves[7]







- **Intensification over Yellow Sea** – region where typhoons usually weaken
- **Marine Heat Wave** – Korean IEODO Platform observations
- **Increased Stratification** – warmer surface waters delays mixing with cooler subsurface waters

GOOS | Ocean Observing Co-Design

by The Global Ocean Observing System

Tropical Cyclone Exemplar

Purpose & Deliverables

The Tropical Cyclone Exemplar, an initiative under the GOOS Ocean Observing Co-Design Programme, aims to co-design ocean observing systems for improving tropical cyclone forecasts and warnings **regionally** and **globally**.

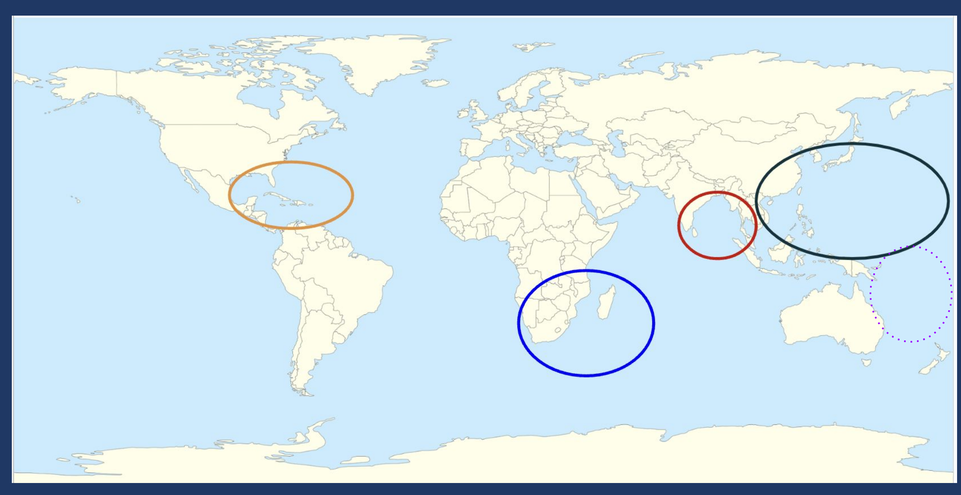
The Exemplar proposes to deliver:

- Co-designed, regionally distributed ocean observing pilot studies – *to develop collaborative capacity and demonstrate mutual value*
- Increased coverage and delivery of ocean data to forecasting centers and scientists – *to expand critical observations across international borders[3] and support predictions and services*
- More accurate characterization & understanding of essential ocean features & air-sea processes – *to improve Earth System Models & tropical cyclone forecasts*

Global Approach Accelerated by Regional Pilots

The Tropical Cyclone Exemplar has defined four regional pilot studies to advance the principles of ocean observing co-design and improve tropical cyclone forecasts and warnings:

- Tropical Americas and Caribbean (TAC) – *Capacity building for the most damaging TCs*
- Southwest Indian Ocean (SWIO) – *Co-designing the response to the triple threat of changing BCs, MHWs and TCs*
- Bay of Bengal, Indian Ocean – *Fostering national networks for the most deadly TCs*
- North Pacific Ocean and Marginal Seas (NPOMS) – *Coupled air-sea science in the most intense TCs*
- *Tentative:* Pacific Islands – *Initial co-development of regional stakeholder needs*



Each proposed pilot study has different regional needs for ocean observing and different capacities for implementation. The pilots will accelerate progress regionally and lessons learned will be shared globally.

DISCUSSION

- **Essential Ocean Features** impacting TC intensity in both deep & shallow water have been identified for initial pilot studies aligned with GOOS Regional Alliances.
- **Observing System Experiments** (OSEs) and **coupled atmosphere-ocean model sensitivity studies** demonstrate the value of properly representing Essential Ocean Features & Air-Sea Interactions in Earth System models.
- The **TAC pilot study** is focused on filling subsurface data gaps across SIDS through **capacity development** with autonomous floats and uncrewed gliders.
- The **NPOMS pilot study** is focused on filling knowledge gaps in **air-sea interactions** during the strongest TCs with uncrewed surface vehicles.
- Lessons learned in **regional pilot studies** are **shared globally** across GOOS and are being expanded to Indian Ocean and Pacific Island regional pilots.
- Pilot studies increase the variety of **case studies** with **concurrent atmosphere, near surface ocean & subsurface ocean datasets** for advanced model coupling & OSEs

References

[1] Krichene et al. 2023. The social costs of tropical cyclones. *Nat Commun* 14, 7294.
[2] WMO Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970-2019), WMO-No. 1267.
[3] Ocean Observations in areas under National Jurisdiction (OONJ) GOOS Expert Meeting Report (2020), GOOS-246.
[4] Le Hénaff et al. 2021. The Role of the Gulf of Mexico Ocean Conditions in the Intensification of Hurricane Michael (2018). *JGR Oceans* 126, e2020JC016969.
[5] Lin et al. 2021. A Tale of Two Rapidly Intensifying Super Typhoons: Hagibis (2019) and Haiyan (2013). *Bull. Amer. Meteor. Soc.*, 102, E1645–E1664.
[6] Kosaka et al. 2023. Simultaneous Observations of Atmosphere and Ocean Directly under Typhoons Using Autonomous Surface Vehicles. *SOLA*, Vol.19, 101-104 (TBA).
[7] Pun et al. 2023. Marine heatwave as a supercharger for the strongest typhoon in the East China Sea. *npj Clim Atmos Sci* 6, 128.

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