Data Buoy Cooperation Panel (DBCP) Capacity Building Workshop on Ocean Observations for Operational Services in the Indian Ocean Region

Hyderabad, India, 05 – 07 August 2025

The Role of New Autonomous Ocean Observing Technologies in Reliable Predictions of Tropical Cyclones

Scott Glenn, Rutgers University, USA
& Cheyenne Steinbarger, NOAA, USA
Global Ocean Observing System (GOOS) Co-Design Programme's
Tropical Cyclone Exemplar

WORLD METEOROLOGICAL ORGANIZATION

1950-2025 SCIENCE for ACTION

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  - Mission, Networks, Co-Design, Exemplars, WMO Engagement
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  - North Pacific Ocean and Marginal Seas (NPOMS)
- **Opportunities in the Indian Ocean**
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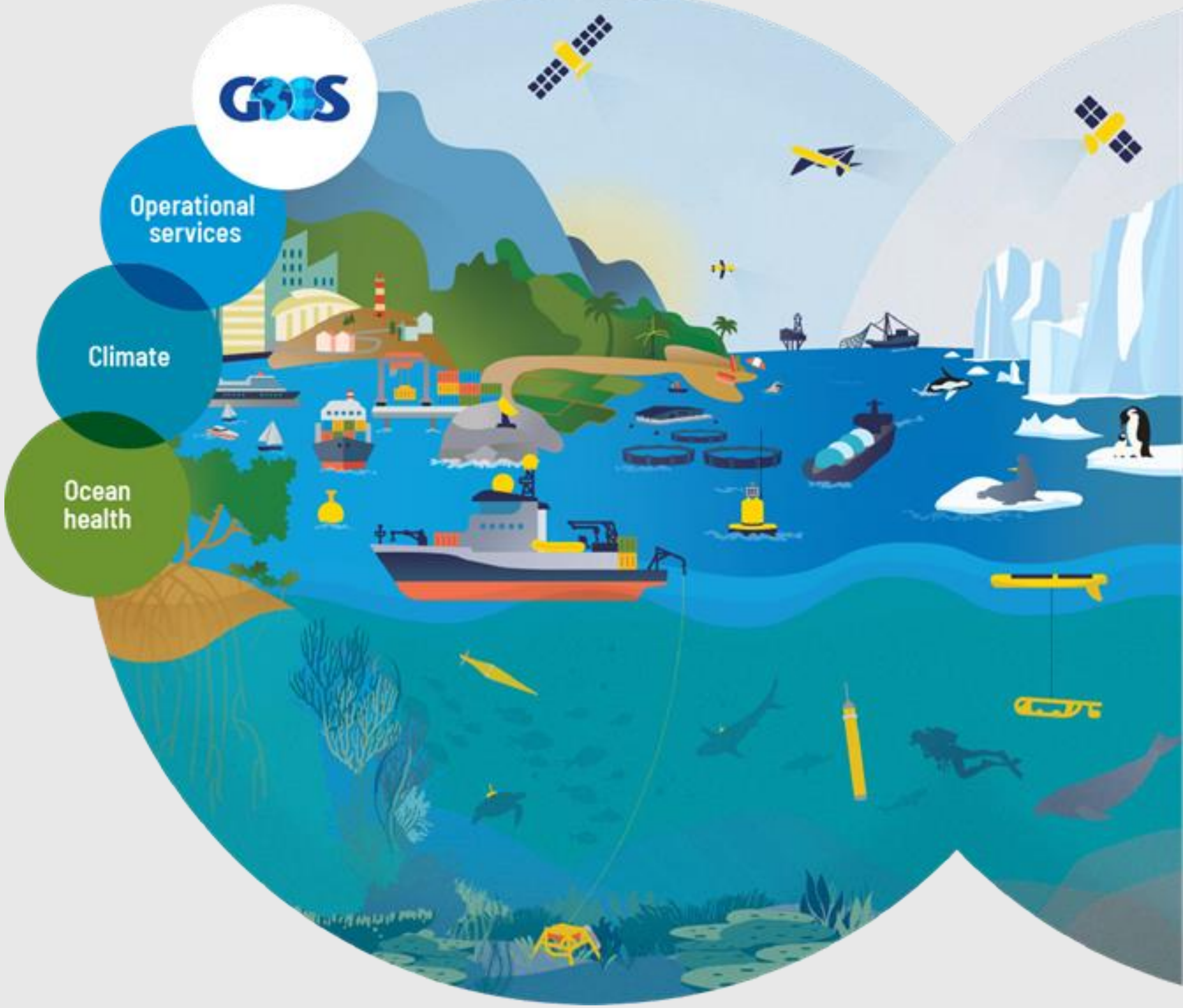
  - South West Indian Ocean (SWIO)

Global Ocean Observing System

GOOS is an **Intergovernmental Oceanographic Commission (IOC)**-led programme. The IOC is part of UNESCO.

Since 1991, GOOS has been leading the development of a truly global ocean observing system that delivers the essential information needed for our sustainable development, safety, wellbeing and prosperity.

Three Focus Areas reflect major societal needs: Climate, **Forecasts & Warnings**, Ocean Health



https://goosocean.org/

Observations Coordination Group / Observing Networks

The Observations Coordination Group (OCG) works to **guide** and **strengthen** the implementation of the Global Ocean Observing System (**GOOS**) and WMO Integrated Global Observing System (**WIGOS**) through identifying, coordinating and developing relevant initiatives across the global ocean observing networks.

https://goosocean.org/who-we-are/observations-coordination-group/global-ocean-observing-networks/

GOOS
in situ networks[1]

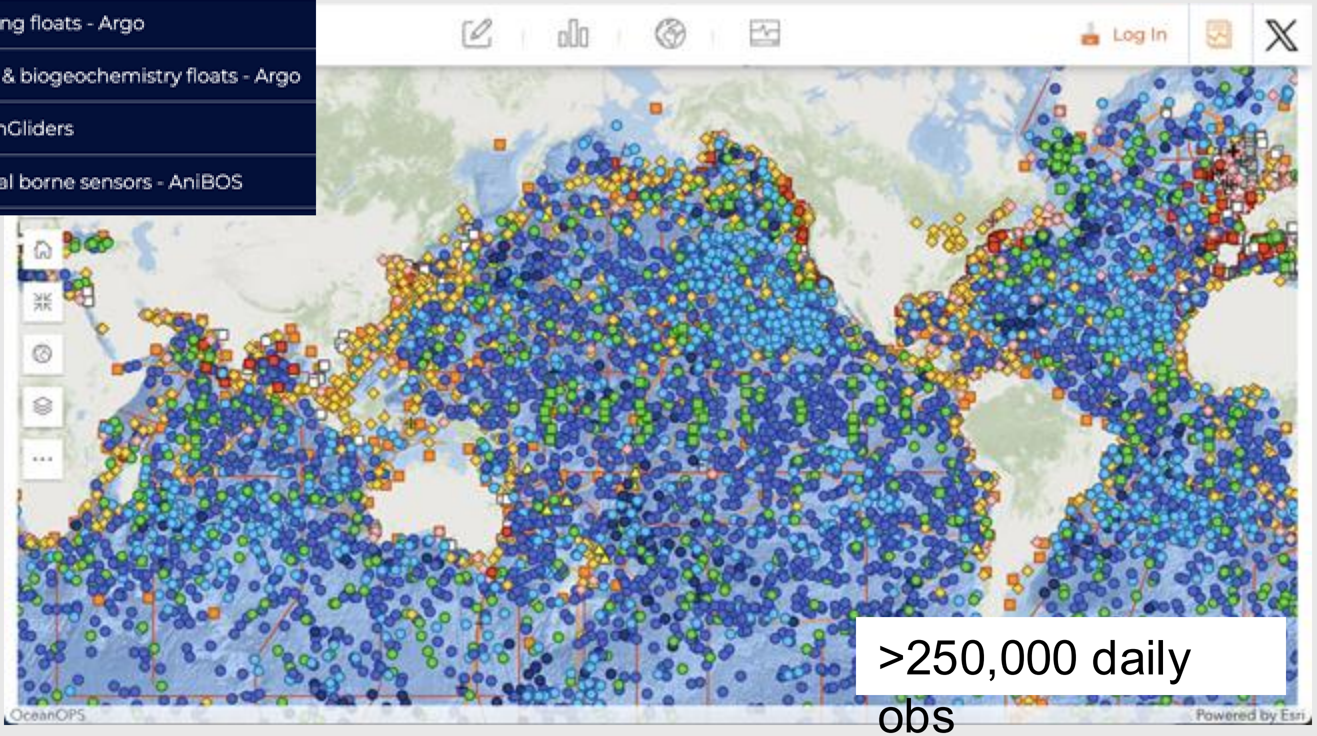
- Ship based meteorological - SOT
- Ship based oceanographic – SOT
- Repeated transects - GO-SHIP
- Sea level gauges - GLOSS
- Time series sites - OceanSITES
- Coastal Moored buoys – DBCP
- Tsunami buoys - DBCP
- Tropical moored buoys - DBCP
- HF radars
- Drifting buoys - DBCP
- Profiling floats - Argo
- Deep & biogeochemistry floats - Argo
- OceanGliders
- Animal borne sensors - AniBOS

Argo

Ocean Gliders

FVON
Fishing Vessel Observing Network

ANIBOS



>250,000 daily obs

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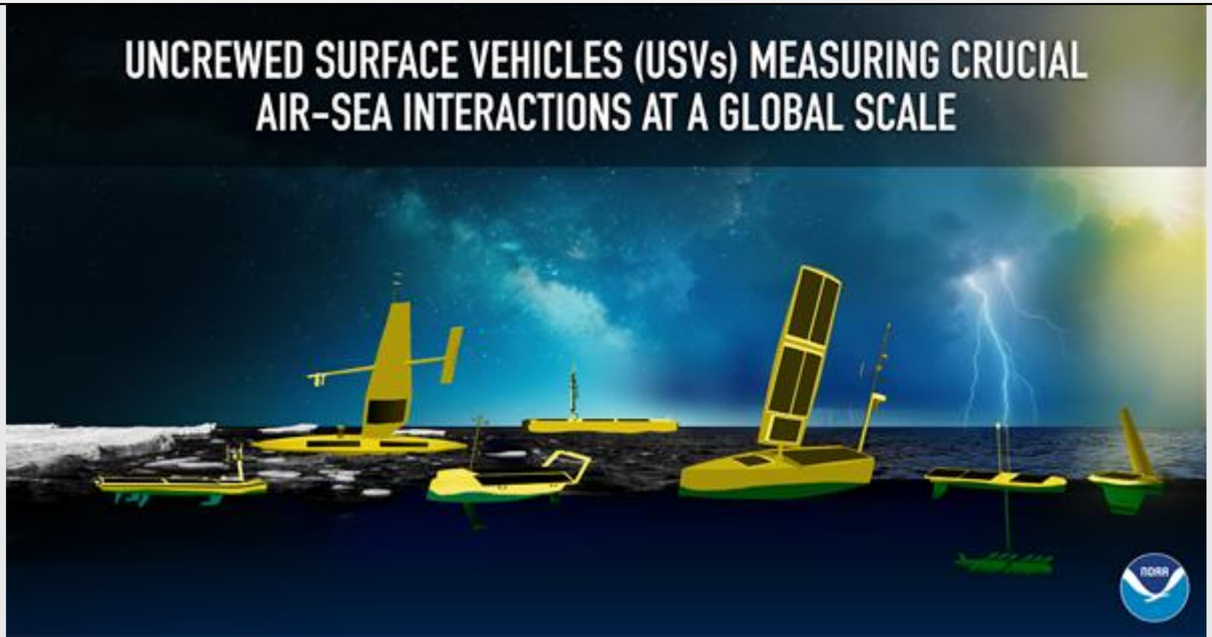
News

Uncrewed Surface Vehicles Go Global: SUN Fleet Joins GOOS as a New Emerging Network

July 4, 2025

A new emerging ocean observing network joins the Global Ocean Observing System (GOOS), marking a key step in expanding coordinated, global ocean surface observations. This fleet of Uncrewed Surface Vehicles, called SUN Fleet, is able to monitor numerous GOOS Essential Ocean Variables and measure important air-sea exchanges in remote areas and under harsh conditions.



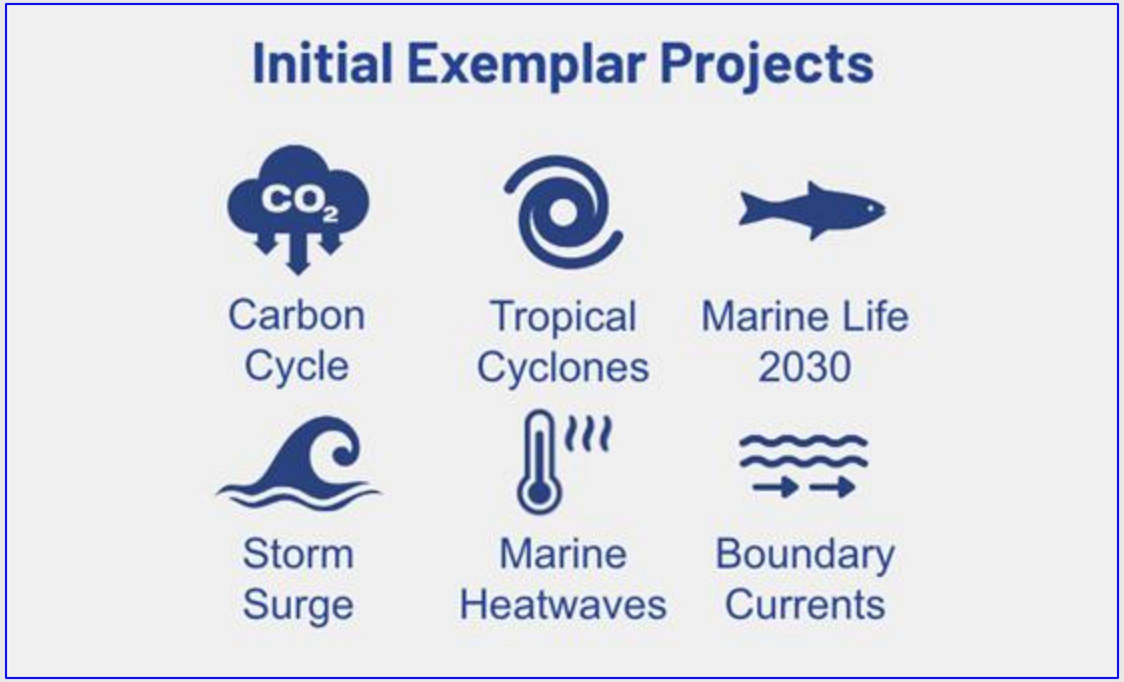
GOOS

Ocean Observing Co-Design

Co-design is about working with end-users of ocean information, in collaboration with ocean observing, modelling and forecasting services, to **understand what information is needed** by whom, to **define the value chain**, and **design an observing system** that can deliver it effectively.

The Programme's approach for piloting and refining co-design processes is to work through an initial set of **Exemplar Projects**.

https://goosocean.org/what-we-do/goos-at-the-heart-of-the-ocean-decade/ocean-observing-co-design/



Tropical Cyclone Exemplar

Tropical Cyclones are among the most destructive weather events on Earth. Impacts are amplified by a warming ocean and rising sea levels. Impacts disproportionately affect less developed countries and small island developing states.

Enhancing ocean observing to improve TC forecasts and warnings will save lives and property, as well as promote economic prosperity and resiliency.

GOOS | Ocean Observing Co-Design
by The Global Ocean Observing System

Tropical Cyclone Exemplar:

Co-Designing Ocean Observing Systems for Improving Understanding and Forecasting of Tropical Cyclones

Co-Leads:

Scott Glenn – *Rutgers University*
glenn@marine.rutgers.edu

Cheyenne Stienbarger – *NOAA*
cheyenne.stienbarger@noaa.gov

Plus International Steering Team

2024 Highlight: NOAA P3 Hurricane Hunter Track in Cat 5 **Hurricane Beryl** over Hurricane Glider RU29 in the Caribbean.

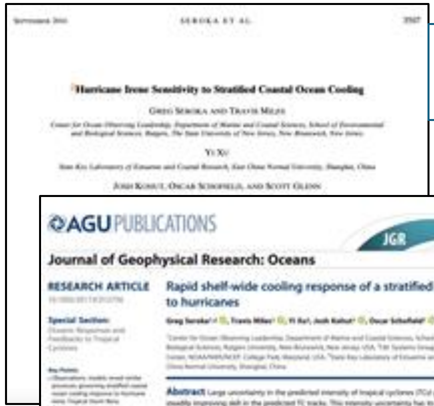
TC Exemplar - WMO Engagement

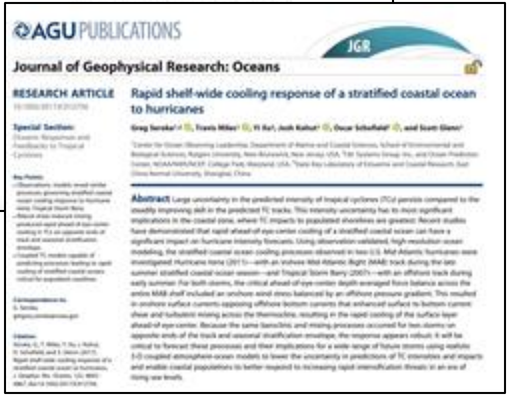
- **WMO RA IV Hurricane Committee**
  - March 2024 - Panama - Ocean Panel
  - Caribbean is undersampled for TCs
  - Expand beyond Marine Scientific Research permissions for uncrewed systems
  - Demonstration projects for capacity building
- **WMO Impact of Observing Systems**
  - May 2024 - Sweden - TC Exemplar/TAC
- **WMO RA V Cyclone Committee -**
  - July 2024 - Australia - TC Exemplar/TAC
  - Aug 2025 - Joint talk with PI-GOOS
- **WMO TECO (Technical Conf for Observations)**
  - Sept 2024 - Austria - Yucatan HF Radar
- **WMO RA II RBON**
  - February 2025 – Hong Kong
- **WMO RA IV Hurricane Committee**
  - April 2025 – El Salvador

WMO Region IV Hurricane Committee

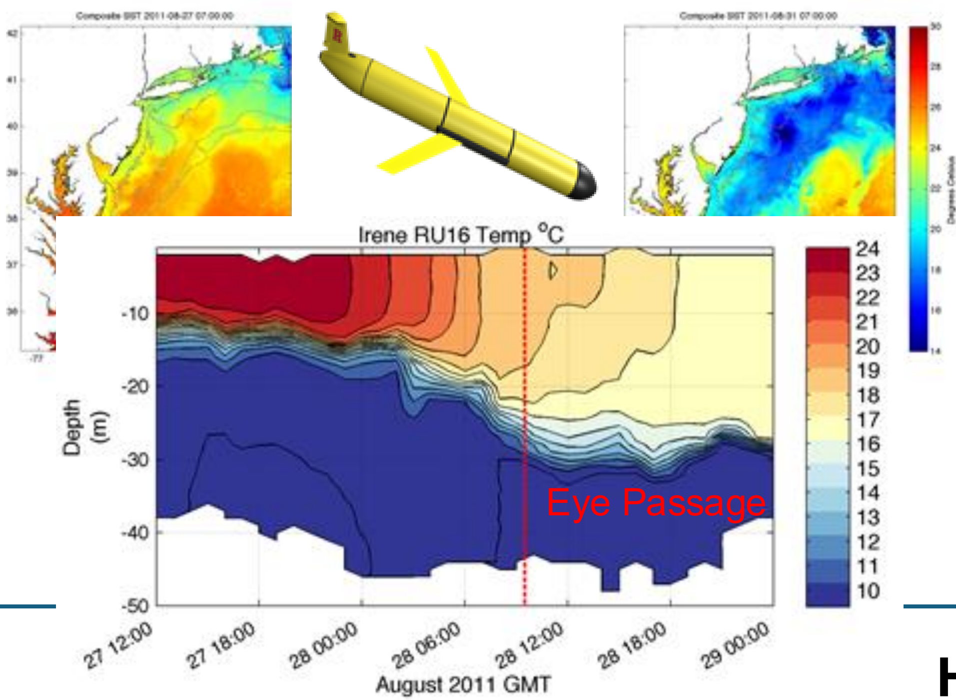
WMO Region IV Ocean Panel

Motivation - Contrasting Ocean Influence on Hurricanes Irene (2011) and Sandy (2012) on the US East Coast





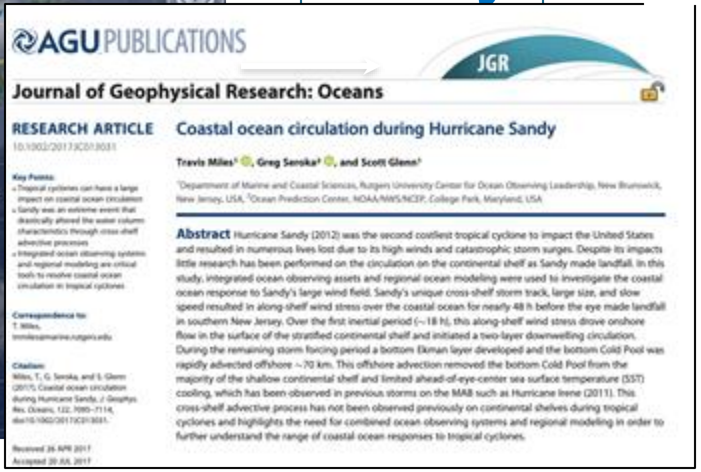
Irene

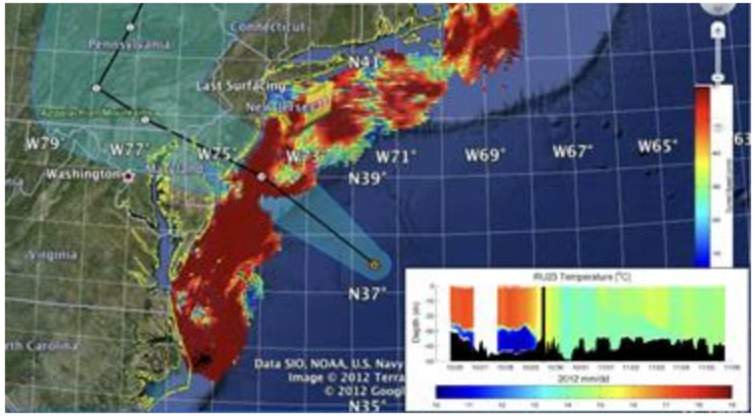


Hurricane Irene

Hurricane-induced ahead of eye mixing and cooling (up to 11C) **weakens Irene** over Mid Atlantic shelf before landfall

Sandy





Hurricane Sandy

Coastal downwelling inhibits ahead of eye mixing and cooling, SSTs remain elevated, **Sandy remains strong** over the Mid Atlantic shelf through landfall

Motivation - Contrasting Ocean Influence on Typhoons Soulik (2018) and Bavi (2020) in the East China Sea (ECS)

Soulik

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Geophysical Research Letters

RESEARCH LETTER

10.1029/2019GL086274

Key Points:

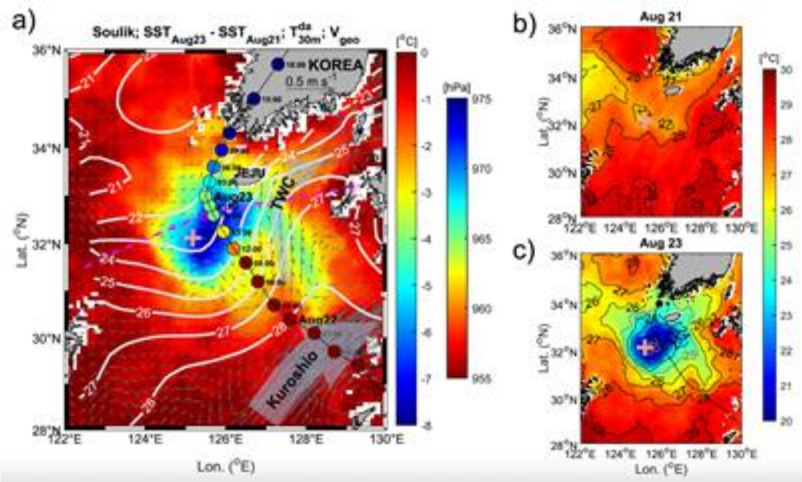
- Two-way interactions between stratified ocean and a slowly translating (~2 m s^{-1}) tropical cyclone yields rapid decay
- Severe (>8 °C) sea surface cooling is primarily caused by vertical mixing with cold subsurface water on the extratropical shelf
- Rapid decay is driven by downward energy transfer enhanced by Soulik's long (~15-hr) residence time over a large cold wake

Rapid Decay of Slowly Moving Typhoon Soulik (2018) due to Interactions With the Strongly Stratified Northern East China Sea

Jae-Hyoung Park[1], Da-Eun Yeo[2], KyungJae Lee[2], Hojun Lee[2], Seung-Woo Lee[2], Suyun Noh[2], Seongjung Kim[2], JiYun Shin[2], Yeon Choi[2], and SungHyun Nam[2,3]

[1]Ocean Circulation and Climate Research Center, Korea Institute of Ocean Science and Technology, Busan, Republic of Korea, [2]School of Earth and Environmental Sciences, College of Natural Sciences, Seoul National University, Seoul, Republic of Korea, [3]Research Institute of Oceanography, College of Natural Sciences, Seoul National University, Seoul, Republic of Korea

Abstract Typhoon Soulik decayed rapidly via two-way interaction with the northern East China Sea, the extratropical shelf region, before landing on the Korean Peninsula on 23 August 2018. In the northern East



Typhoon Soulik
Typhoon-induced ahead of eye mixing and cooling (~8C) **weakens Soulik** over ECS before landfall

Bavi

npj | climate and atmospheric science

www.nature.com/npjclimatsci

ARTICLE OPEN

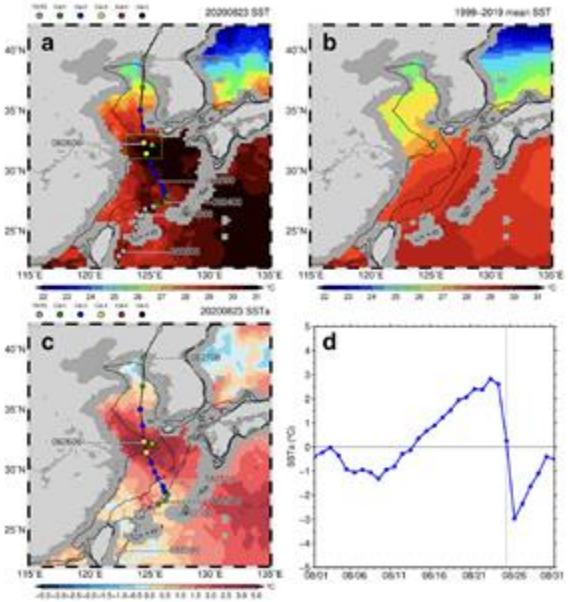
Check for updates

Marine heatwave as a supercharger for the strongest typhoon in the East China Sea

Iam-Fei Pun[1], Huang-Hsiung Hsu[2], Il-Ju Moon[3], I-I Lin[4] and Jin-Yong Jeong[5]

Due to the cold water temperatures, the East China Sea (ECS) is usually unfavorable for typhoon development. Recently, in a rare event, Typhoon Bavi (2020) reached major typhoon status and became the strongest typhoon in the ECS in the past decade. Based on in situ observations and model simulations, we discover that this typhoon is fueled by a marine heatwave, which creates a very warm ocean condition with sea surface temperature (SST) exceeding 30 °C. Also, because of suppressed typhoon-induced SST cooling caused by the shallow water depth (41 m) and strong salinity stratification (river runoff) within the ECS, the SST beneath the typhoon remains relatively high and enhances the total heat flux for the typhoon. More interestingly, due to the fair weather ahead of the typhoon, we find that the rapid development of this marine heatwave is likely, in part, attributed to the typhoon itself. As the risks from typhoons and marine heatwaves are heightening under climate change, this study provides important insights into the interaction between typhoons and marine heatwaves.

npj Climate and Atmospheric Science (2023)6:128 ; https://doi.org/10.1038/s41612-023-00449-5



Typhoon Bavi
Marine Heat Wave inhibits ahead of eye mixing and cooling, SSTs remain elevated, **Bavi intensifies** over the ECS before landfall

WMO Bulletin Vol 70 (1), 2021

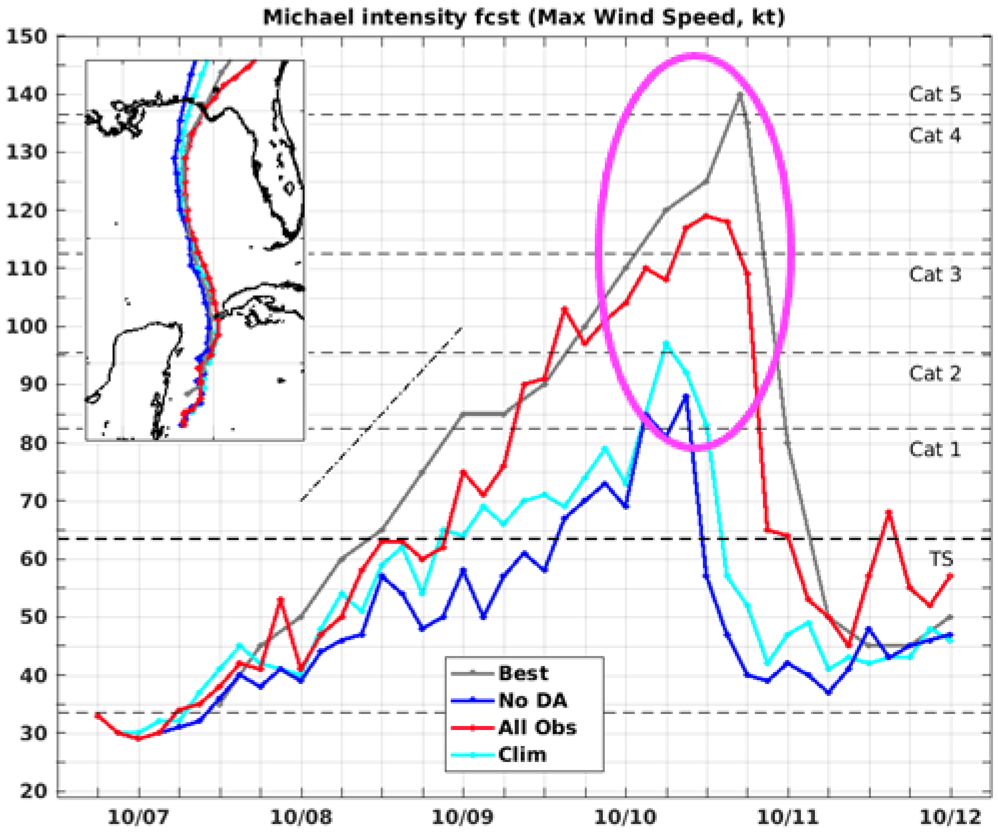
"If you like your 7-day weather forecast, thank an Oceanographer"

Earth System Prediction (ESP) Systems

- Forecasts of storm track, intensity, size, surge & rainfall require sufficient accuracy and lead time to be actionable
- Improved Tropical Cyclone forecasts increasingly require an ESP approach for model guidance, which then requires the observations to support the ESP system
- A well represented ocean - both features and processes - is an essential component of a modern ESP system
- ESPs require initial conditions that include the essential ocean features that impact Tropical Cyclone evolution
- ESPs must properly represent essential ocean and air-sea interaction processes that can vary rapidly in space and time during intense forcing

Justification for Ocean Sampling - Coupled Ocean-TC OSEs:

- Domingues et al. (2021) on H. Maria in 2017; Le Hénaff et al. (2021) on H. Michael in 2018:
  - Use outputs from ocean OSEs as Initial Conditions for coupled ocean-TC forecast
  - Quantify impact of ocean observations on TC forecasts



Example: Hurricane Michael (2018)

- All forecasted Hurricane tracks close to observed
- **Realistic ocean conditions** (through assimilation of ocean observations): **rapid intensification** to Cat. 4, close to observed
- Unconstrained ocean and climatological ocean cases do not intensify as much (Cat. 1-2)

Observed wind intensities (Best, grey), with simulated ones from coupled ocean-TC forecasts: case in which all ocean observations are assimilated prior to the TC forecast (All Obs, red), the case in which no ocean observations are assimilated (No DA, blue), and the case with ocean climatology (cyan).

Slide From Matthieu Le Henaff

WMO 2024 Workshop: Impact of Observing Systems

3.1. Recommendations for WMO Members and Observing Network Operators

3.1.4. To sustain routine observations of the ocean temperature and salinity profiles (for example, Argo, gliders).

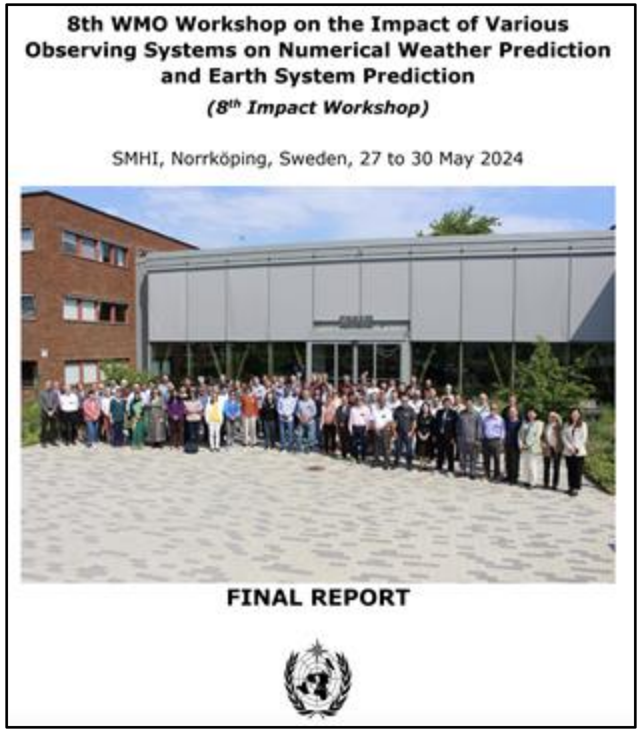
3.3. Recommendations for the scientific community

3.3.6. To continue the development of coupled ESP systems and, where possible, to develop and promulgated common metrics of skill for such systems, in collaboration with the operational NWP centres.

3.4. Recommendations for WMO and other International Organizations

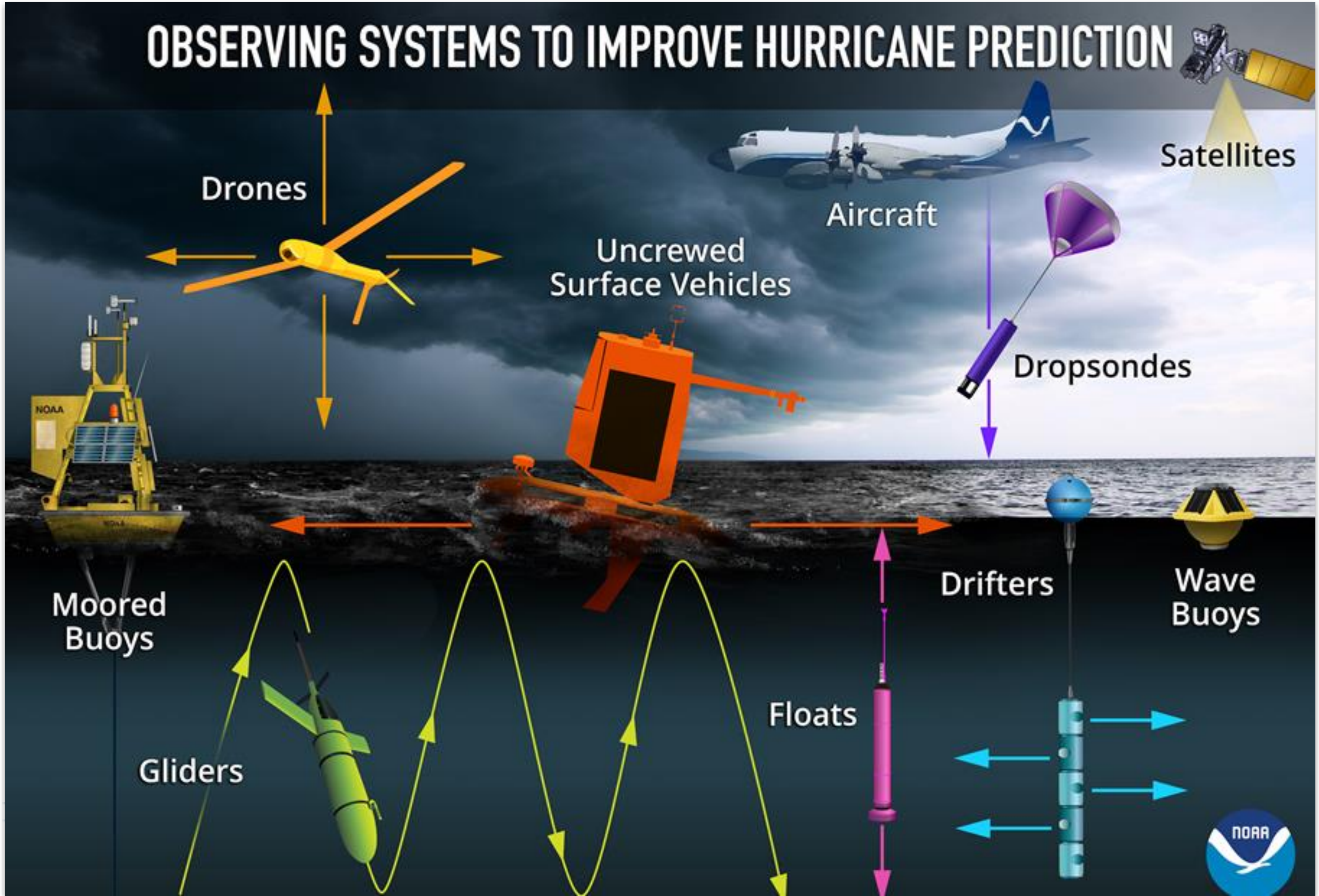
3.4.1. Intergovernmental Oceanographic Commission (IOC), WMO and relevant coordination entities to work together to expand ocean profiling observing systems and secure sustainable funding for them.

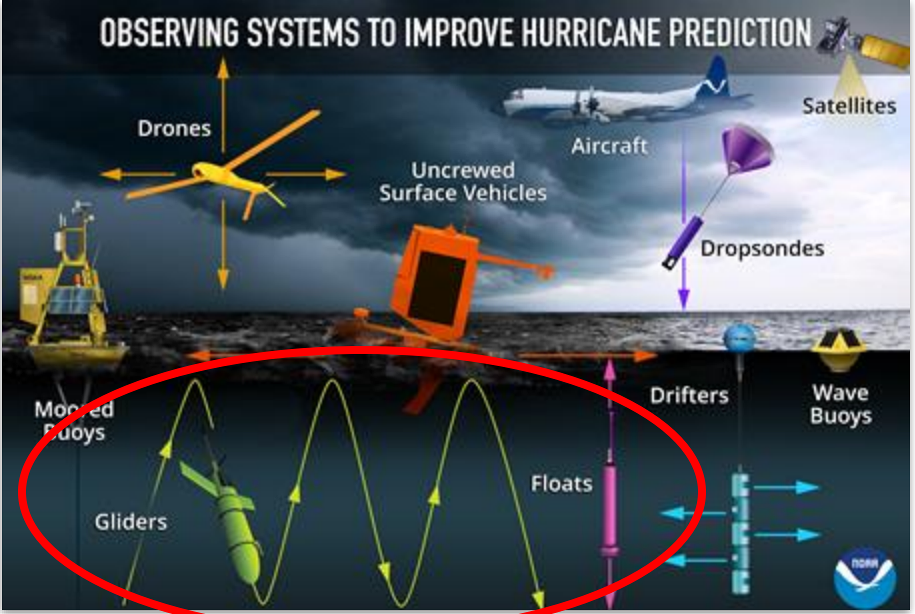
Workshop Report Link   Yellow Highlights Mine



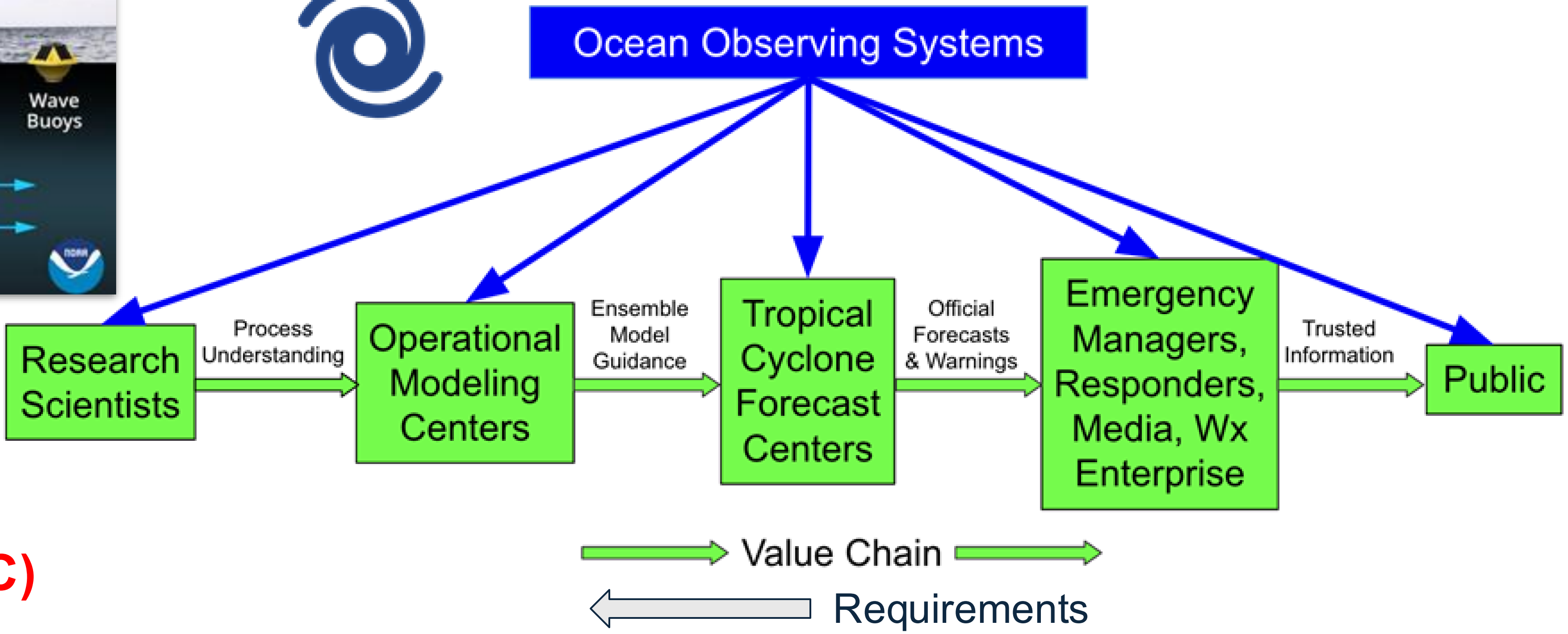
Both OSEs and OSSEs have shown that assimilation of satellite-derived altimetry and temperature data is essential for constraining the intermediate/mesoscale variability, while the simulation of ocean heat and freshwater contents is better constrained by Argo data (O3.3) (page 14).

OUR TC CO-DESIGN STARTING POINT: *Numerous observing technologies have been demonstrated to positively impact TC research & prediction*





THE CO-DESIGN PROCESS: Defining the Value Chain and the Reverse Flow of Requirements



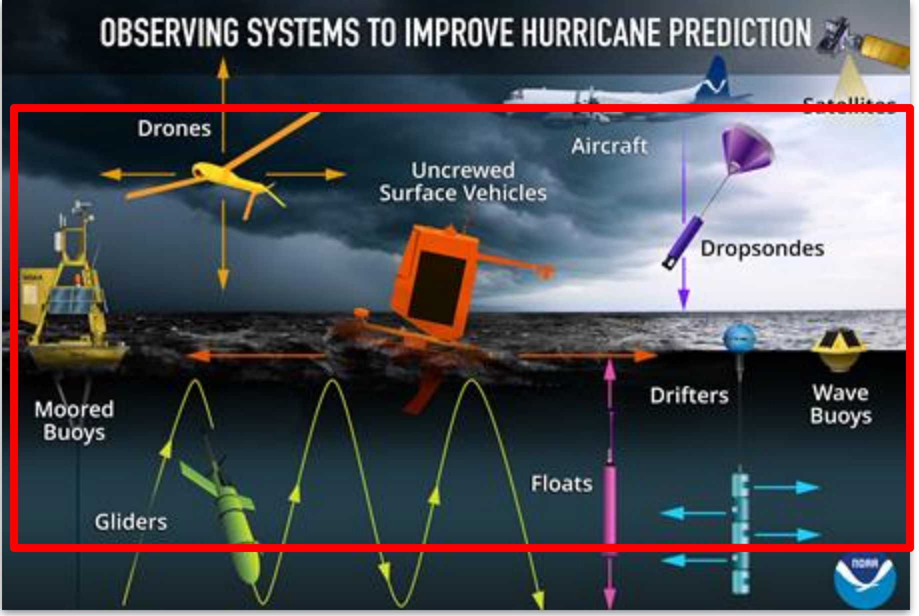
"There is a dearth of subsurface profile data"

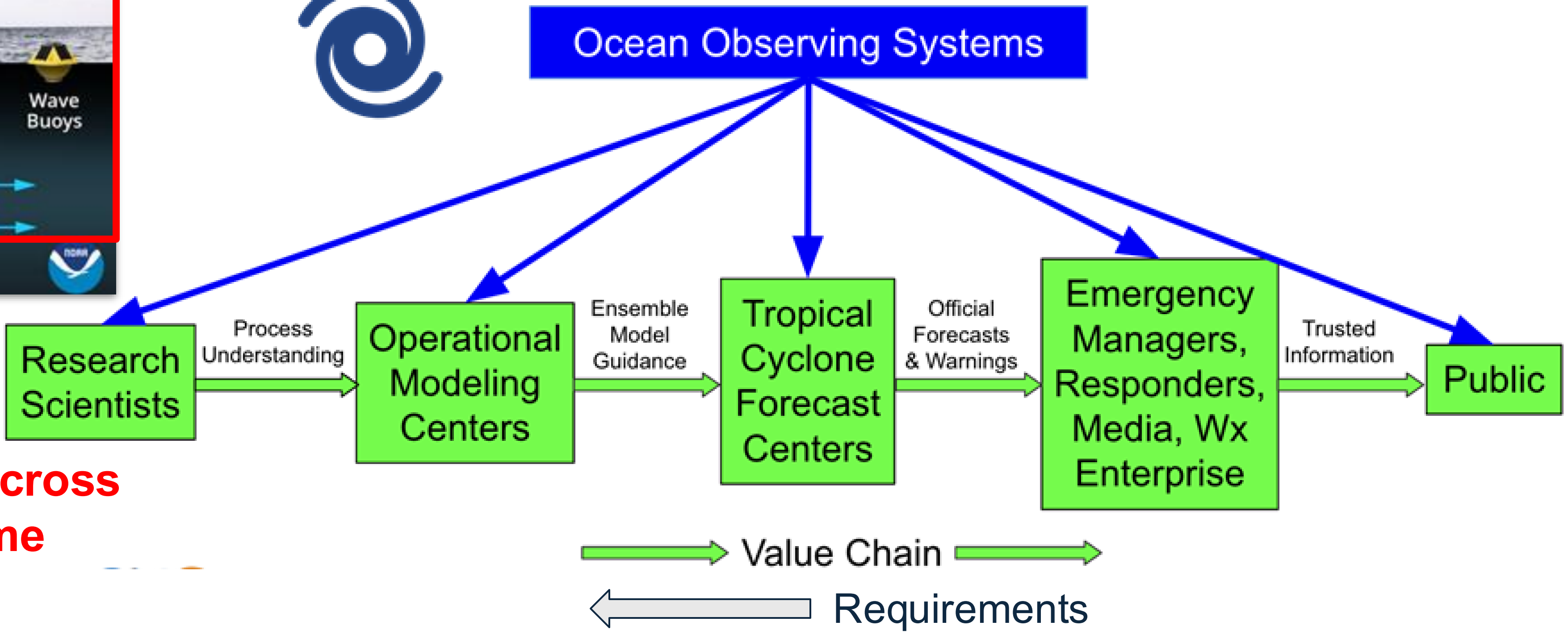
- **NOAA Environmental Modeling Center (EMC)**

Requirements are fed back through the value chain starting with public needs:

- **Public** requires trusted information to make evacuate vs shelter in place decisions
- **Emergency Managers** require forecasts and warnings with sufficient accuracy and lead time to guide decisions
- **Forecast Centers** require improved numerical model guidance products to make better forecasts
- **Modeling Centers** require more and better ocean observations to improve Earth System model guidance
- **Observing System Operators** prioritize deployment of the most critical observing systems to improve

THE CO-DESIGN PROCESS: Defining the Value Chain and the Reverse Flow of Requirements





We need co-located in situ observations in the lower atmosphere & upper ocean across the air-sea interface in extreme winds - Research Scientists

Requirements are fed back through the value chain starting with public needs:

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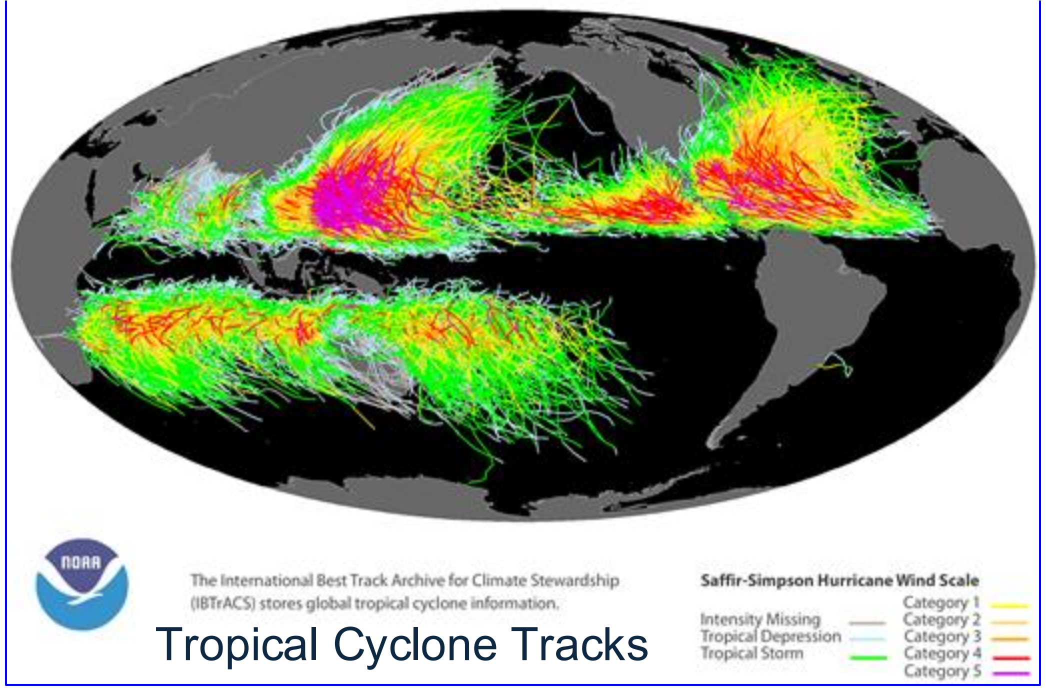
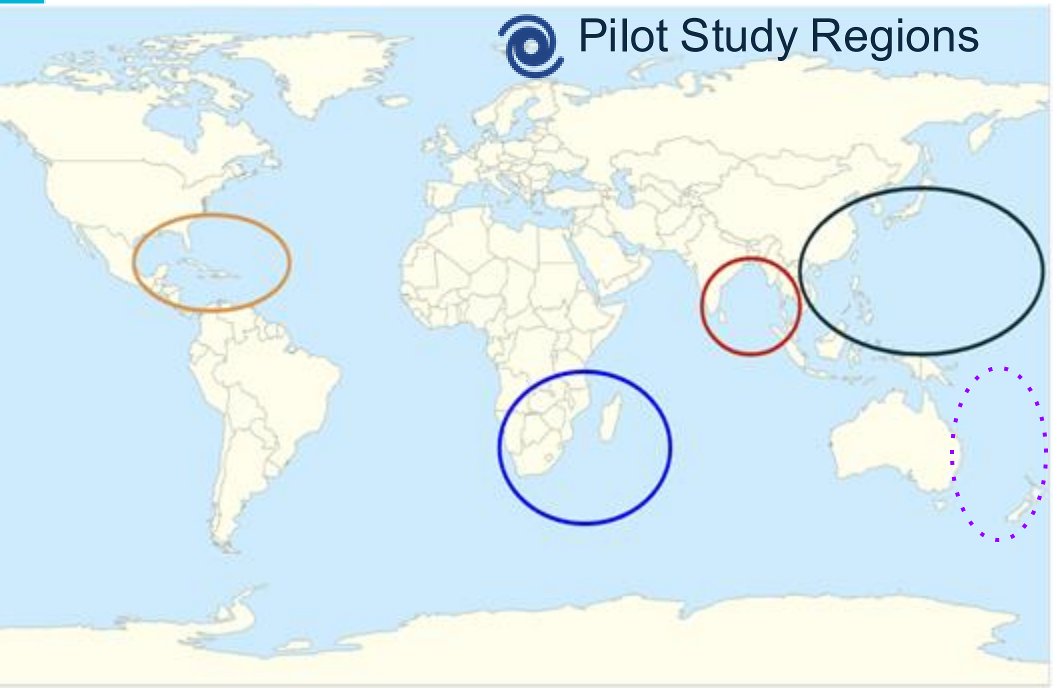
Concept of Operations

- **Argo & OceanGliders** target ocean profiles along the entire forecast cone well ahead of the storm - *to improve the current coupled ocean-atmosphere forecasts*

- **Surface UNcrewed (SUN) Fleet** targets the high winds near the center of the storm - *to improve scientific understanding of air-sea interaction processes in extreme winds for future models*





ACCELERATING GOOS IMPLEMENTATION: Five Regional TC Pilot Studies

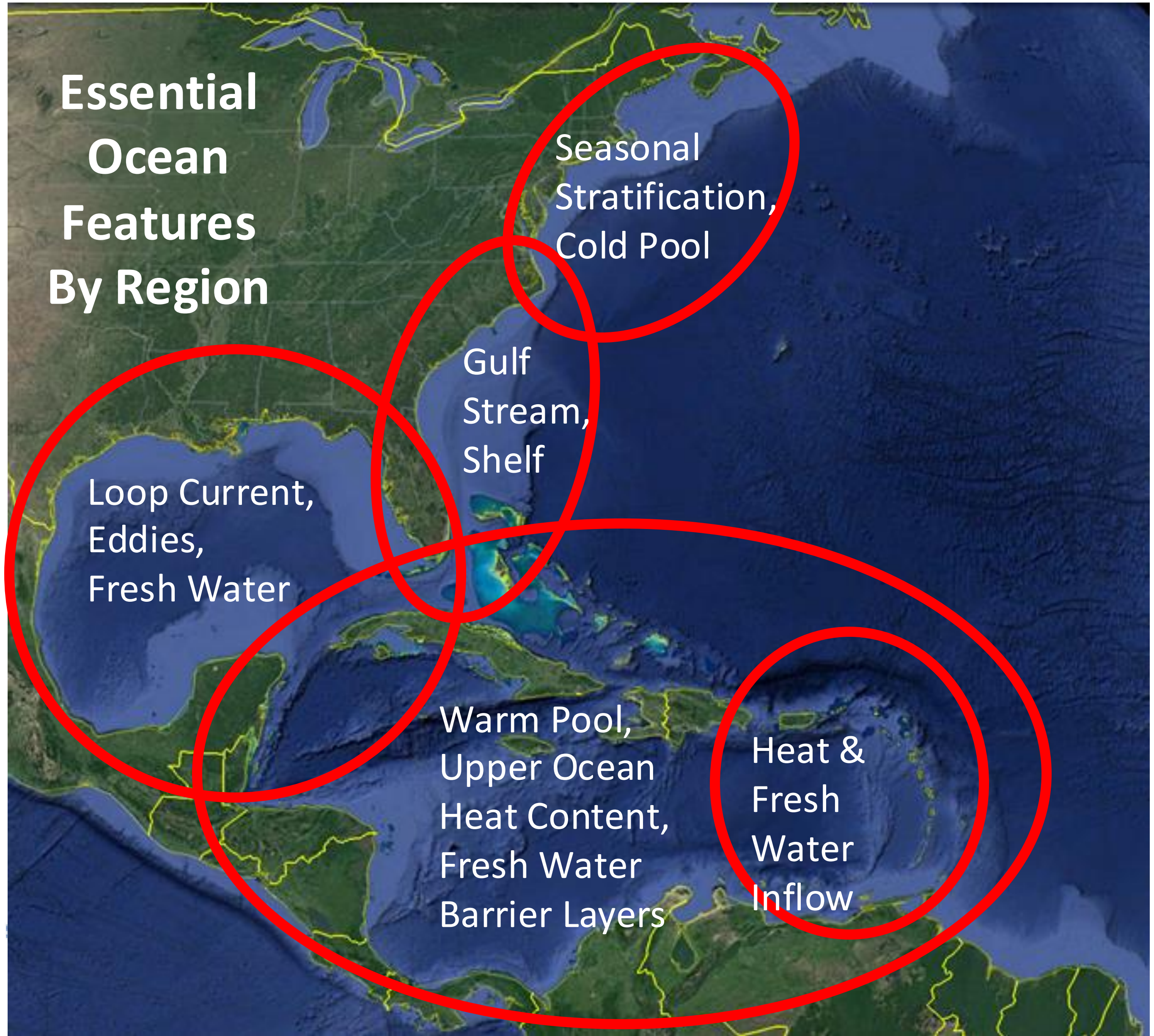
Tropical Americas and Caribbean (TAC)
Capacity building for the **most damaging** TCs

North Pacific Ocean and Marginal Seas (NPOMS)
Coupled air-sea science in the **most intense** TCs

Bay of Bengal, Indian Ocean
Fostering national networks for the **most deadly** TCs

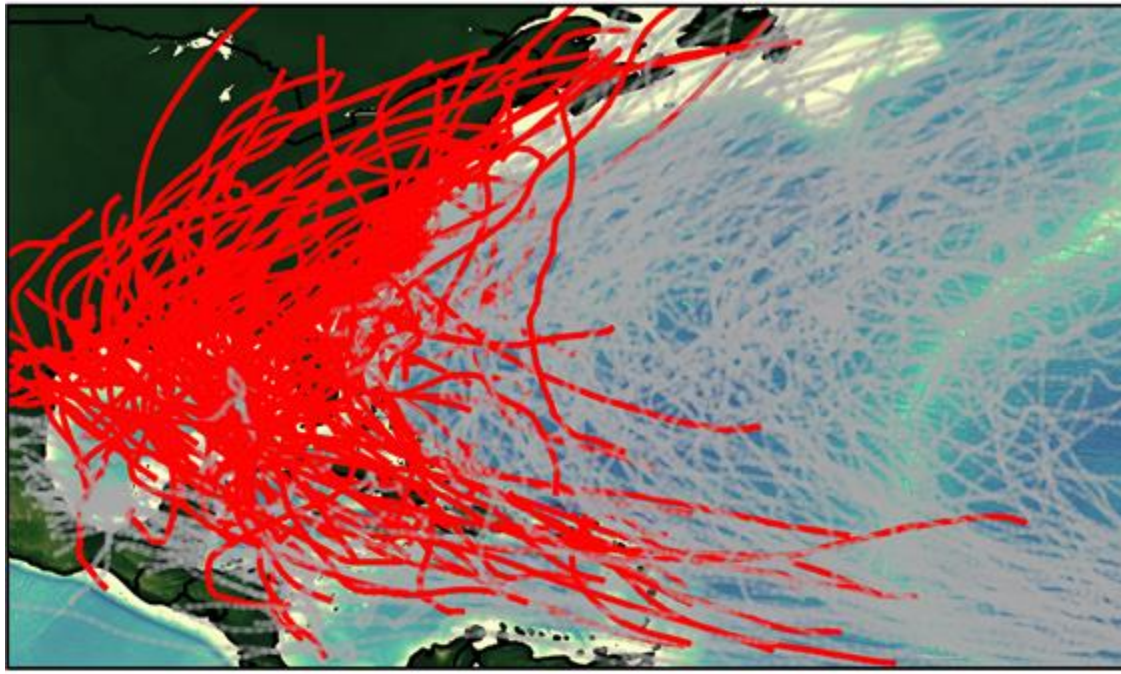
Southwest Indian Ocean (SWIO)
Co-designing the response to the **triple threat** of changing boundary currents, MHWs, & TCs

Pacific Islands – *New*
Initial co-development of **regional value chain** and observing system requirements for stakeholder needs



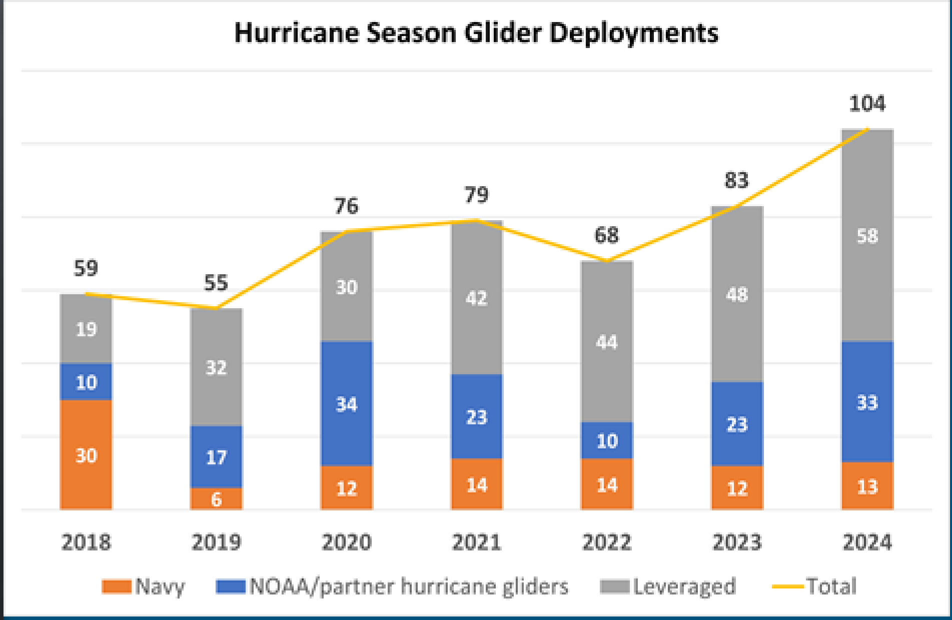
Tropical Americas and Caribbean (TAC) Pilot Study

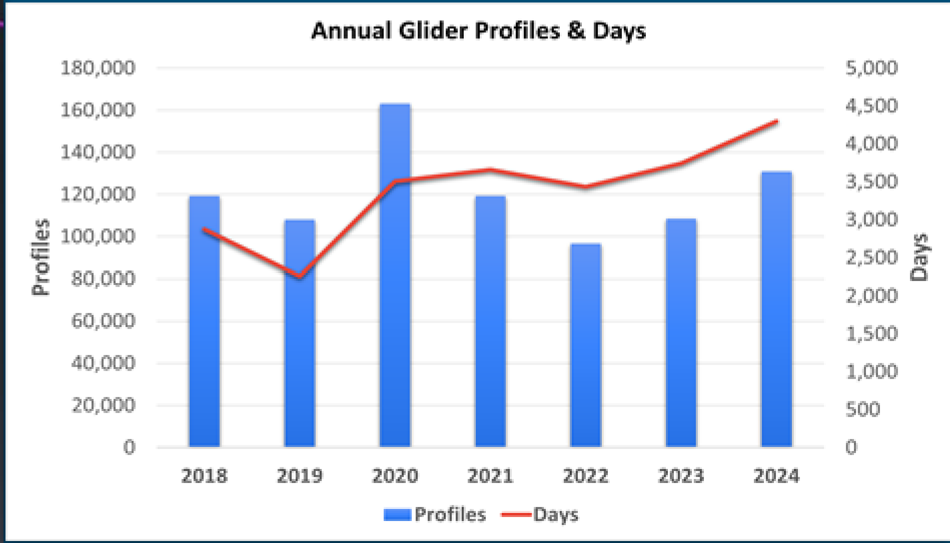
- Essential Ocean Features impacting Hurricane Intensity along the North Atlantic Hurricane track have been documented (left)
- Hurricanes are not constrained by national boundaries (below)



Hurricane tracks since 2020: 5 days before US landfall

2024 Hurricane Season Operations Overview





2024 By the Numbers -- Atlantic

Glider contributions to the Atlantic hurricane intensity forecasts:

104 Total Atlantic glider deployments

- **46** Hurricane gliders (per funding purpose)
  - ***25** Disaster Supplemental-funded gliders*
- **43** Leveraged gliders participating in the Collaboration
- **15** Leveraged other-mission gliders

13 Navy Glider deployments

100% (5) U.S. landfalling hurricanes with gliders in the 5-day forecast cone

100% (4) Major Hurricanes aimed at the U.S. with gliders in the 5-day forecast cone

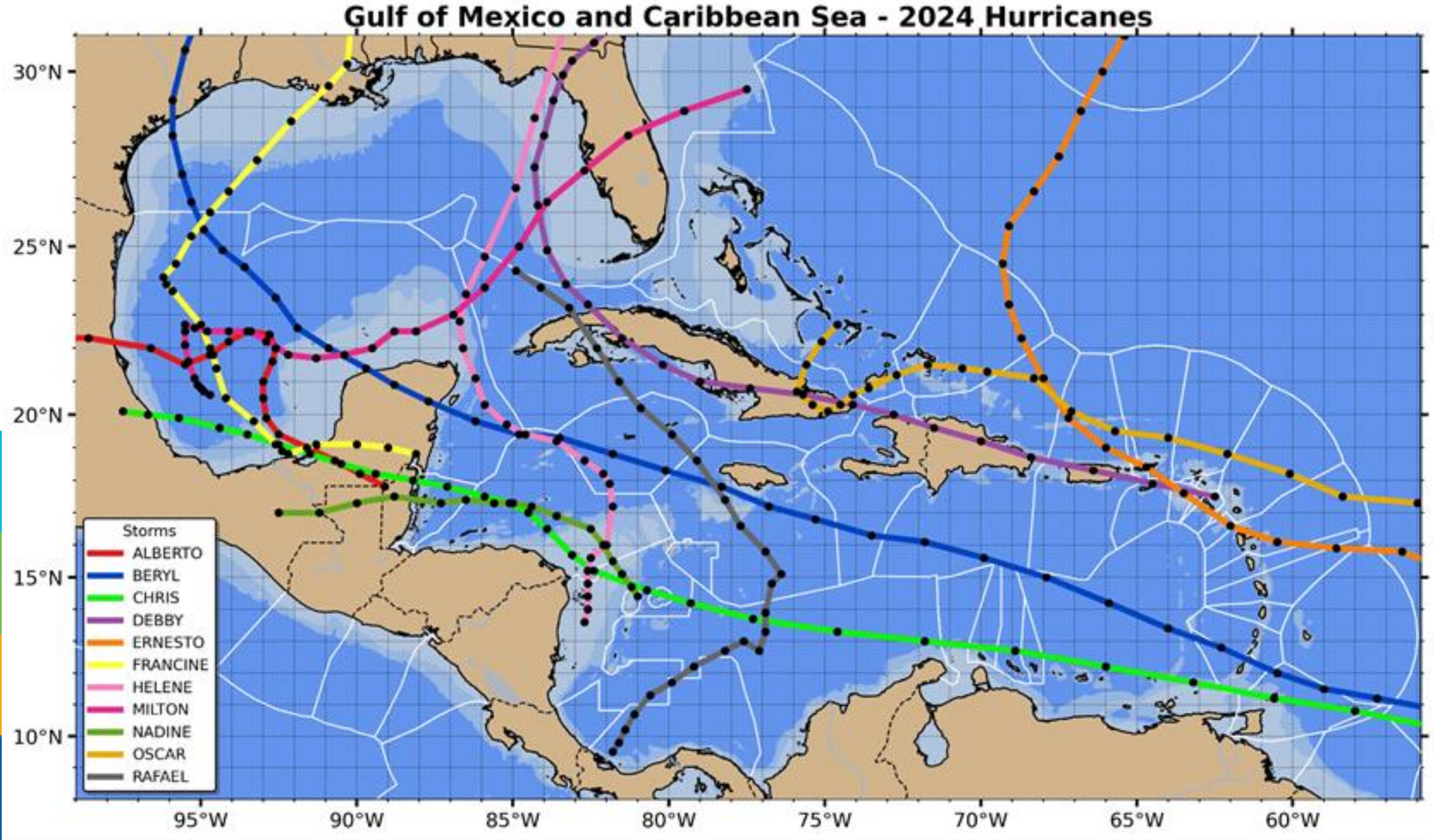
Fortuitous events for the benefit of research:

24 Gliders underneath a Tropical Cyclone (within extent of Tropical Storm force winds)

7 Named storms with gliders inside Tropical Storm force winds

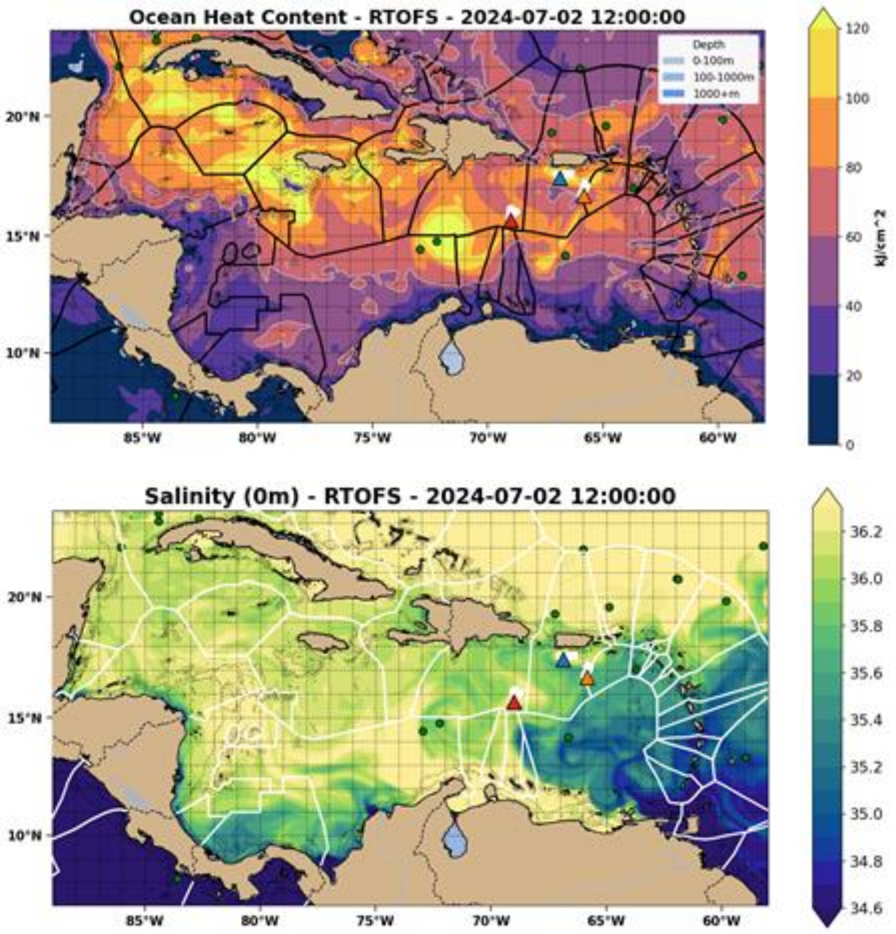
Overall: 840,000 Glider profiles collected since 2018

2024 Tropical Cyclone Tracks



Essential Ocean Features

Ocean Heat Content



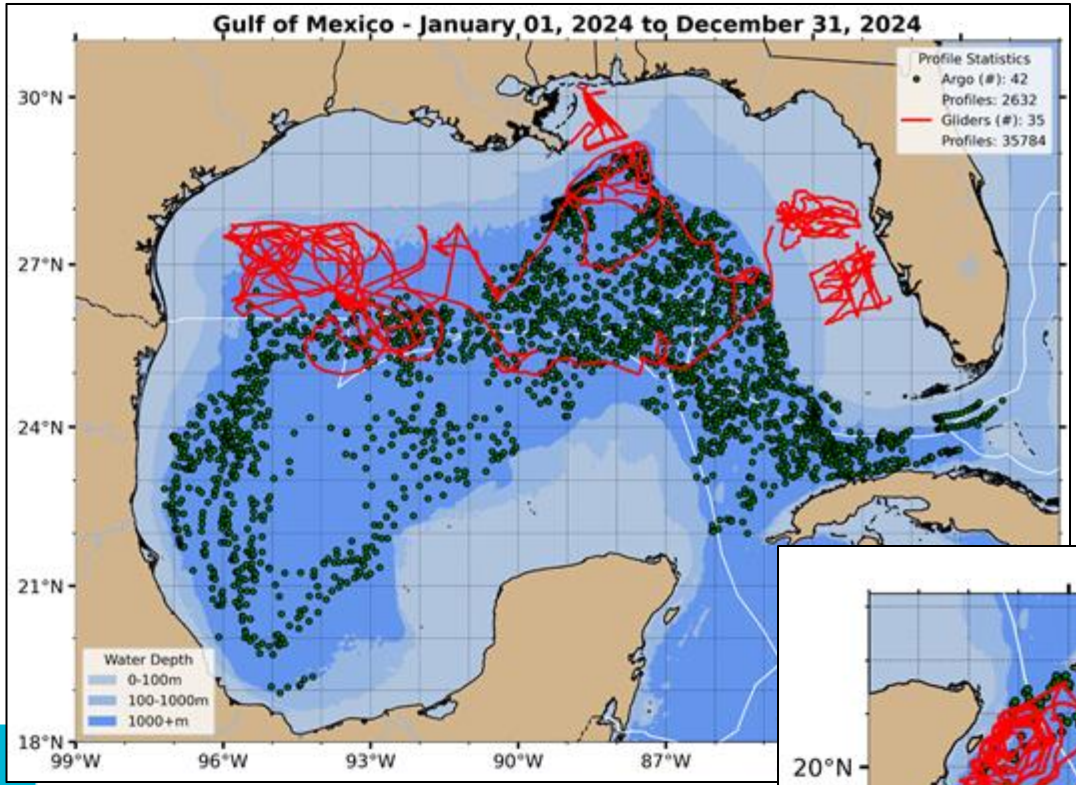
Surface Salinity for Barrier Layers

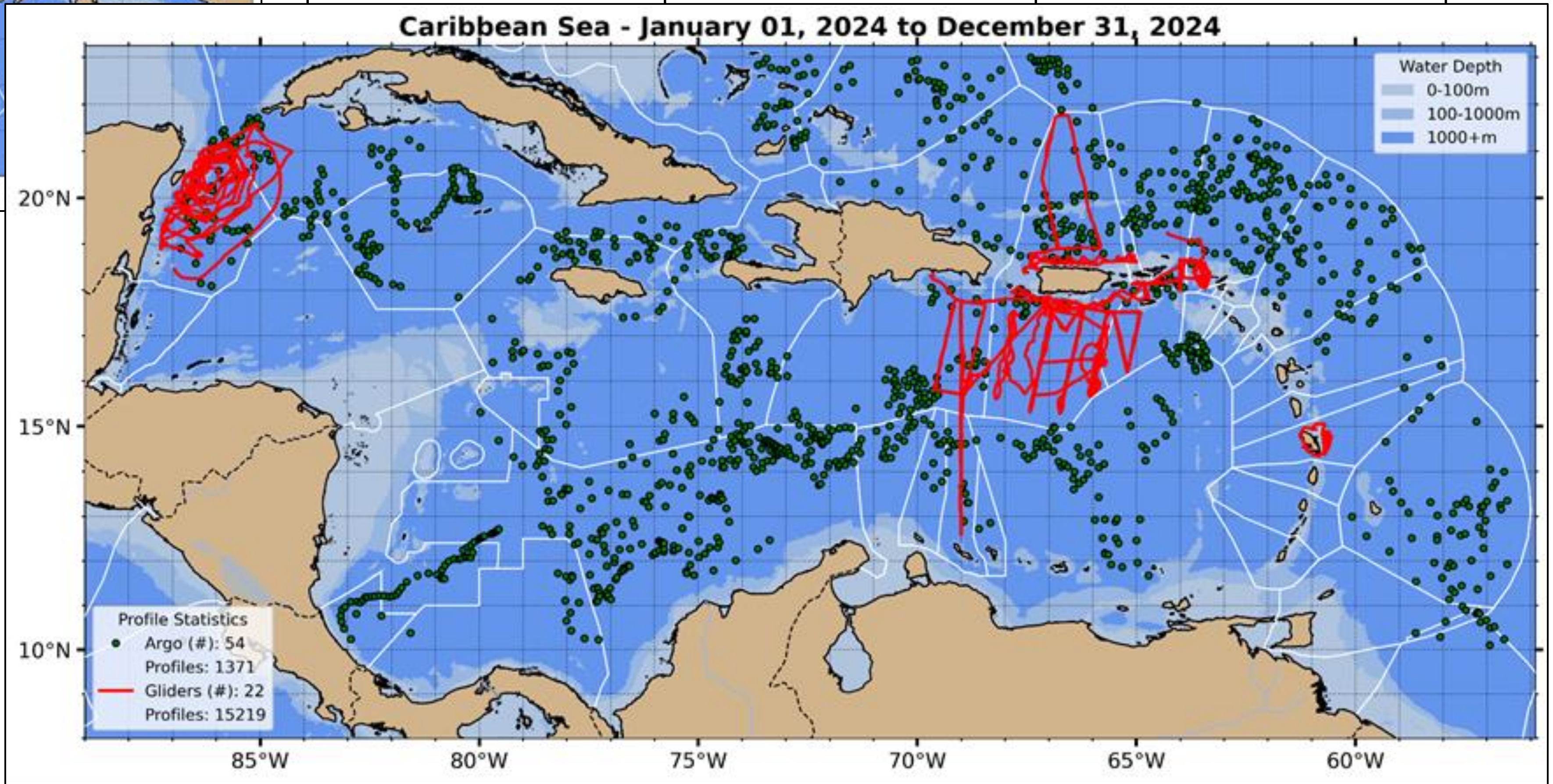
WORLD METEOROLOGICAL ORGANIZATION

1950-2025 75 SCIENCE for ACTION

Profile Data Available for Assimilation

2024	Gulf of Mexico	Caribbean Sea
Surface Area	1.55M km^2	2.75M km^2
Argo Profiles	2,632	1,371
Glider Profiles	35,784	15,219





Glider

Argo

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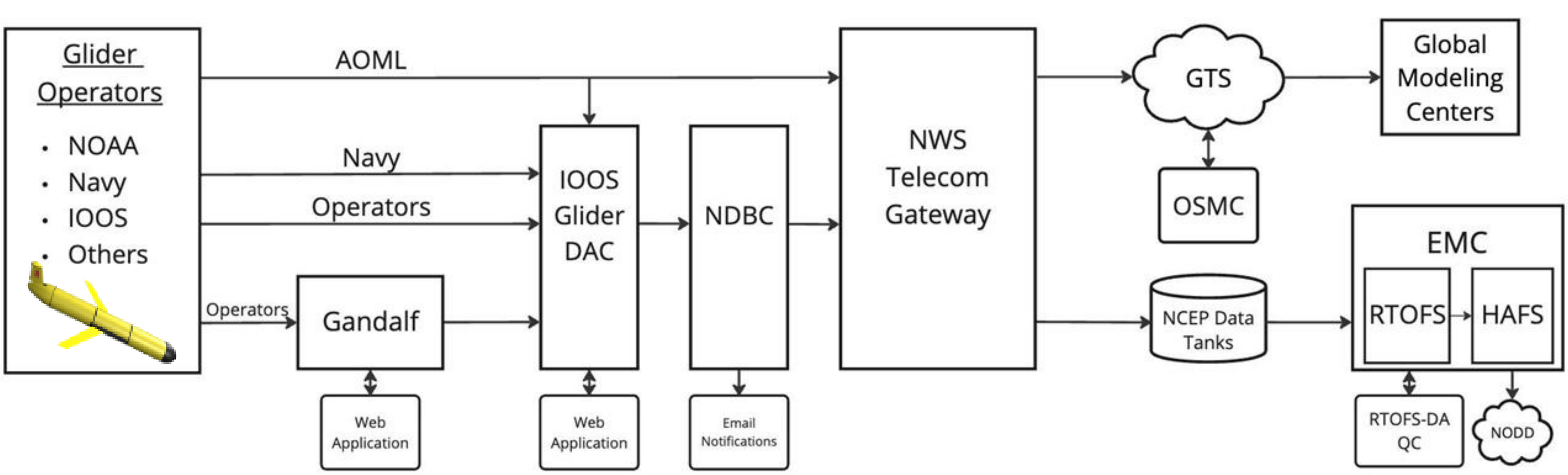
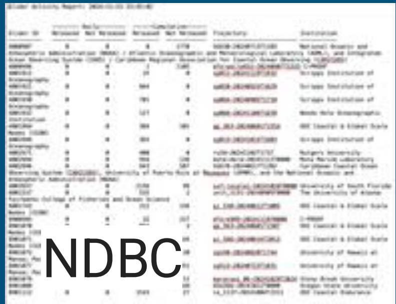
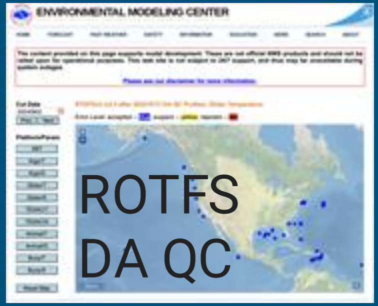
Glider Data Flow - Operators (left) to EMC (right)



Glider Data Flow (above) & Monitoring (below)

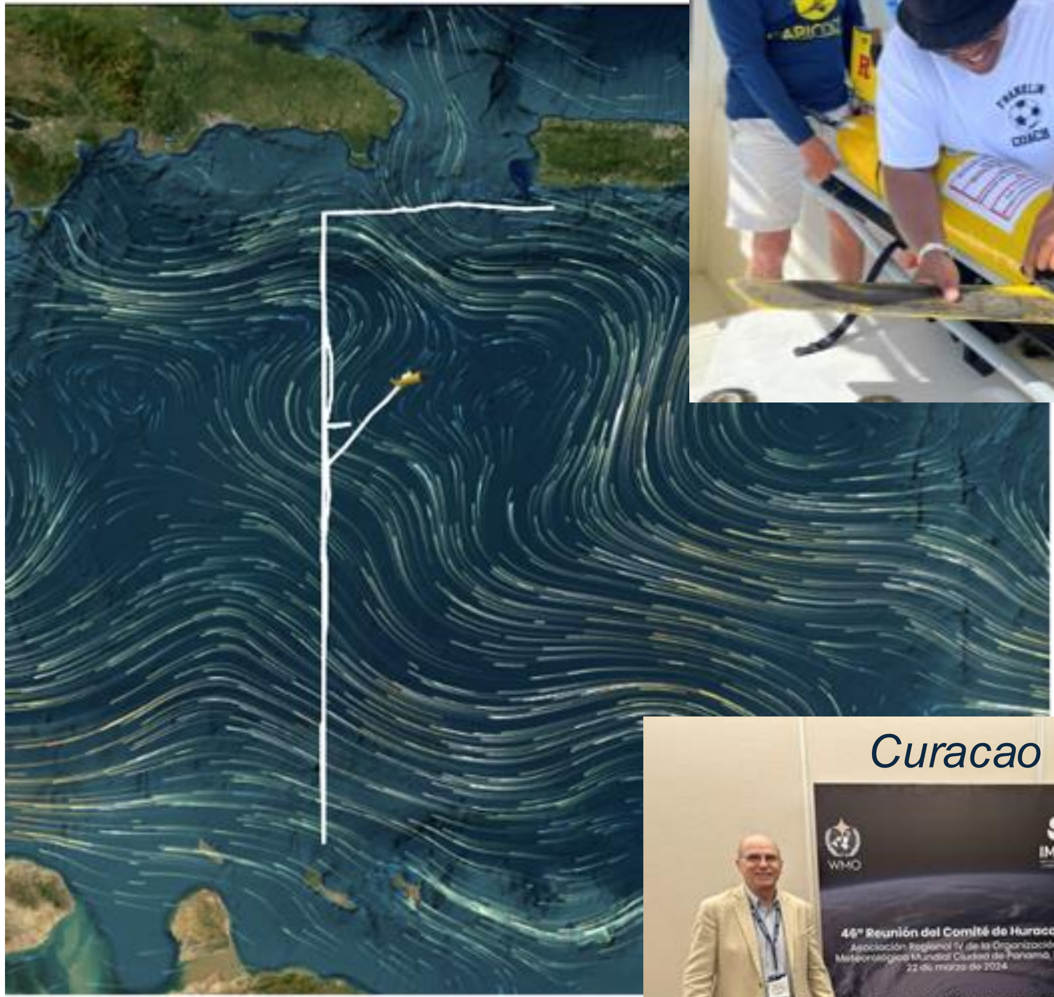




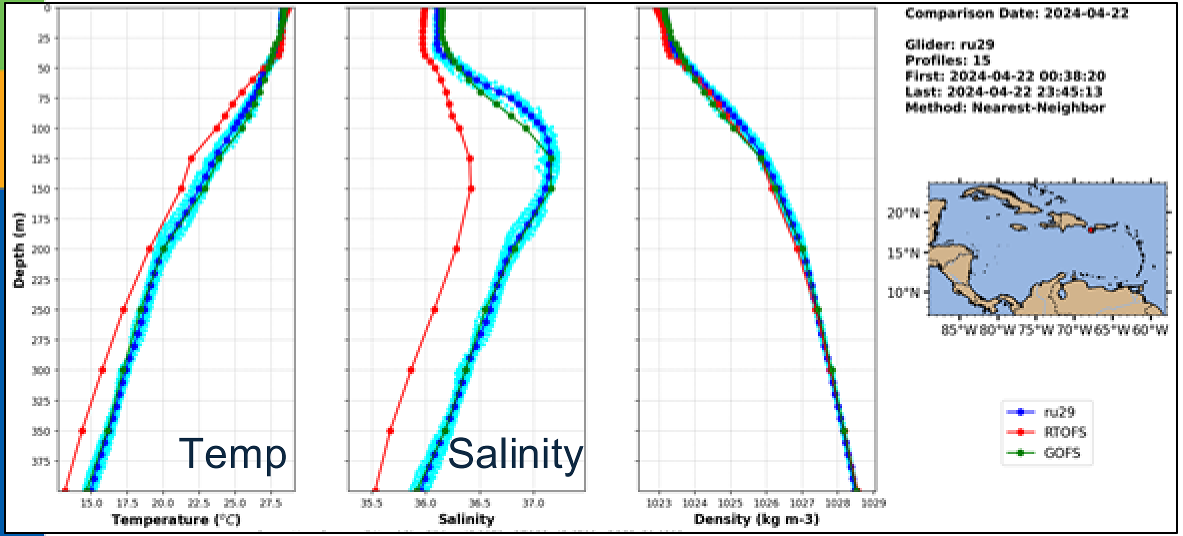
Caribbean Throughflow Glider Mission

Exploratory Repeat Transect:
Puerto Rico to Dominican Republic to Curacao

THE
G. UNGER VETLESEN
FOUNDATION

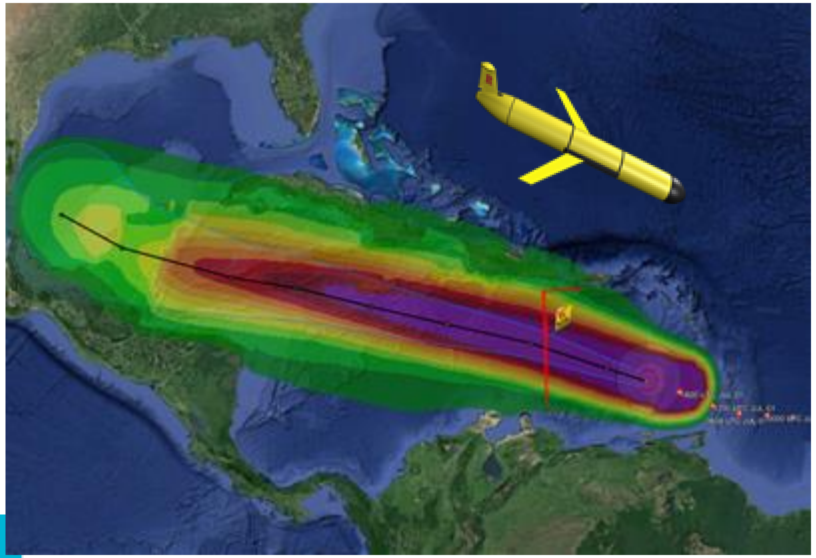


Before **Glider Data** Assimilation -
ROTFS Operational Model is Biased Cold & Fresh



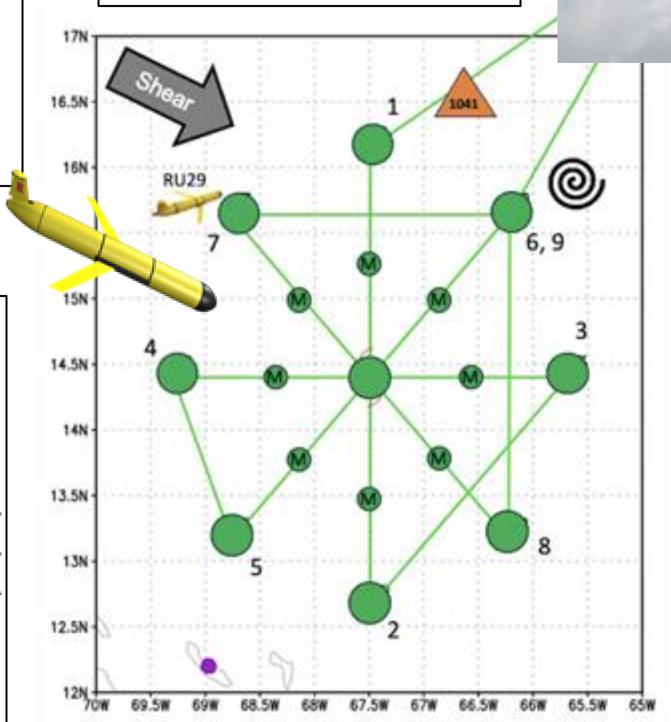
WMO Region IV Coordination

BERYL - Hurricane Hunter & Hurricane Glider Coordination



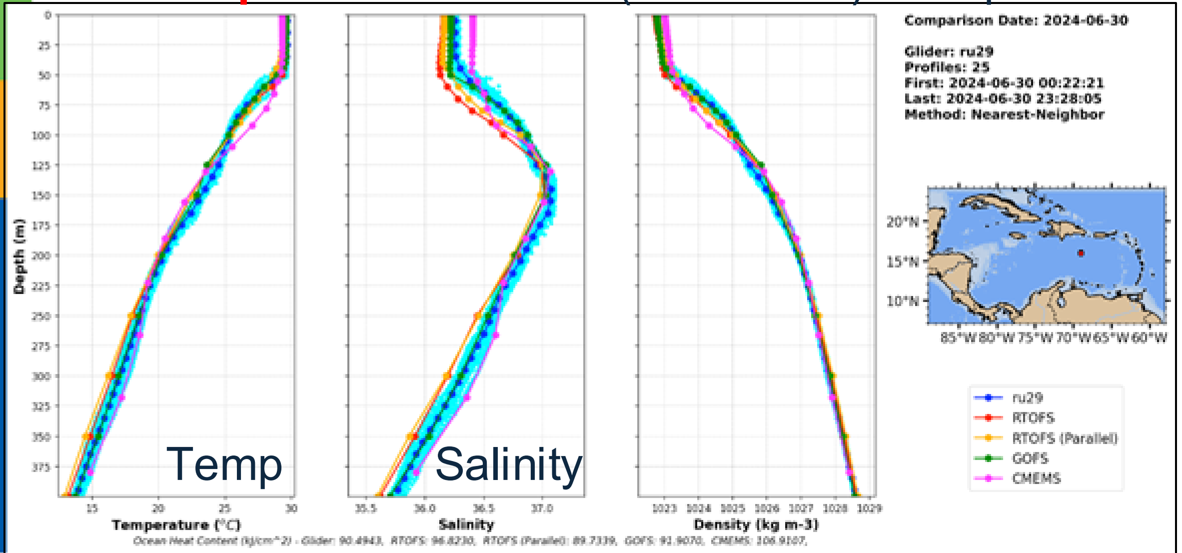
Glider data is shared on the GTS in real time and assimilated in operational ocean models used for hurricane forecasts

World Record: Closest approach of any uncrewed system to a hurricane eye.
- NOAA



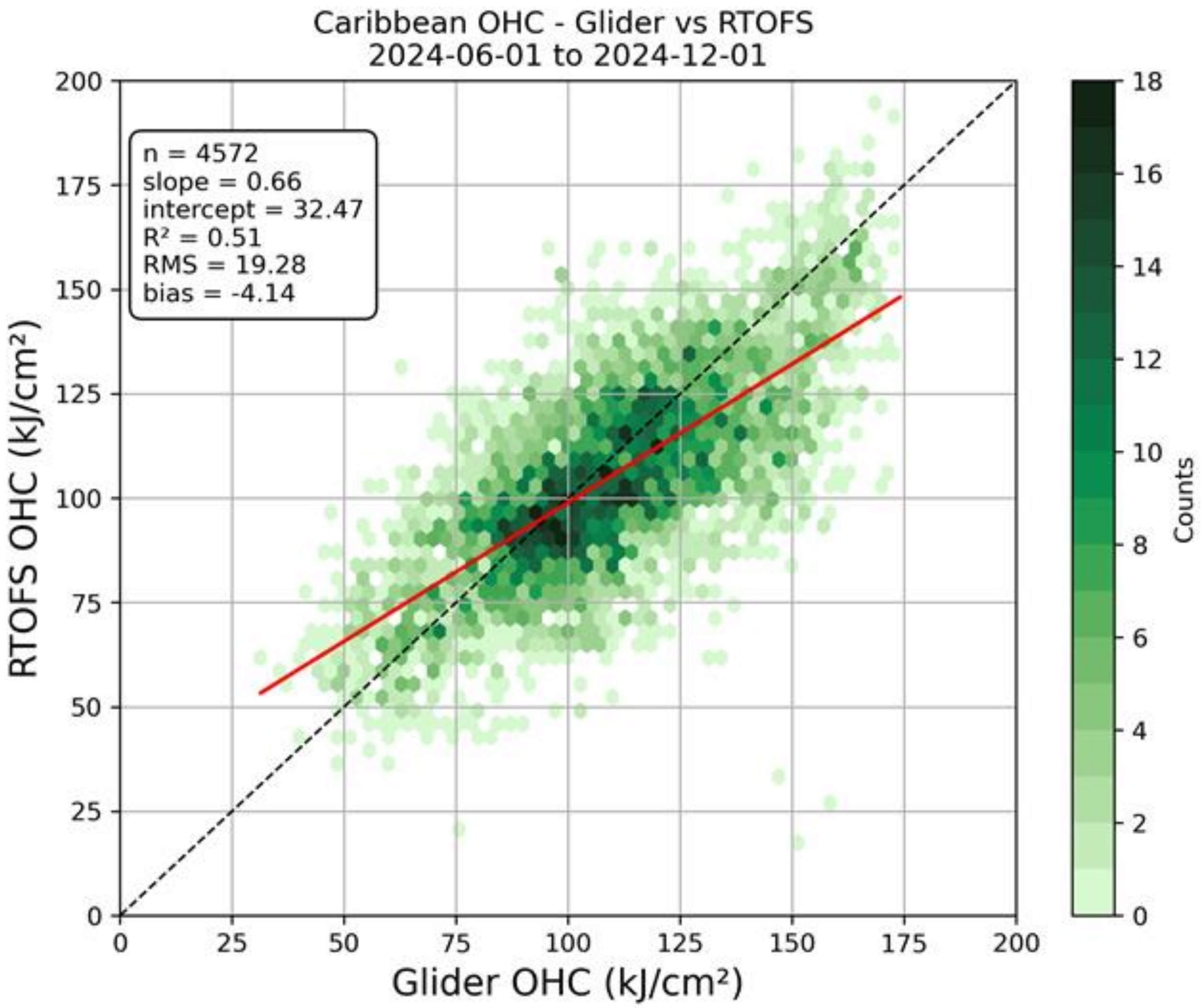
NOAA P3 Hurricane Hunter dropsonde deployments coordinated with underwater glider RU29 location in Cat 5 Hurricane Beryl

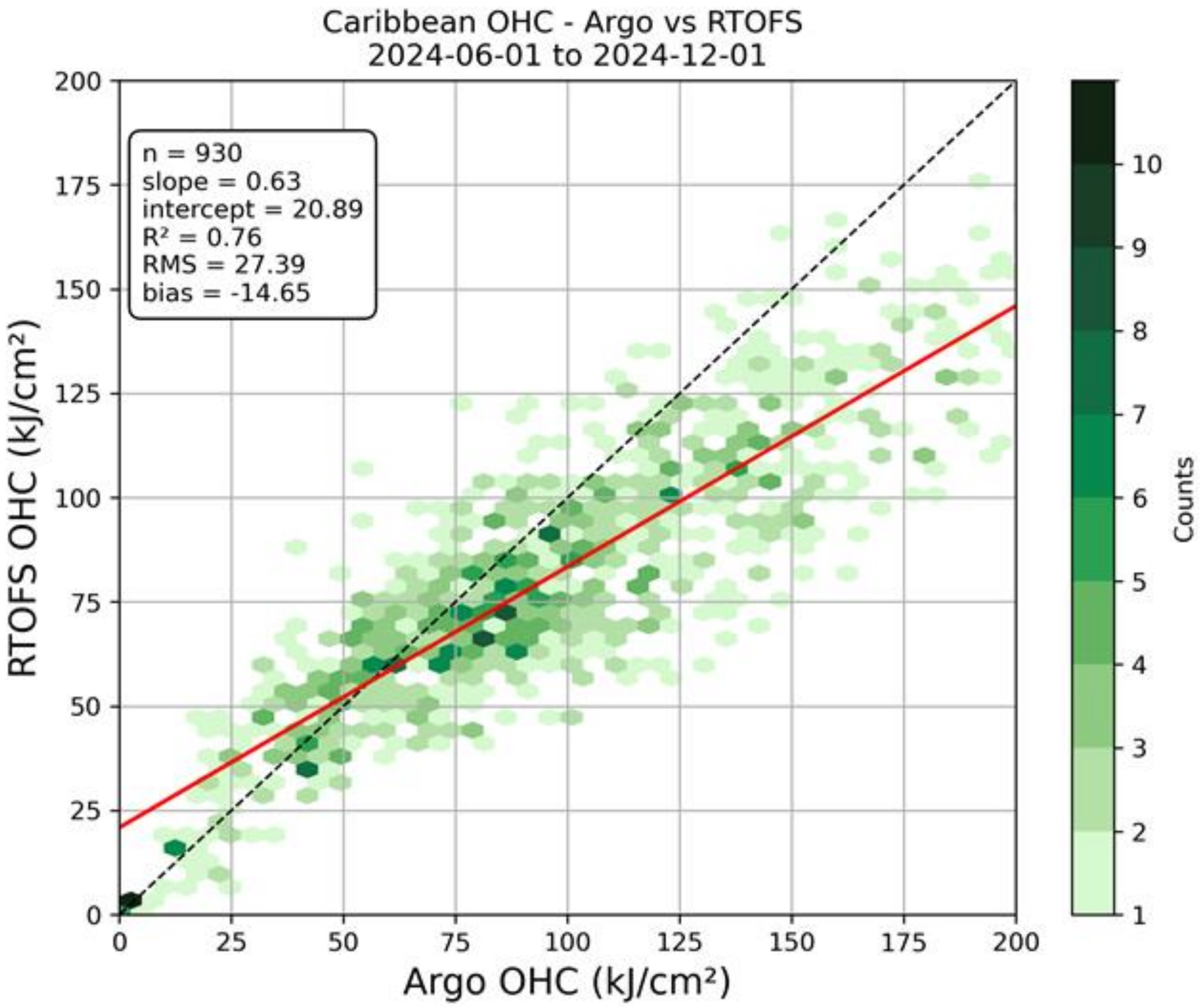
After **Glider Data** Assimilation -
ROTFS Operational Model (and others) all improved



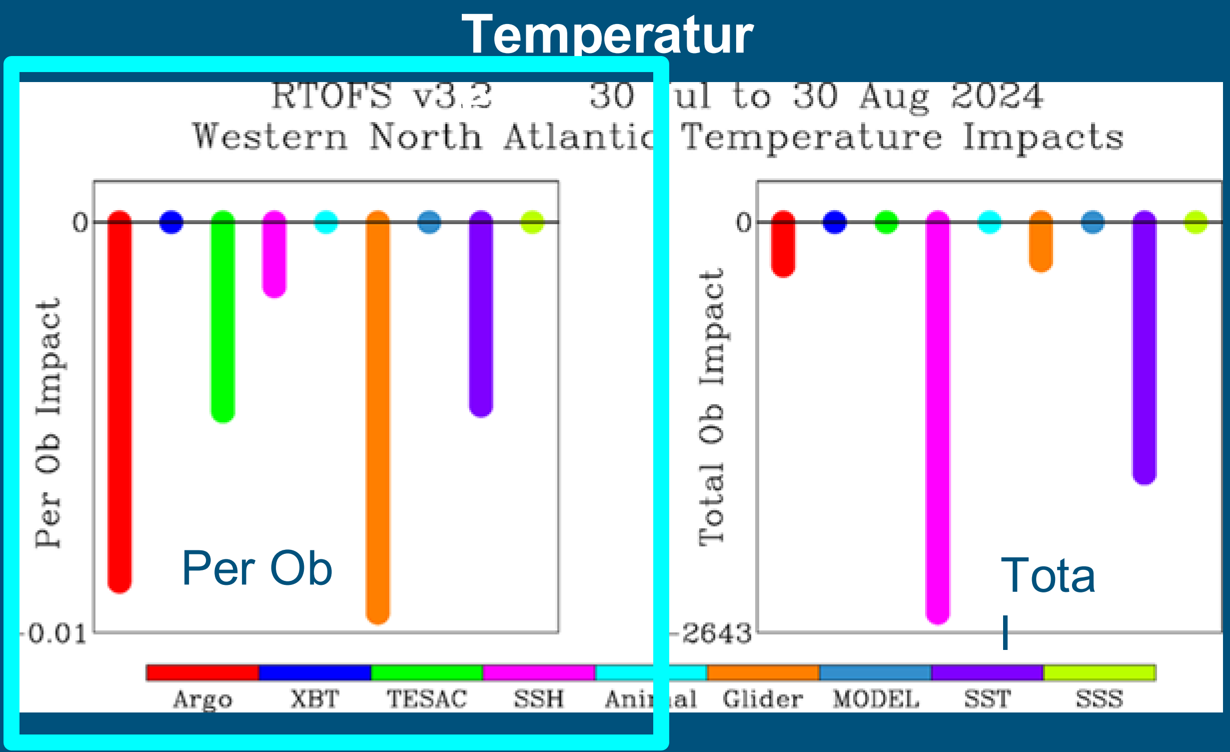
Operational hurricane forecasts and downstream ESP research enabled by the same datasets!

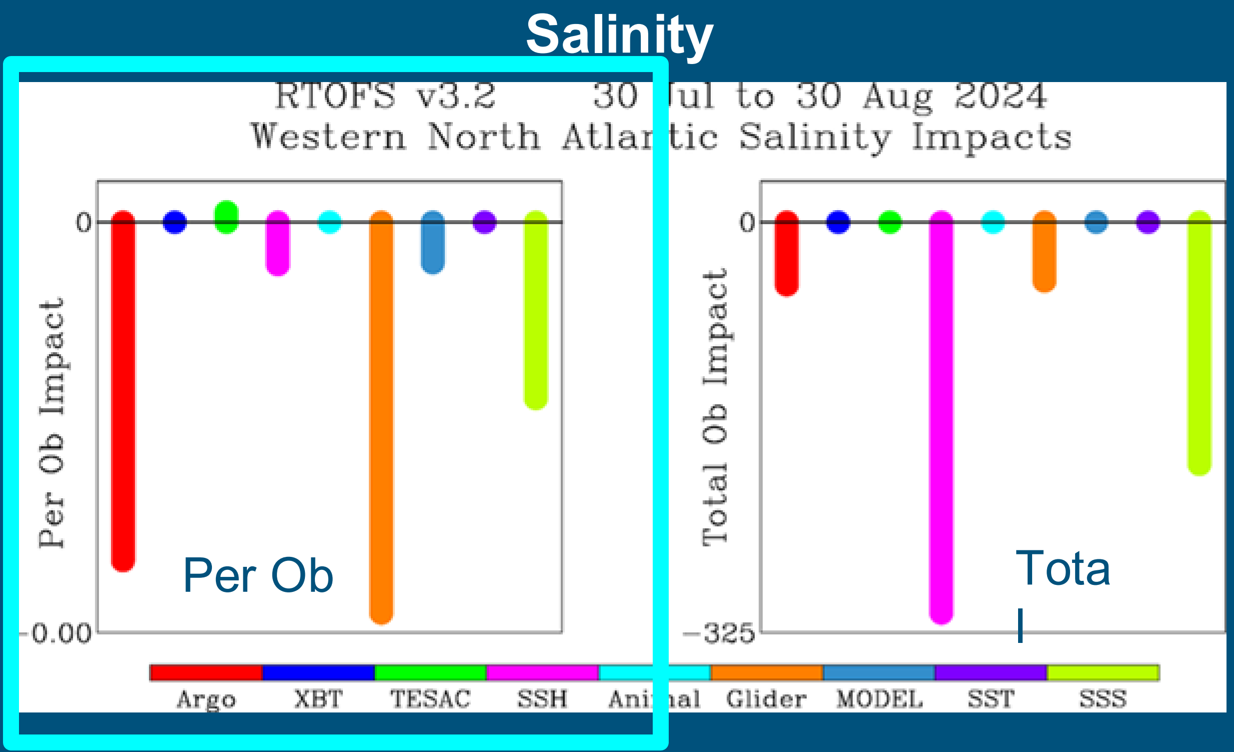
RTOFS OHC comparisons before Assimilation: 2024





RTOFS Adjoint Model - Profile Impacts Comparison

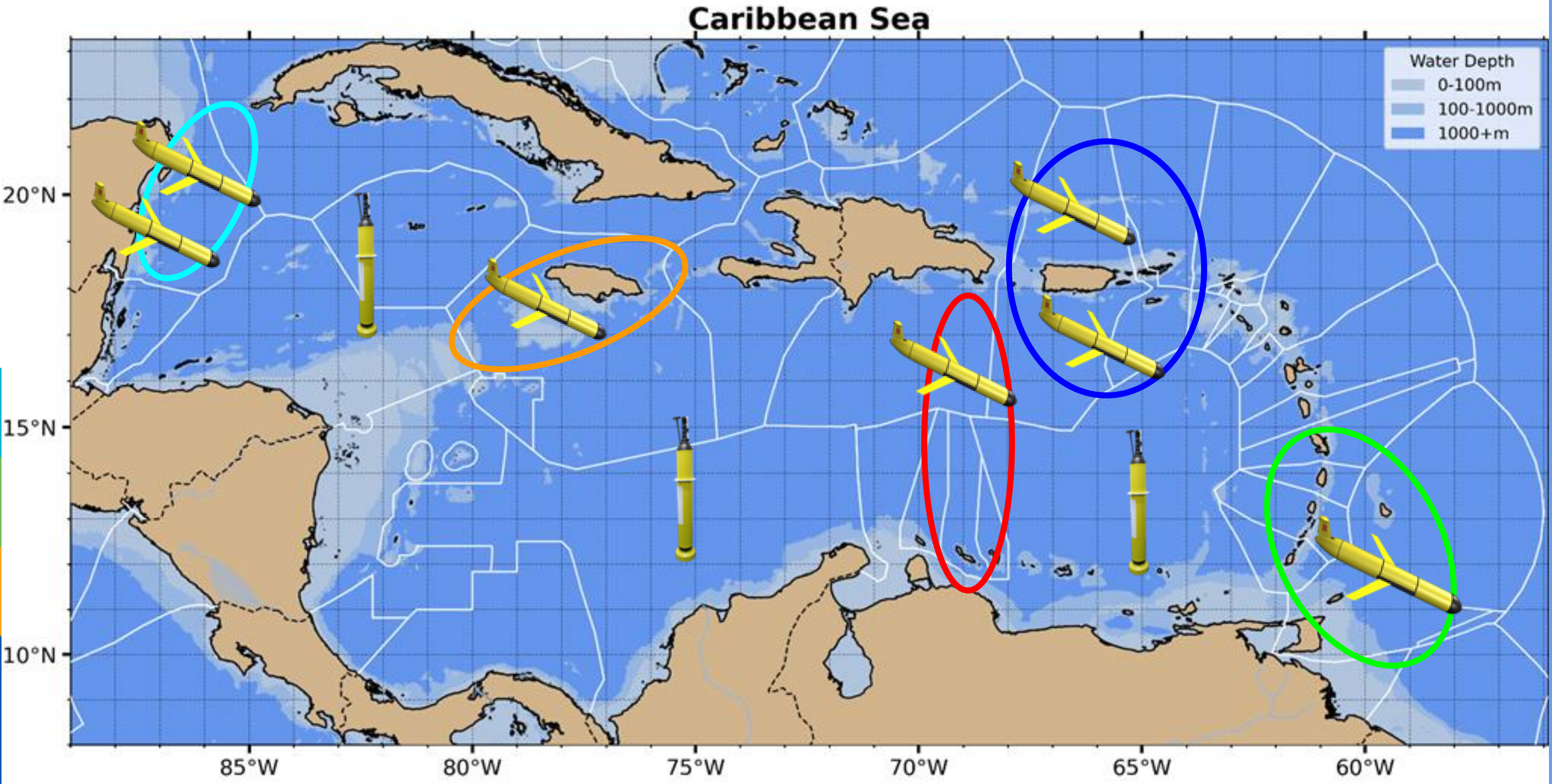




- On a **per observation** basis, T&S profiles from **Argo** and **Gliders** outperformed all other data observing systems, including **Satellite Altimetry (SSH)**.
- This supports the idea that prioritizing T&S profiles could improve RTOFS model performance the most.

2025 Planned Caribbean Glider Missions

Combined with Argo floats deployed across the Caribbean provide real-time profile data for assimilation by hurricane forecast models



North Atlantic Inflow - PR-USVI-BVI (US Hurricane Gliders)

Throughflow - DR to Curacao (2024 Vetlesen to US NSF)

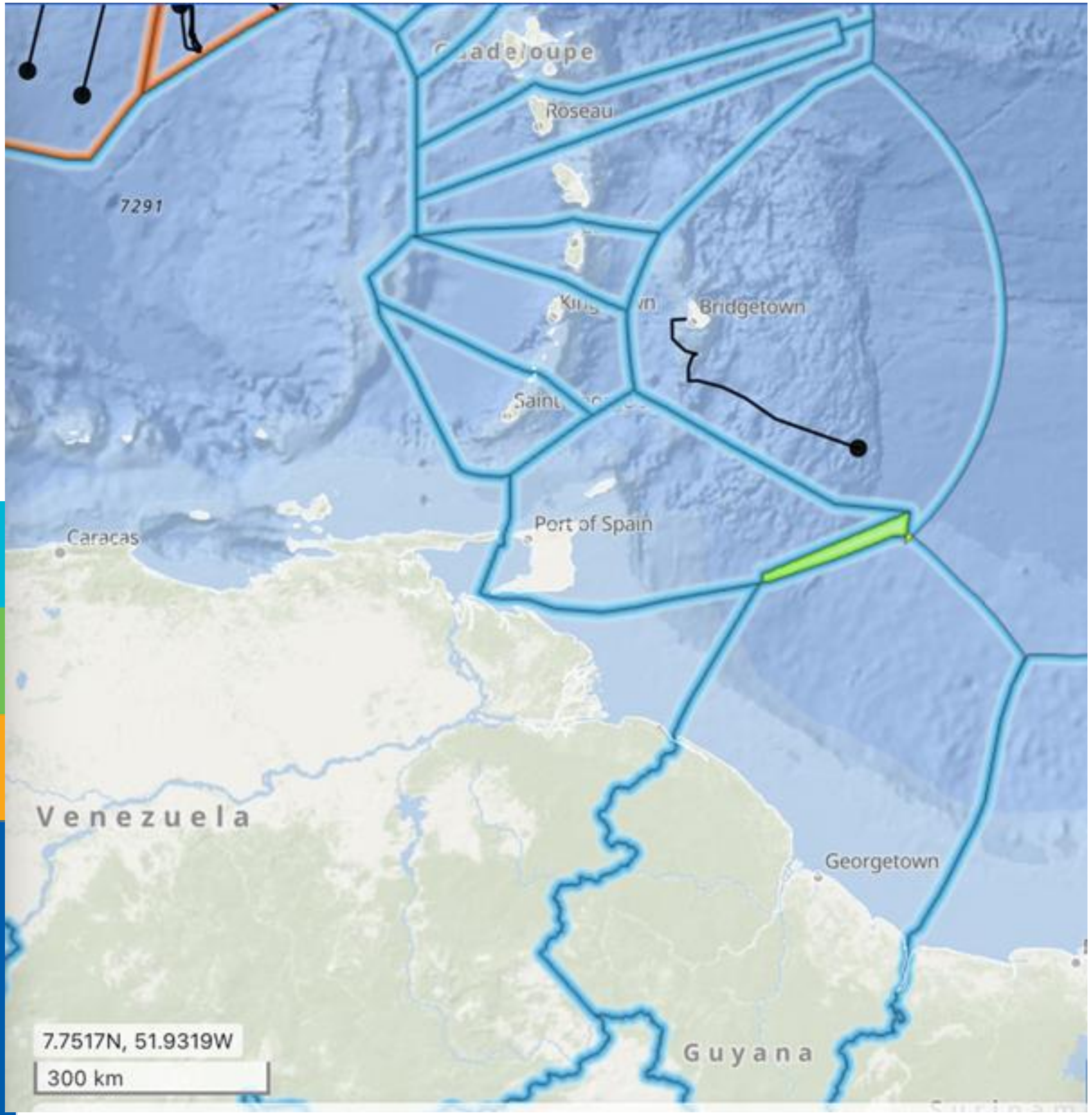
Throughflow - Nicaraguan Bank (US NSF)

Yucatan Outflow - Mexico (US NAS/ Mexico)

South Atlantic Inflow - Barbados to Guyana (2025 Vetlesen)

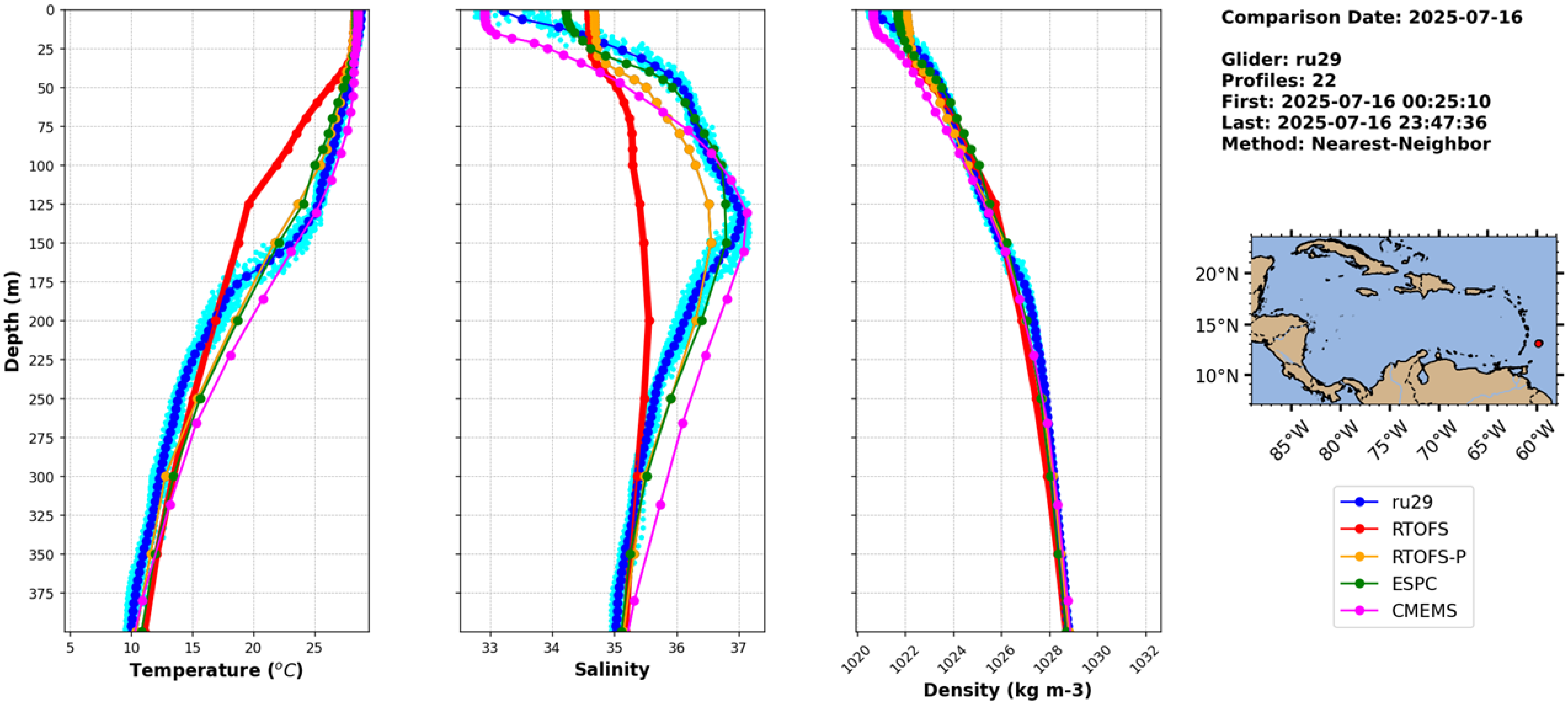
2025 Barbados Glider Deployment with IOCARIBE-GOOS

Combined with Argo floats deployed across the Caribbean provide real-time profile data



Glider RU29 deployed 15 July 2025

Operational Model/Data Profile Comparisons

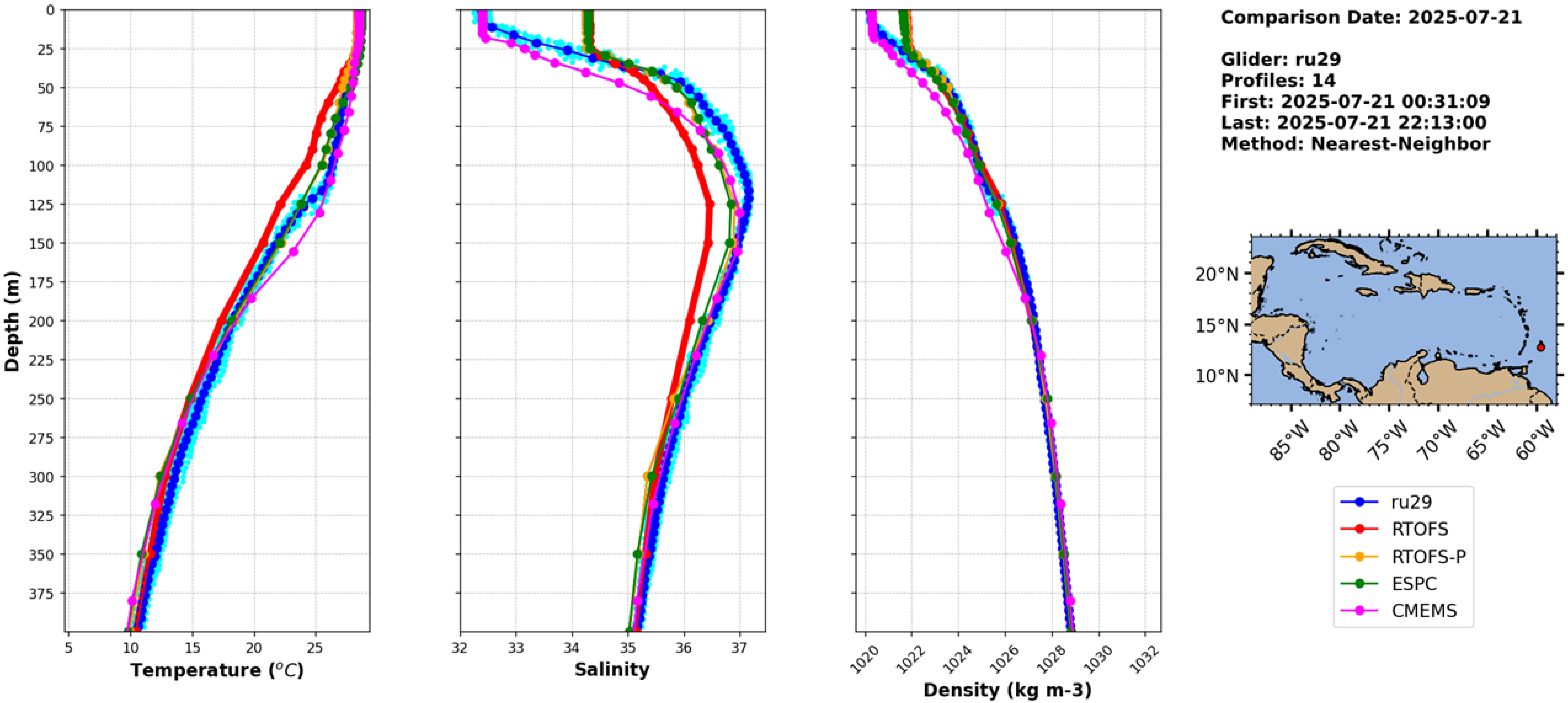


Comparison Date: 2025-07-16

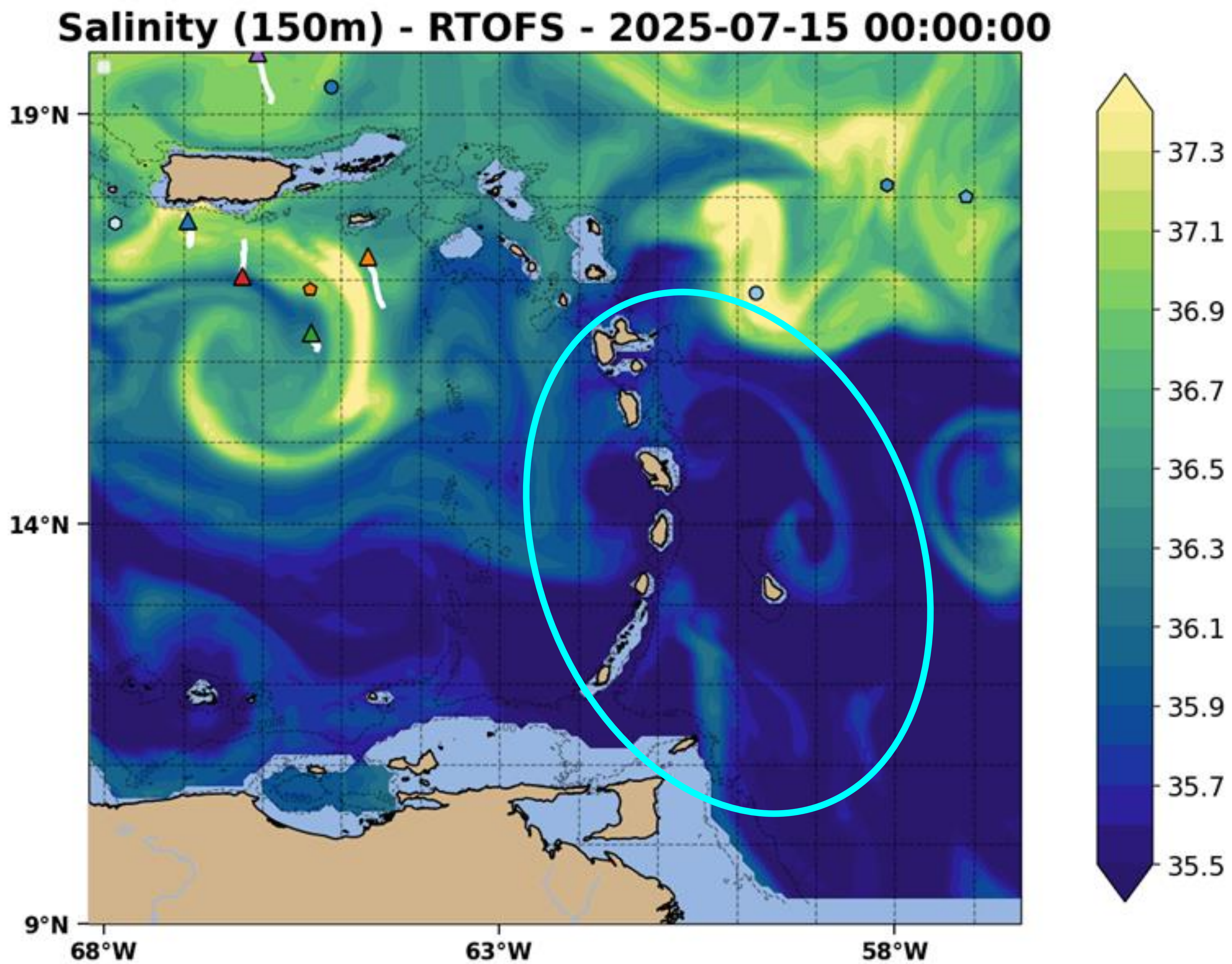
Glider: ru29
Profiles: 22
First: 2025-07-16 00:25:10
Last: 2025-07-16 23:47:36
Method: Nearest-Neighbor

Ocean Heat Content (kJ/cm^2) - Glider: 64.7789, RTOFS: 37.1015, RTOFS (Parallel): 50.6383, ESPC: 52.1993, CMEMS: 83.4706, NESDIS: 83.4762,

Operational Model/Data Profile Comparisons

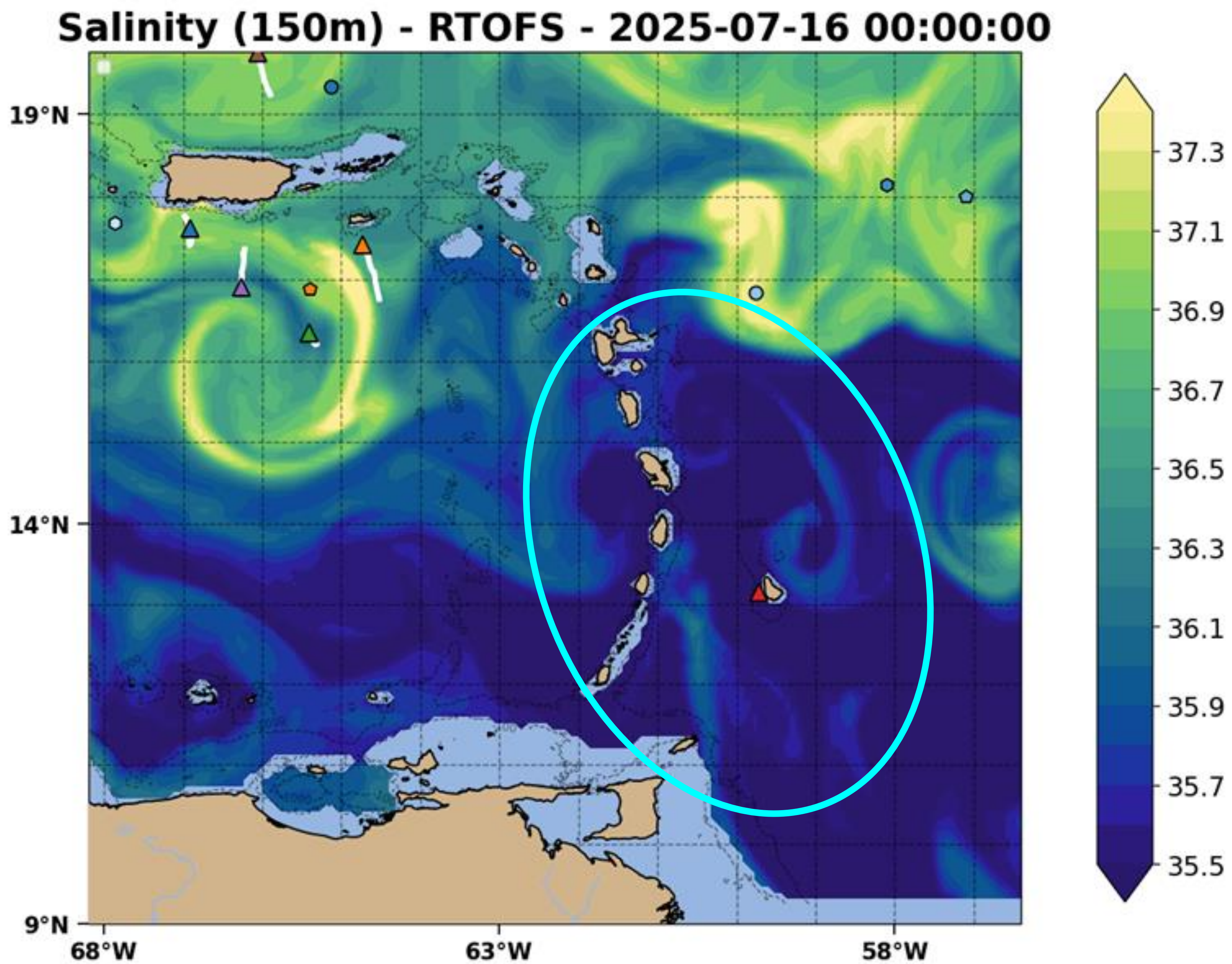


Ocean Heat Content (kJ/cm^2) - Glider: 64.0652, RTOFS: 41.7157, RTOFS (Parallel): 51.4132, ESPC: 62.0807, CMEMS: 75.9580, NESDIS: 76.4399,



WORLD METEOROLOGICAL ORGANIZATION

1950-2025 SCIENCE for ACTION



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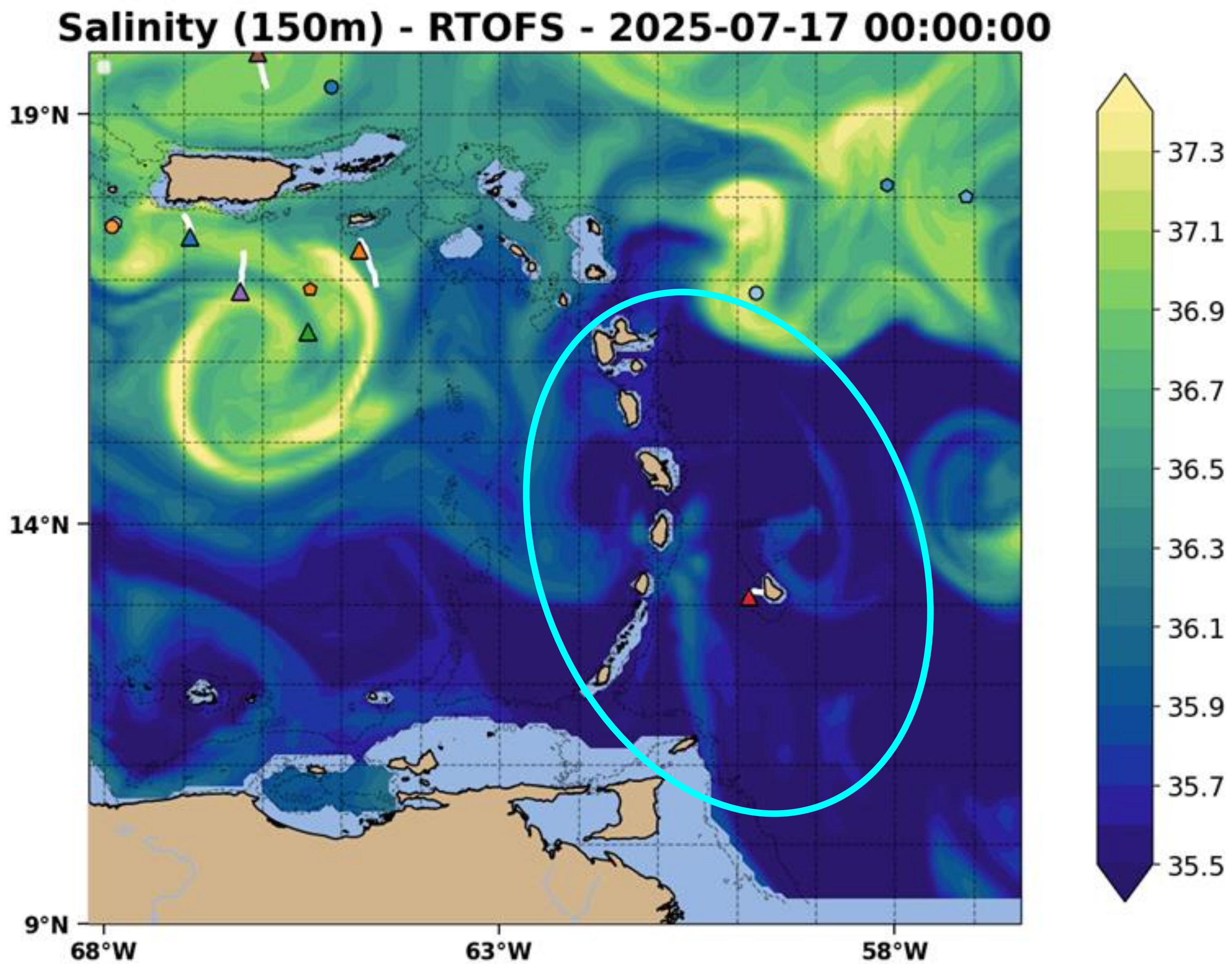

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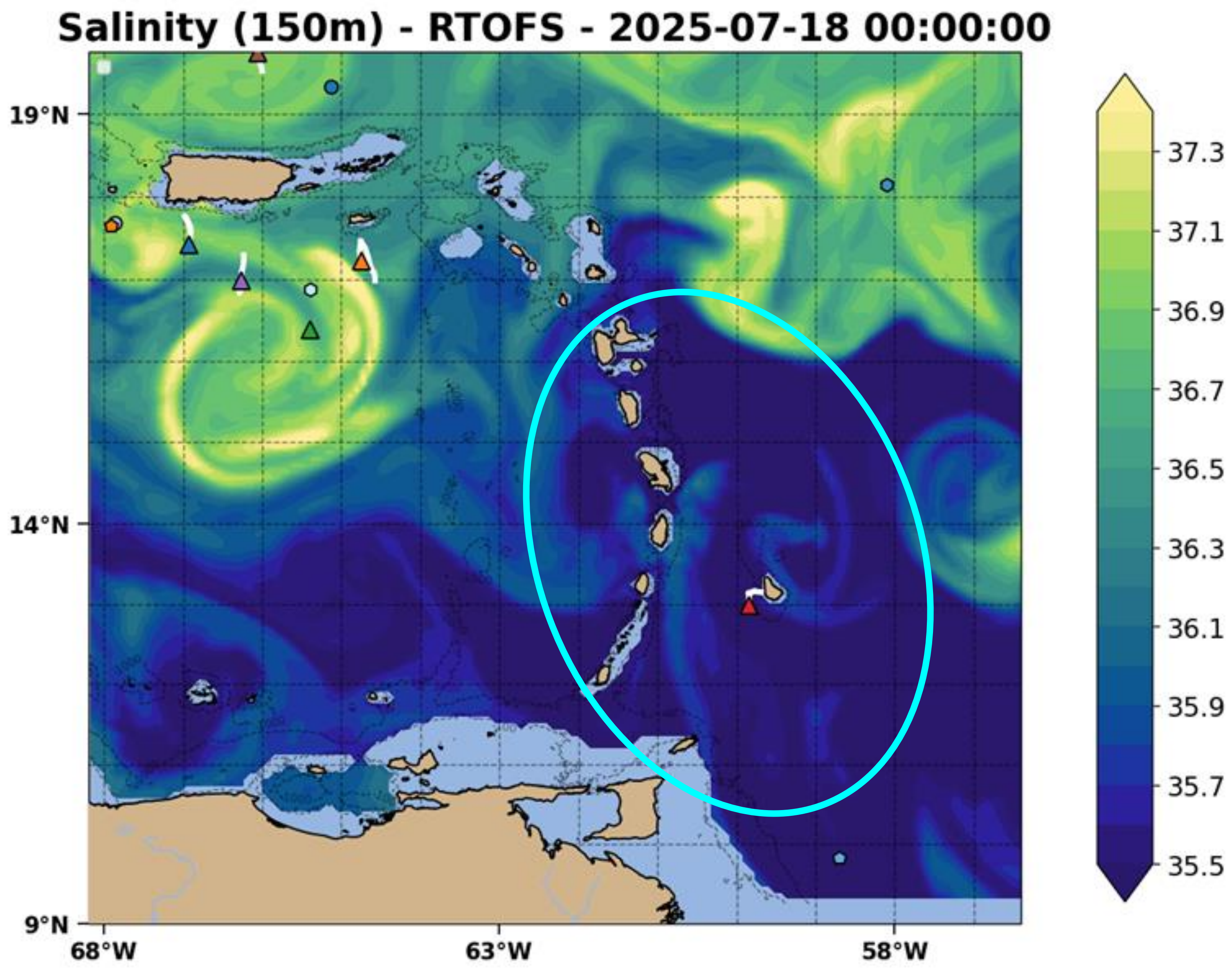

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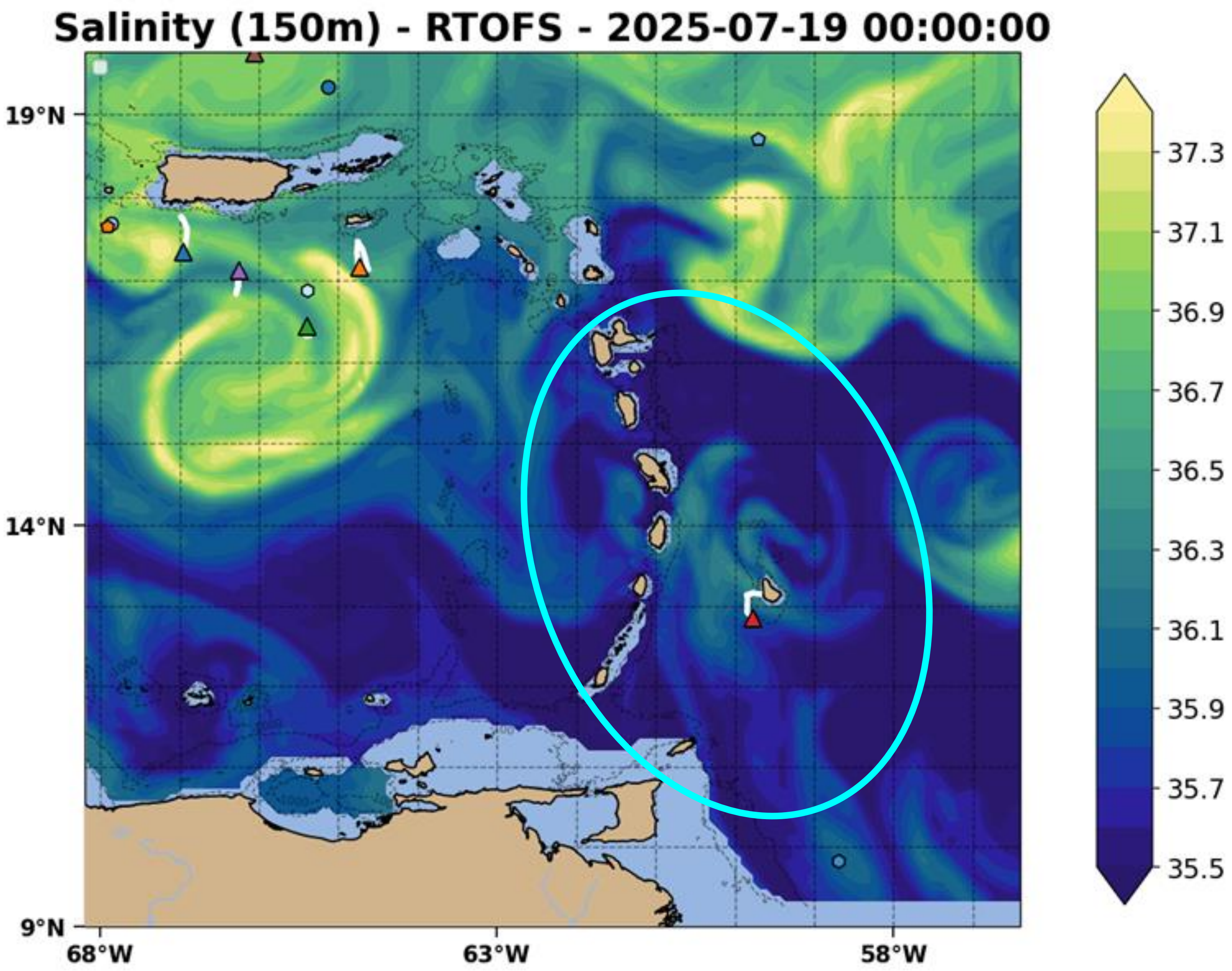

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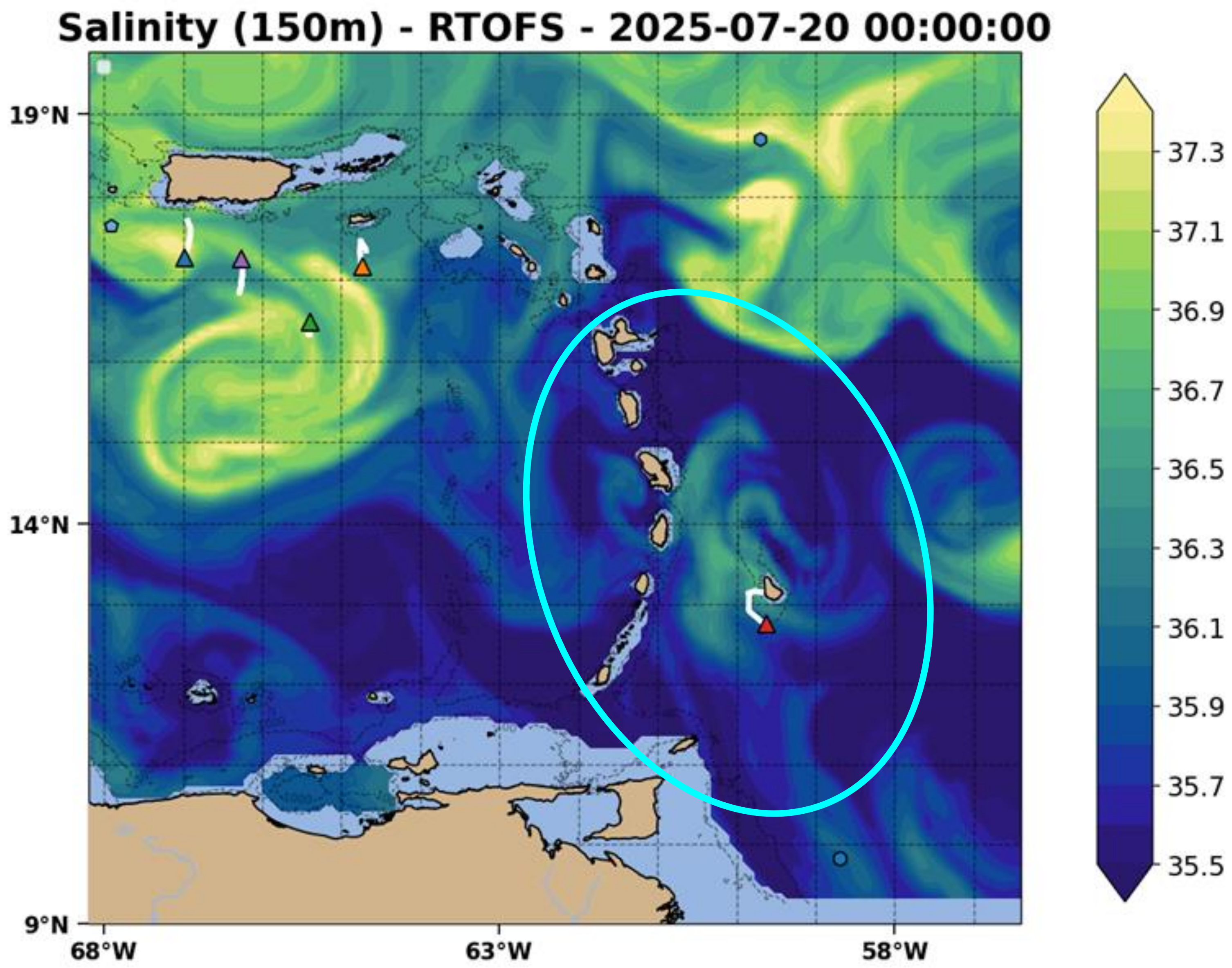
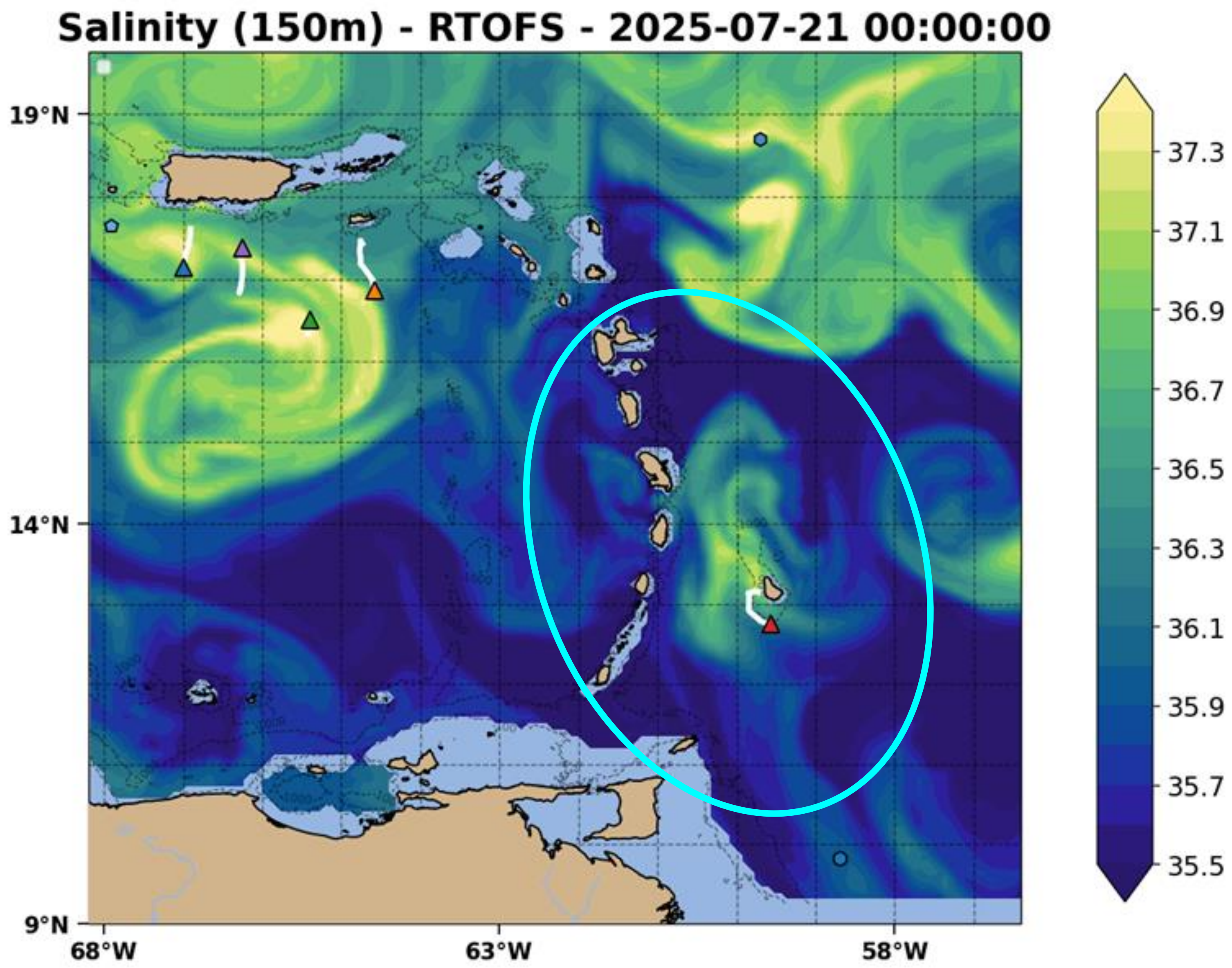


Salinity (150m) - RTOFS - 2025-07-20 00:00:00
19°N
14°N
9°N
68°W
63°W
58°W
37.3
37.1
36.9
36.7
36.5
36.3
36.1
35.9
35.7
35.5



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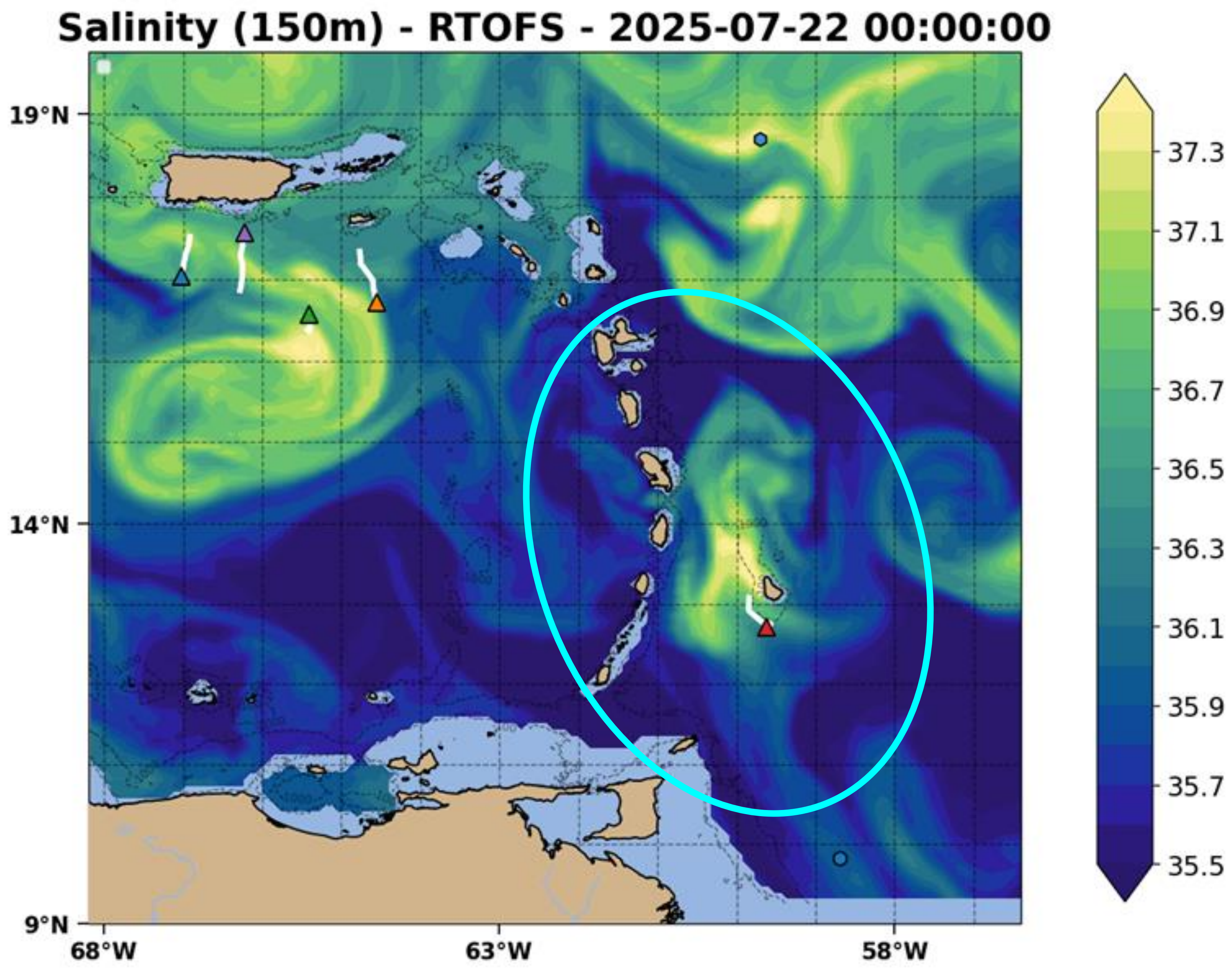
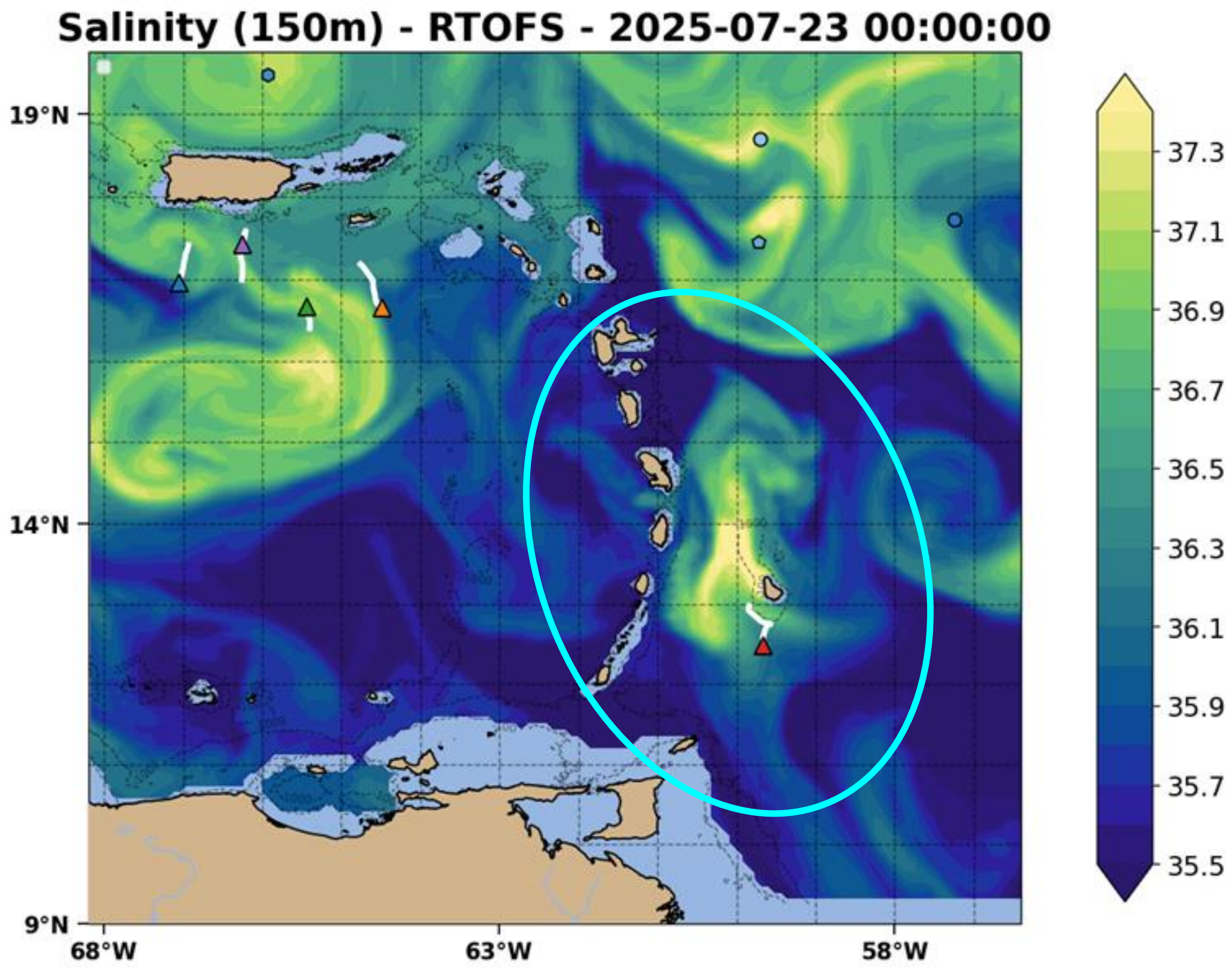


WORLD METEOROLOGICAL ORGANIZATION

1950-2025 75 SCIENCE for ACTION



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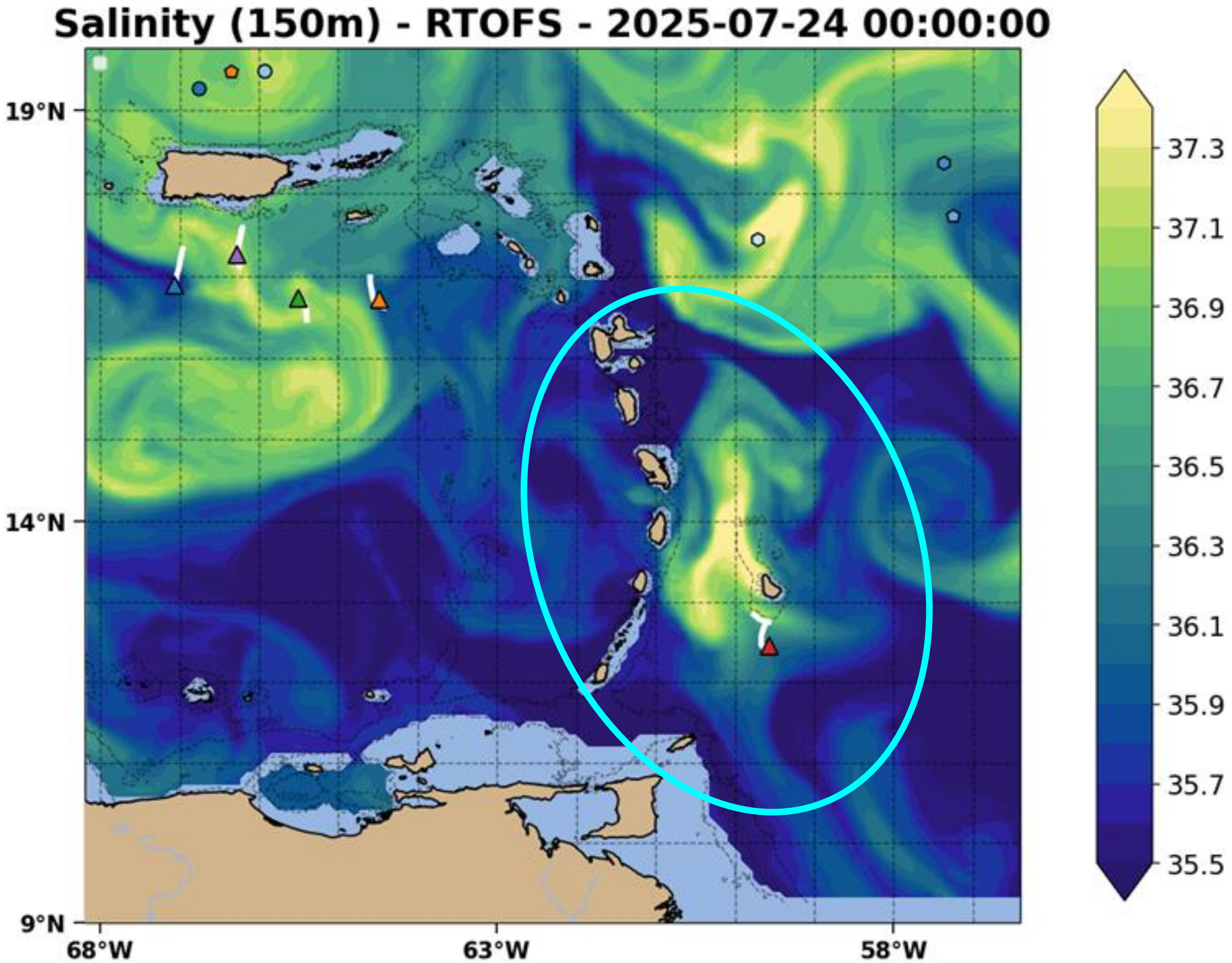
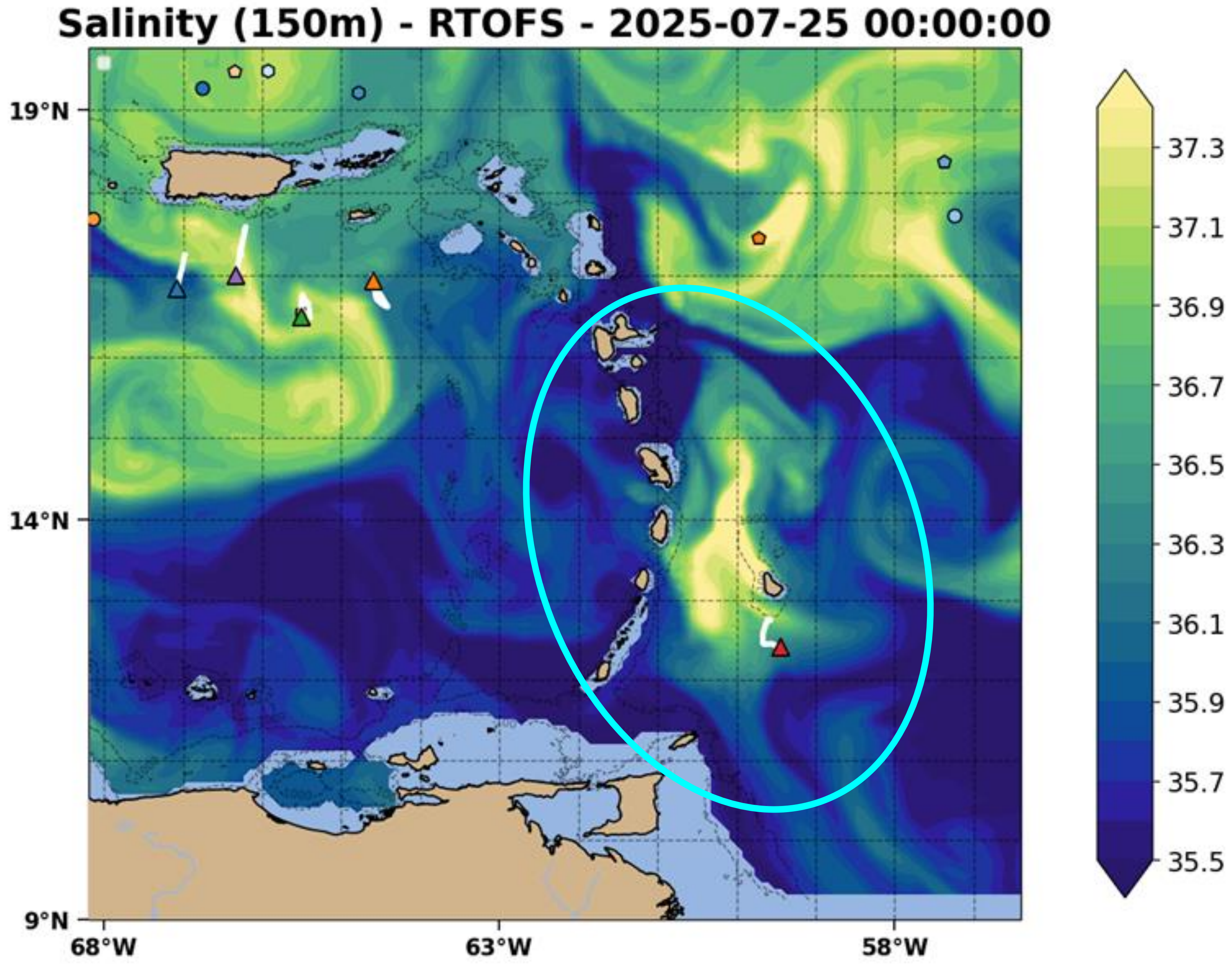


WORLD METEOROLOGICAL ORGANIZATION

1950-2025 75 SCIENCE for ACTION


Salinity (150m) - RTOFS - 2025-07-25 00:00:00
19°N
14°N
9°N
68°W
63°W
58°W
37.3
37.1
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36.7
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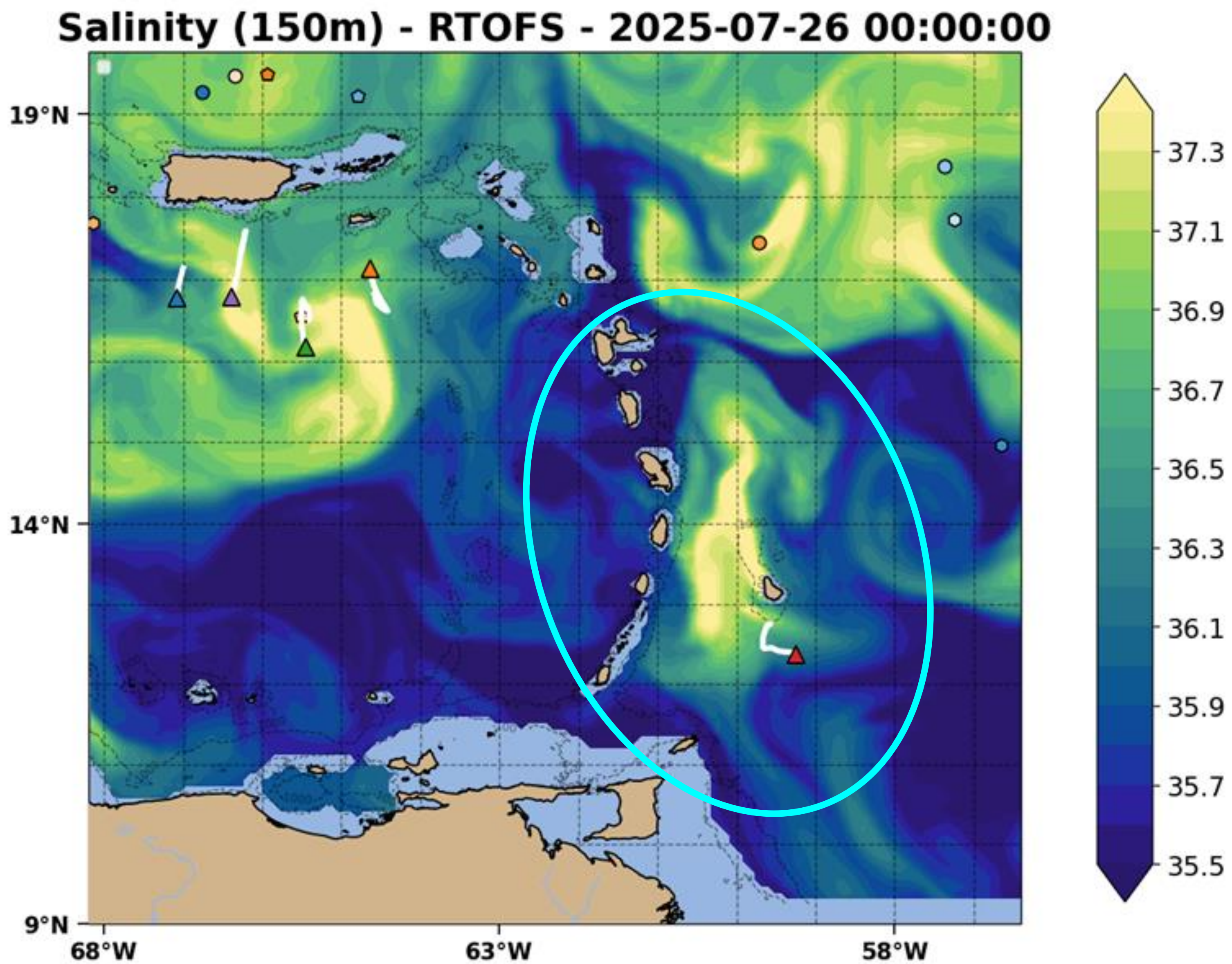
35.9
35.7
35.5



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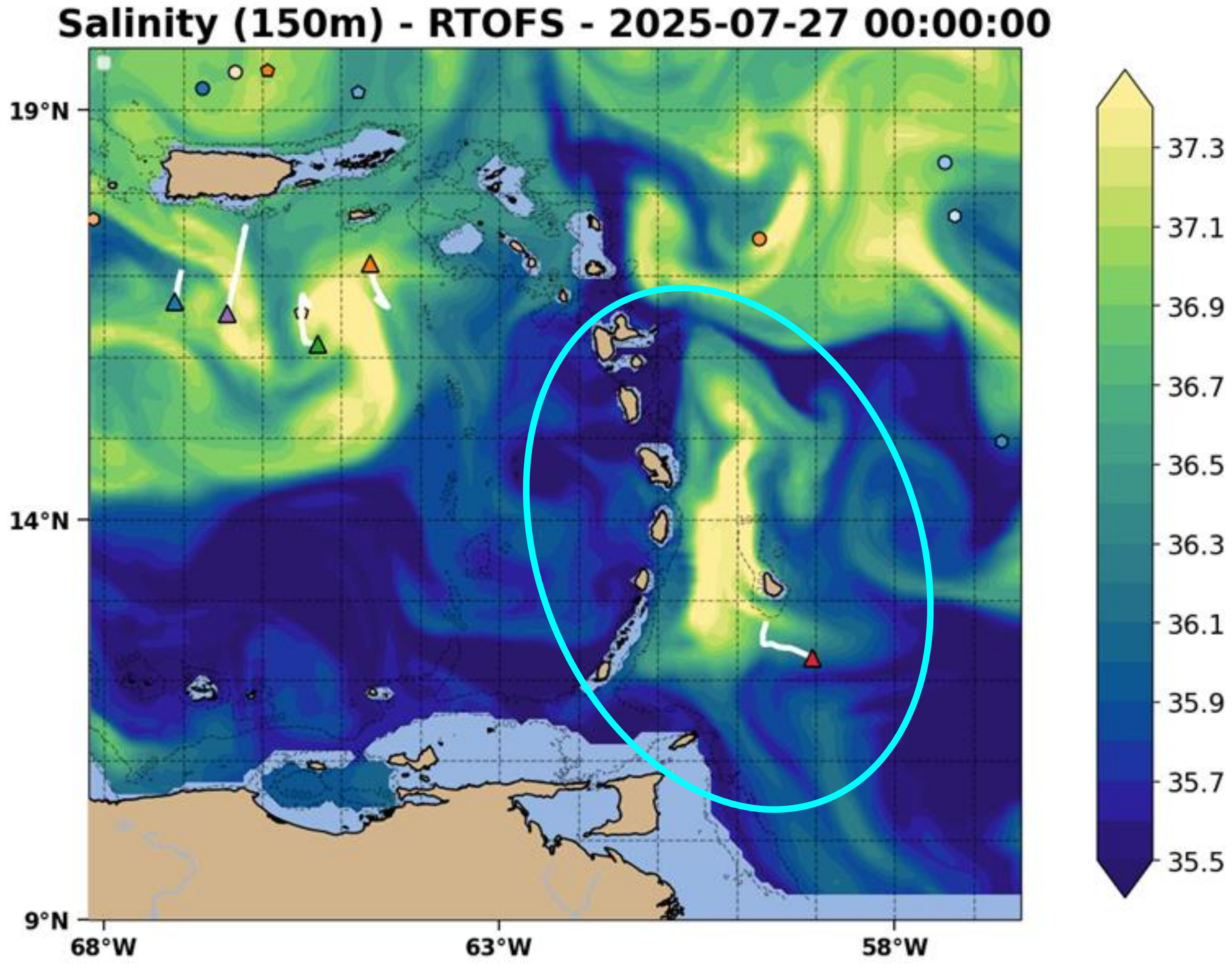

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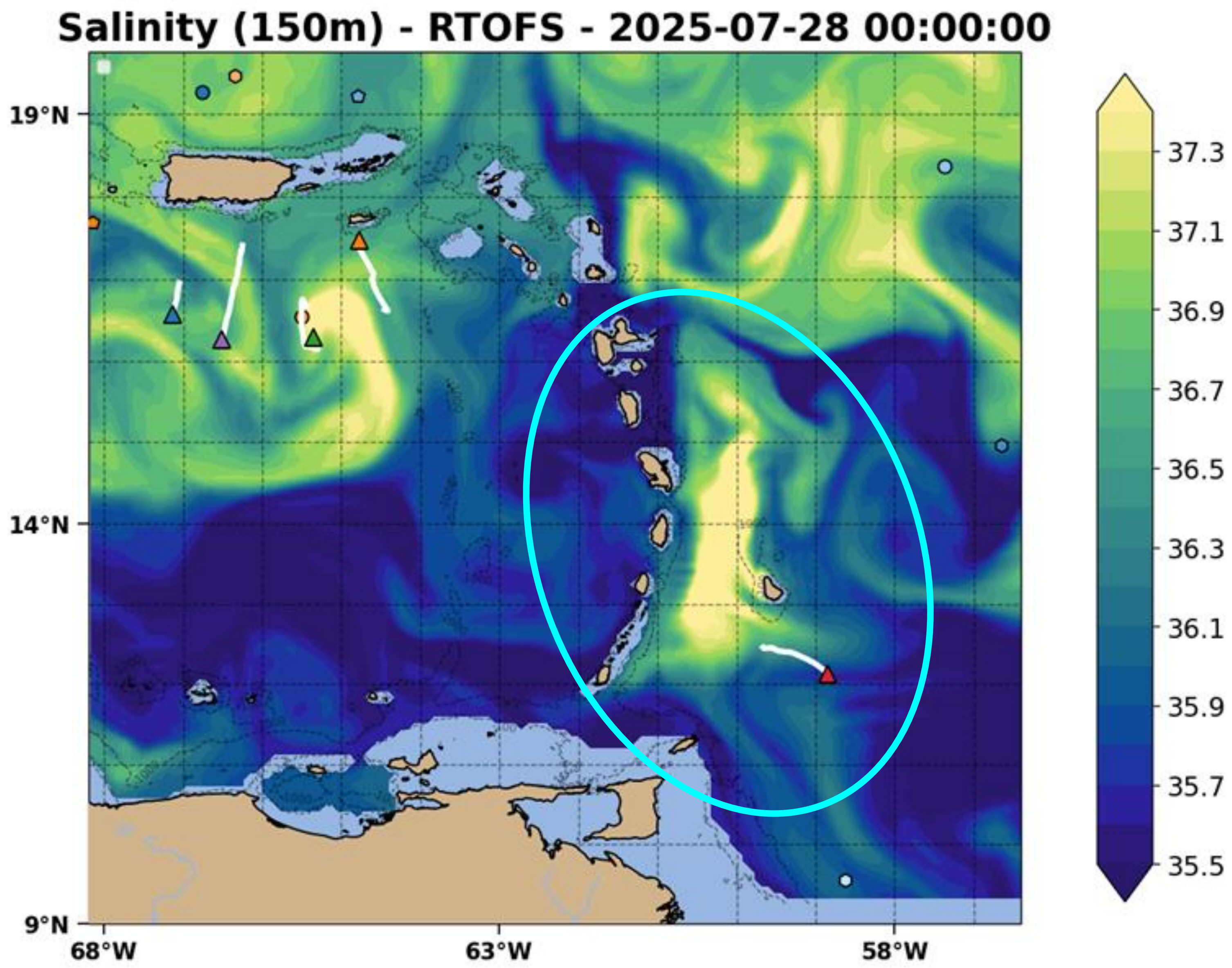

Salinity (150m) - RTOFS - 2025-07-28 00:00:00
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14°N
9°N
68°W
63°W
58°W
37.3
37.1
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36.1
35.9
35.7
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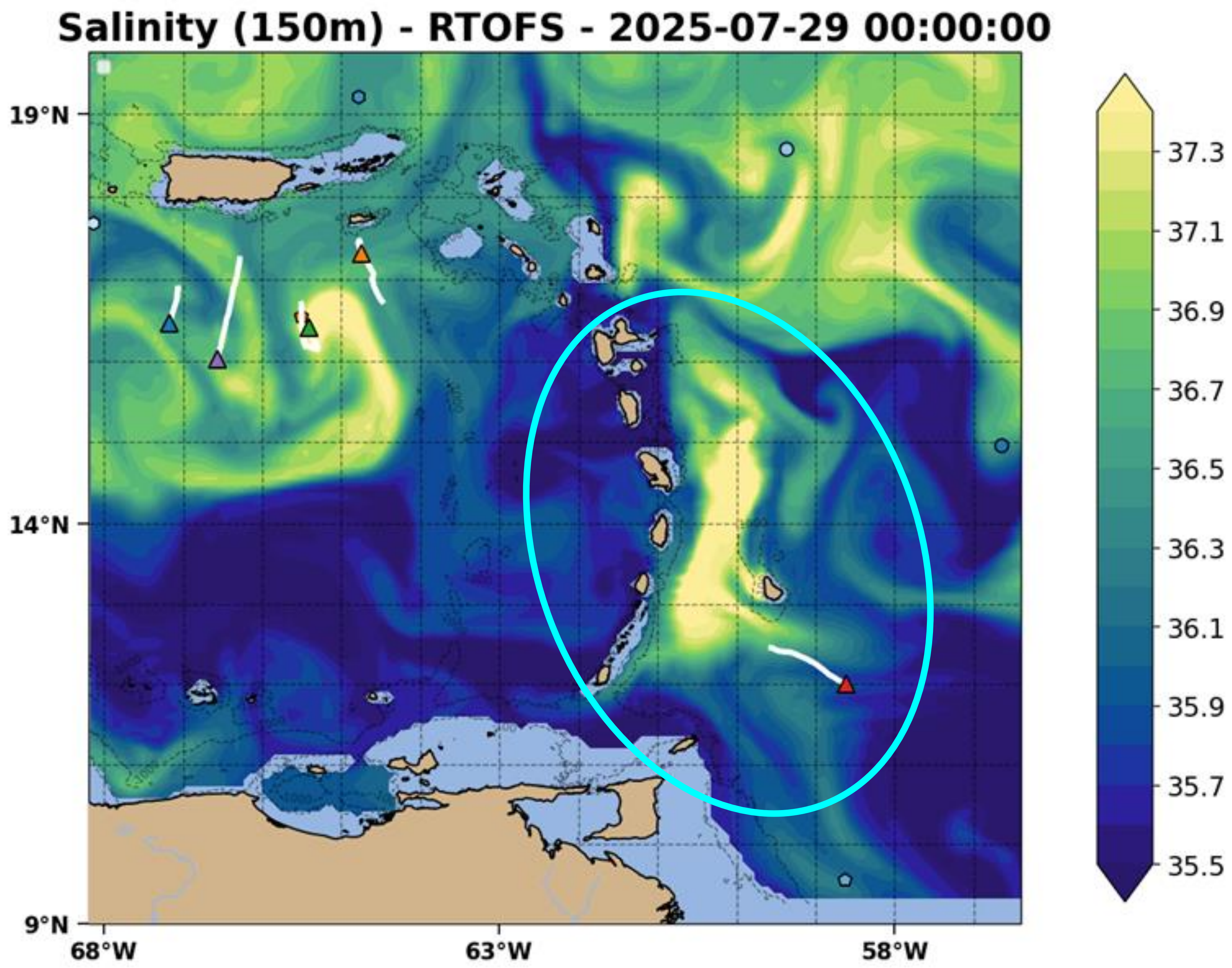

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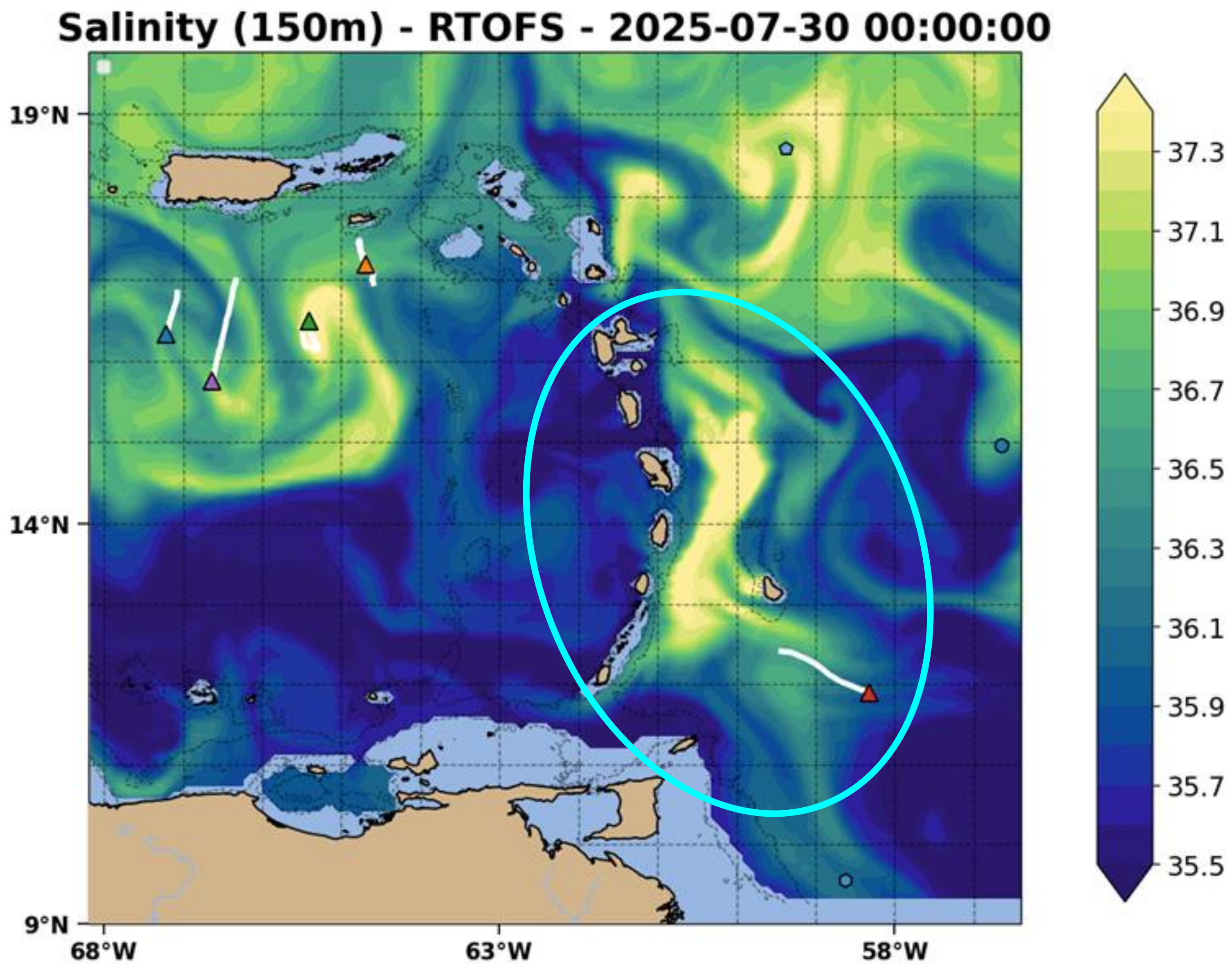

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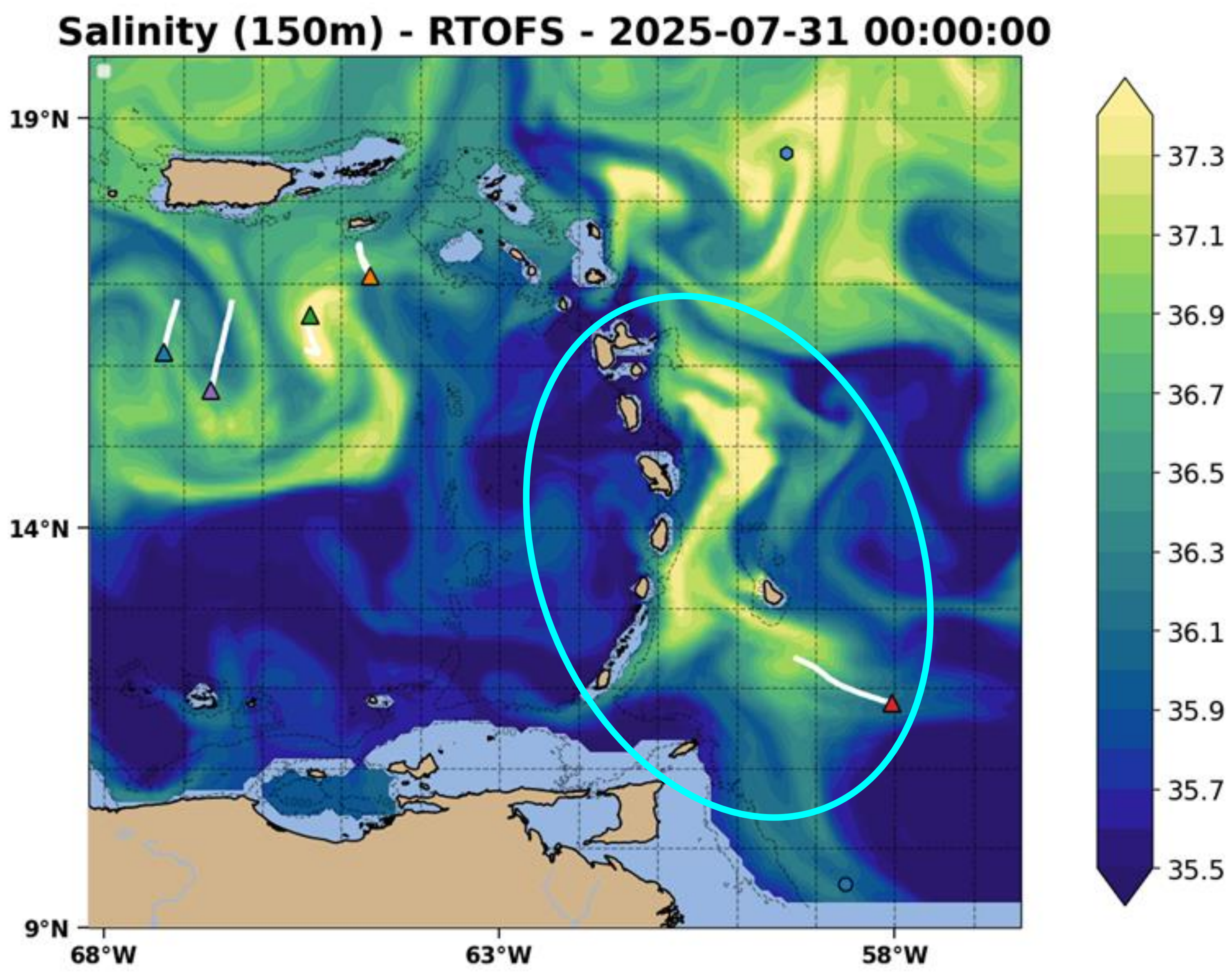
1950-2025 SCIENCE for ACTION


Salinity (150m) - RTOFS - 2025-07-31 00:00:00
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9°N
68°W
63°W
58°W
37.3
37.1
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36.1
35.9
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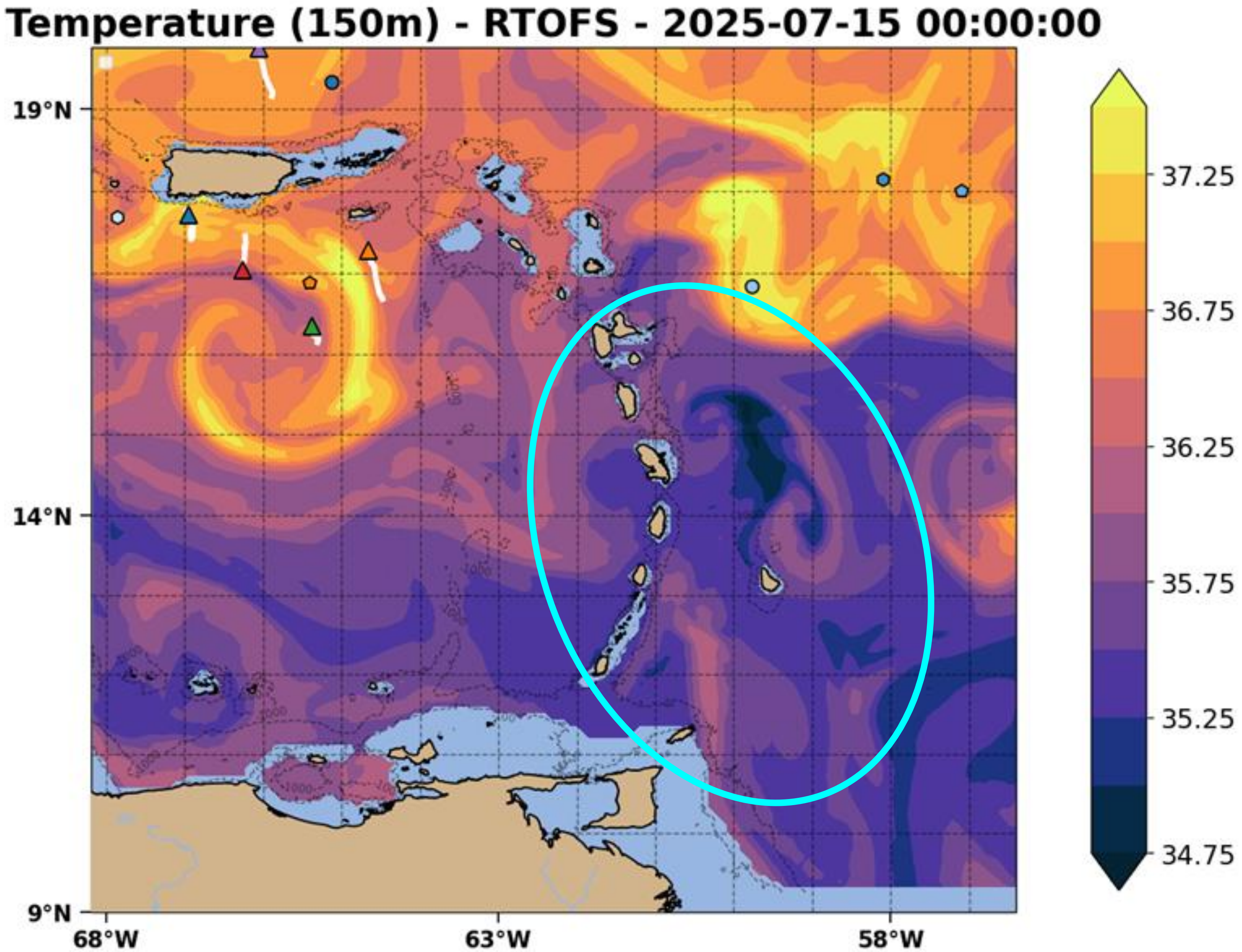

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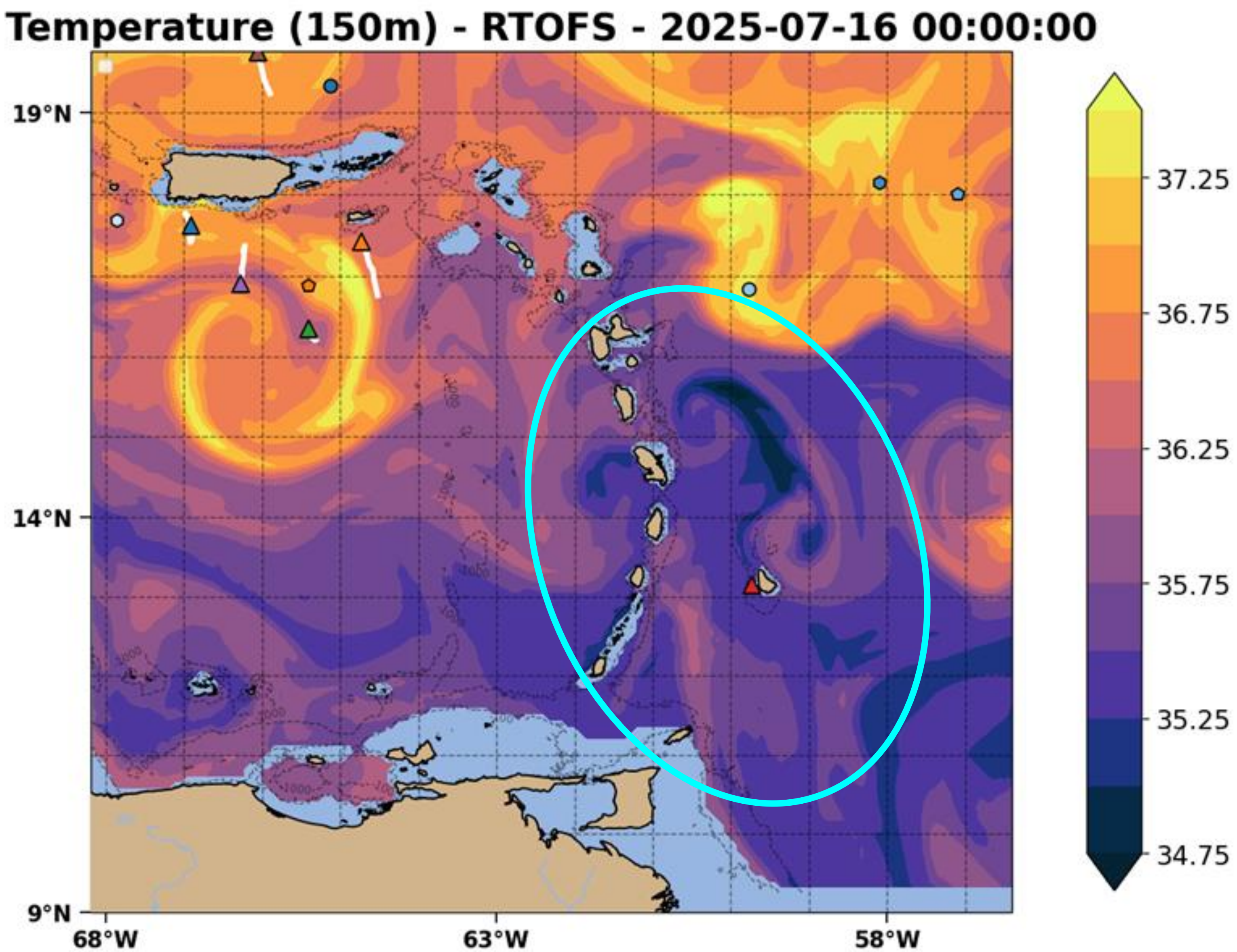

WORLD METEOROLOGICAL ORGANIZATION

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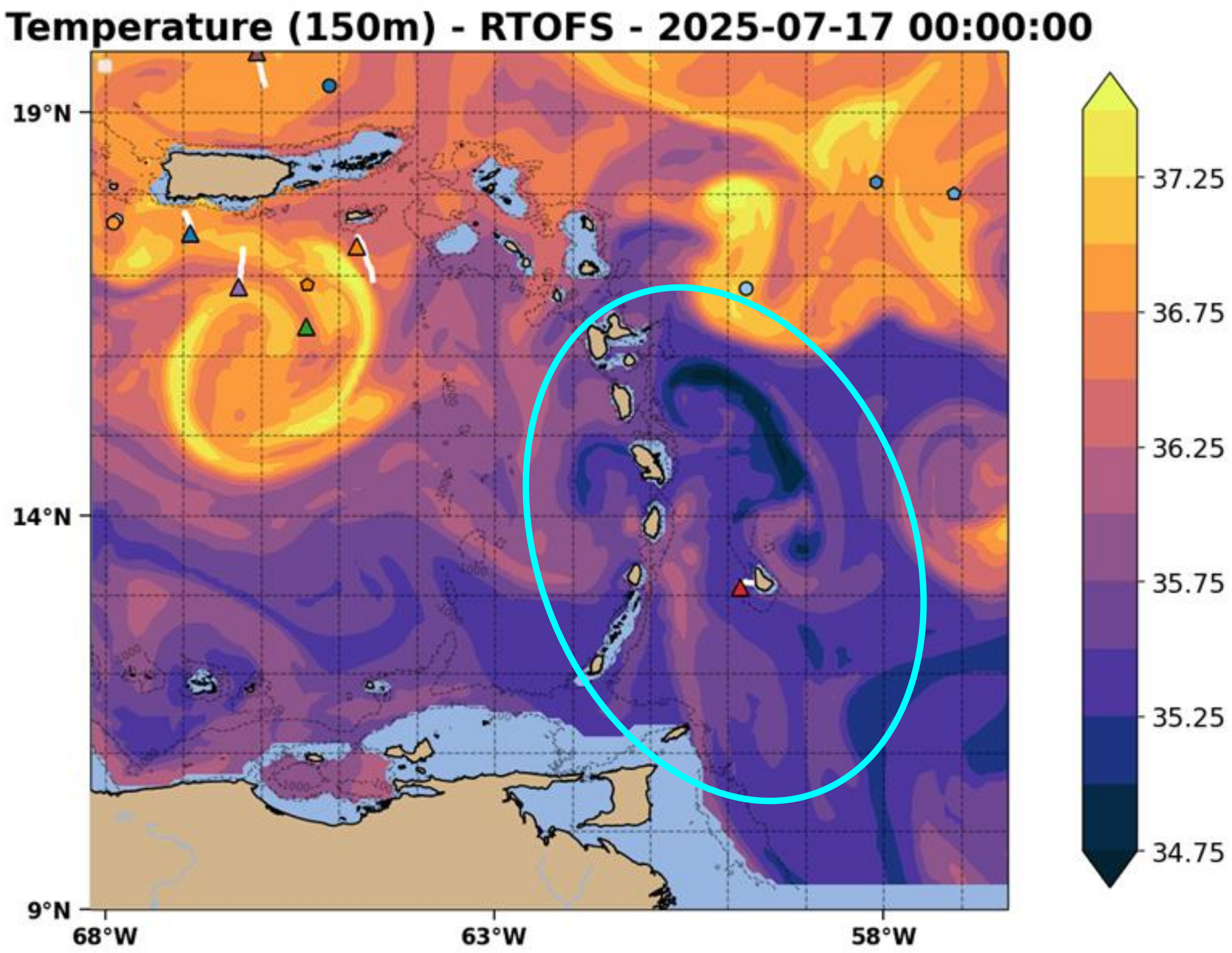
Temperature (150m) - RTOFS - 2025-07-17 00:00:00
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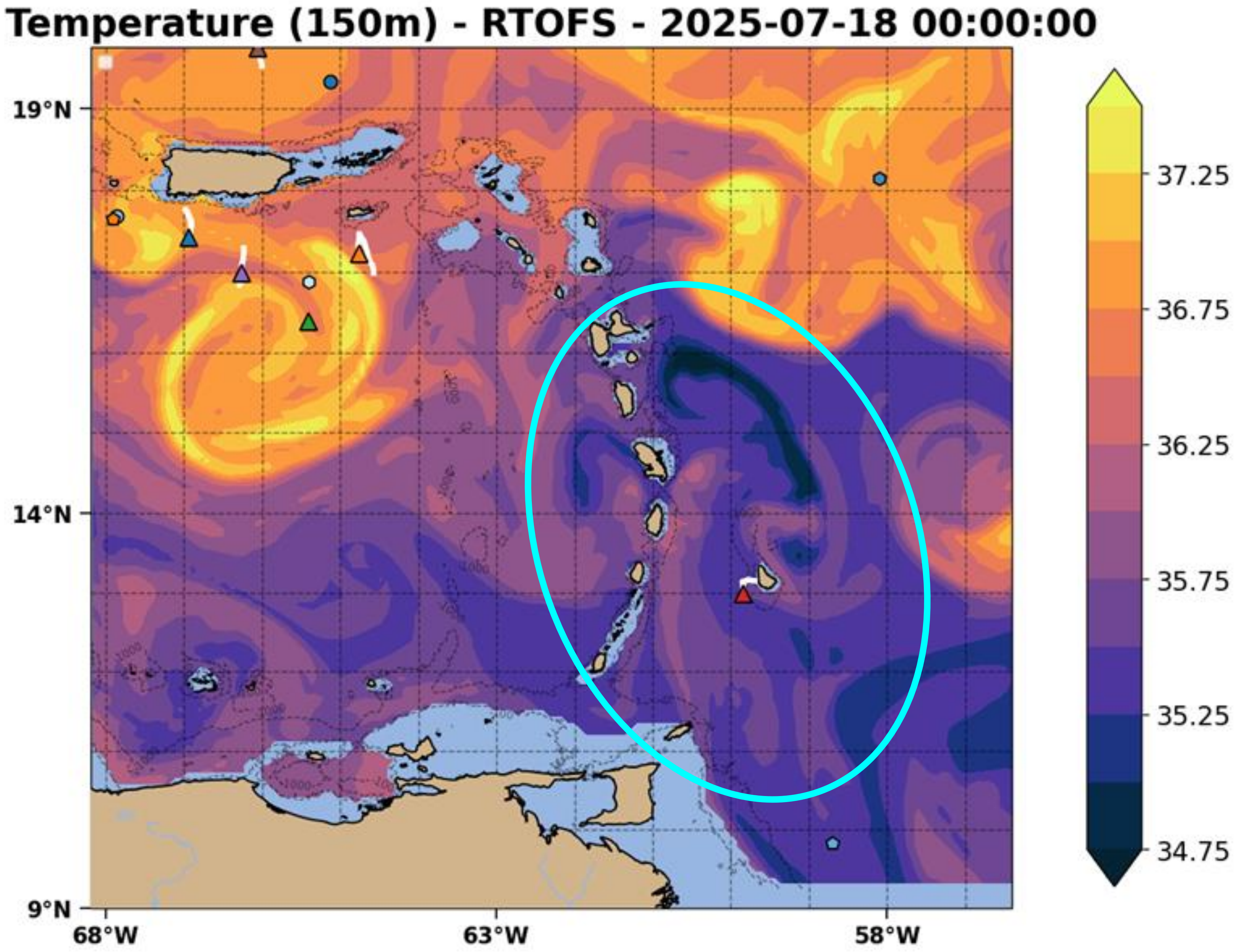
14°N
9°N
68°W
63°W
58°W
37.25
36.75
36.25
35.75
35.25
34.75



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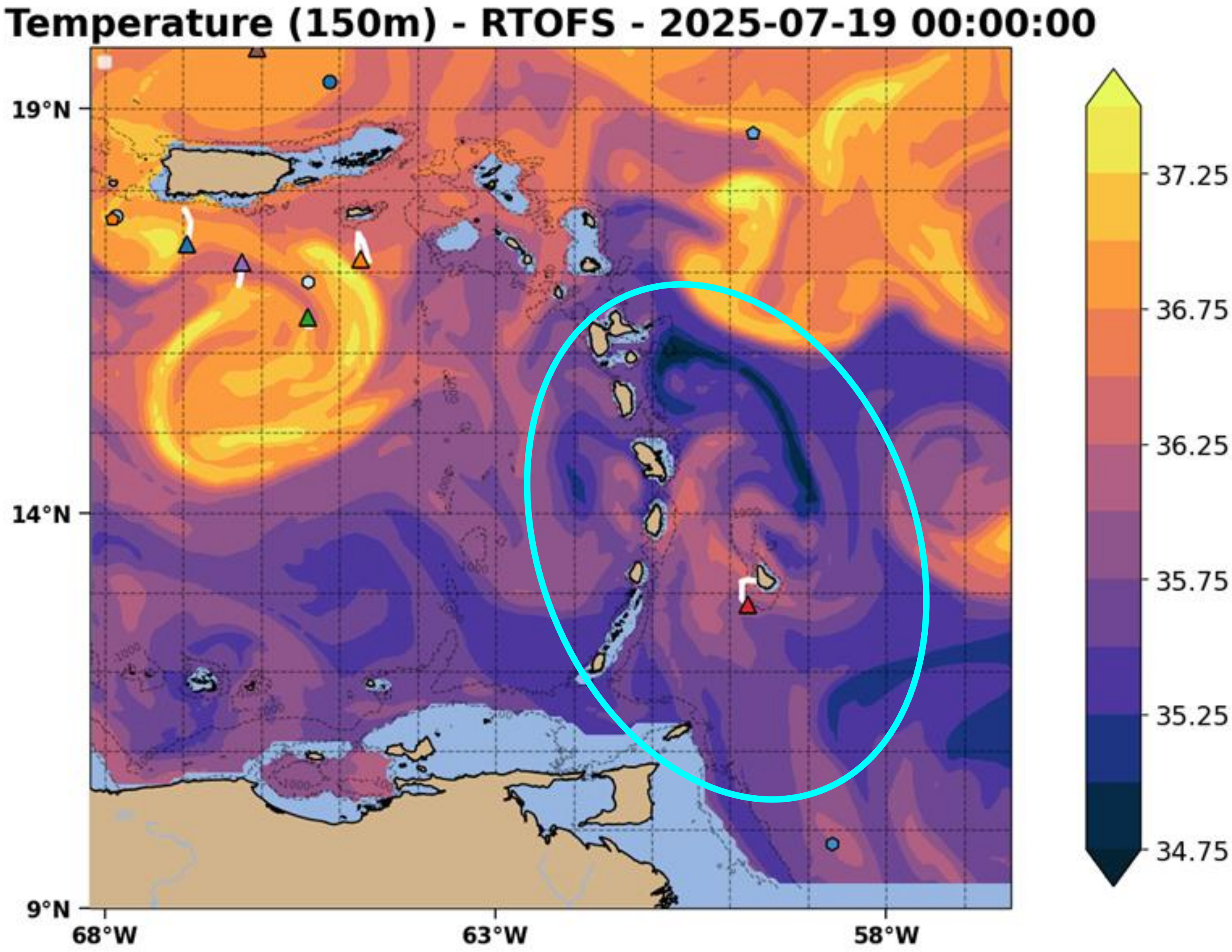

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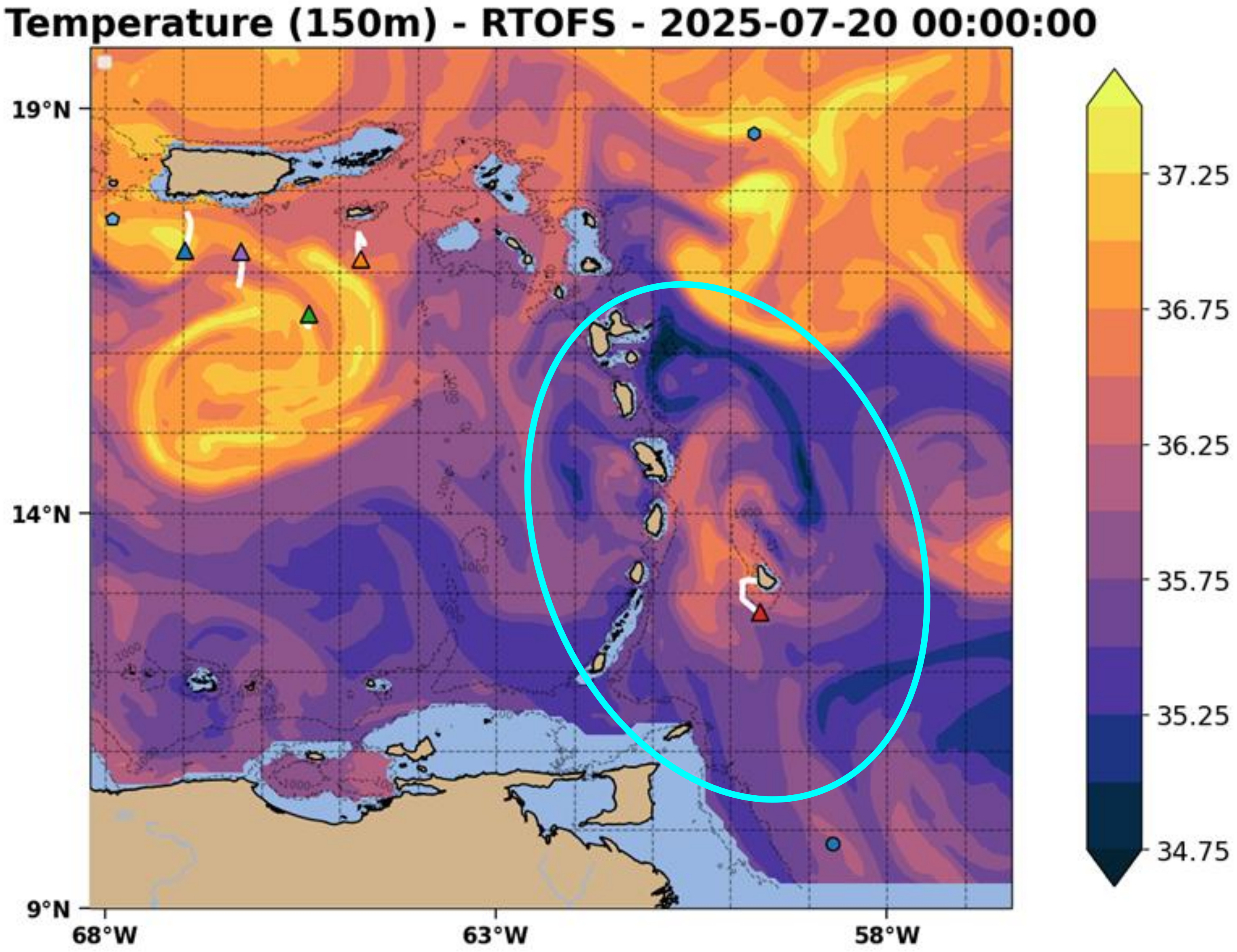
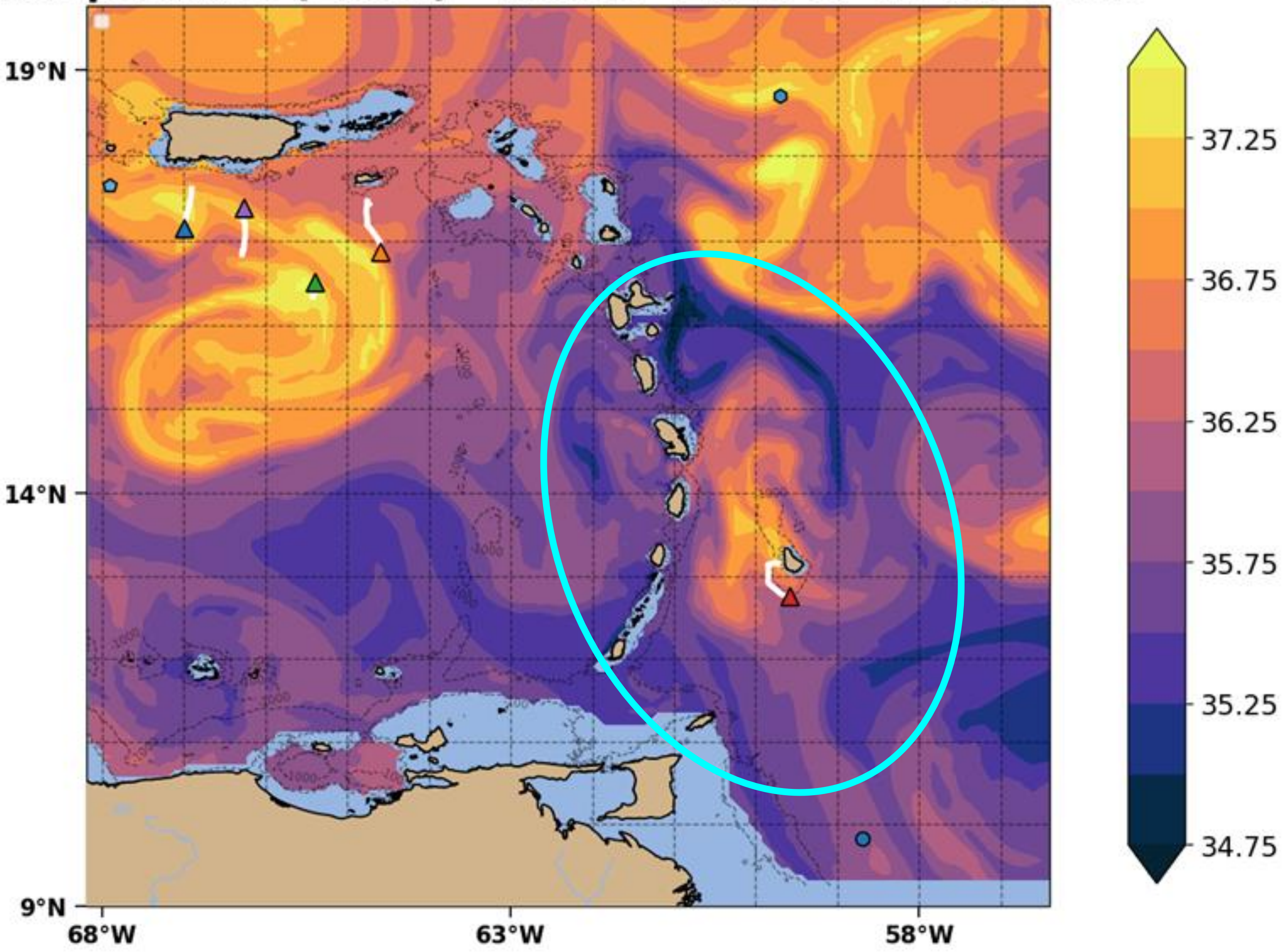

Temperature (150m) - RTOFS - 2025-07-20 00:00:00
19°N
14°N
9°N
68°W
63°W
58°W
37.25
36.75
36.25
35.75
35.25
34.75

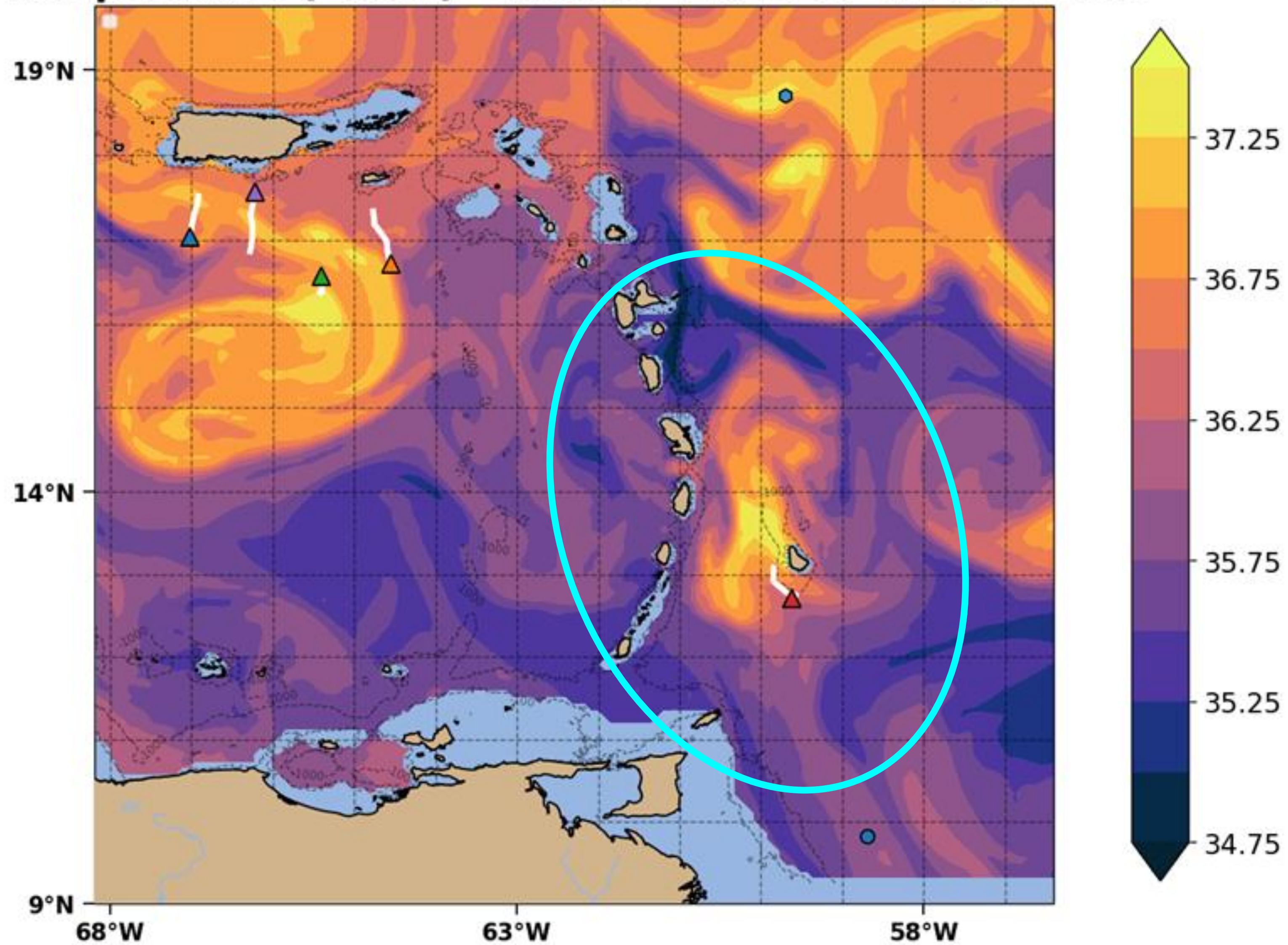
Temperature (150m) - RTOFS - 2025-07-21 00:00:00

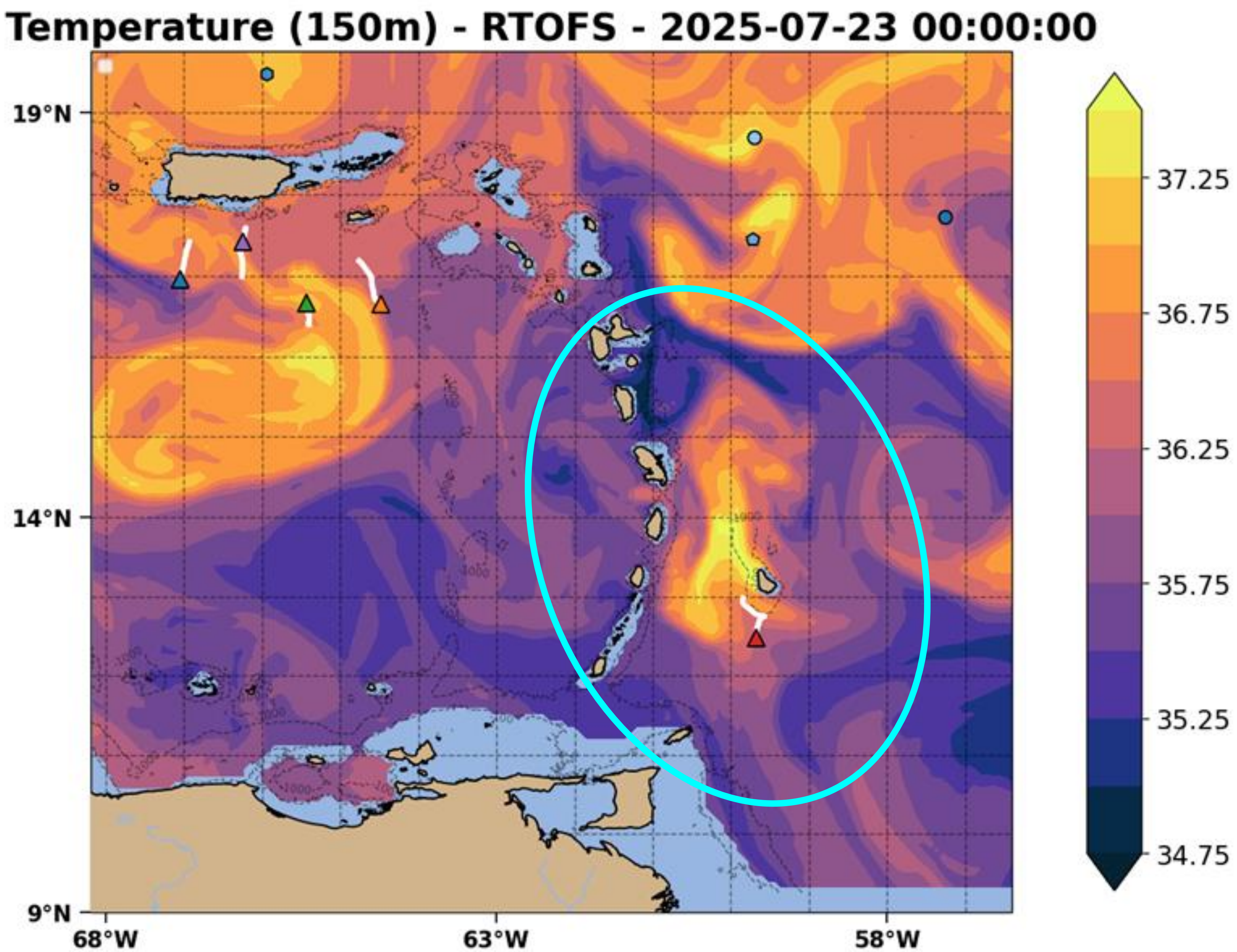


WORLD METEOROLOGICAL ORGANIZATION

1950-2025 SCIENCE for ACTION

Temperature (150m) - RTOFS - 2025-07-22 00:00:00





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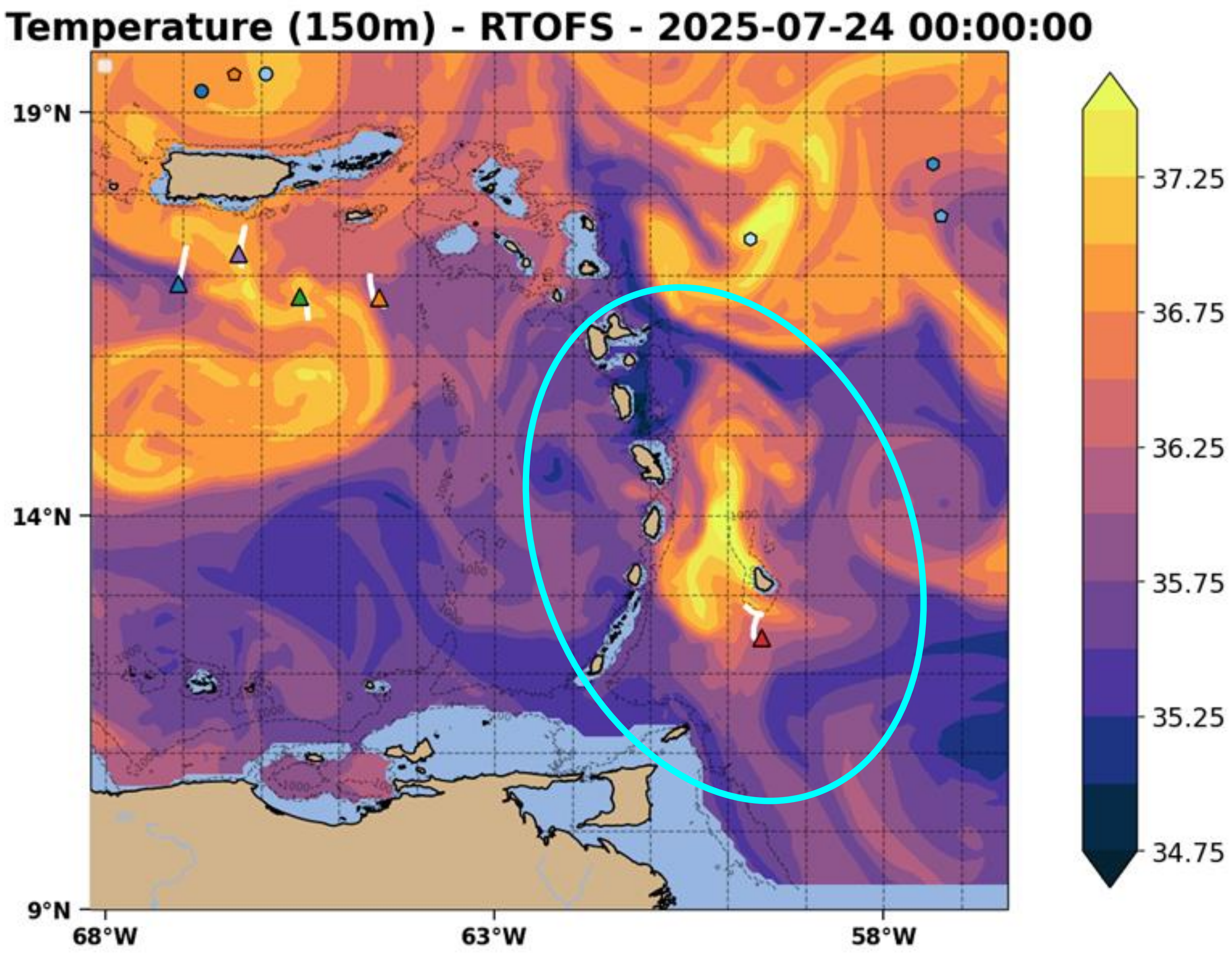

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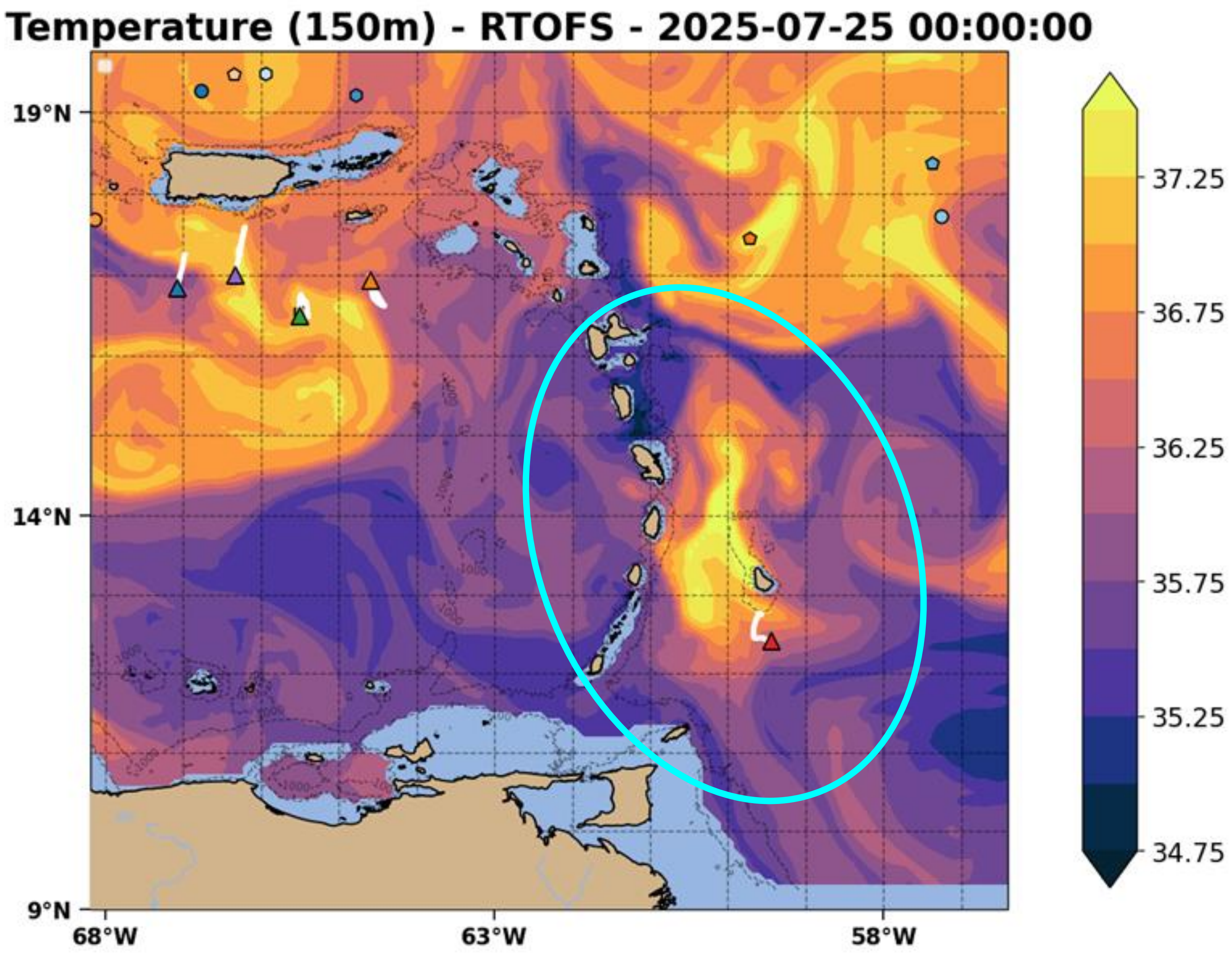

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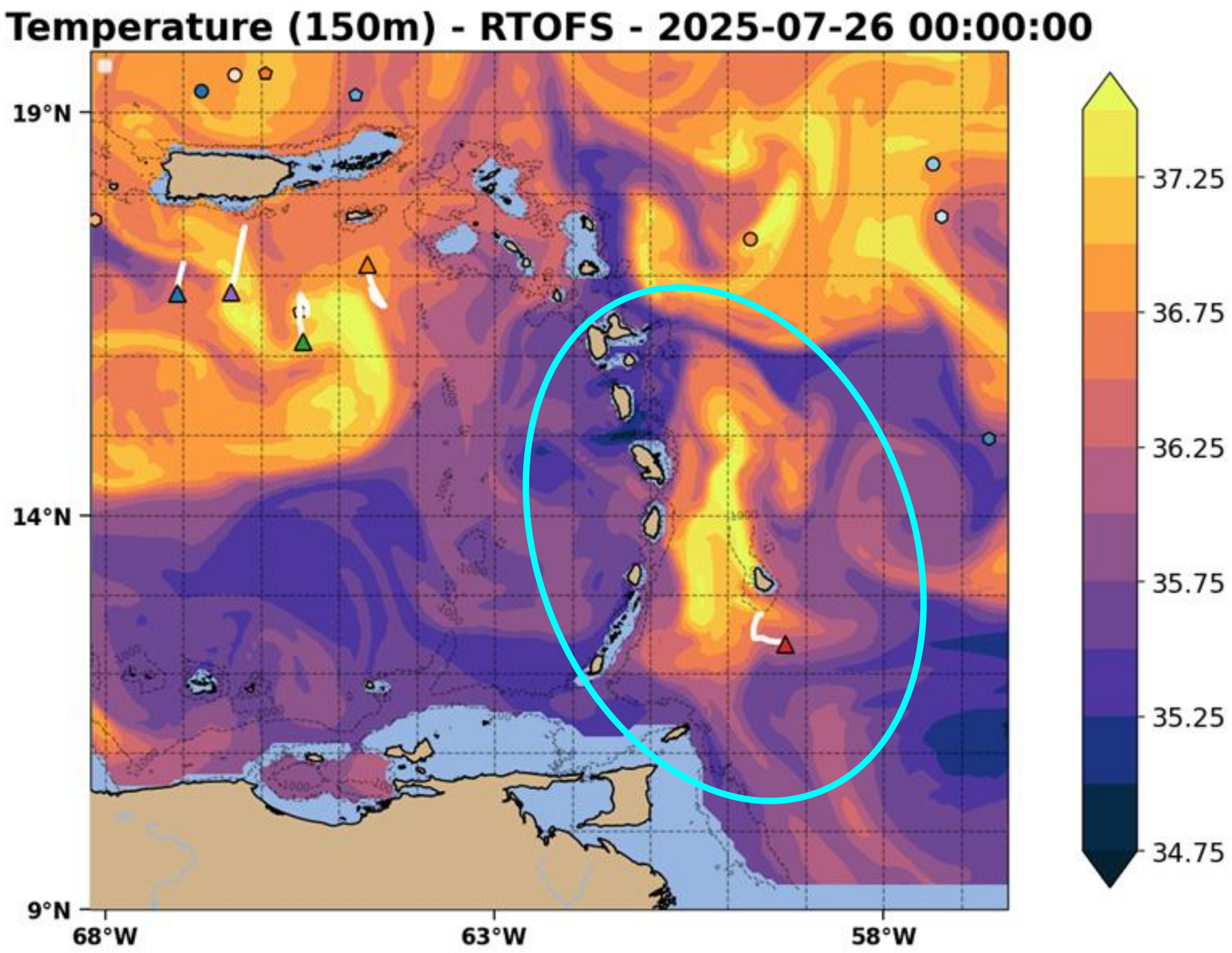

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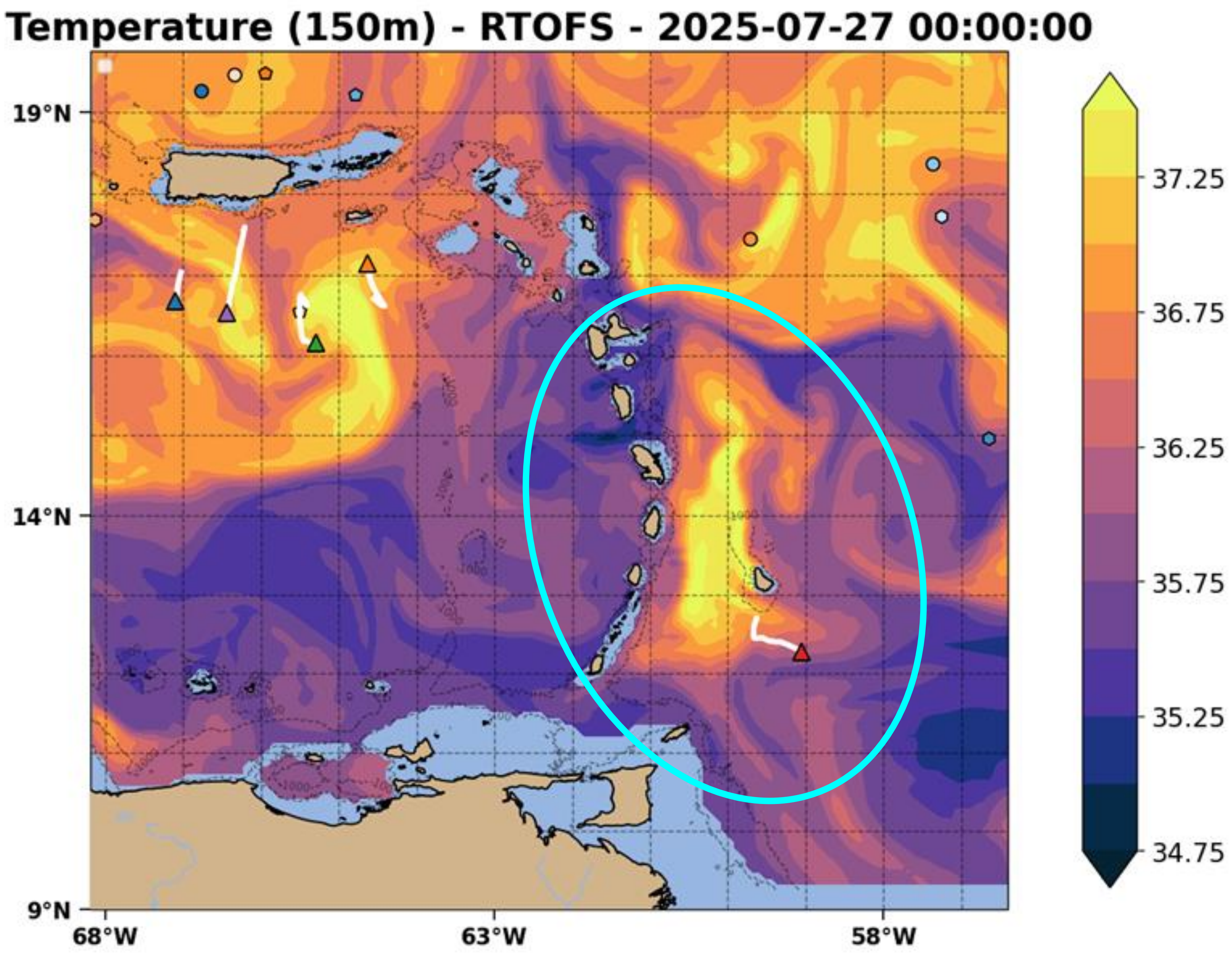
1950-2025 SCIENCE for ACTION



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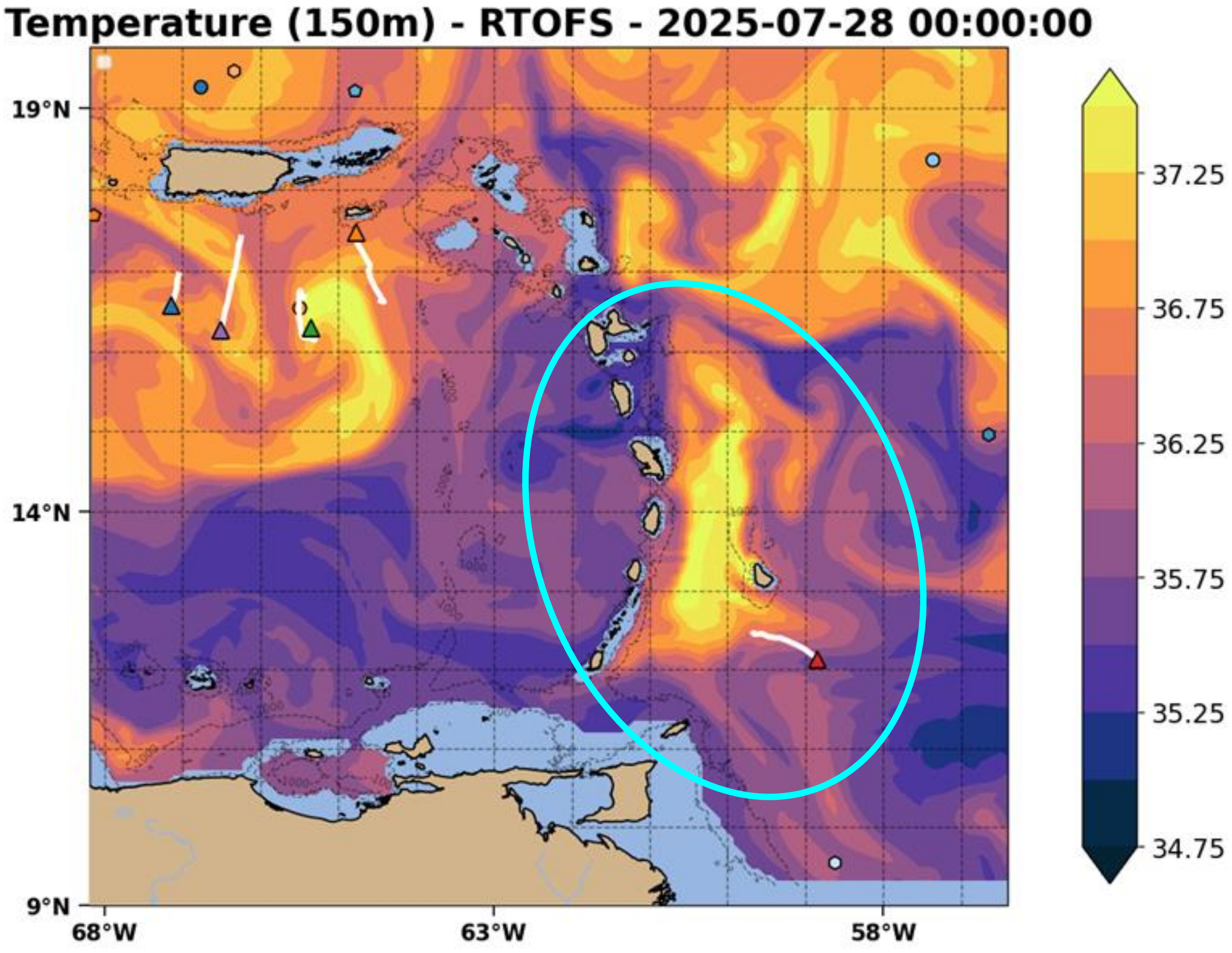
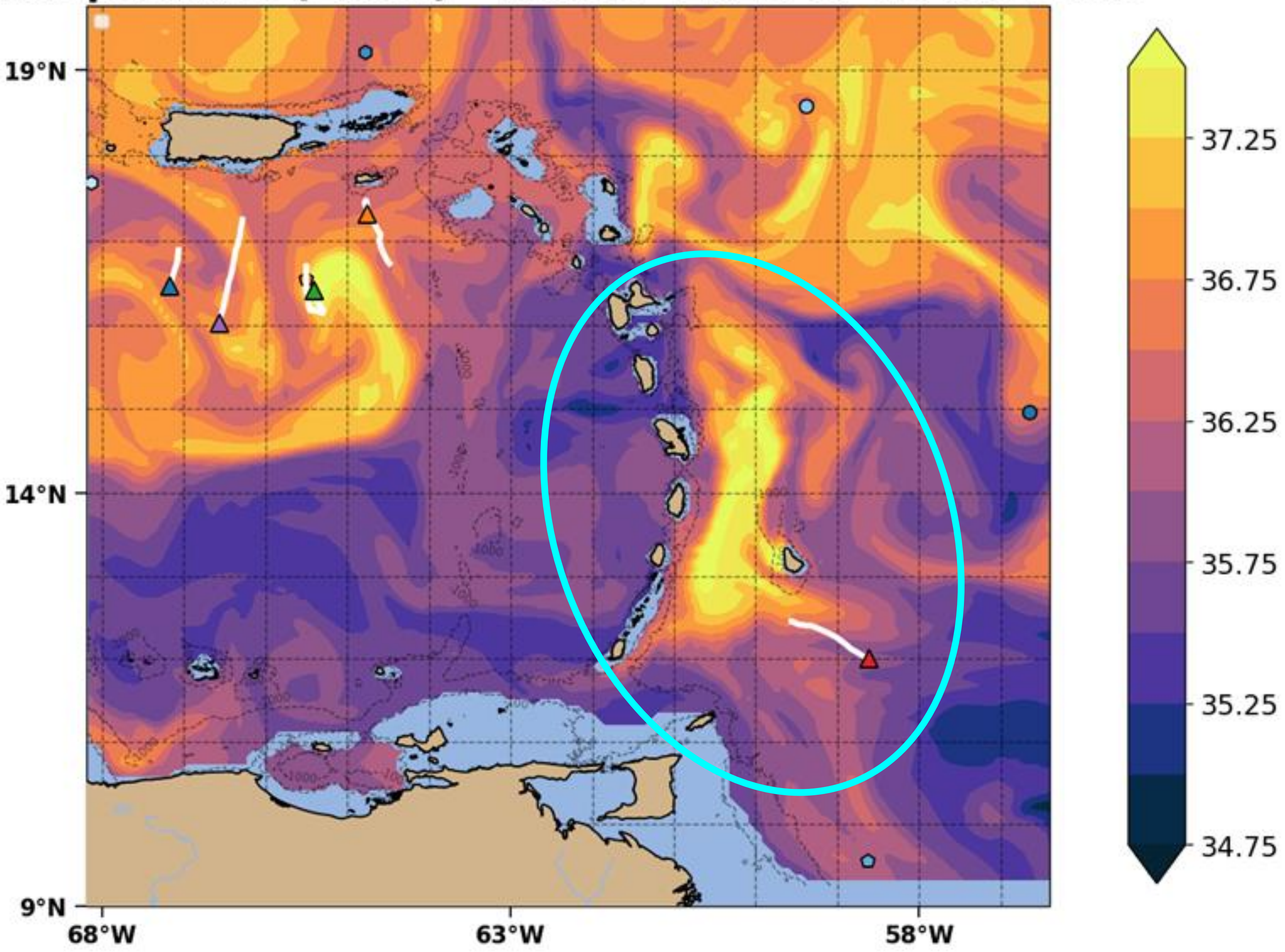
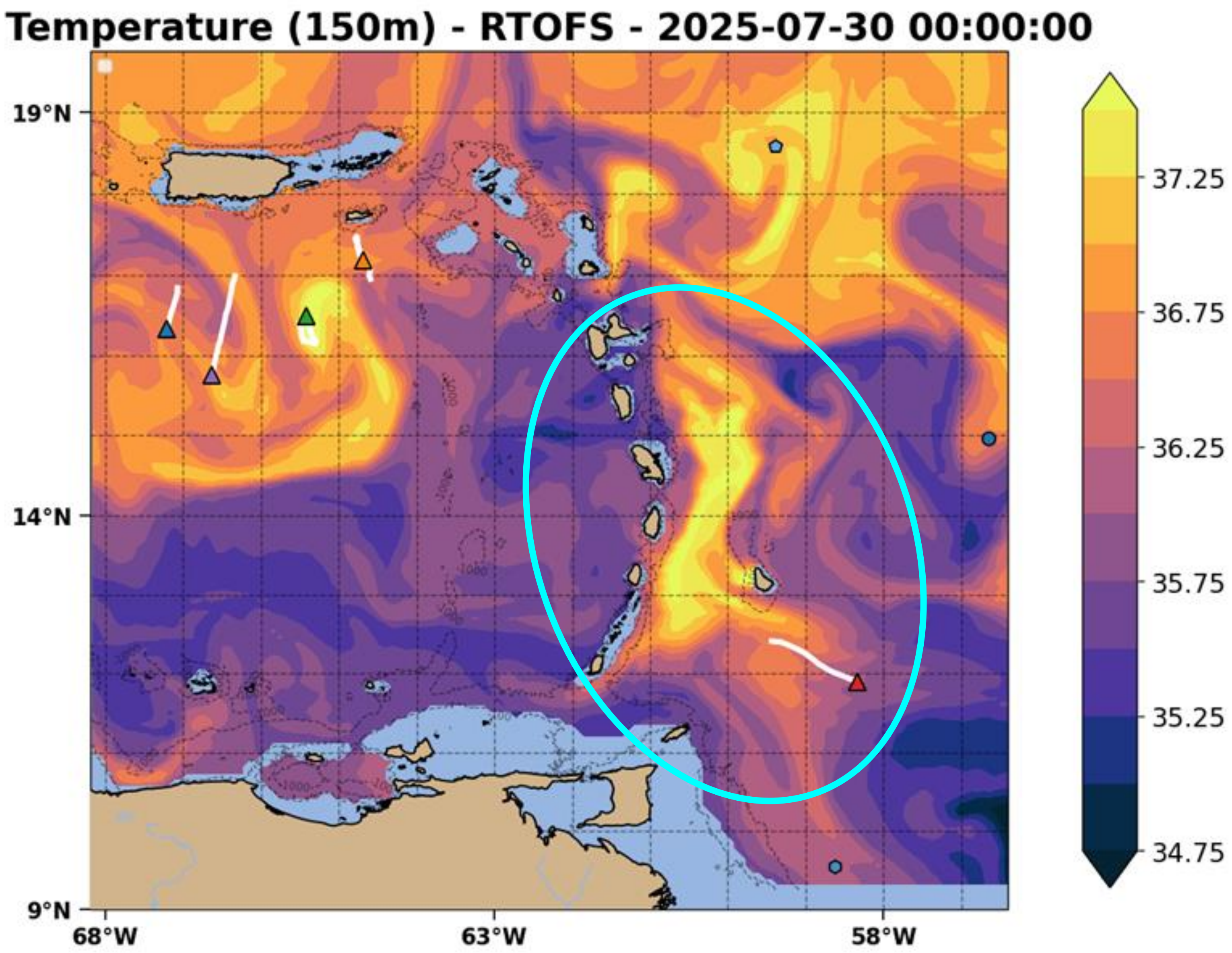


Temperature (150m) - RTOFS - 2025-07-28 00:00:00
19°N
14°N
9°N
68°W
63°W
58°W
37.25
36.75
36.25
35.75
35.25
34.75

Temperature (150m) - RTOFS - 2025-07-29 00:00:00





Temperature (150m) - RTOFS - 2025-07-30 00:00:00
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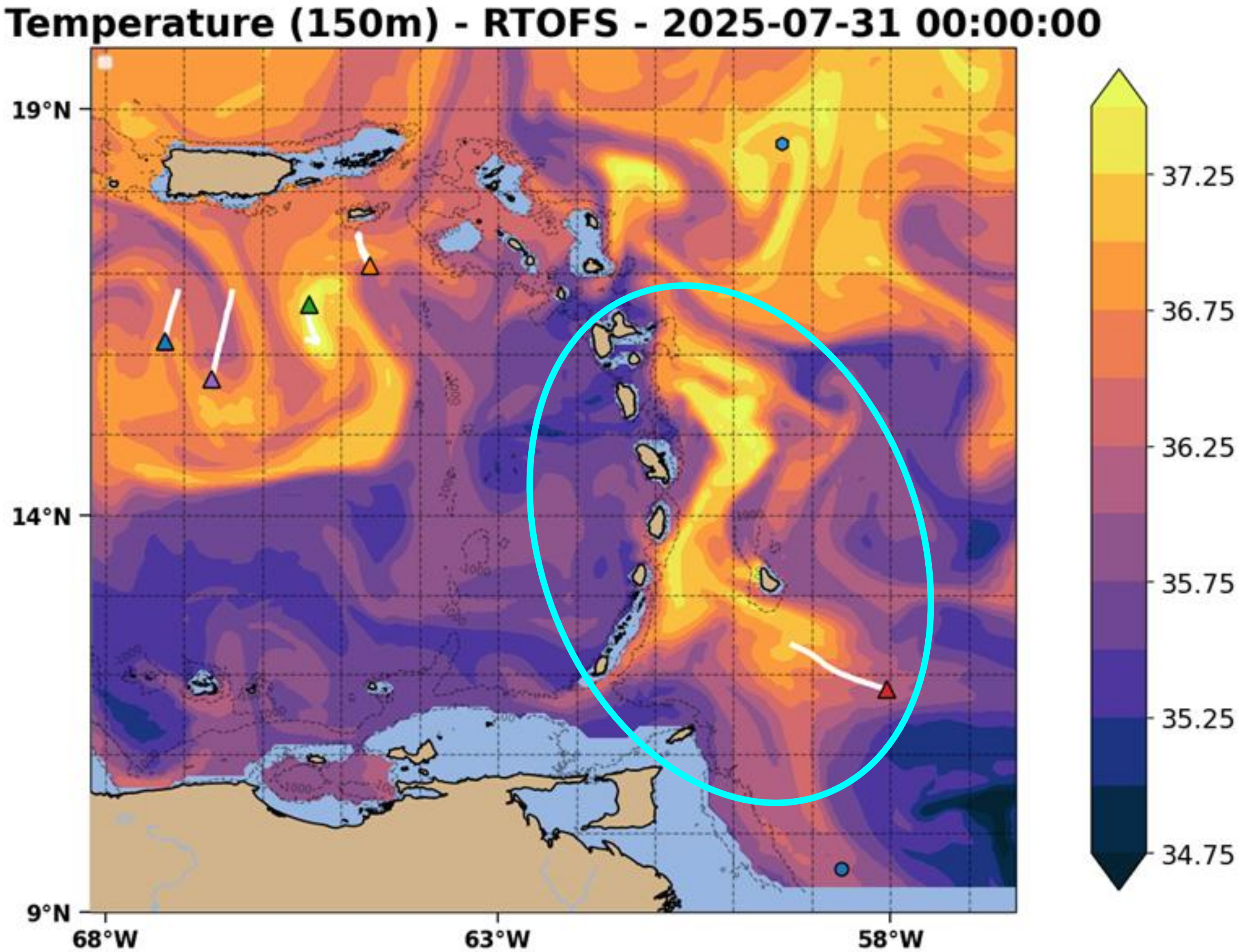
Temperature (150m) - RTOFS - 2025-07-31 00:00:00
19°N
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9°N
68°W
63°W
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36.25
35.75
35.25
34.75

North Pacific Ocean & Marginal Seas : Characteristics

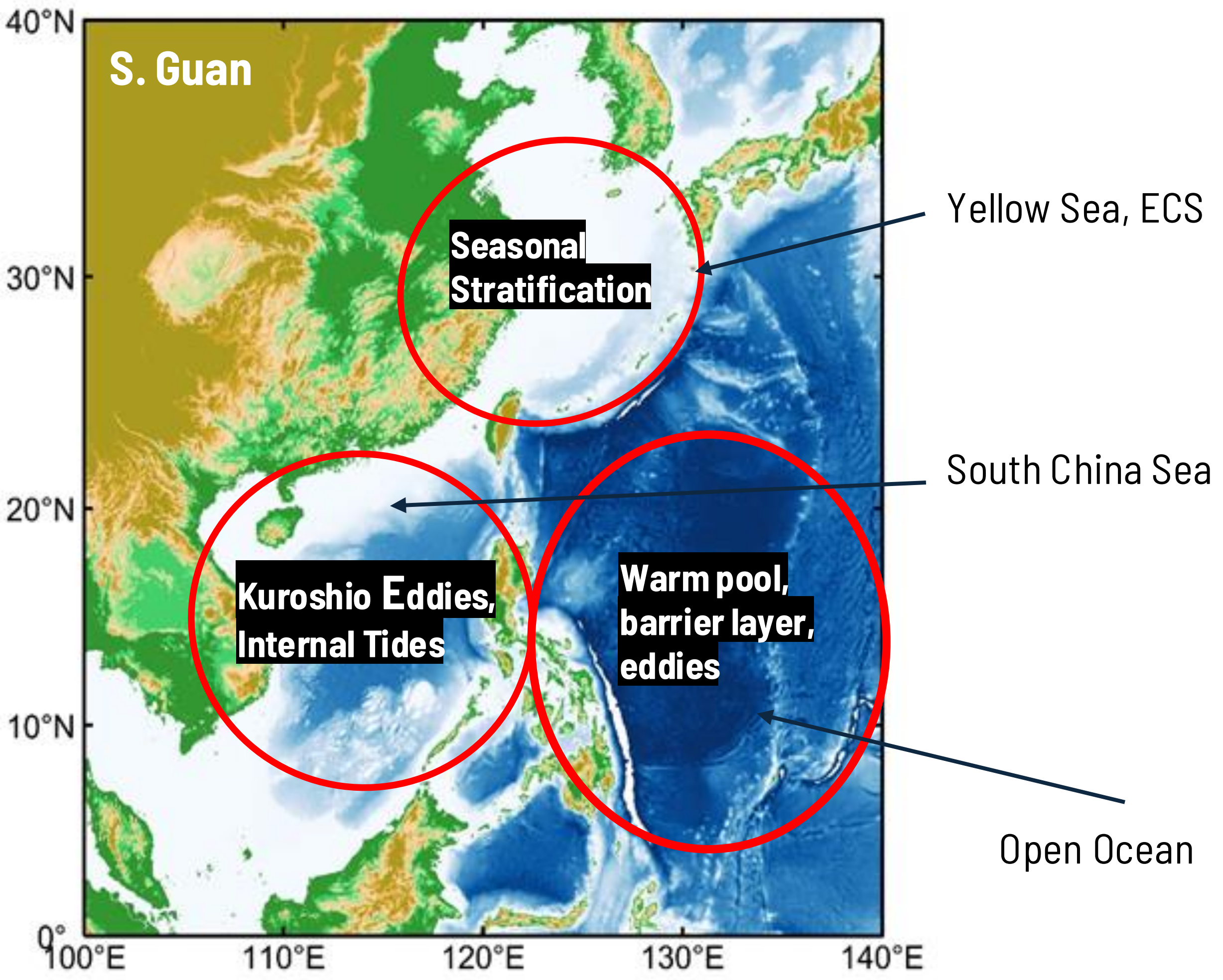
Region:
North Pacific Ocean and Marginal Seas (NPOMS) is the largest TC basin on Earth with the **highest number** and **most intense TCs**

Goals:
Collaboratively increase understanding of key **ocean processes** in the **most extreme storm environments** through targeted field campaigns & experiments

Develop regional approaches for observing and sharing data on essential ocean features that contribute to **TC intensity change**:

- Kuroshio Warm Current
- North Equatorial Current
- 2 Eddy-rich Zones
- Seasonal Stratification
- Fresh-water Barrier Layers

60% of all Category 5 TCs are from the NPOMS region



NPOMS Example: JMA-MRI Observations

- **Japanese Meteorological Agency-Meteorological Research Institute** will be conducting intensive observations targeting both the atmosphere and the ocean from **May–October 2025**

- Goals:
  - Enhancement of marine observations
  - Introduction of new observing equipment
  - Expanding the observational range

Conducting intensive atmospheric and oceanic observations of linear precipitation bands, typhoons, etc.

Very Intense Tropical Cyclone Freddy

Very intense tropical cyclone (SWIO scale)
Category 5 tropical cyclone (SSHWS)

Cyclone Freddy at its peak intensity while northeast of Rodrigues on 19 February.

Formed	4 February 2023

Cyclone Freddy is the longest-lived tropical cyclone on record, beating the previous record of Hurricane John in 1994.[1] It also has the highest accumulated cyclone energy (ACE) of any tropical cyclone on record worldwide, surpassing Hurricane Ioke in 2006.[1] Additionally, Freddy is the only known tropical cyclone to achieve seven separate rapid intensification cycles.[2]

The Global Ocean Observing System

Agulhas Current Observing System Design Workshop

9 – 12 Sep 2024, Cape Town, South Africa

Overview

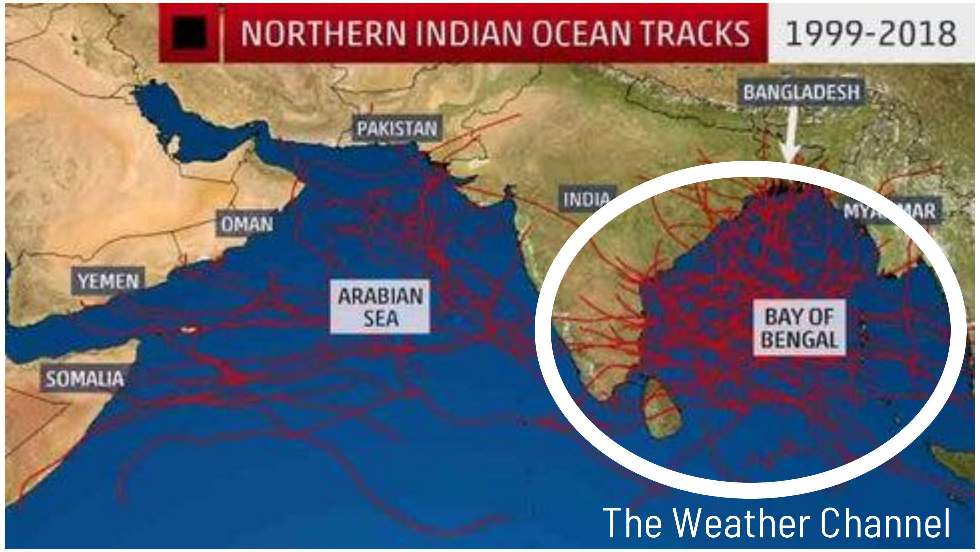
Date: 9-12 September 2024

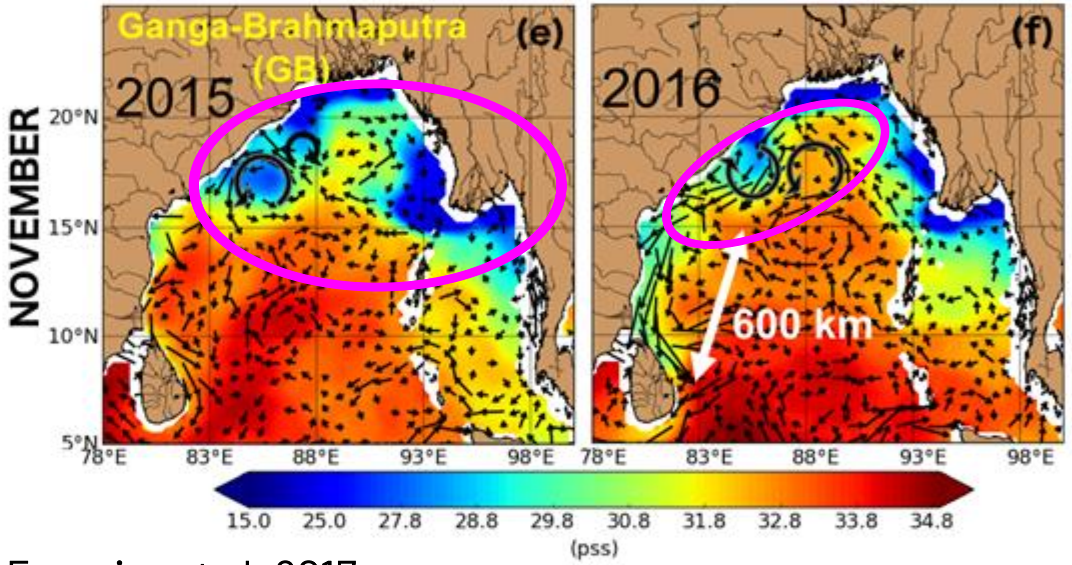
Location: Cape Town, South Africa

South West Indian Ocean - Intersection of Four Co-Design Programme Exemplars:

- **Marine Life (ML) Exemplar** - Vulnerable coastal populations dependent on subsistence fisheries are vulnerable to changing ecosystems
- **Boundary Currents (BC) Exemplar** - Variability in the Agulhas Current impacts ecosystems
- **Marine Heat Wave (MHW) Exemplar** - MHWs are more prevalent and longer lasting, stressing temperature sensitive ecosystems
- **Tropical Cyclone (TC) Exemplar** - Tropical cyclones that disrupt ecosystems can be intensified by MHWs, but TC-induced mixing can reduce MHWs

Bay of Bengal, Indian Ocean: Characteristics





Fournier et al. 2017

Region: Indian Ocean - Bay of Bengal

- Historically the region with the largest number of TC casualties due to high populations in low-lying, less-developed coastal areas

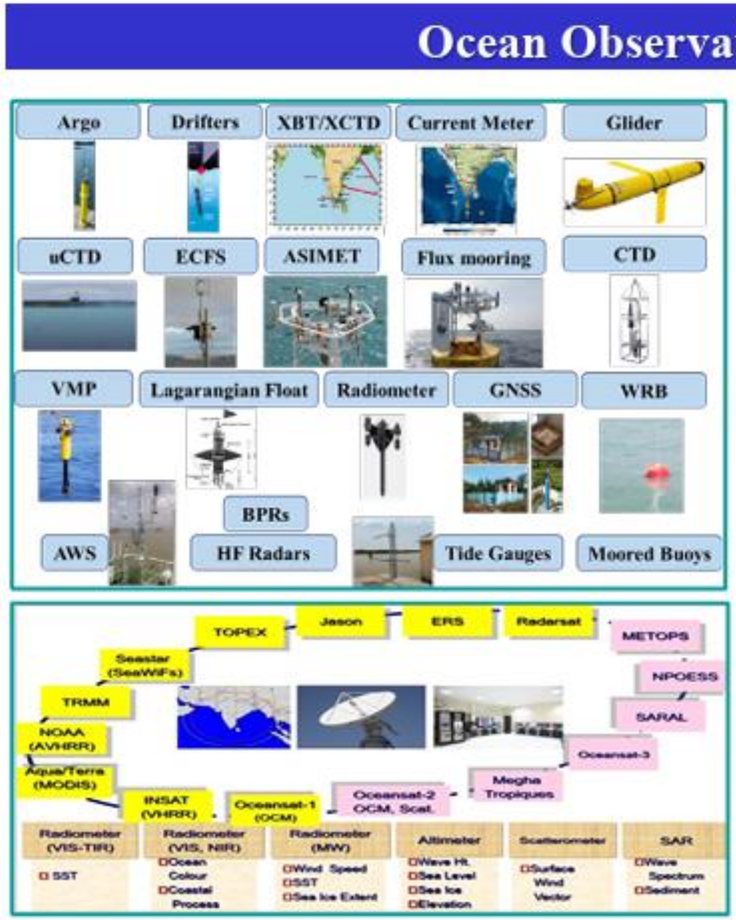
Goal: Share best practices and demonstrate value of ocean observations to motivate further national interest and investments in ocean observing as national networks continue growing

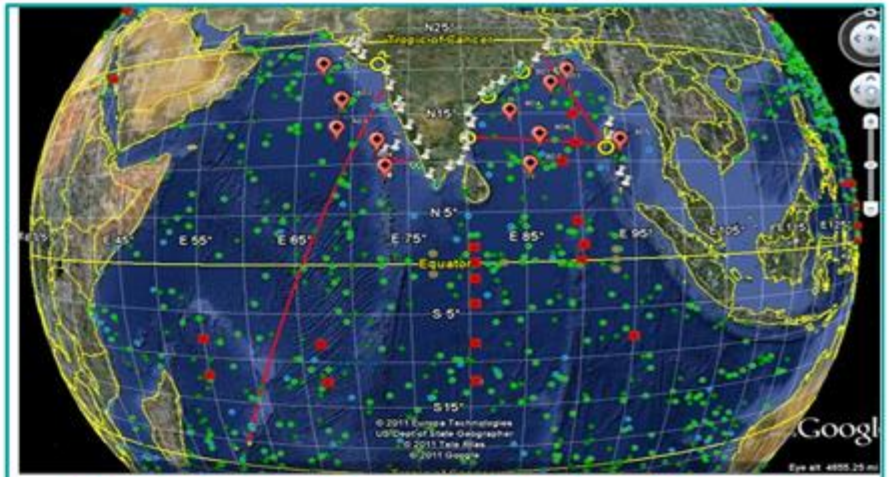
Essential ocean features and processes likely contributing to TC intensity change in this region:

- **Low salinity waters** from the discharge of the Ganges, Brahmaputra, and Irrawaddy Rivers
- **Barrier layers** and **temperature inversion**
- Ocean vertical structure is modulated by mesoscale **eddies**
- Sea surface temperature anomalies modulated by the Madden-Julian Oscillation (**MJO**) & **MHW**s

TC Exemplar - INCOIS Engagement

- Briefed INCOIS team in April 2023
  - Learned about the significant investment from INCOIS and the impressive observation network
  - Pattabhi Rama Rao joined the TCE Steering Team as a result



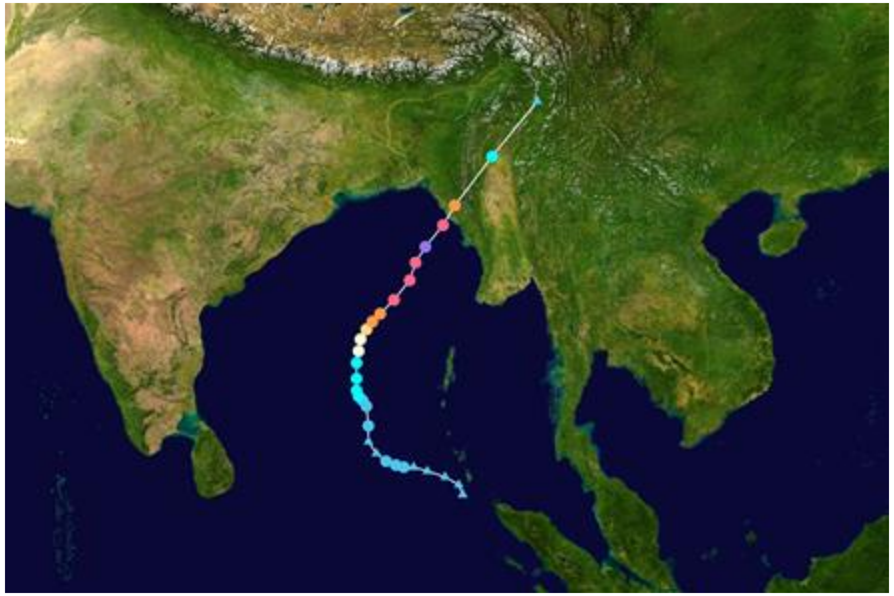


Green – Argo, Red line – XBT, Blue – Drifters, Red square – RAMA, Yellow- CODAR, green oval- ADCP, Red oval – Moorings, white mark - TG

Credit: Srinivasa Kumar Tummala, INCOIS

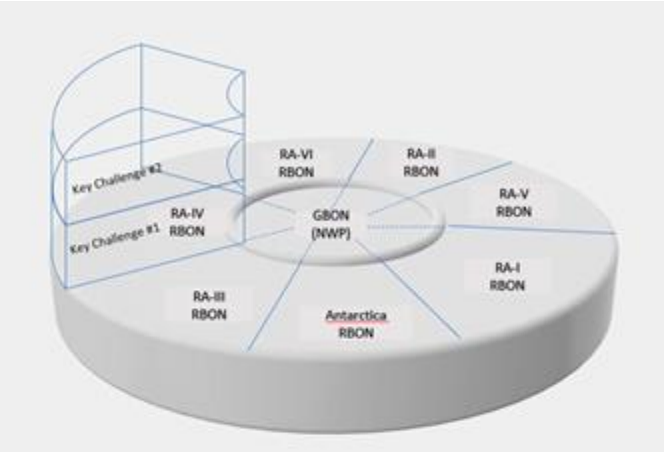
TC Exemplar - INCOIS Engagement

TC Mocha: 9-15 May 2023

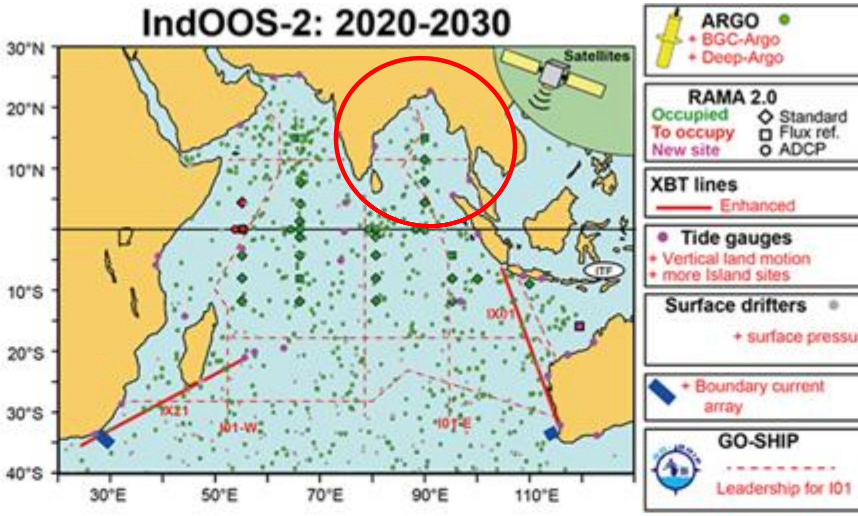


- Bay of Bengal pilot region for TC Exemplar
  - "Encourage national investment" - INCOIS and NIOT have already done this!
  - Share lessons learned (e.g., Caribbean pilot - freshwater plumes), contribute knowledge to global program
  - Enhanced stakeholder connectivity in the region

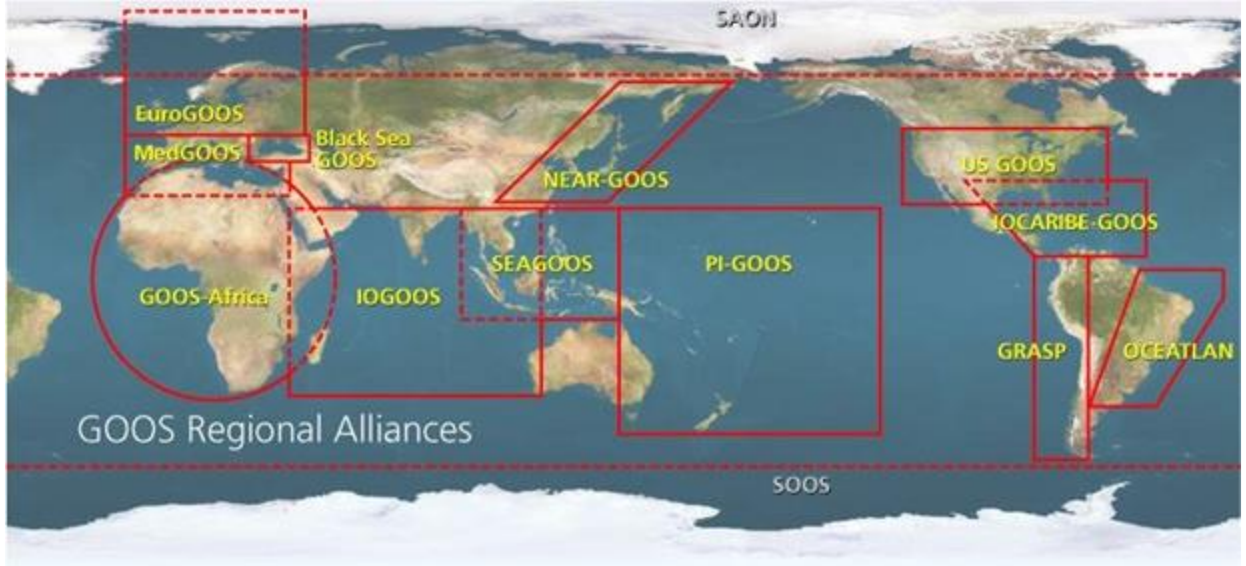
- Opportunities with the WMO
  - Global Basic Observing Network (GBON)
  - Regional Basic Observing Network (RBON)



Beal et al. 2020

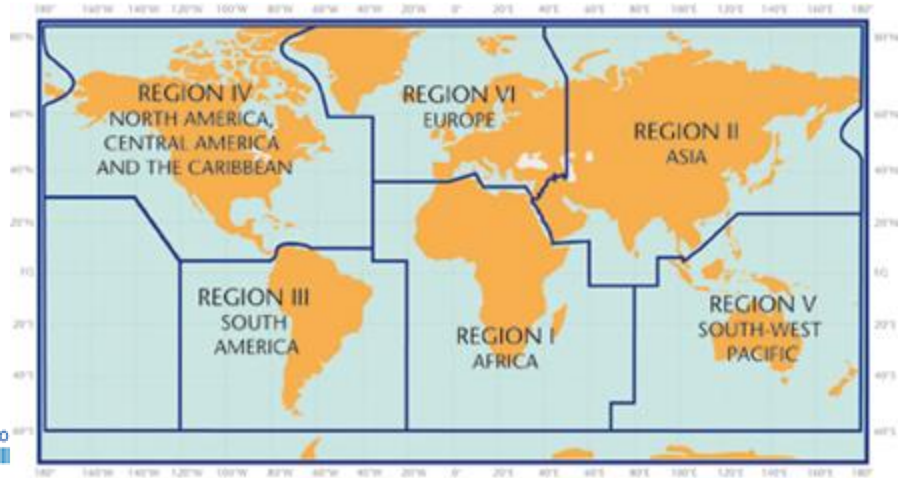


Continued Indian Ocean Engagement through GOOS & WMO



WMO

Regional Associations



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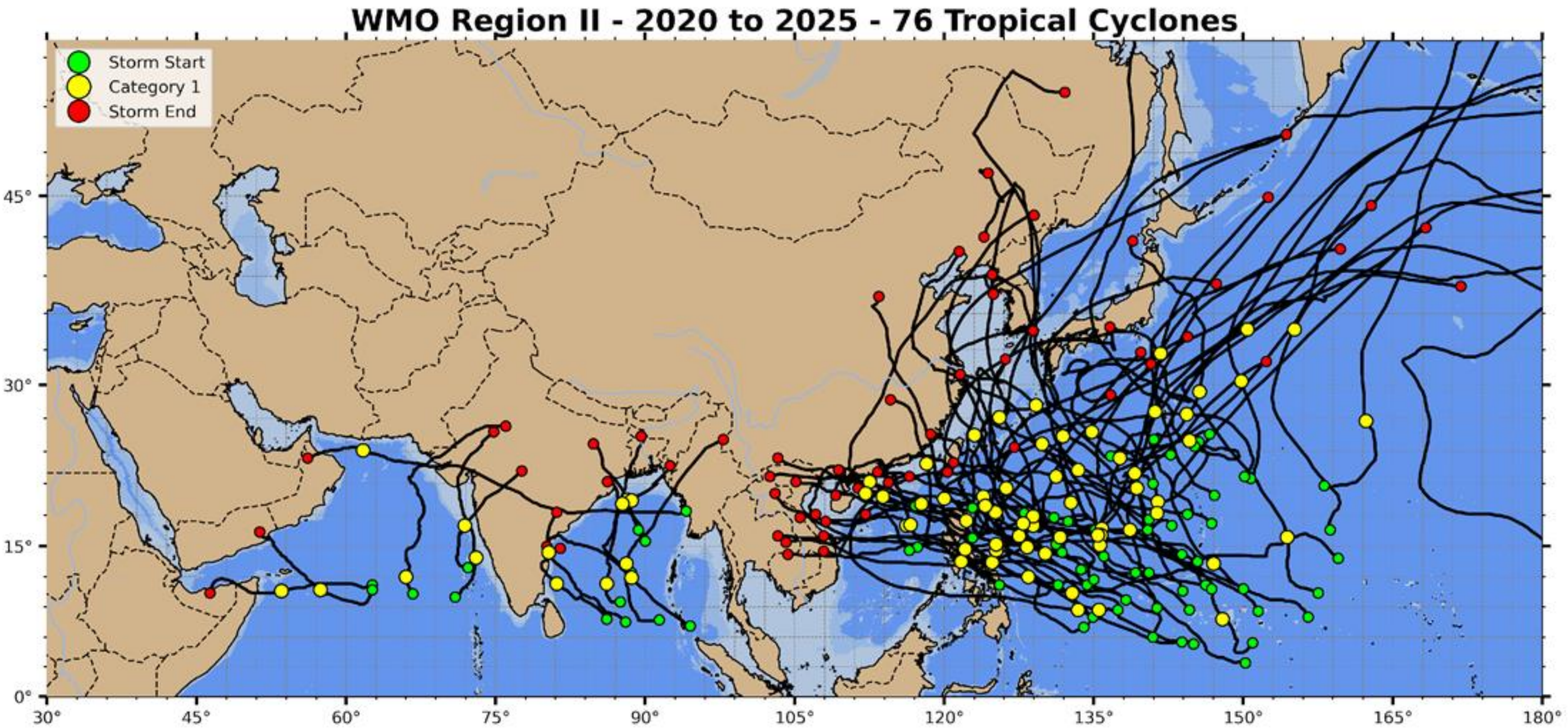
Existing **Regional Organizations** provide opportunities for collaborative international Co-Design

- **GOOS Regional Alliance:**
  - IOGOOS
- **WMO Regional Associations:**
  - Region I Africa
  - Region II Asia
  - Region V South West Pacific

Tropical Cyclone Tracks: 1st Occurrence Cat 1



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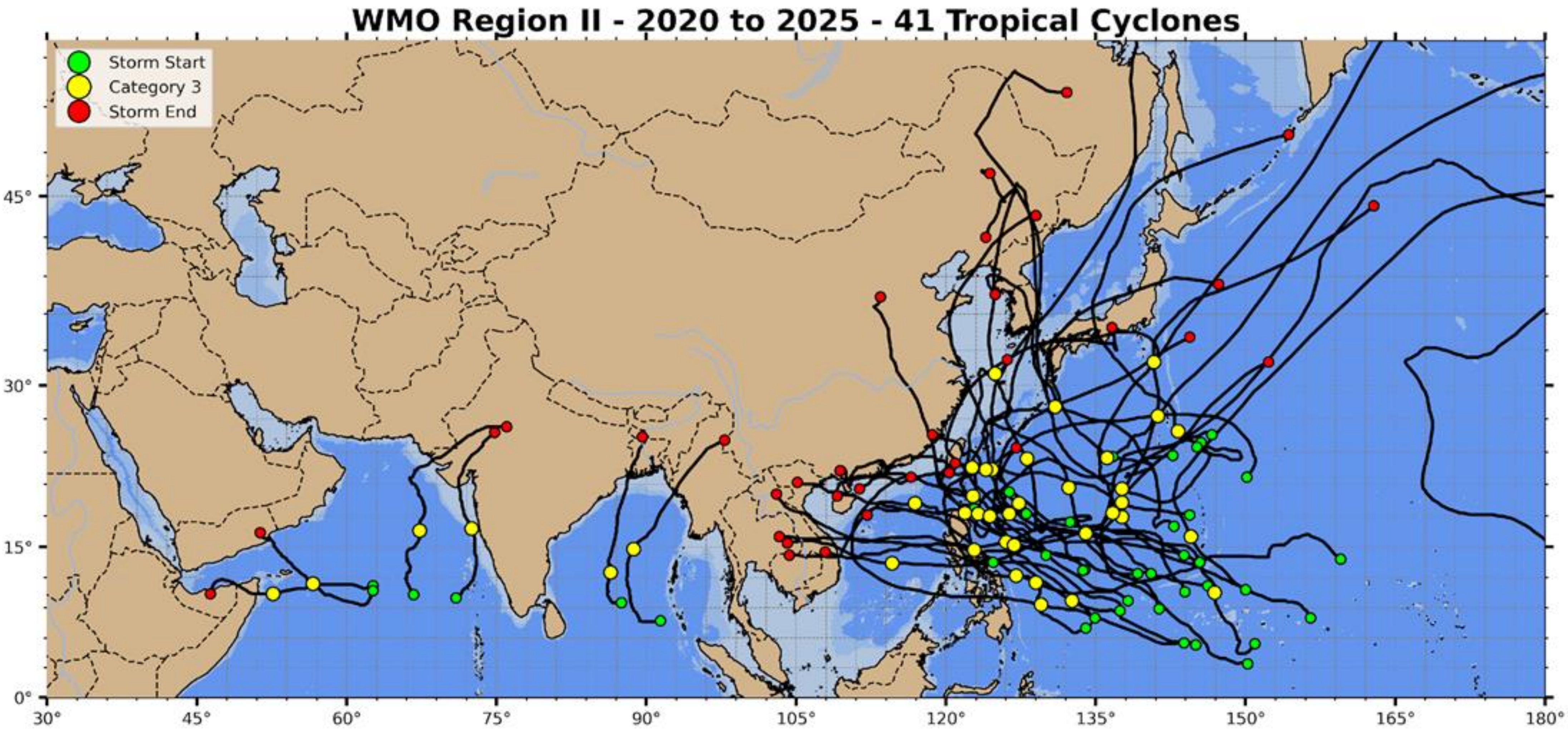
Tropical Cyclone Tracks: 1st Occurrence Cat 3



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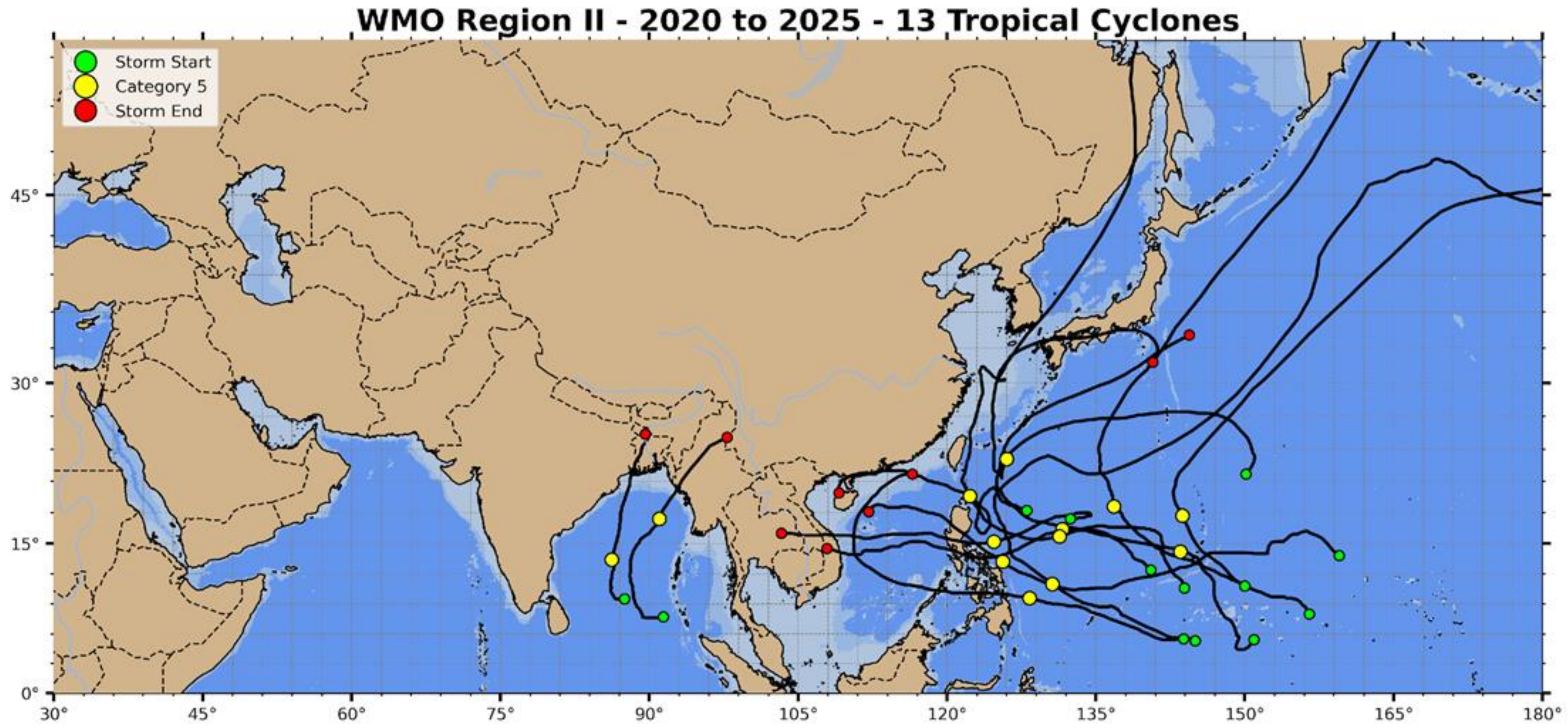
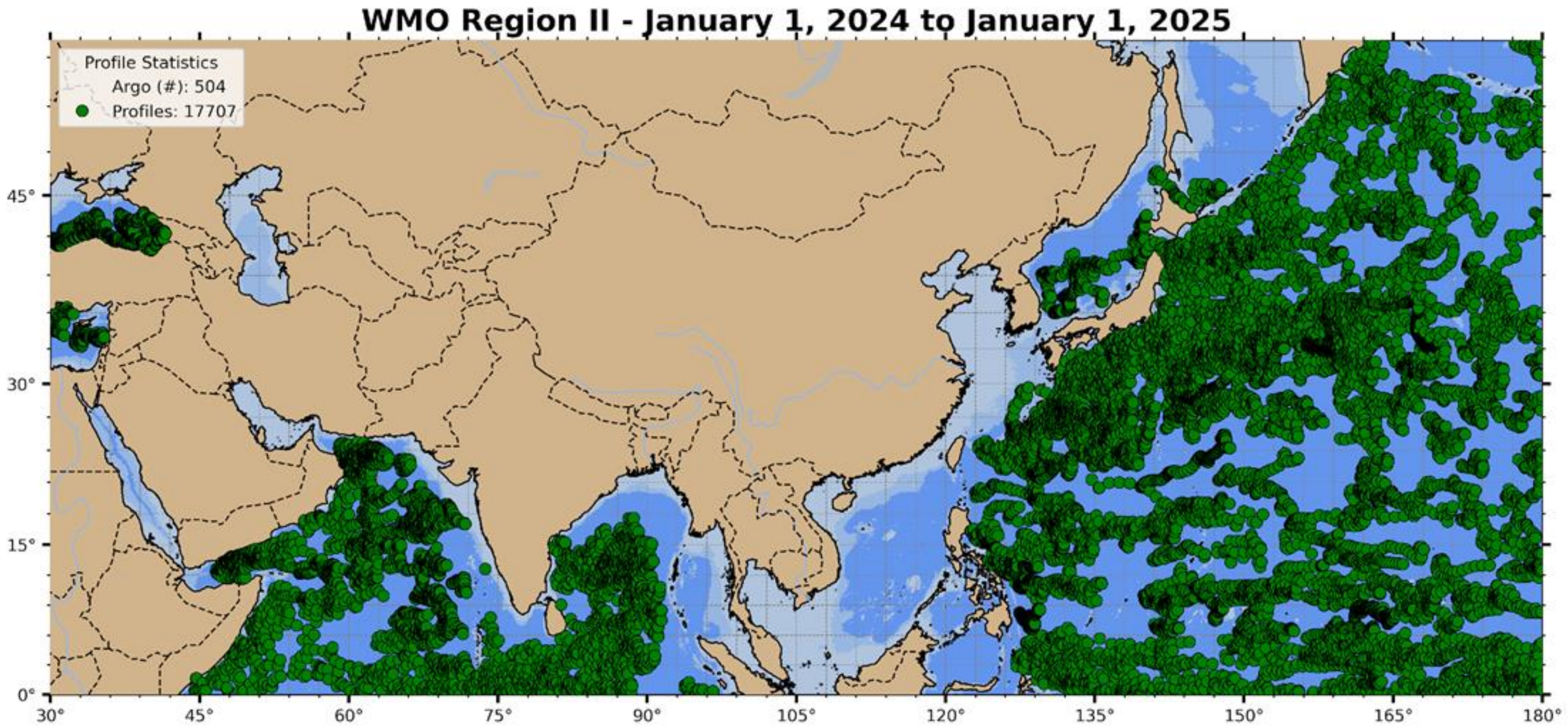
Tropical Cyclone Tracks: 1st Occurrence Cat 5



Argo T&S Profile Data: All of 2024



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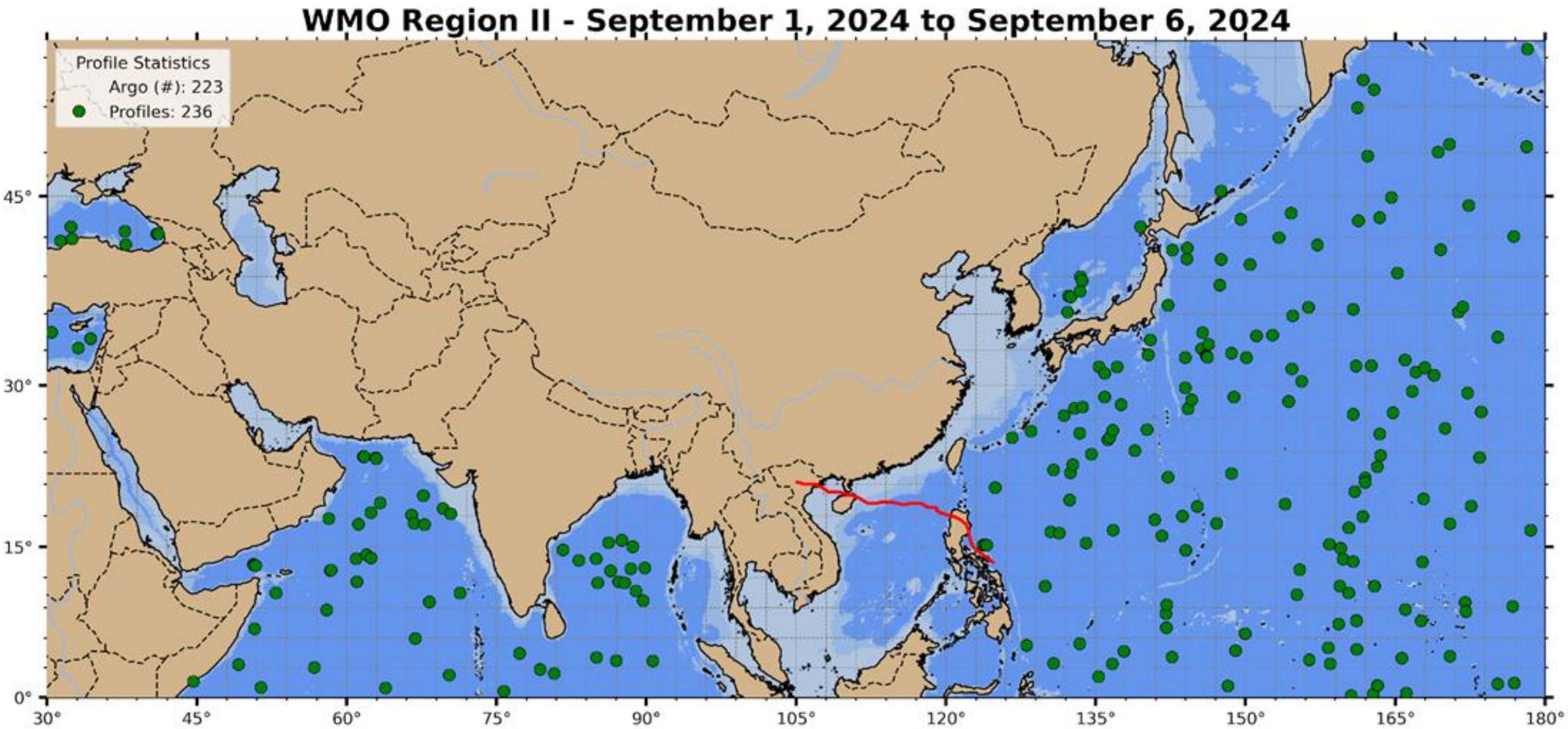
Argo is designed for ocean basin scale climate observations, not marginal seas, ocean mesoscale, or atmospheric weather scales!

Argo T&S Profile Data: 5 days in Typhoon Yagi



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Typhoon Yagi (red line): Upper end Cat 4, strongest to hit Vietnam in 70 years.
Regionally, ~600 people killed, >300,000 homes destroyed, ~$16B in economic losses.

Ocean Observing Requirements & *Technologies*

Existing WMO GBON Requirements

- 1 Sea Surface Temperature (SST) observation every hour on a 500 km resolution grid or better – *Ocean Surface Buoys*

Tropical Pacific Observing System (TPOS) Requirement

- 1 Temperature & Salinity (T&S) profile every 5 days in each 3x3 degree grid cell (~333 km resolution or better) – *Argo*

Candidate Recommendations for WMO RA II RBON

- Threshold – Match TPOS T&S Profile requirement in deepwater portions of RA II Marginal Seas - *Argo*
- Breakthrough – Extend T&S profile sampling to boundary currents and coastal waters – shorter space and time scales - *Gliders*
- Goal – Essential Ocean Features sampled with >1 T&S profile every day to match typical global ocean model assimilation cycles – *Argo* + *Gliders* + *SUN*

Take Away Messages

- **Autonomous or Uncrewed ocean observing technologies have advanced from scientific tools into mature or emerging global networks**
  - e.g., Argo, OceanGliders, Surface UNcrewed (SUN) Fleet
- **GOOS Co-Design Process fosters Tropical Cyclone applications**
  - Five pilot study regions identified
- **Encouraged by IOCARIBE-GOOS & WMO RA IV, the Tropical Americas & Caribbean (TAC) Pilot Study progressed from planning to demonstration**
  - 2024 Test Mission with Hurricane Beryl
  - 2025 Caribbean-wide implementation
- **Opportunities in the Indian Ocean**
  - North East Indian Ocean (Bay of Bengal) & South West Indian Ocean (SWIO)
  - Regional Coordination: IOGOOS + WMO RAs I, II & V

Thank you!

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