Operational Real Time Ocean Forecast System at NOAA/NWS/NCEP

NATIONAL WEATHER SERVICE

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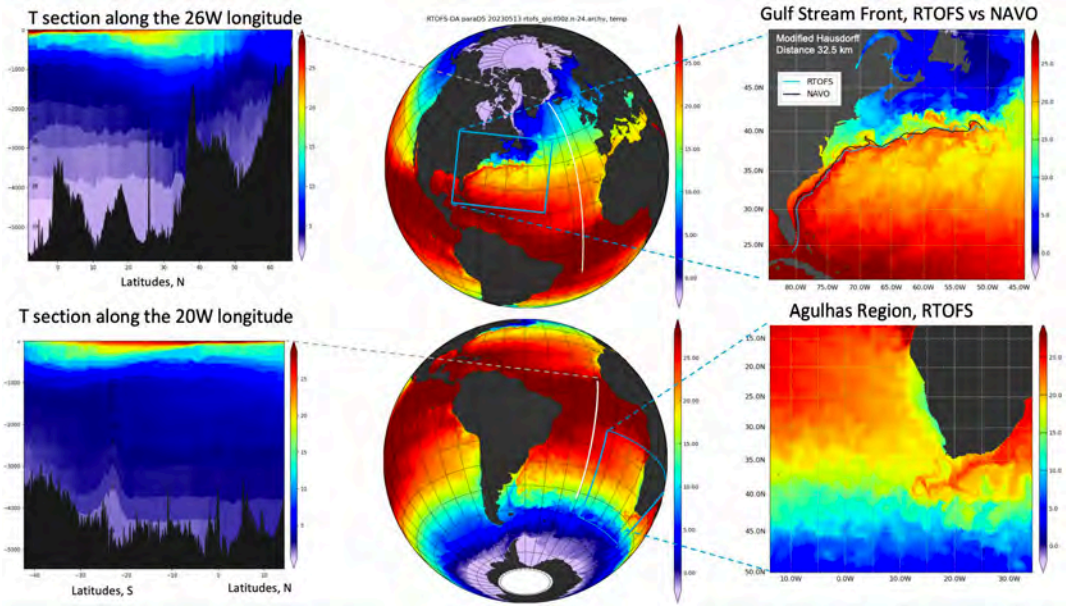
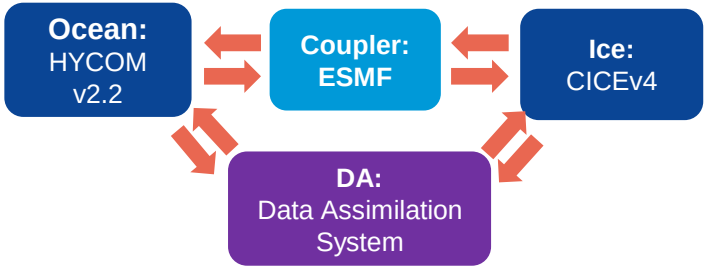
Operational Real Time Ocean Forecast System (RTOFS v2)

T fields from RTOFS forecast, 2023/05/13



RTOFS-DA



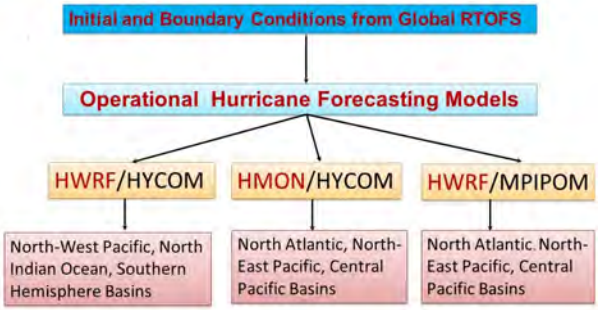
- Operational Eddy Resolving Ocean Modeling and Initialization
- Coupled Modeling for Hurricanes (Air- Sea- Wave flux interactions, mixing)
- Inputs to operational Global and Coastal storm-surge models to admit wave-current interactions
- Coupled Ecosystem Forecasting (Biogeochemical, NPZD, tracers)

- RTOFS includes HYbrid Coordinate Ocean Model (HYCOM) and the Los Alamos Community Ice Code (CICE)
- Global 1/12.5^{o} tripolar grid based on the Navy GOFS3.1 with DA
- RTOFS-DA includes a multivariate 3DVAR data analysis (T,S, geopotential, U ocean, ice coverage, thickness, ice surface temperature)
- Executed daily producing 6-hr 8-day forecasts of global ocean and sea ice fields
- Atmospheric forcing: hourly fields from the NCEP atmospheric Global Forecast System (GFS)

Outputs, Services, Users

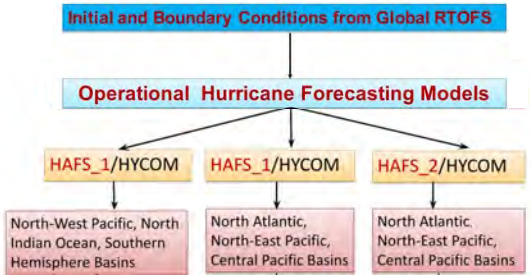
- RTOFS Initial and boundary conditions for Operational Hurricane Forecasting Models: HWRF, HMON, and HAFS.
- RTOFS Initial and boundary conditions for the NOS Operational Forecast Systems.
- RTOFS surface currents provided to operational Global and Coastal storm-surge models to admit wave-current interaction: GFSv16-waves, operational the Nearshore Wave Prediction System domains.
- RTOFS sea levels are used by NOS's Storm Surge & Tide Operational Forecast (STOFS) to admit baroclinic effect on storm surge
- Public servers with RTOFS outputs:
  https://nomads.ncep.noaa.gov/pub/data/nccf/com/rtofs/prod/
  https://registry.opendata.aws/noaa-rtofs/

Operational Hurricane Modeling Systems



UFS-based Hurricane Analysis and Forecast System (HAFS)

Put in operations on June 27, 2023



Data Flow through RTOFS Data Assimilation System

- >3.3 × 10^6 observations/day
- 3DVAR in ~8 minutes using 360 CS500 processors

Observations

SST satellites: METOP, JPSS, NPP, GOES, Himawari, AMSR2

In situ SST: ERI, Ship, Buoy, Drifters, fixed ocean sites, saildrones

SSS: SMAP, SMOS

Profile Temp/Salt: XBT, CTD, Argo Floats, Buoys, Gliders, ALAMO, Animal-borne sensors, Saildrone & wave-gliders (ready when NRT data available)

Altimeter SSH: Jason-3, CryoSat-2, Altika, Sentinel (3A, 3B)

Sea Ice: SSMI/S, AMSR2

Velocity: ADCP, Drifters, HFR (QC'ed, not assimilated in operations)

Ocean Data QC

Fully automated, executed in real-time

Stage 1: Sensibility data checks (Land/Water test, valid value test, duplicates, location/speed test, …)

Stage 2: QC tests with decision: accepted, rejected, flagged (background field check, cross-validation, profile shape comparison)

Stage 3: innovation error check in 3DVAR analysis

Innovations: $[y - H(x_b)]$

3DVAR

- Multivariate analysis of T,S, U, sea ice coverage
- Hourly FGAT for ICE, SST, SSS

$$x_a = x_b + BH^T(HBH^T + R)^{-1}[y - H(x_b)]$$

Increments: $[x_a - x_b]$

HYCOMv2.2 CICEv4

First Guess

Forecast Fields Prediction Errors

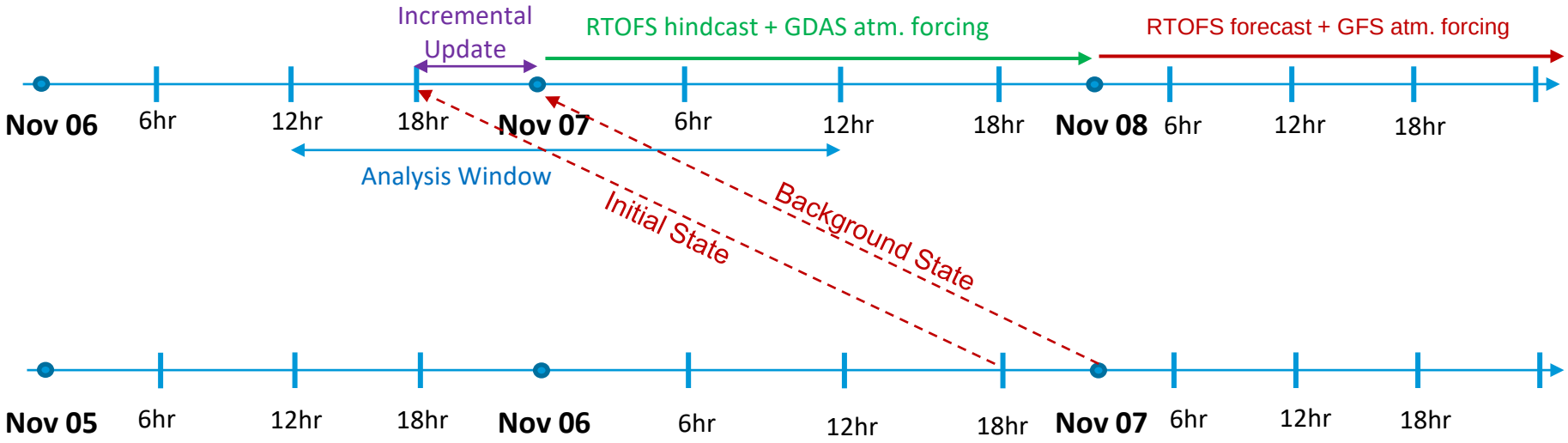
Adaptive Sampling Data Impacts

Sensors

Assimilation

Forecast Model

RTOFS Forecast Diagram, Start of the Forecast: Nov. 8



The RTOFS 3DVAR analysis: $x_a = x_b + BH^T(HBH^T + R)^{-1}[y - H(x_b)]$

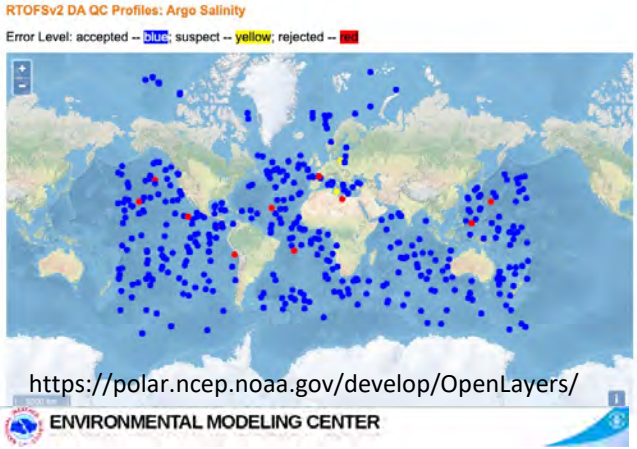
First guess: Instantaneous 24-hour forecast in hybrid layers. Surface fields: maintains model diurnal cycle using First Guess Appropriate Time (hourly SST, SSS, IceCov fields)

Domain: Single analysis global domain (HYCOM tripolar grid)

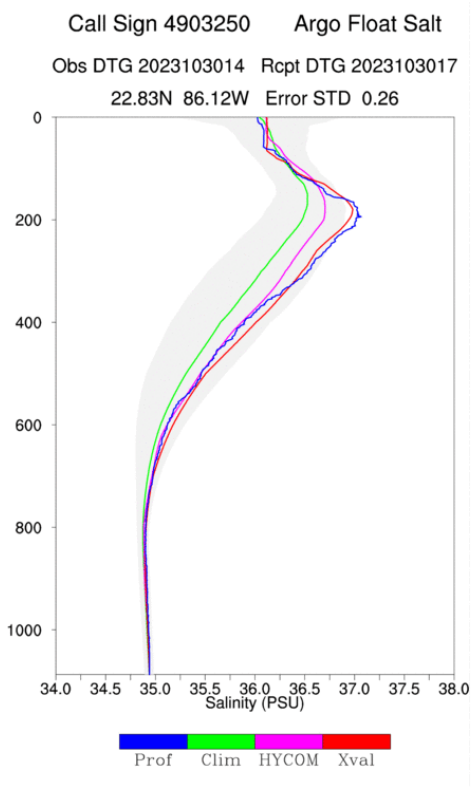
ADT/SSH: Assimilates ADT observations using full column direct method

RTOFS-DA QC of Observational Data

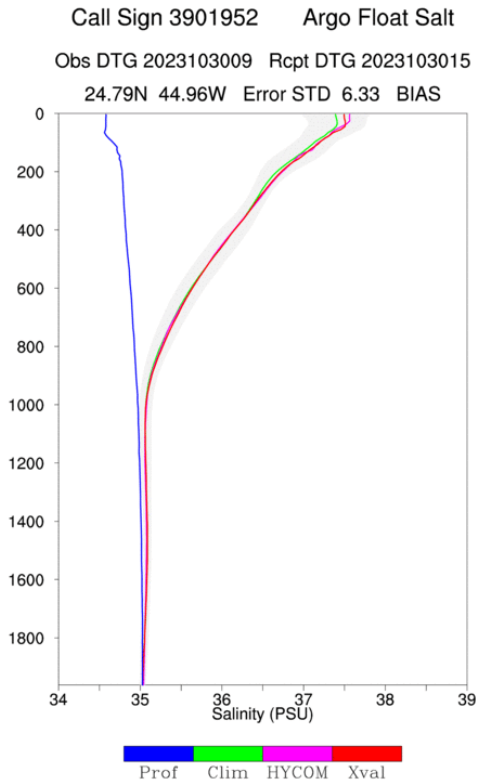
Accepted, flagged, and rejected Argo S profiles, 2023/10/31



Accepted S profile



Rejected S profile



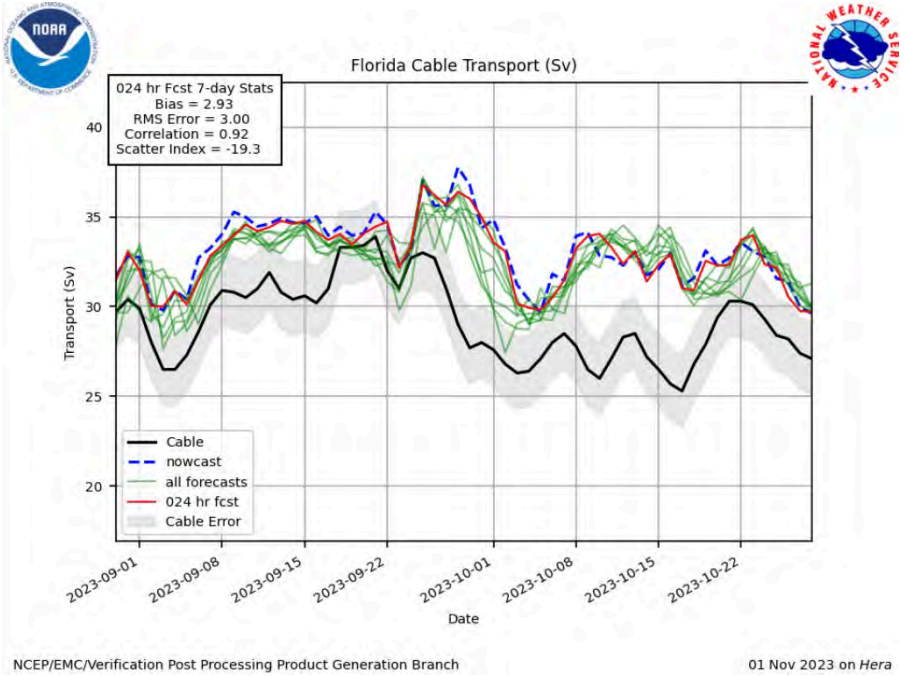
RTOFS-DA Evaluation

- EMC Model Verification Group:
https://polar.ncep.noaa.gov/global/
  - = Global and Regional SST & SSS RMSE/Bias errors
  - = Regional MLD RMSE/Bias errors
  - = Ocean Heat Content
  - = Florida Cable Transports Stats
  - = Gulf Stream North Wall location stats
  - = Sea Ice Concentrations RMSE/Bias errors

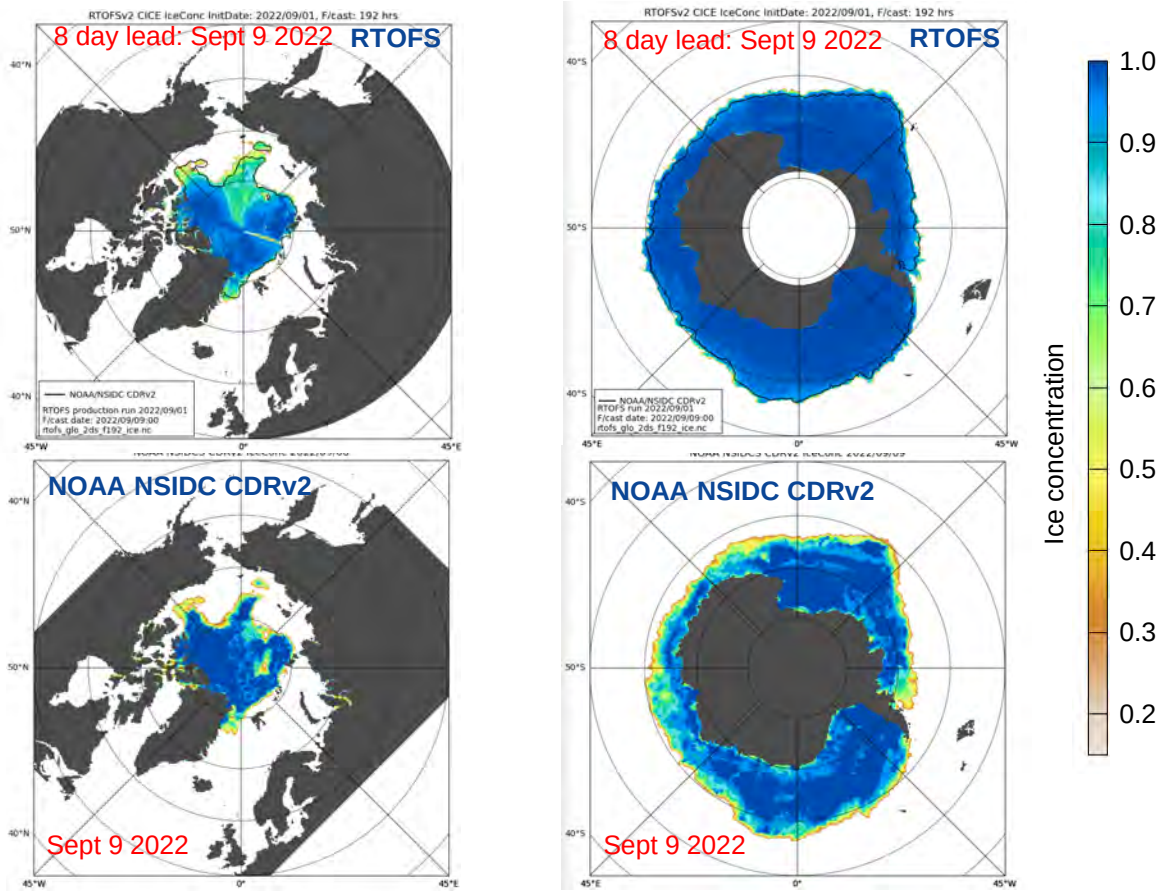
- EMC RTOFS group:
  - = Validation of operational and parallel runs
  - = Verification of RTOFS is performed using the Argo OS

- RUTGERS group (led by Dr. S. Glenn):
  - = Verification of RTOFS in the Caribbean Sea & Gulf of Mexico using gliders and Argo observations

Volume Transport of the Florida Current from RTOFS 24-hr Forecast vs Cable Observations



Sea Ice Concentration from RTOFS forecasts and NSIDC CDRv2



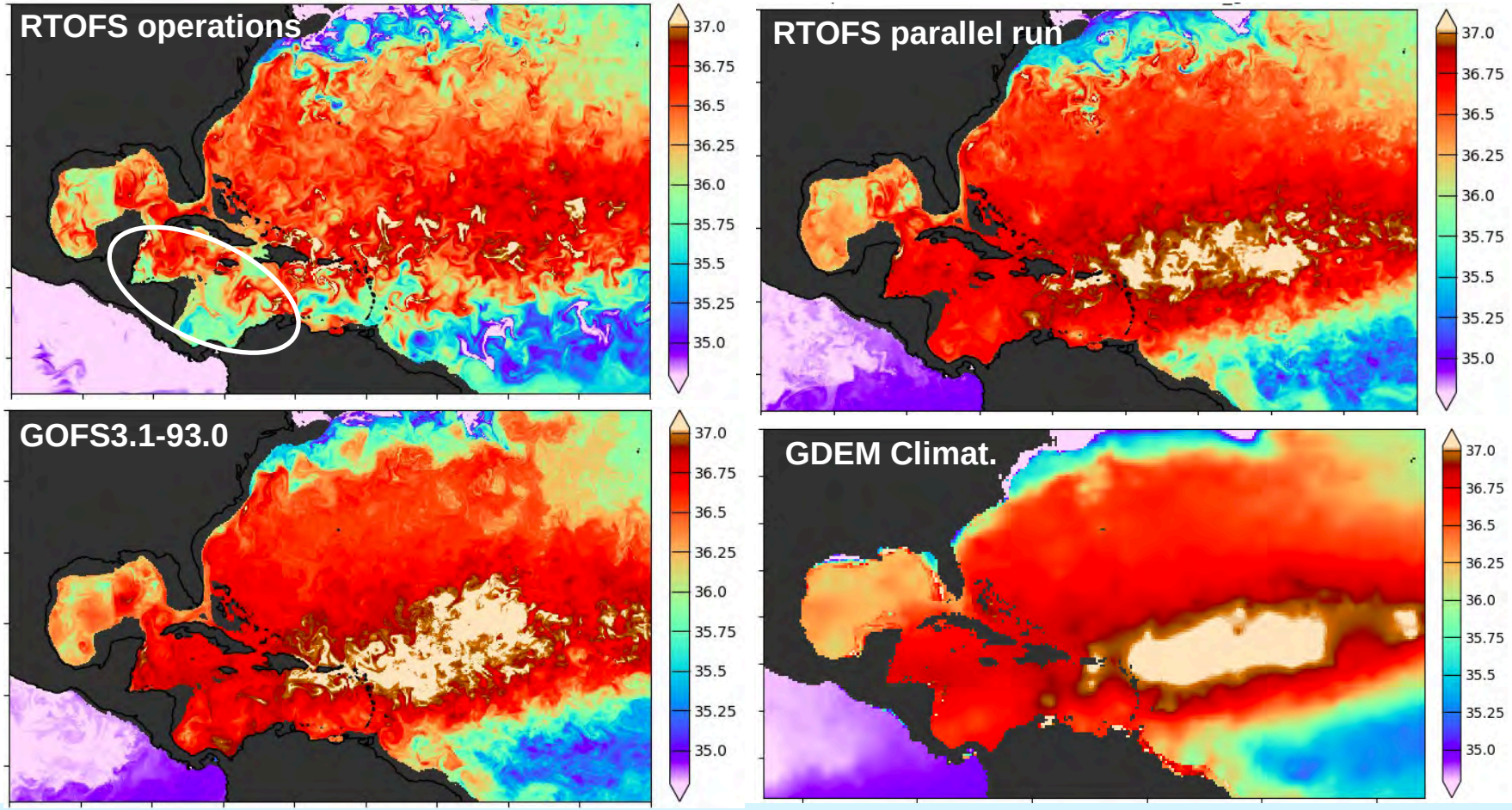
Recent Updates and Ongoing RTOFS-DA Developments

- **New ocean observations added for assimilation in RTOFS-DA**
  = Satellite L2 METOP-C SST's
  = Ready to assimilate: Sentinel-6 ADT's
  = Saildrone and wave-glider T, S (ready when observations from these platforms become available in real-time)
  = Surface currents from HFR and drifters
  = Test-ready for ingestion of SWOT SSH datasets (nadir); in progress: prepare the DA system for SWOT swath data.

- **Recent Updates**
  = Added climatological constraints for temperature and salinity for SSH assimilation in the analysis (to reduce negative S bias in the Caribbean Sea)
  = The DA system has been modified to provide increments on HYCOM hybrid layers vs the depth-fixed layers in the old approach (to reduce error during mapping of the increments onto HYCOM vertical grid from the DA system)
  = Changes in the decoder codes for getting Argo and glider data that were missing due to changes or ambiguities in the data headers and codes.
  = Updated version of RTOFS-DA is planned for operations by June 2024.

- **Ongoing algorithmic advancements for RTOFS-DA**
  = Explore use of WOA23 climatology to replace GDEM climatology.
  = Explore use of an updated climatological database based on ocean profiles (from NESDIS) to project sub-surface increments for SSH assimilation.

Salinity at 150m, 2023/10/30

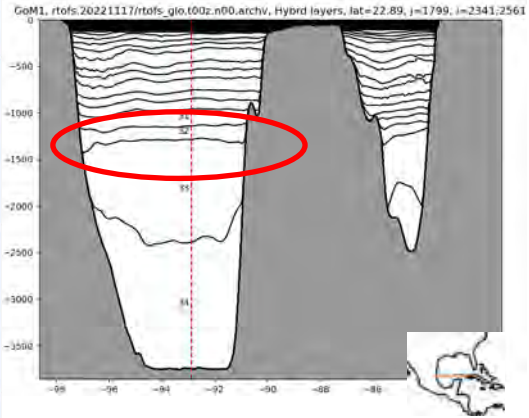


Collapsing Layers

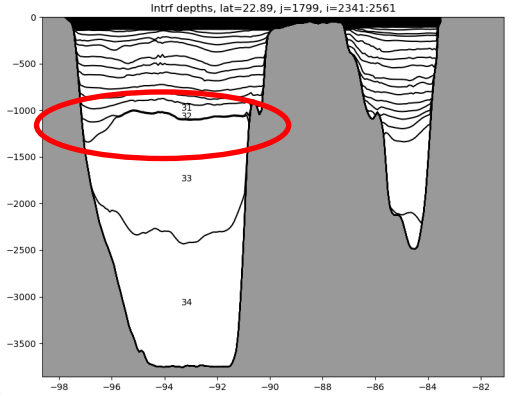
- External interface maps increments computed on a fixed vertical grid of the DA system onto HYCOM hybrid layers.
- Errors during this conversion, may result in large changes of the layer thickness of HYCOM hybrid layers leading to “collapsing” (very thin) layers in the deep ocean and possible instabilities in numerical solutions.
- To mitigate the “collapsing” layer problem , the DA system has been modified to provide increments in HYCOM hybrid layers with higher accuracy than the original external interface.

Hybrid layers in the Gulf of Mexico

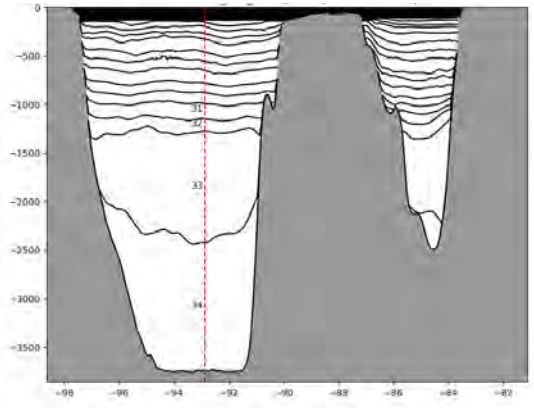
Background Fields



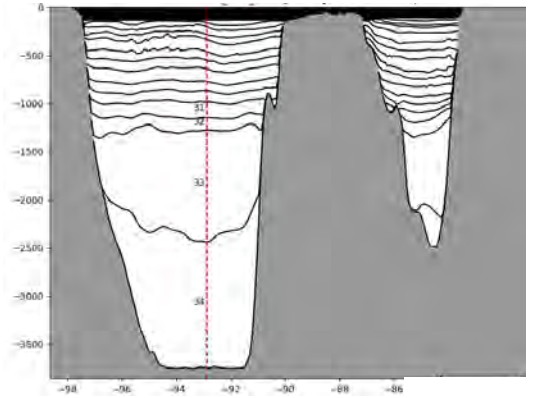
After incremental update of the innovations



After incremental update

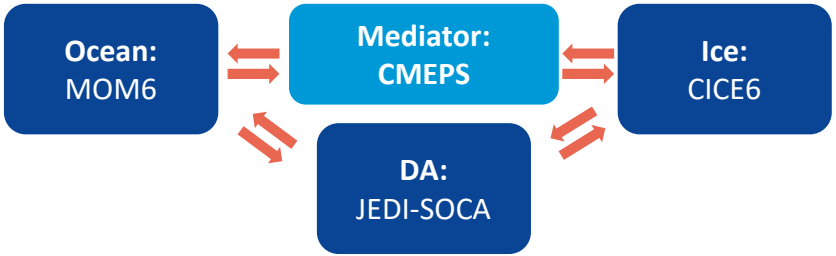


24-hr forecast

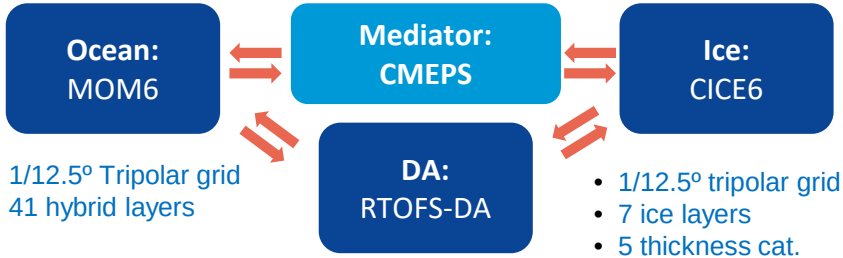


Future UFS-based Global Operational Ocean-Ice Forecasts at NCEP

Global Operational RTOFSv3



In transit to Global Operational RTOFSv3



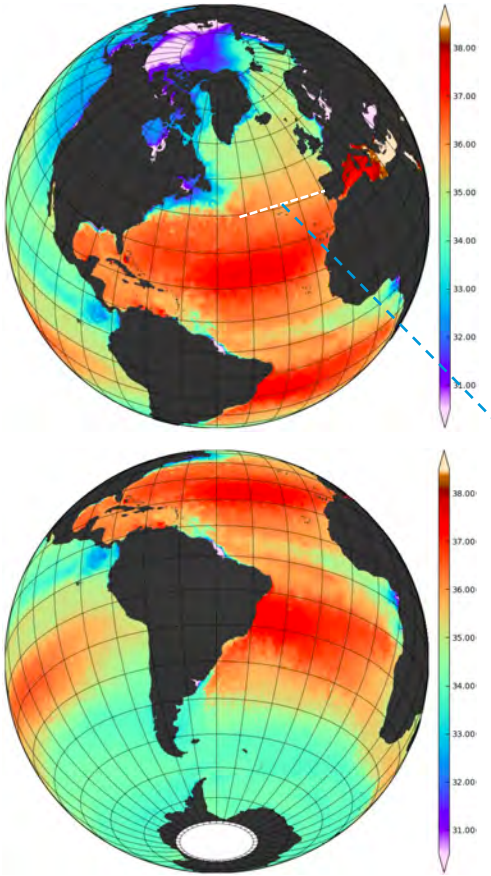
- 1/12.5º Tripolar grid
- 41 hybrid layers

- 1/12.5º tripolar grid
- 7 ice layers
- 5 thickness cat.
- 1 snow layer

- UFS-based global operational forecast RTOFSv3 will be based on coupled MOM6-CICE6 via CMEPS.
- Currently, a UFS-based global RTOFSv3 prototype is tested with DA used in RTOFSv2.
- RTOFSv3: JEDI-SOCA assimilating system will replace the DA currently used in RTOFSv2.
- RTOFSv3 will be merged into future GFSv18.

MOM6-CICE6 Test Free Runs

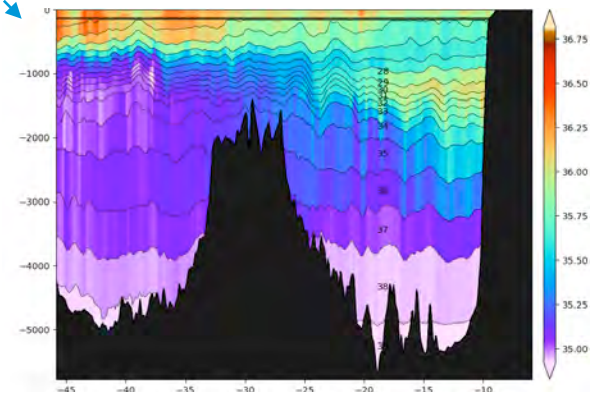
Surface salinity



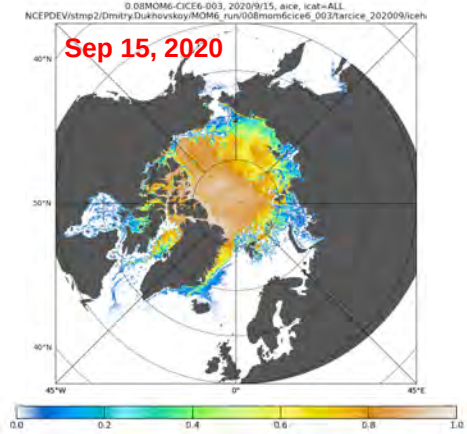
Test run: 2020-2022

- 1/12.5º tripolar grid
- 41 vertical hybrid layers
- Atmospheric forcing: 6-hr CFSR
- 7 ice layers, 5 thickness categories
- 1 snow layer
- EVP rheology
- Initial conditions: GOFS3.1-93.0 January 1, 2020

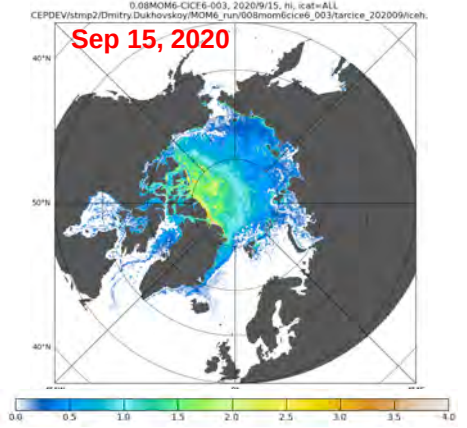
Salinity section



Sea ice concentration



Sea ice thickness (m)



Summary

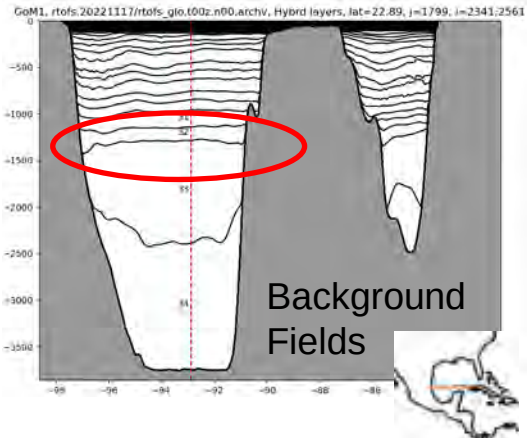
- Real-Time Ocean Forecast System (RTOFSv2 - DA)
  - Recently implemented updates have improved ocean forecasts demonstrating better agreement with observations and other reanalysis products
  - Updated version is planned for operations by June 2024
  - RTOFS-DA will continue to be improved (e.g., assimilating new observations like saildrones and SWOT, incorporating sea ice/snow thickness, surface temperature analysis into RTOFS)

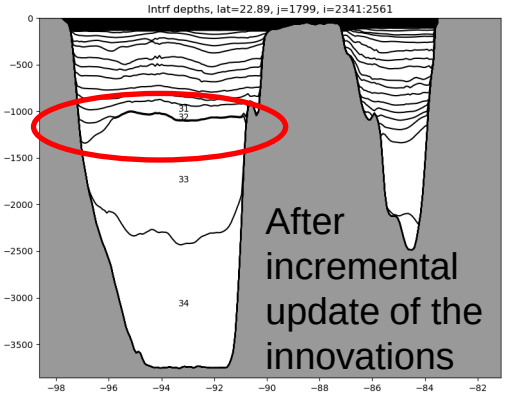
- Future developments:
  - Transition to the UFS-based MOM6-CICE6 with JEDI-SOCA
  - Test simulations are in progress with MOM6-CICE6: free runs, forecasts (initialized from RTOFSv2), and DA runs with RTOFS-DA

END

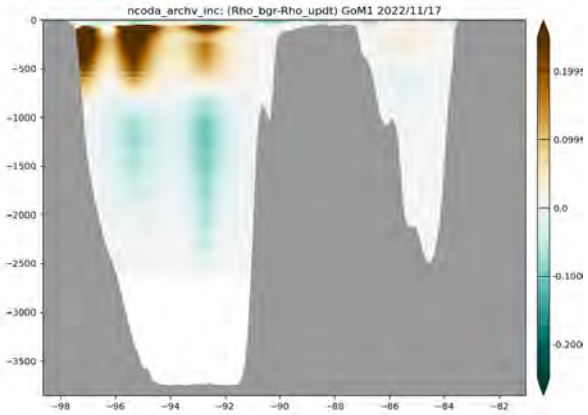
Problem of collapsing layers

Hybrid layers in the Gulf of Mexico

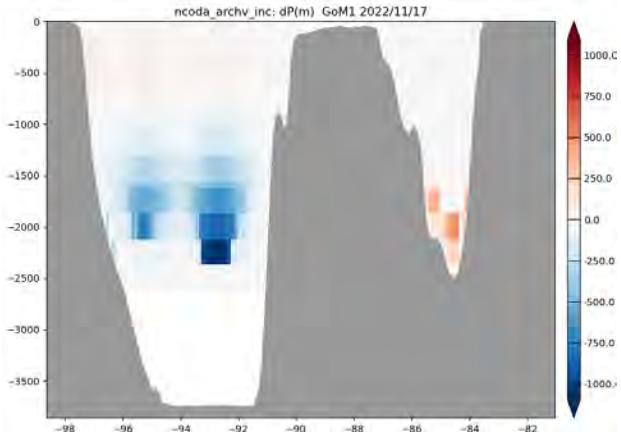




$$\delta\rho = \rho_{prior} - \rho\left(t_{prior} + t', s_{prior} + s'\right)$$

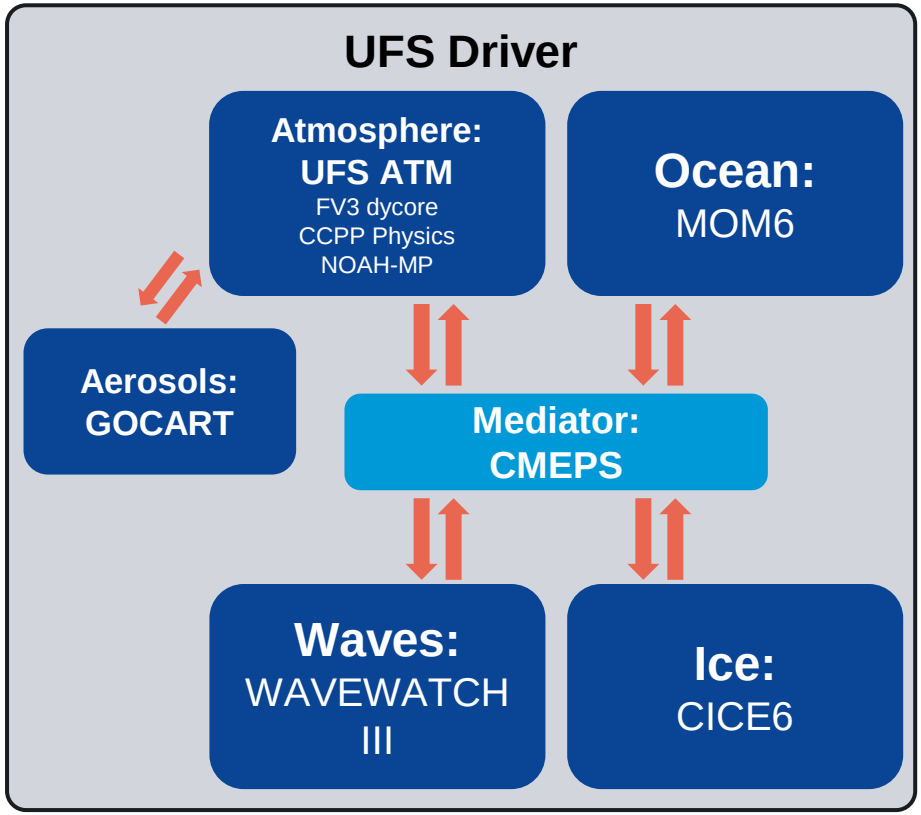


HYCOM layer thickness change dictated by $\delta\rho$

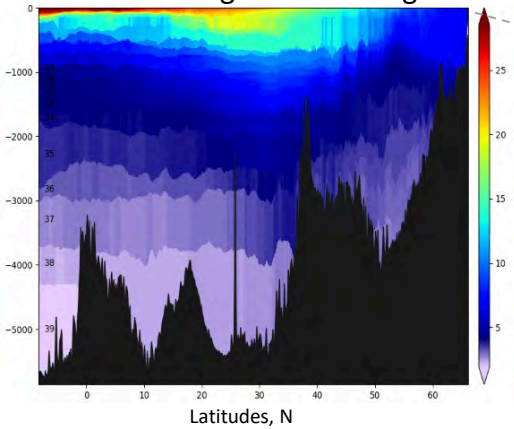


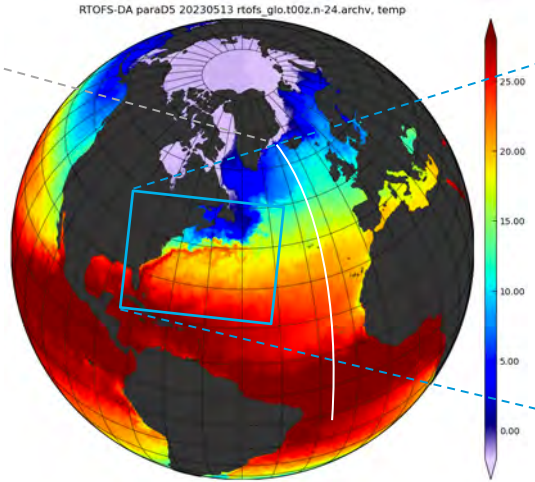
Unified Forecast System (UFS)

- *Purpose:* a comprehensive, community-developed Earth modeling system, designed as both a research tool and as the basis for NOAA's operational forecasts.
- *Scope:* configurable into multiple applications that span local to global domains and predictive time scales from less than an hour to more than a year.
- Global Development For:
  - GFSv17
  - GEFSv13
  - Seasonal Forecasting System (SFSv1)

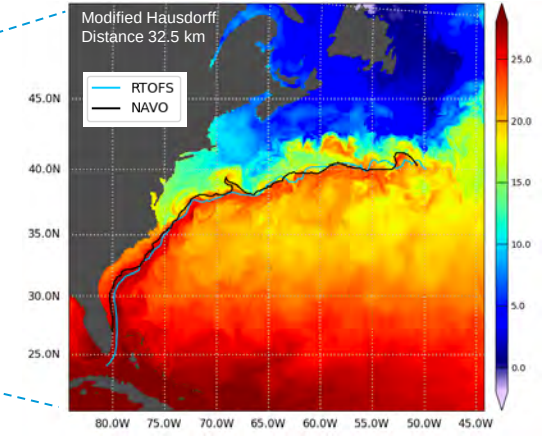


T section along the 26W longitude

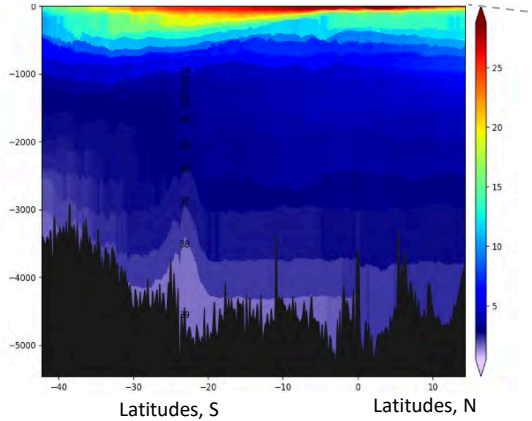


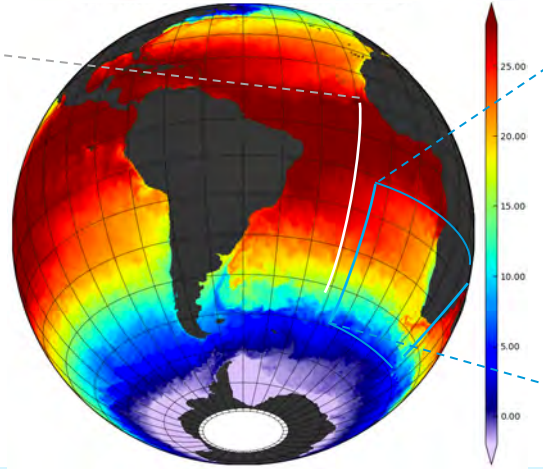


Gulf Stream Front, RTOFS vs NAVO



T section along the 20W longitude





Agulhas Region, RTOFS