Beyond the HAFS IOC: ocean and wave model

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and
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OUTLINE:

1. Review of HYCOM coupling
2. Benefits of additional coupling: examples
3. Development of regional MOM6 and JEDI-based SOCA (Sea-ice Ocean and Coupled Analysis)
4. Summary and future plans

HYCOM coupling

Two Operational numerical guidance models have demonstrated the modeling skill since

1. HWRF in the operation in 2014 for the JTWC basin, including the southern hemisphere
2. HMON in the operational in 2017 for the NHC basin

Regional HYCOM in the coupled system shares the same model configuration as global Real-Time Ocean Forecast System (RTOFS) and seeks solutions in the same way.

Hence, leverage it to provide IC/BC seamlessly from global Real-Time Ocean Forecast System (RTOFS) (that is run daily and produces 48-h nowcasts and 8-day forecasts).

In December 2020, RTOFS is interfaced with NCODA-based assimilation module.

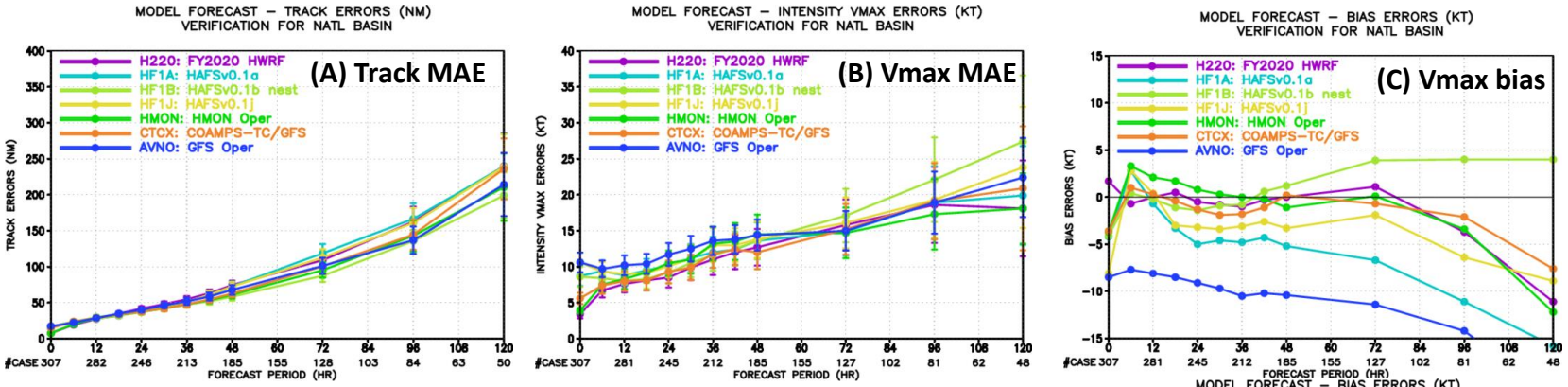
HYCOM coupling

WORKING TOWARD IOC

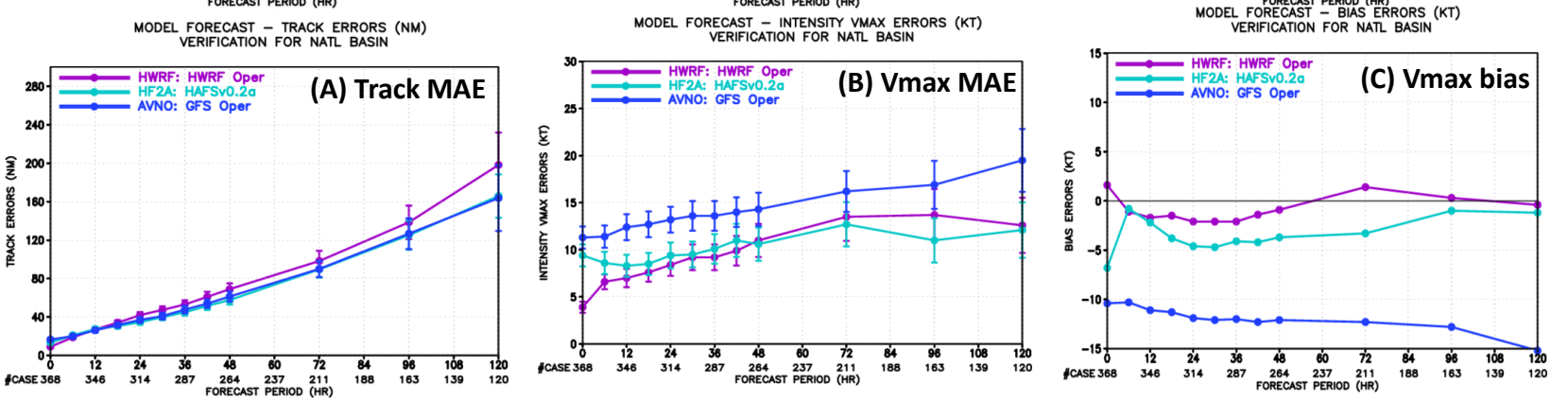
The real-time test for the past 2 seasons demonstrate the robustness of the system. Also, forecast skill is proven to be as skillful as HWRF.

Verification of RT simulations for 2020 (top) and 2021 (bottom)

2020

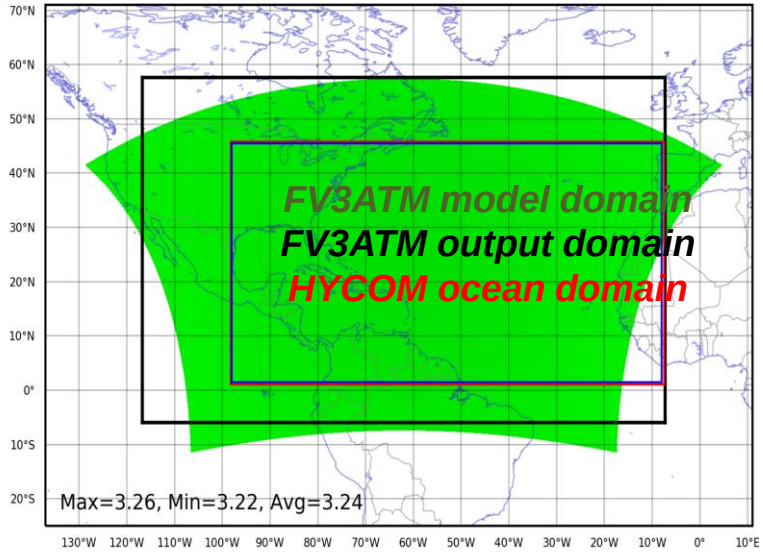


2021

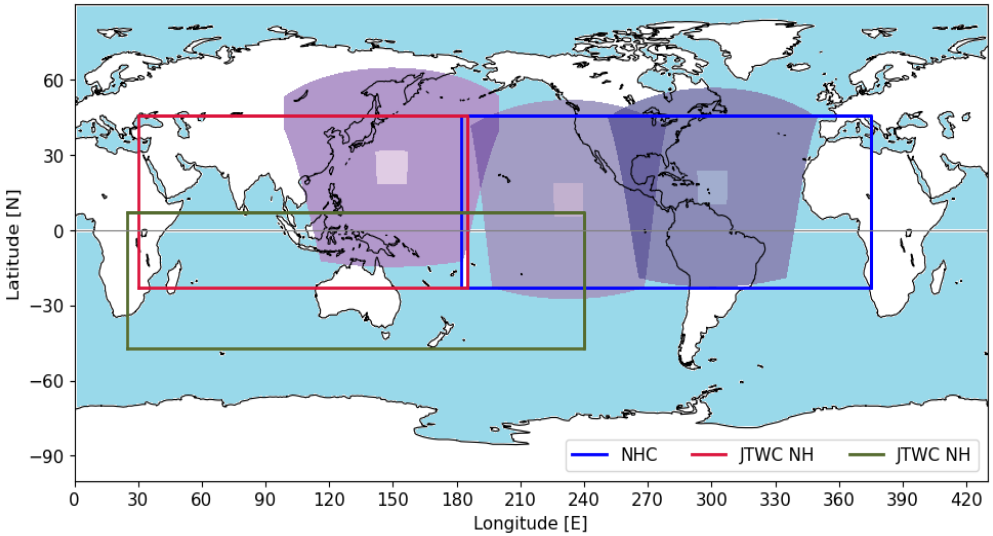


HYCOM coupling

(A) HAFS V0.1 and V0.2



(B) HAFS V0.3



- CMEPS based ocean coupling with updated exchange flux variables
- Updated 1/12-degree NATL domain from (A) to (B)
- 41 hybrid vertical layer
- Ocean IC from RTOFSv2 with persistent oceanic LBC
- Atmospheric forcing from GFSv16 grib2 files for non-overlapping area

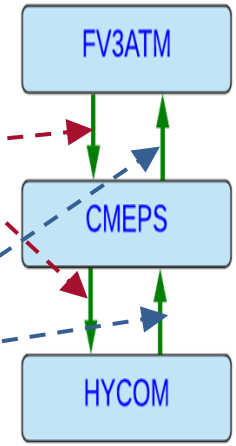
FV3 to HYCOM:

'taux10'	'mean_zonal_moment_flx_atm'	'N_m-2'
'tauy10'	'mean_merid_moment_flx_atm'	'N_m-2'
'prcp'	'mean_prec_rate'	'kg_m-2_s-1
'swflxd'	'mean_net_sw_flx'	'W_m-2'
'lwflxd'	'mean_net_lw_flx'	'W_m-2'
'mslprs'	'inst_pres_height_surface'	'Pa'
'sensflx'	'mean_sensi_heat_flx'	'W_m-2'
'latflx'	'mean_laten_heat_flx'	'W_m-2'

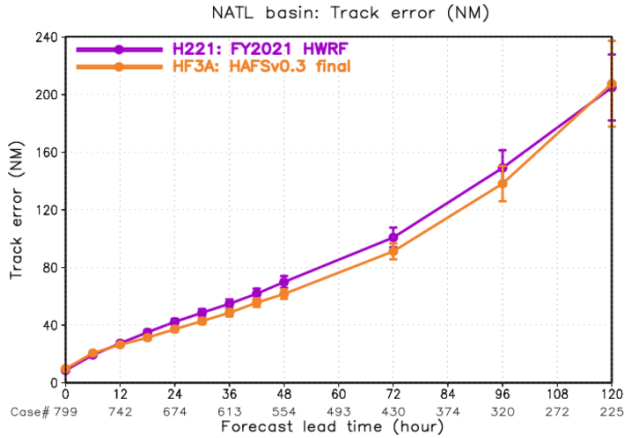
and variables from HYCOM to FV3:

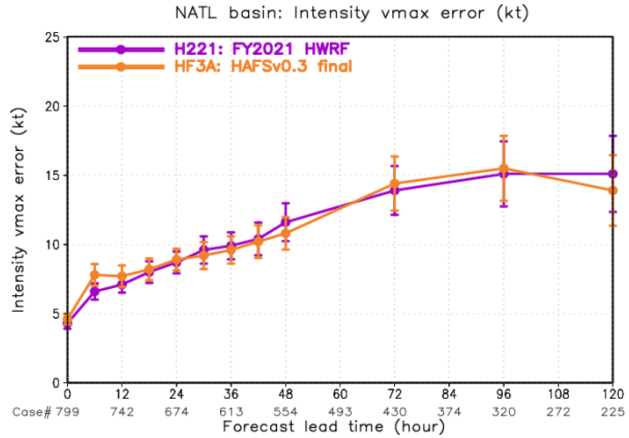
'sst'	'sea_surface_temperature'	'K'
'mask'	'ocean_mask'	'1'
'cpl_scalars'	'cpl_scalars'	'1'

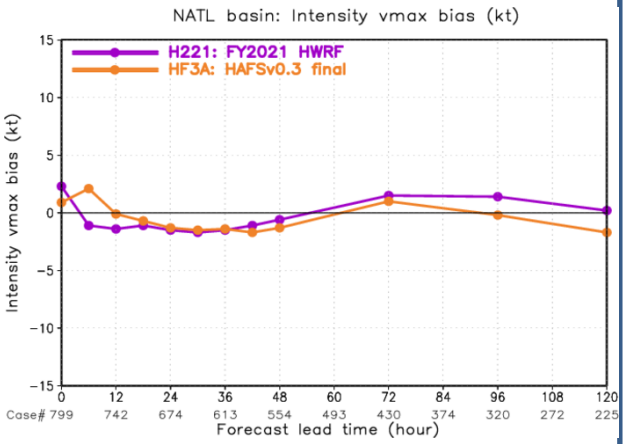
via CMEPS.



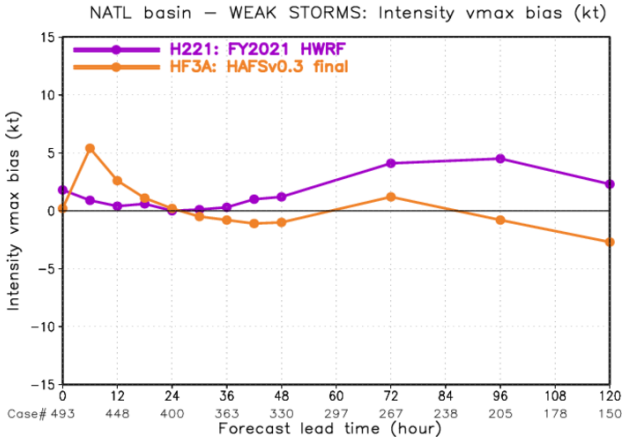
HAFSv0.3A Configuration Performance
For 2020/2021 NATL Storms

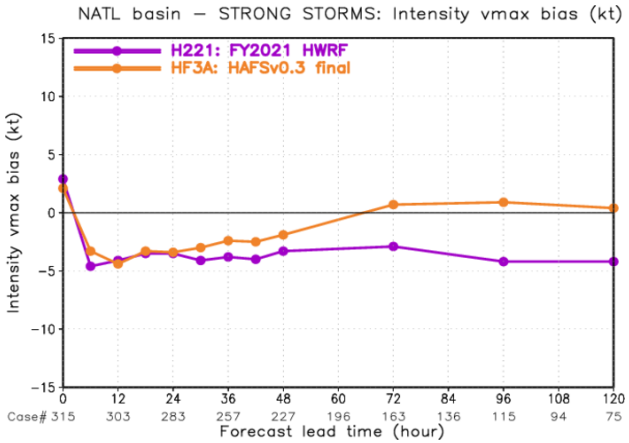






Stratified verification with Vmax=50 kt

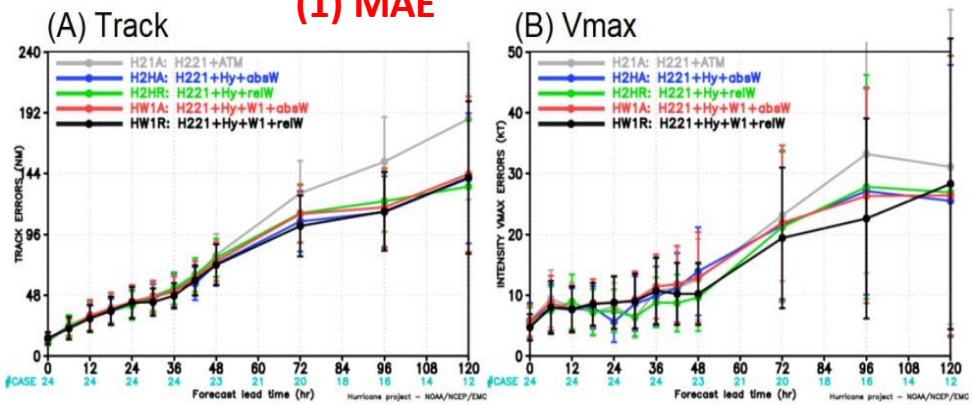




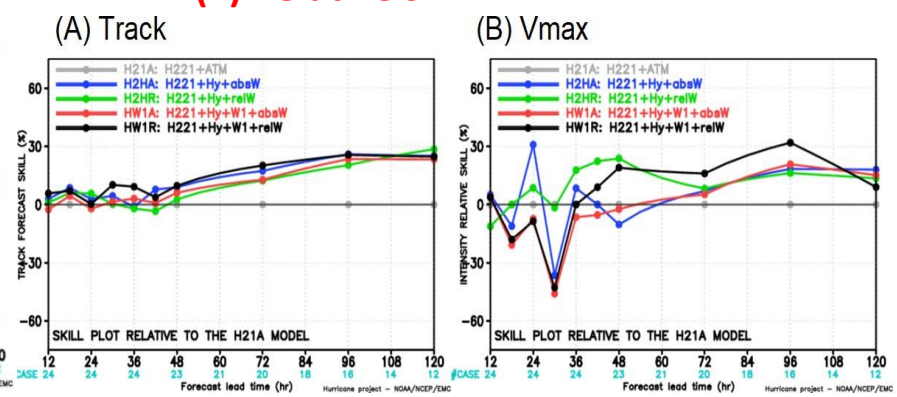
Impact of relative winds and 2-way vs. 3-way coupling

HWRF intensity (Vmax) and track verification for total 24 cases for Hurricane Laura (2020)

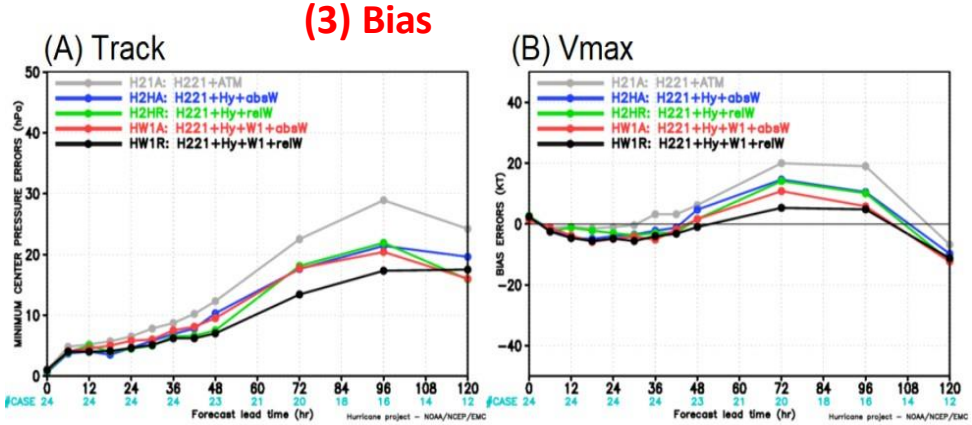
(1) MAE



(2) Relative Skill



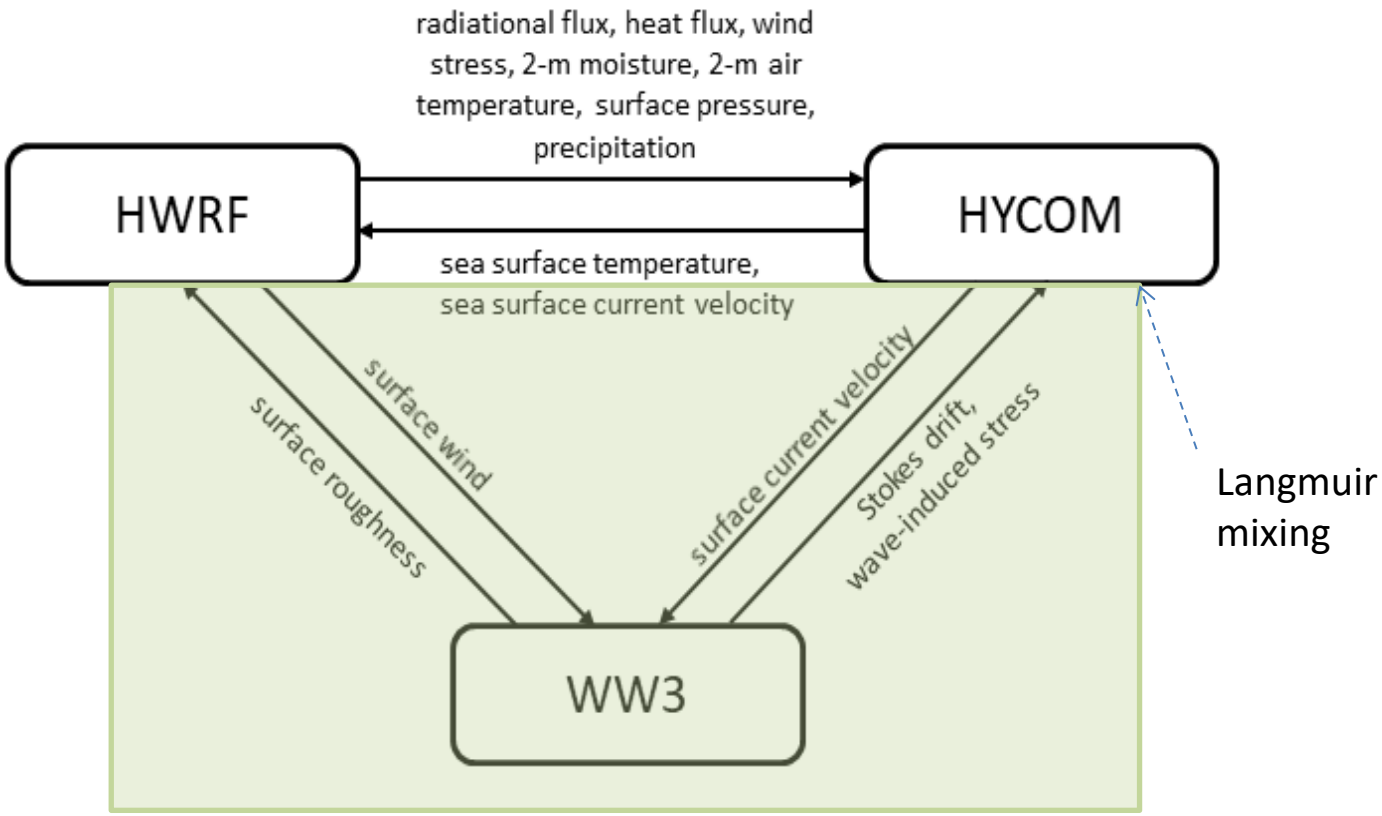
(3) Bias



- H21A
- H21H_absWind
- H21H_relWind
- H3W1_absWind
- H3W1_relWind

Presented at the 35th Hurricane Conference, May 2022

3-way coupling



3-way coupling

ATM SURFACE BOUNDARY LAYER

Bulk exchange coefficients, with the Charnock's relationship:

$$z_o = \alpha \frac{u^{*2}}{g}$$

z_o : surface roughness length scale

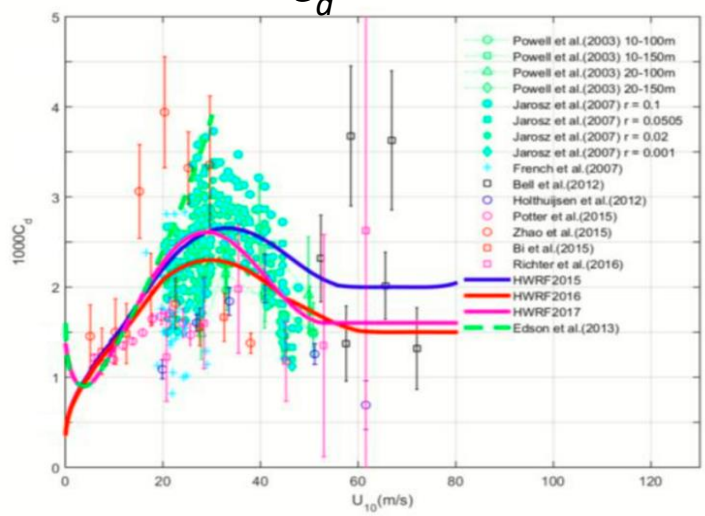
u^* : frictional velocity

g : gravity (9.8 ms^{-1})

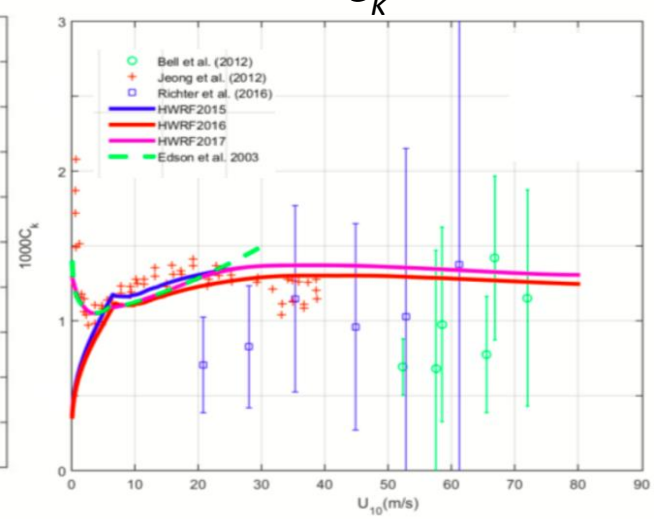
α : Charnock's coefficient

(<u>0.0185 for neutral conditions</u>)

C_d



C_k



HWRF 2017 curves (magenta)

3-way coupling

WW3 AIR SEA INTERACTION MODULE (ASIM) - WAVE BOUNDARY LAYER

WW3 can not resolve the shaded range (due to model resolution)

1. <u>Conservation of the momentum flux</u>

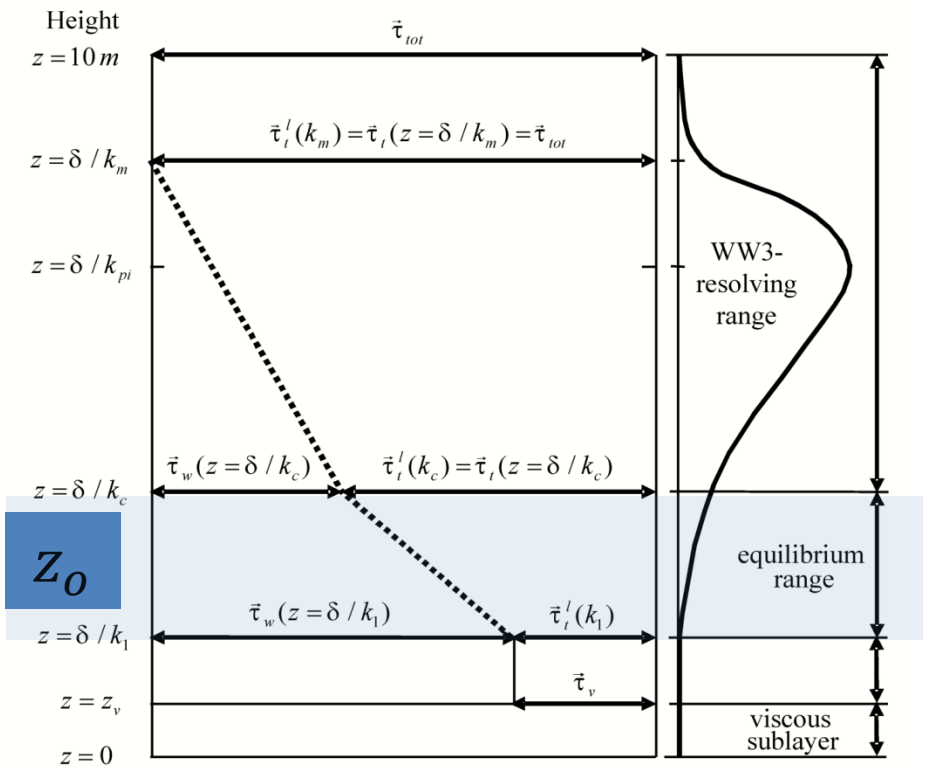
$$\tau_{tot} = \tau_t(z) + \tau_w(z), \quad \text{WBL}$$
$$= \tau_a, \quad \text{@z=10 m}$$

τ_w :wave-induced stress
τ_t : turbulence stress
τ_a : atmospheric mom. flux

2. <u>Conservation of the wave energy</u>

$$\frac{d}{dz}(\mathbf{u} \cdot \boldsymbol{\tau}_{\text{tot}}) + \frac{d\Pi}{dz} + \frac{d\Pi'}{dz} - \rho_a \varepsilon = 0, \qquad (4)$$

where $\mathbf{u}$ is the mean wind vector, Π is the vertical transport of the kinetic energy of the wave-induced motions, Π' is the vertical transport of the turbulent kinetic energy, ρ_a is the air density, and ε is the viscous dissipation rate of the turbulent kinetic energy. The dissipation rate



k_m : low bound wavenumber, k_1 : upper bound wavenumber,
k_{pi} : peak input wavenumber, k_c : cut-off wavenumber,
$\vec{\tau}_{tot}$: total stress, $\vec{\tau}_t(z) + \vec{\tau}_w(z)$, $\vec{\tau}_w(z)$: wave-induced stress at z,
$\vec{\tau}_t(z)$: turbulent stress at z, $\vec{\tau}_t^{\,l}(k)$: local turbulent stress at k,
z_v : roughness scale of the viscous sublayer, $\vec{\tau}_v$: viscous stress.

Moon et al. (2004)

3-way coupling

HWRF intensity (V_{max}) and track verification for total 27 cases for Hurricane Laura (2020)

Track MAE (A):

- H3W1 improved by <40 nm, over H21A. Similarly H21H.
- statistically significant for lead time from 96-h.

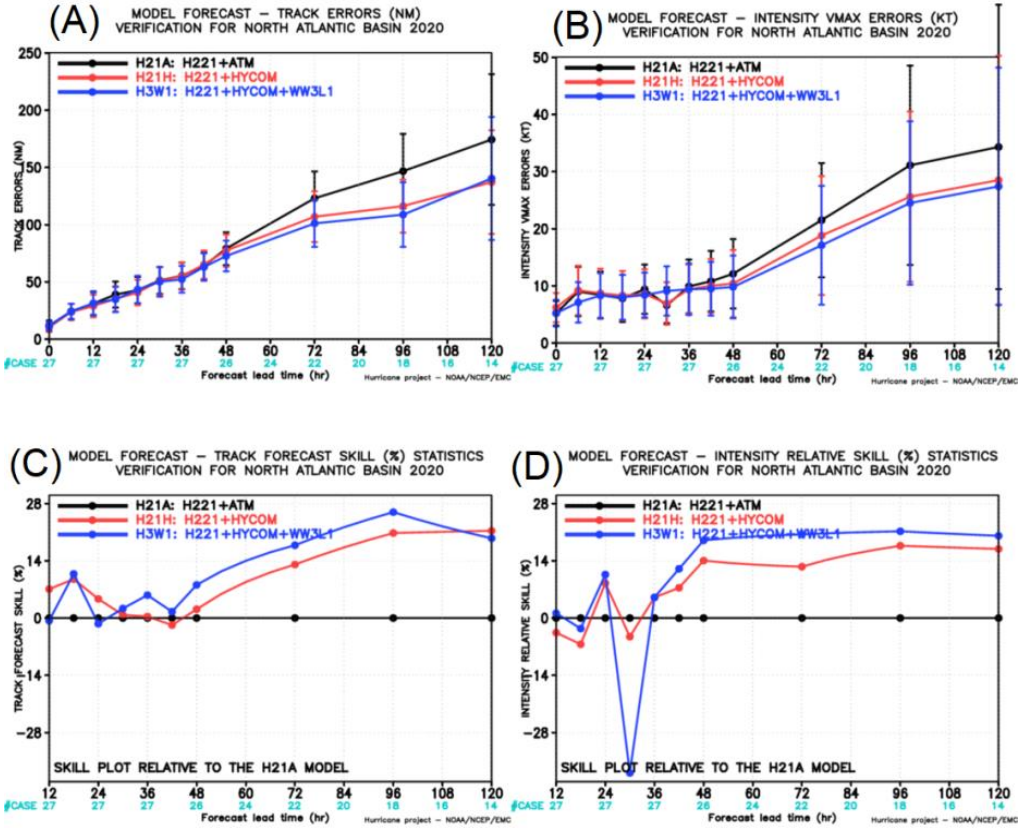
V_{max} Intensity MAE (B):

wrt H21A and H21H,

- MAE Reduction <7 kt and < 2kt, respectively (not statistically significant)
- Bias improvement by 6 kt and 3 kt.

Relative skill (C-D) w/ H21A:

- H3W1 - <~28% for track and <17% for V_{max}.
- H21H – <25% for track and <15% for V_{max} .

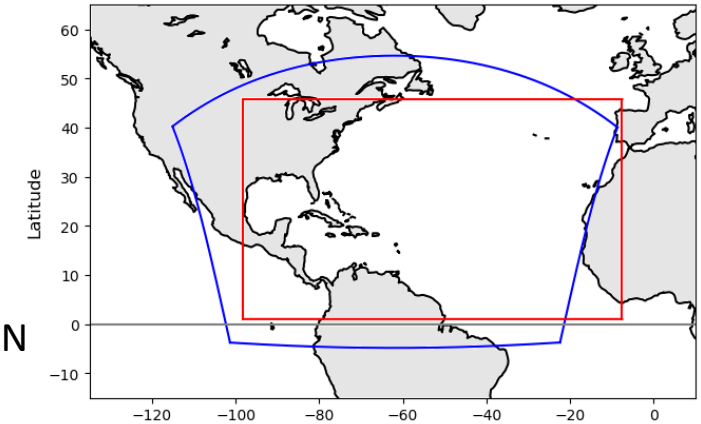


Kim et al. (2022)

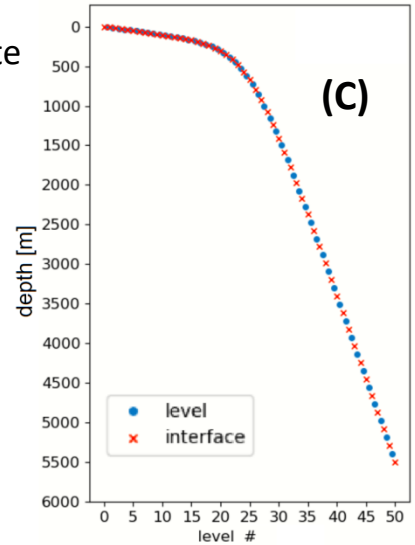
Development of high resolution regional MOM6 and JEDI SOCA

- **Domain**
  - 1/12-d and 50-layer (z*) with 5-m thickness for the top layer
  - North Atlantic (261.7-352.5E, 1.0-45.8N)
- **IC/OBC** – global RTOFS nowcasts & forecasts by remapping
  - OBC – super grid (2xBC cell) for T,S,U,V and SSH
  - FLATHER,ORLANSKI,NUDGED,ORLANSKI_TAN,NUDGED_TAN
  - Nudging scale – 3 and 365 days for inflow and outflow
- **Forcing**
  - 0.25-d GFS forcing
  - Vars: SLP, U10/V10, T2, Q2, DS/DLWRF, Prate
  - River runoff – off
  - Tides – off
- **Runs** for year 2020 -
  - Free run – Jan to Dec
  - 3DVar – mid-Jan to Dec

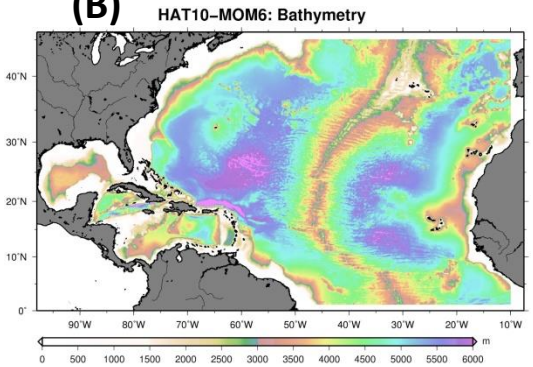
(A) **HAFS** v0.1 and v0.2



Blue: FV3atm
Red: MOM6 (HYCOM)



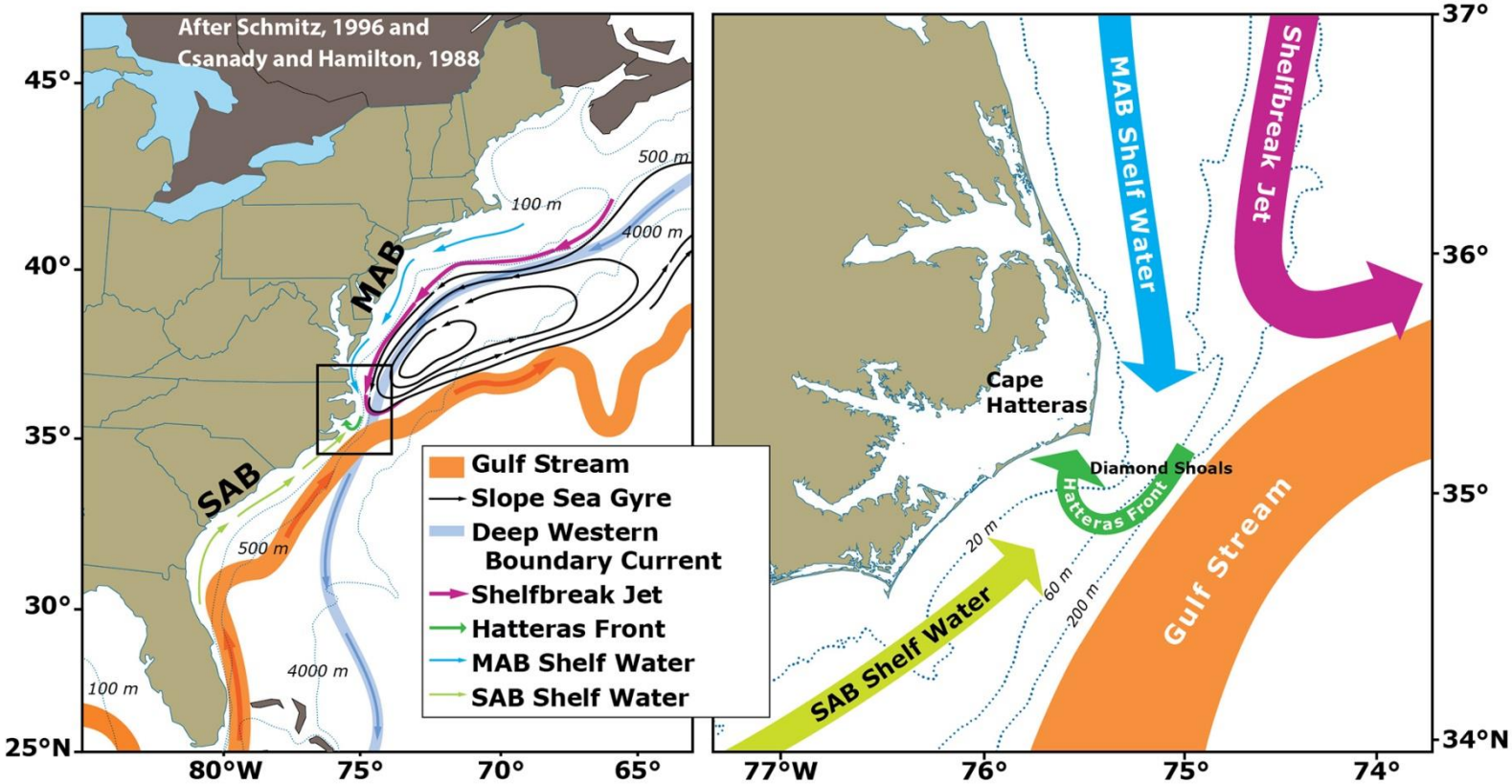
(B)



Metrics

1. **The Gulf Stream separation**
2. **The Florida Cable (FC) transport**
3. **Comparisons against GOFS 3.1 (based on NCODA+HYCOM**
4. The Loop Current extent and eddies in GOM
5. Mass conservation in a domain
6.)

Ocean circulation in MAB and SAB

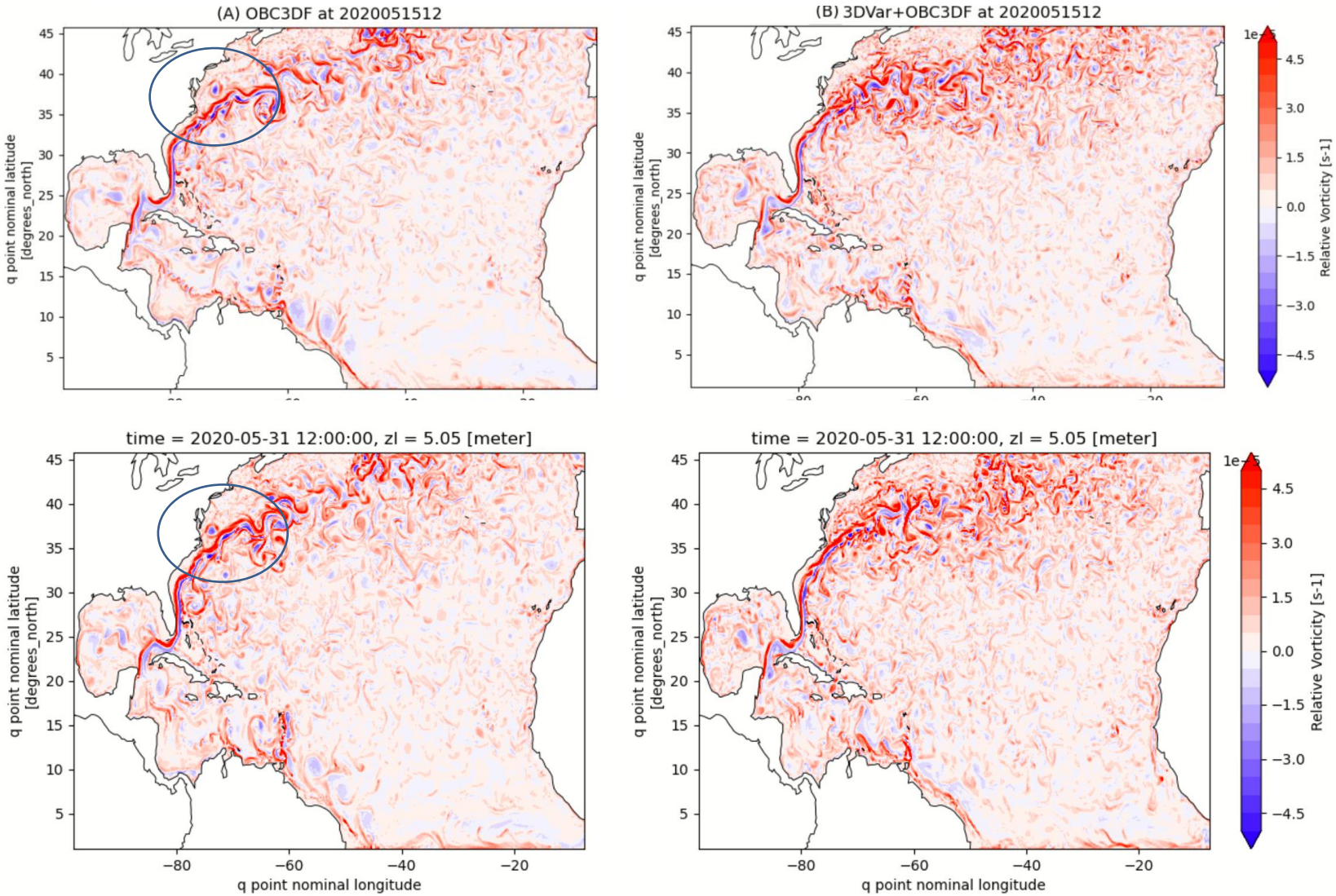


North Atlantic MOM6 experiment: **OBC3DF**

I. Relative vorticity for May 15 (top) and 30 (bottom), 2020

(1) Free run: OBC3DF

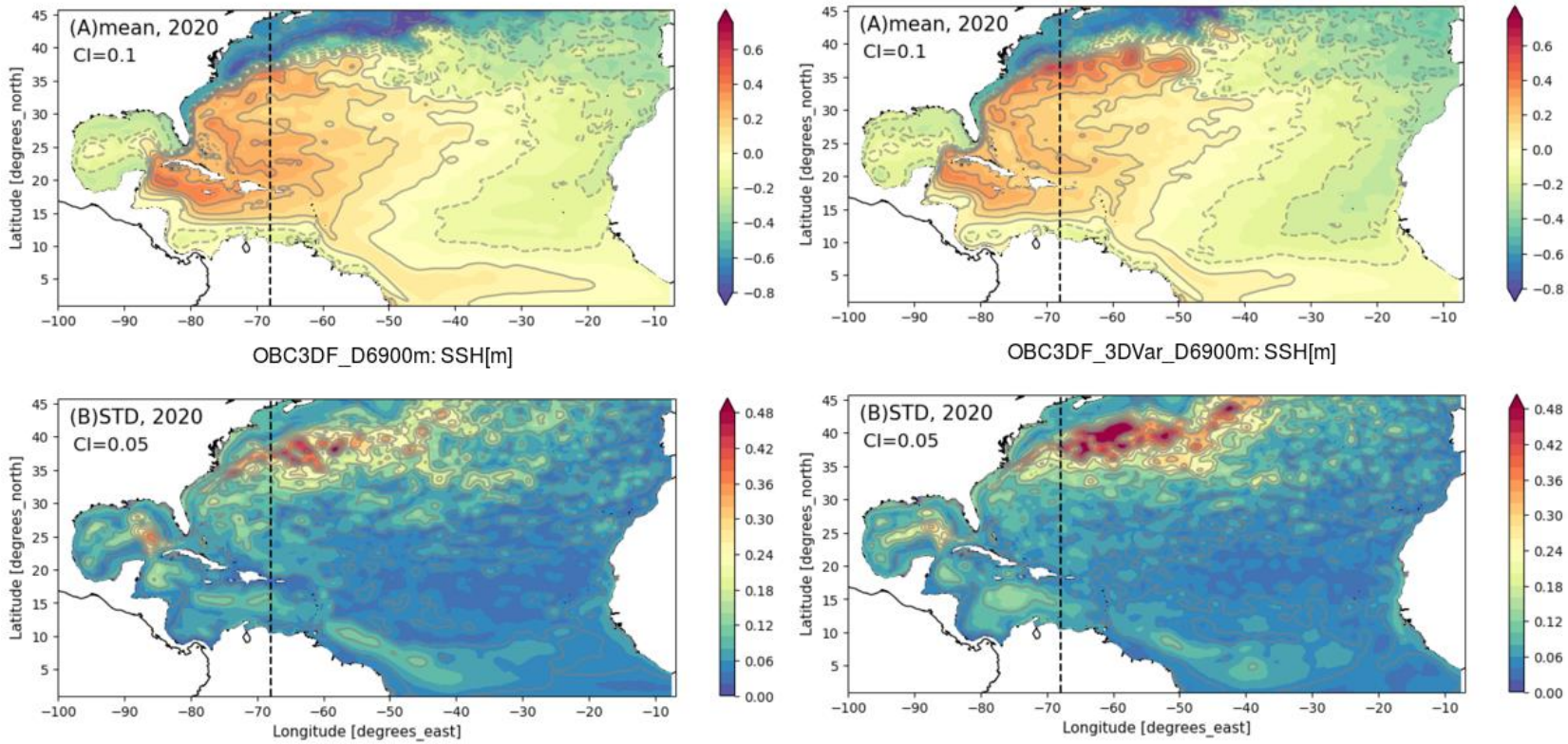
(2) 3Dvar+OBC3DF



North Atlantic MOM6 experiment: **OBC3DF**

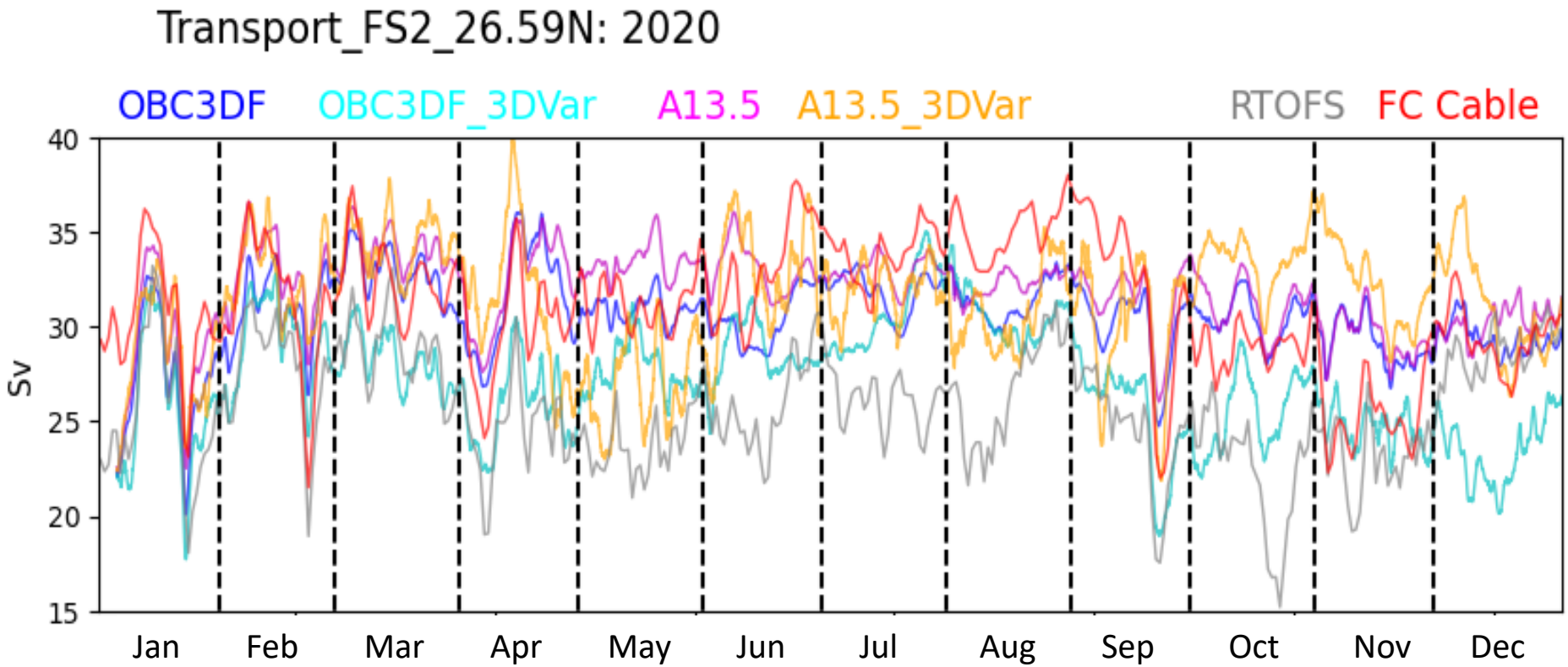
II. Annual mean SSH for year 2020

(1) Free run: OBC3DF **(2) 3Dvar+OBC3DF**



- Free run (1) simulates a warm core, and 3DVar (2) removes it
- Opposite downstream of the GS from Cape Hatteras
- GOM – relatively positive SHA reduced by 3DVar (2)

1: Volume Transport at the Florida Current cable

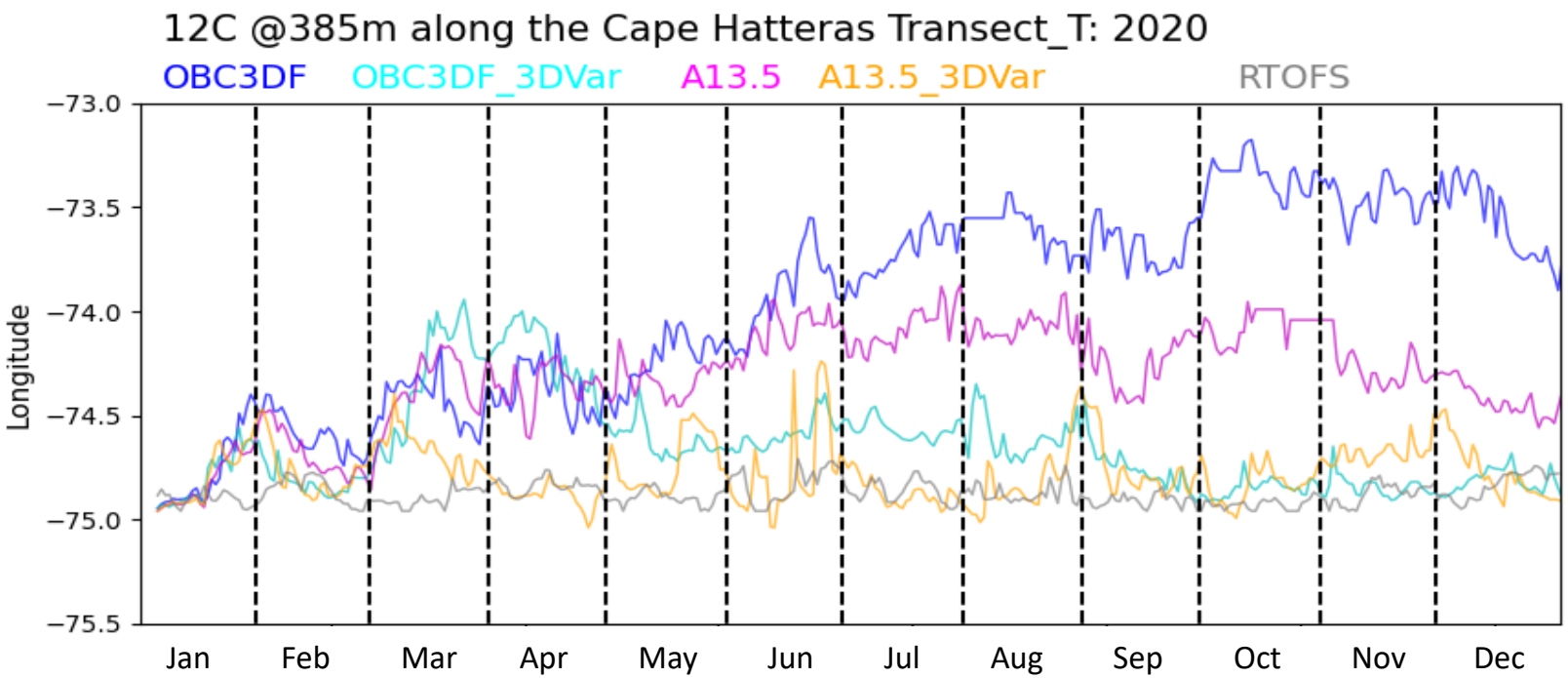


	Obs	OBC3DF	A13.5	OBC3DF+3Dvar	A13.5+3DVar	RTOFS
mean	31.17	30.55	31.85	27.12	31.28	25.67
STD	3.46	2.17	2.22	3.04	3.18	3.13
RMSE	-	3.04	2.79	4.73	3.13	6.29
R		0.601	0.622	0.719	0.218	0.572

NWS global Real-Time Ocean Forecast System (RTOFS)

2: Gulf Stream separation

Use the longitudinal location of the GS north wall (i.e. Z12 for ~400 m)



- OBC3DF+3DVar corrects the location of the GS separation and keeps it at 75-74.5W, whereas A13.5+3DVar exhibits anomalously an eastward position (74W) than its free run, but gradually shifts to the west.

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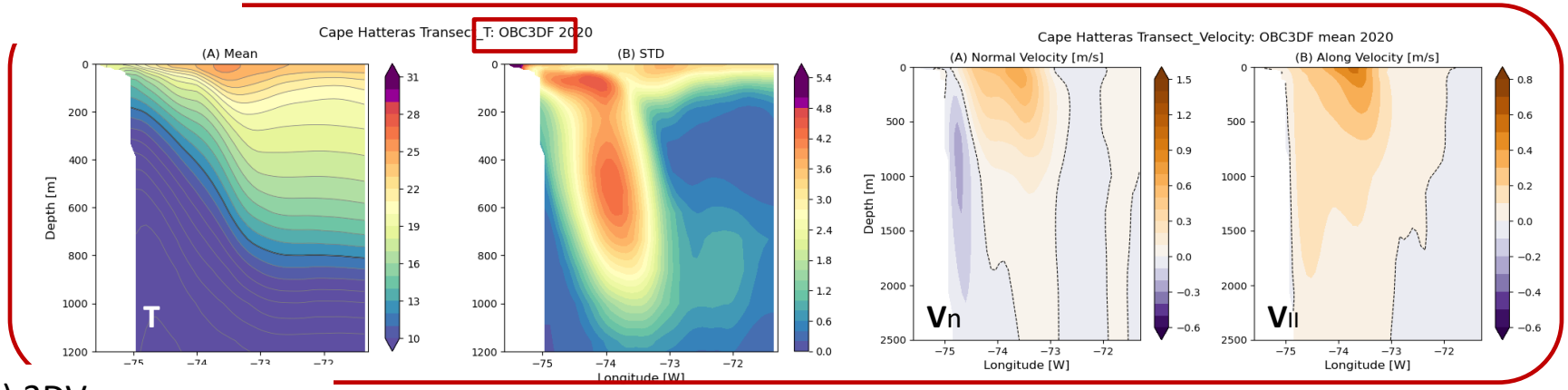
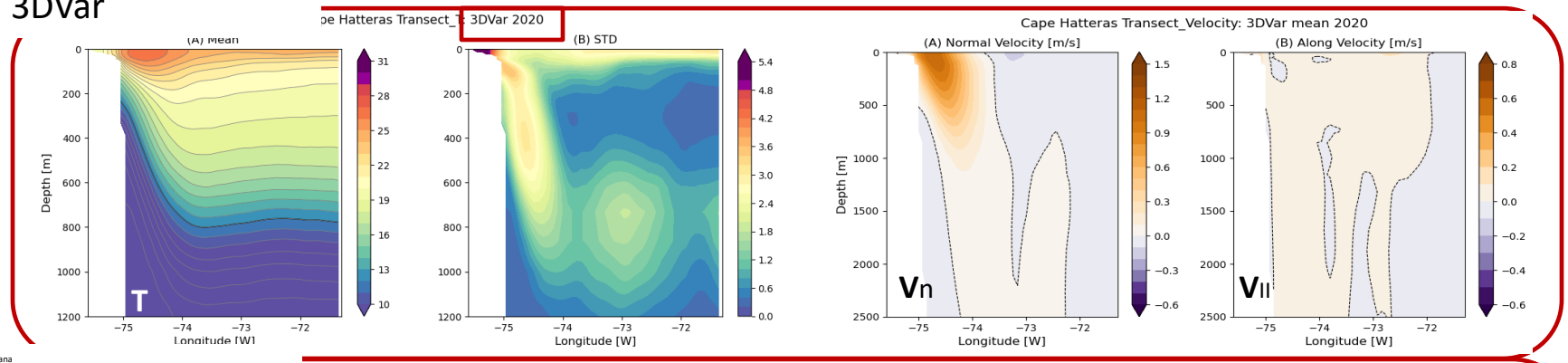
2: Gulf Stream separation

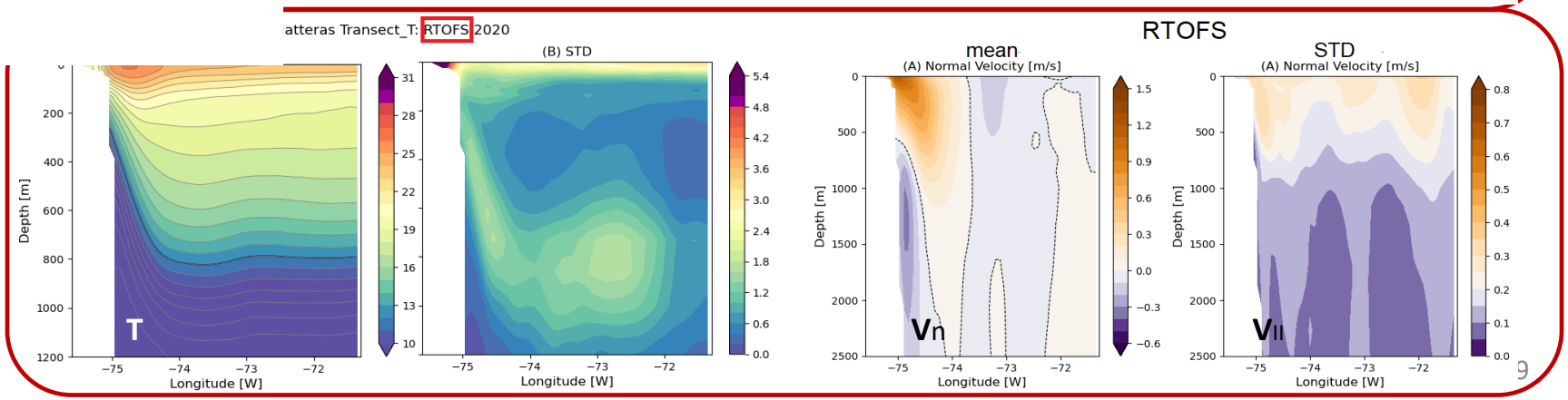
(A) Free run



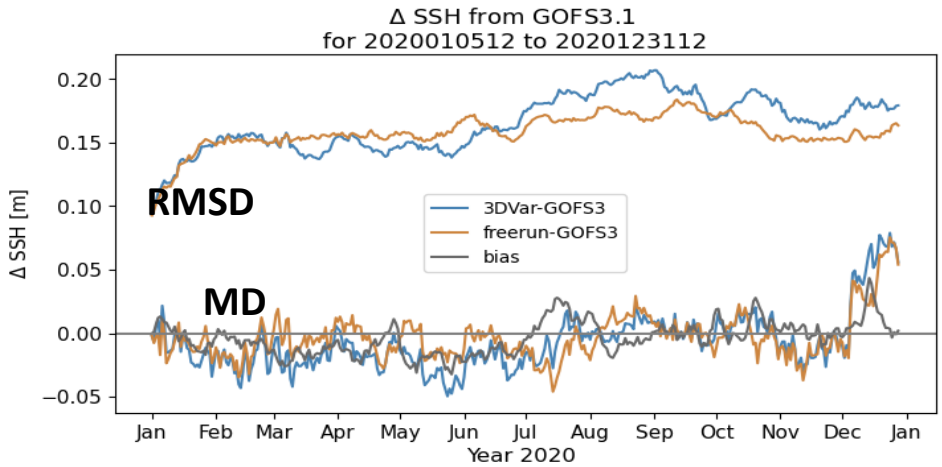
(B) 3DVar

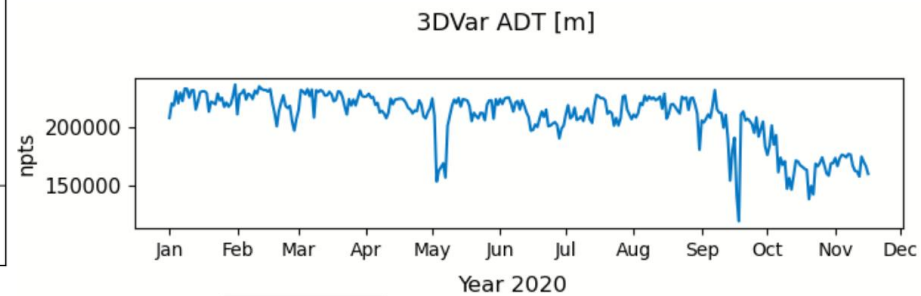


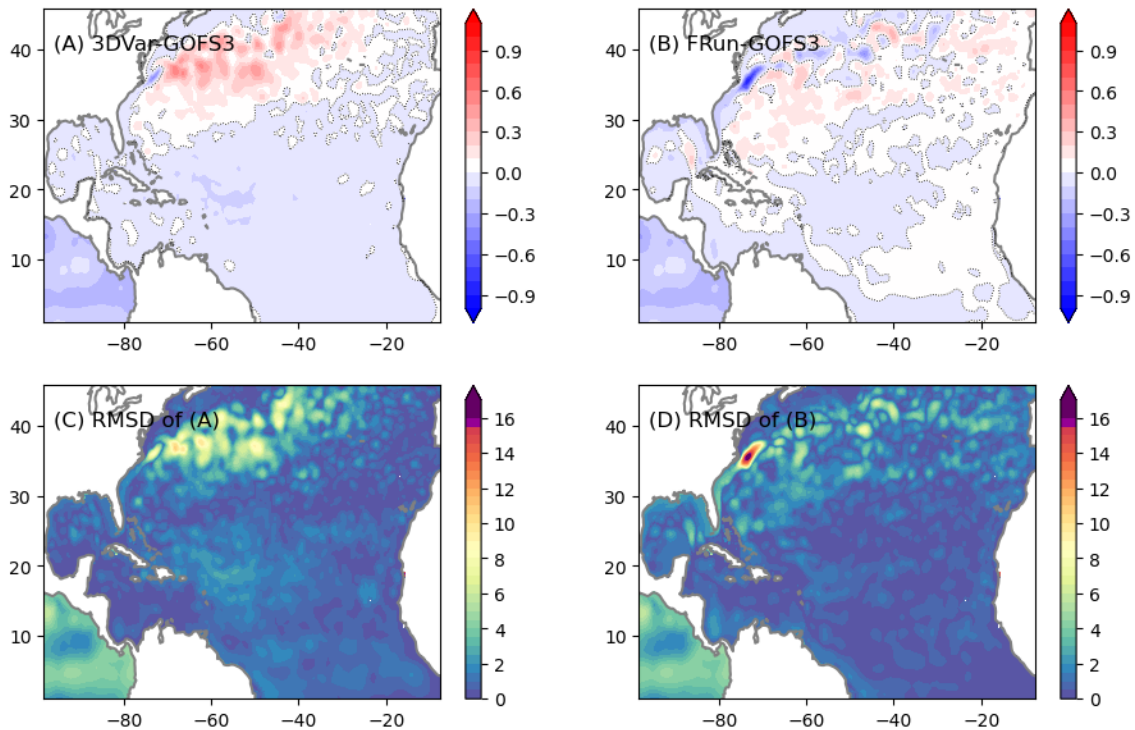
(C) RTOFS ana



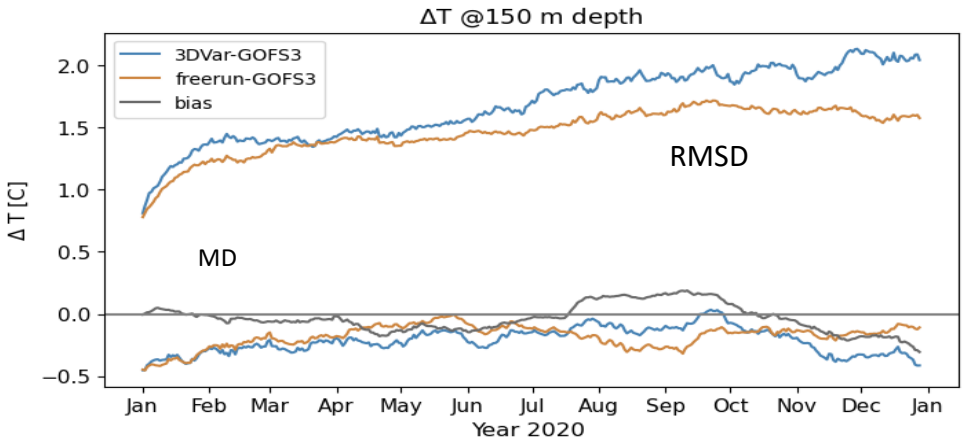
3. 3DVar, Free run (OBC3DF) and GOFS (NCODA+HYCOM): SSH

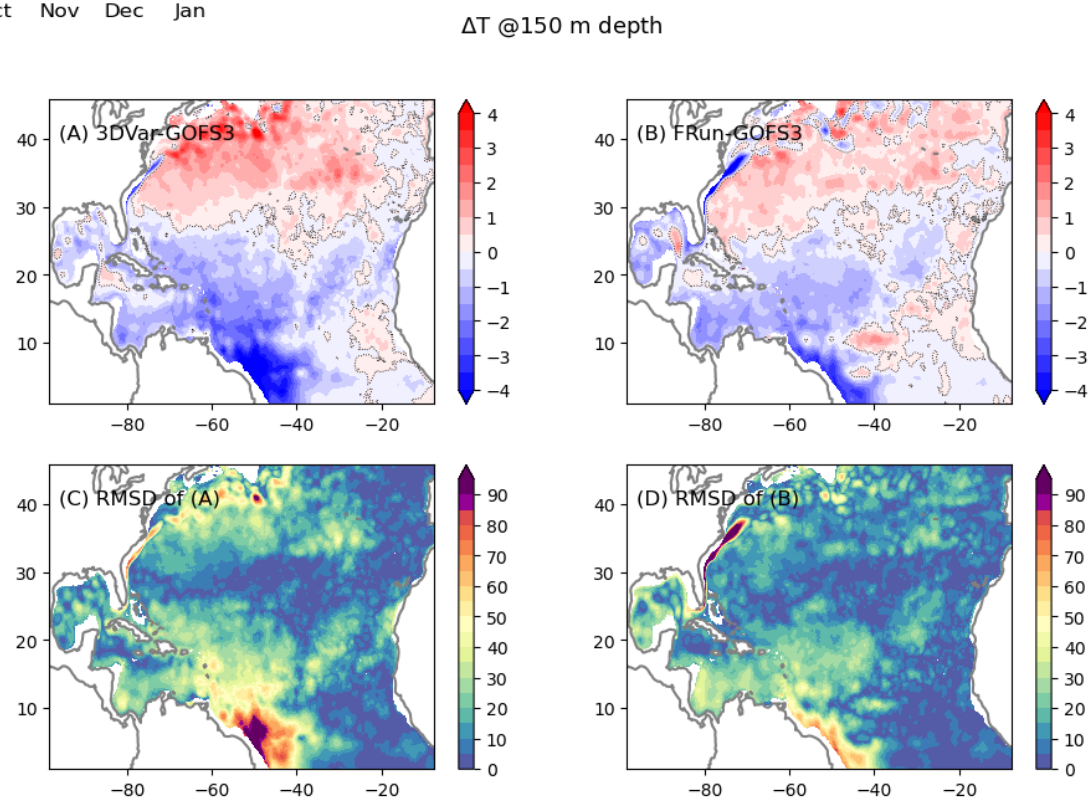






3. 3DVar, Free run (OBC3DF) and GOFS (NCODA+HYCOM): 150-m T





HAFS (Hurricane Analysis and Forecast System)

1. SUMMARY

1) Enhancement in coupling is needed, e.g. SSC, PGF (Pressure Gradient Forcing), and precipitation, to have better simulations in the upper layer
2) Wave coupling is needed to have better simulations of air-sea interactions

2. FUTURE PLAN

1) Implement relative winds in both FV3 and HYCOM
2) Improve fresh water simulations including precipitation and river discharge
3) Include the pressure gradient forcing
4) Implement a high-resolution regional MOM6, including data assimilation (*partial support from NAS UGOS-3)*
5) Implement full 3-way FV3-HYCOM-WW3 coupling or Implement full 3-way FV3-MOM6-WW3 coupling (*partial support from NAS UGOS-3*)
6) Merge the Joint Efforts for Data Assimilation Integration (JEDI) framework to UFS HAFS
7) Develop strongly coupled data assimilation for (*JTTI w/OU and SOW for the OAR weather portfolio*)