

Simulation of Atlantic warm pool in the Hybrid-Coordinate Ocean Model (HYCOM)

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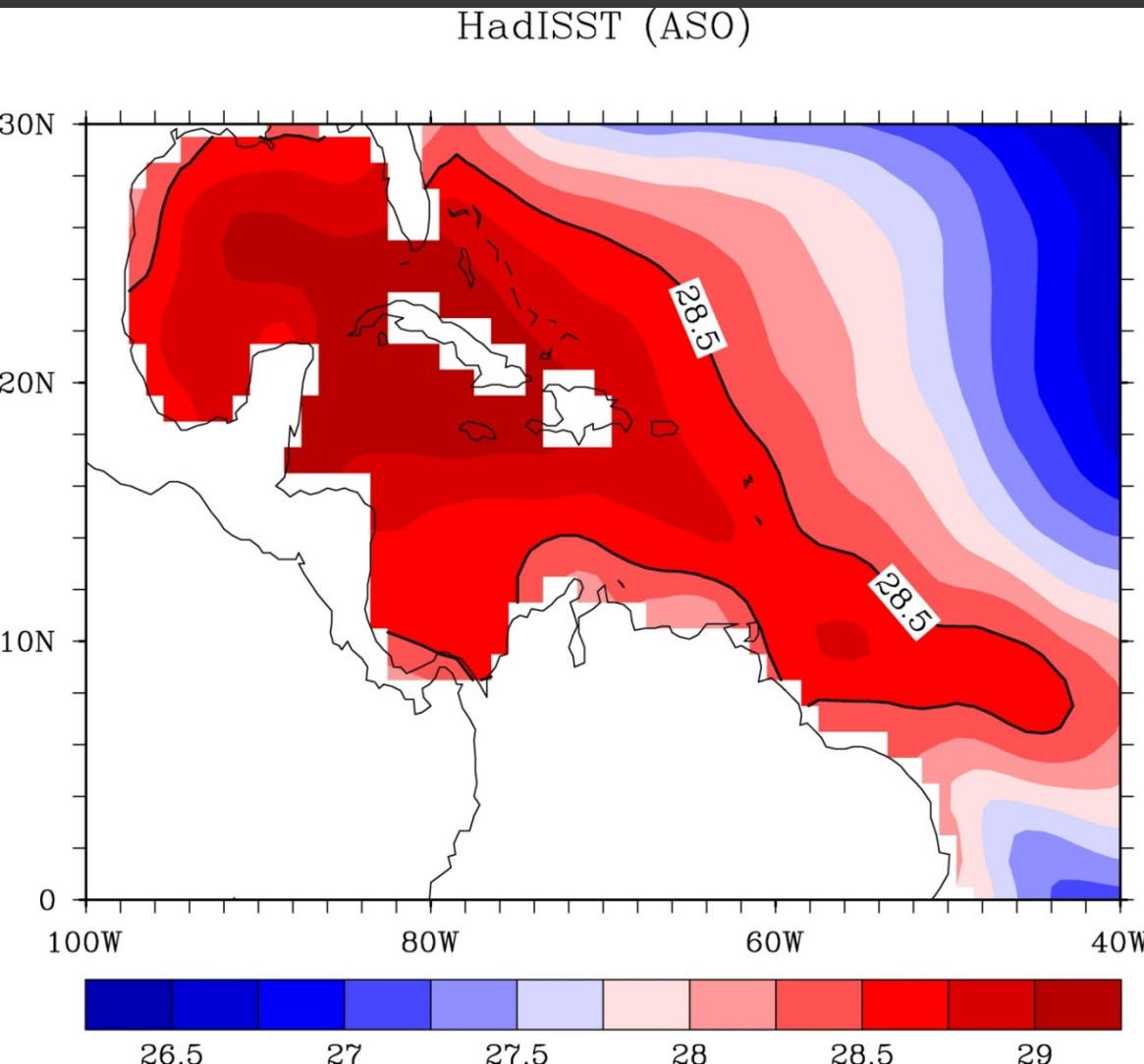
³NOAA/NCEP/EMC

Outline

- 👉 What is Atlantic warm pool (AWP) and why is it important for hurricane?
- 👉 JHT project: diagnose and improve AWP simulation in HYCOM-based RTOFS at NCEP/EMC
- 👉 How do we measure the performance of HYCOM in simulating AWP?
- 👉 AWP bias inherent in HYCOM
- 👉 AWP bias associated with GFS surface flux fields
- 👉 Accomplishments, conclusions and future works

What is Atlantic Warm Pool (AWP)?

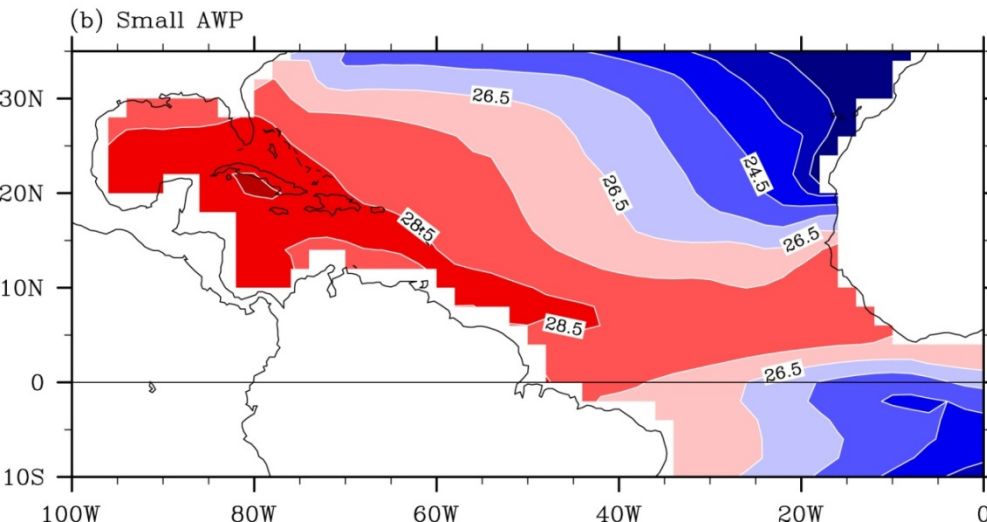
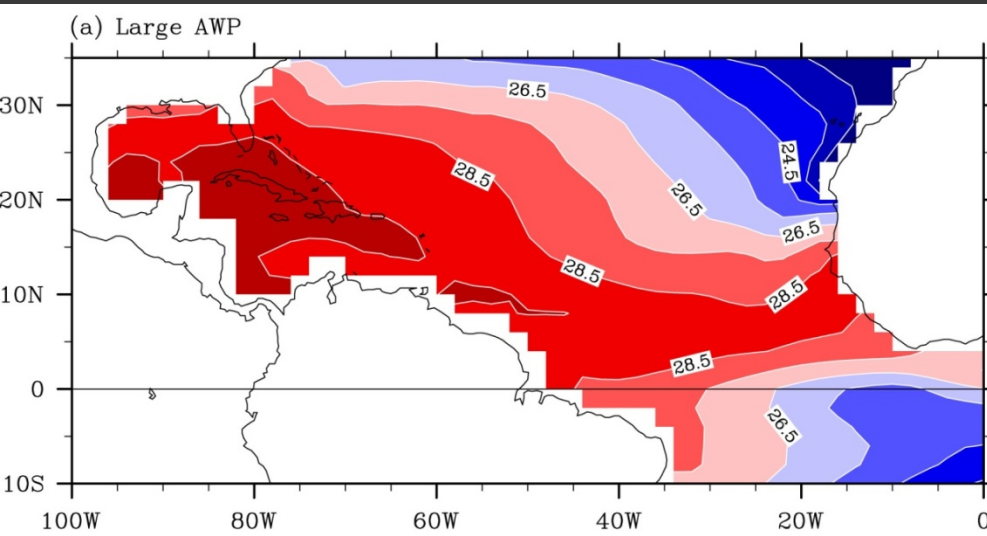
NOAA ERSST2: Atlantic warm pool SST in August-September-October



- ➔ AWP is a body of warm surface water ($\geq 28.5^{\circ}\text{C}$) in the Gulf of Mexico and Caribbean Sea
- ➔ AWP appears exclusively in boreal summer and fall and disappears in other seasons
- ➔ Wang and Enfield (2001 GRL)

What is Atlantic Warm Pool (AWP)?

NOAA ERSST2: SST composites of large & small AWP for 1854-2006



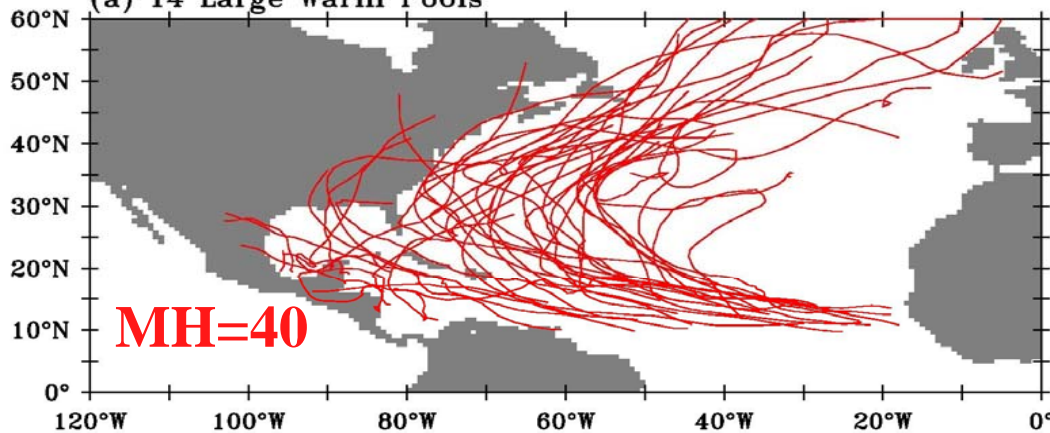
- 👉 Large AWP are almost three times larger than small ones
- 👉 AWP has a large amplitude of variability
- 👉 Wang, Enfield, Lee and Landsea (2006 JCL)

Why is AWP Important for Atlantic hurricanes?

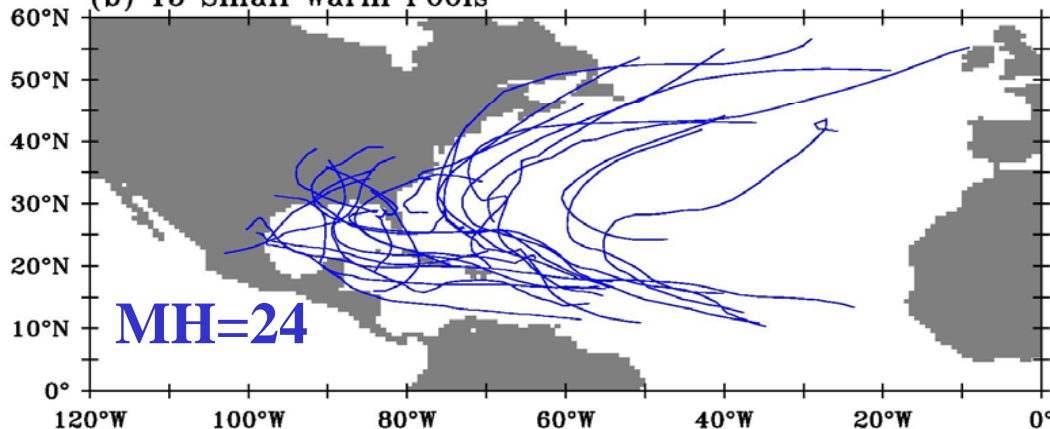
Major hurricane tracks for large and small AWP years during 1950-2003

Major Hurricanes and Atlantic Warm Pool

(a) 14 Large Warm Pools



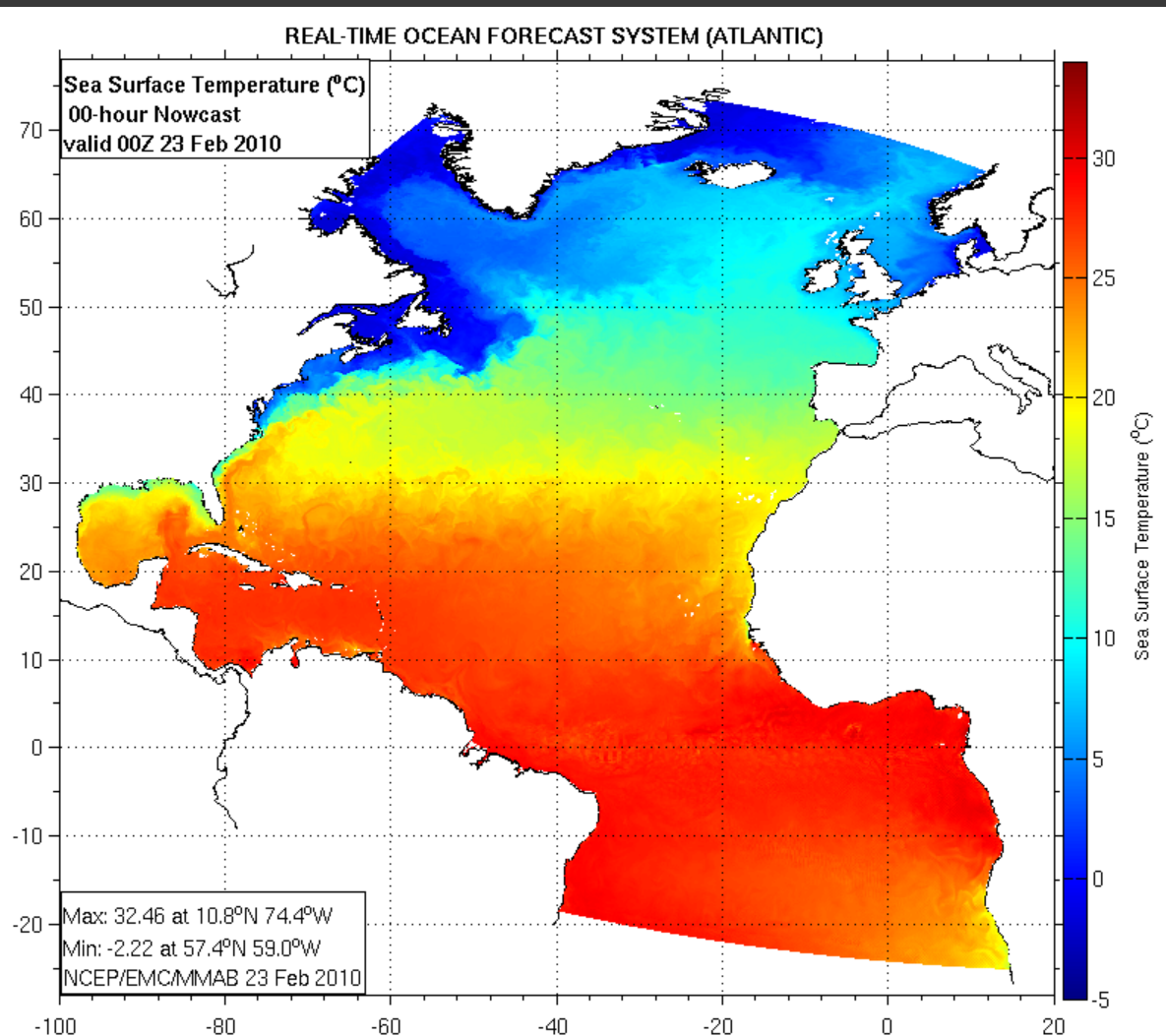
(b) 15 Small Warm Pools



- ➡ AWP is significantly correlated with tropical storm indices: $COR(\#TS, AWP) = 0.51$
- ➡ Large AWP provides favorable environment for storm formation & intensification by reducing the vertical wind shear and increasing the convective available potential energy in the MDR
- ➡ AWP also affects North Atlantic Subtropical High, thus it may also influence storm tracks
- ➡ Thus, it is important to properly simulate AWP in hurricane forecast models

JHT project: diagnose and improve AWP simulation in RTOFS

Real-Time Ocean Forecasting System - Atlantic (RTOFS) at NCEP/EMC



➡ RTOFS provides initial and boundary conditions for HWRF-HYCOM, which is an experimental hurricane forecast system at NCEP/EMC

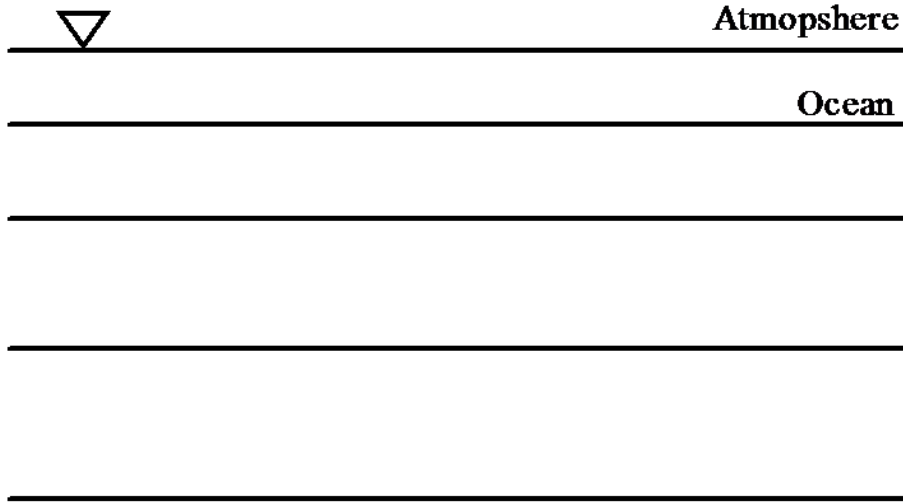
➡ Both RTOFS and HWRF-HYCOM are based on HYCOM

➡ Thus, it is important to evaluate how well HYCOM simulates AWP

How do we measure the performance of HYCOM in simulating AWP?

HYCOM uses a conventional bulk formula at the air-sea interface

q_{10} , θ_{10} , u_{10} and v_{10} are fixed from observation



- ➡ Is the simulated AWP SST a good measure of HYCOM's performance?
- ➡ No: If atmospheric variables are fixed, the model SST is relaxed toward observation
- ➡ HYCOM error is dumped into Q_{LHF} and Q_{SHF} .
- ➡ Thermodynamic inconsistency at the air-sea interface may causes problems if HYCOM is coupled to HWRF

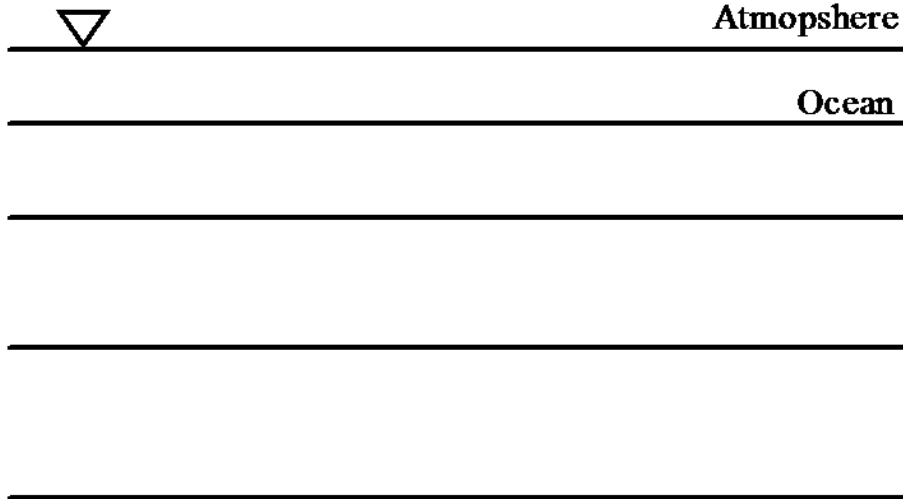
How do we measure the performance of HYCOM in simulating AWP?

Atmospheric mixed layer (AML) model is coupled to HYCOM

u_{10} and v_{10} are fixed from observation

$$\frac{\partial \theta}{\partial t} + u \nabla \theta + \omega \frac{\partial \theta}{\partial p} = \frac{\partial(\overline{\omega' \theta'})}{\partial p} + R,$$

$$\frac{\partial q}{\partial t} + u \nabla q + \omega \frac{\partial q}{\partial p} = \frac{\partial(\overline{\omega' q'})}{\partial p}$$



- ➡ AML model of Seager et al. (1995) is implemented and coupled to HYCOM
- ➡ AML-HYCOM is an effective way to allow physically consistent air-sea thermal interaction
- ➡ Minimize thermodynamic inconsistency at the air-sea interface for HWRF-HYCOM
- ➡ For this study: AML-HYCOM can truly reveal the problems inherent in HYCOM

How do we measure the performance of HYCOM in simulating AWP?

👉 **Optimal surface flux dataset:**

1) Global flux dataset of Large and Yeager (2008) provides a complete set of bias-corrected global surface flux for CORE2 program

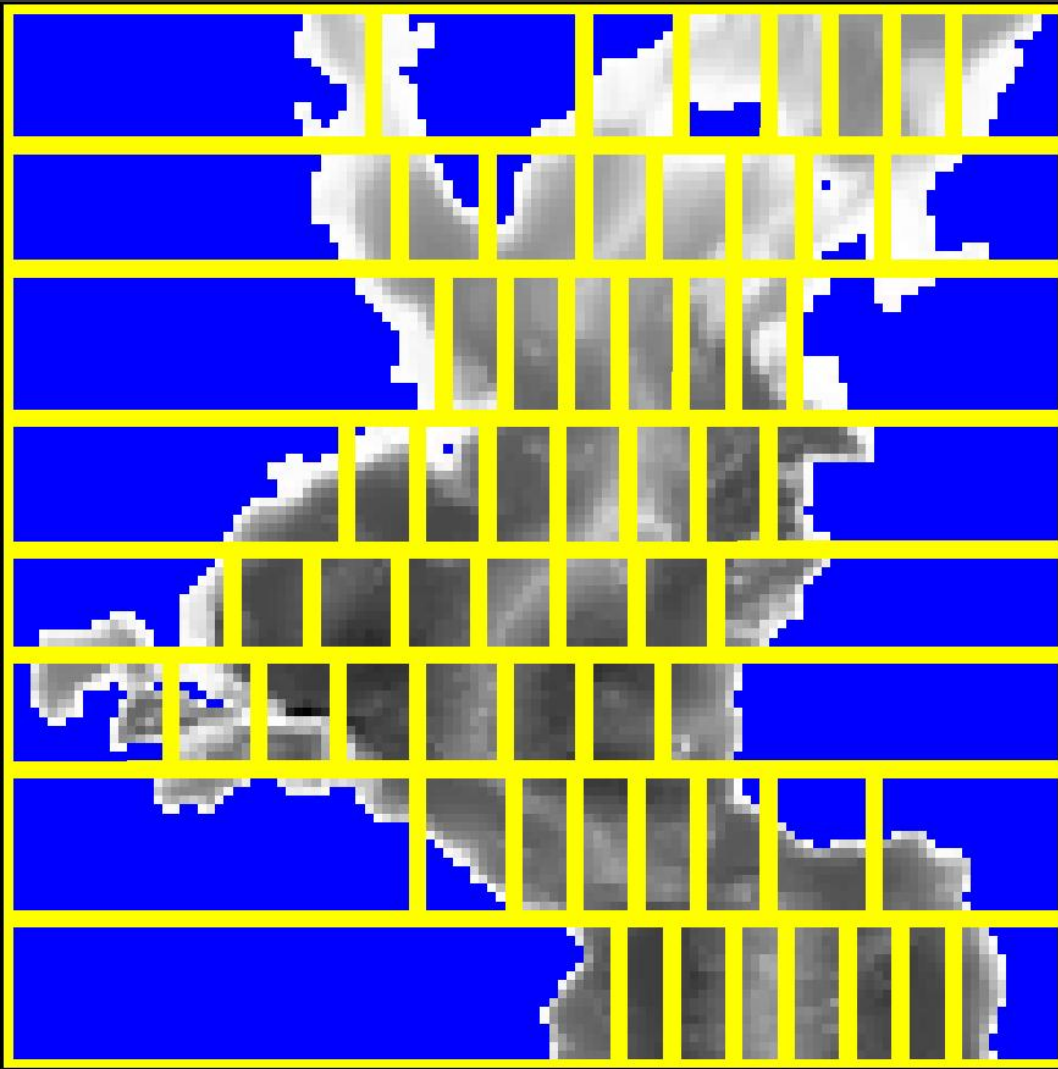
2) CORE2 flux dataset is used as the optimal flux dataset to force HYCOM in this study

Three AML-HYCOM experiments (Preliminary)

- ☞ Three sets of surface flux datasets are used
 1. CORE2: 1949-2006
 2. NCEP reanalysis-1: 1949-2009
 3. GFS (RTOFS is forced with GFS): 2009
- ☞ Three sets of multi-year (1949-2009) surface flux datasets are prepared: NCEP reanalysis is used to fill in the missing years for CORE2 and GFS
- ☞ Three AML-HYCOM experiments are carried out
 - EXP-1) NCEP1_CORE2
 - EXP-2) NCEP1 (not shown here)
 - EXP-3) Pseudo GFS: (We are currently evaluating)

Three AML-HYCOM experiments (Preliminary)

AML-HYCOM is forced with three surface flux datasets for 1949-2009



➡ 1×1 deg resolution AML-HYCOM is configured for Atlantic domain (20S-70N) on Mercator coordinate

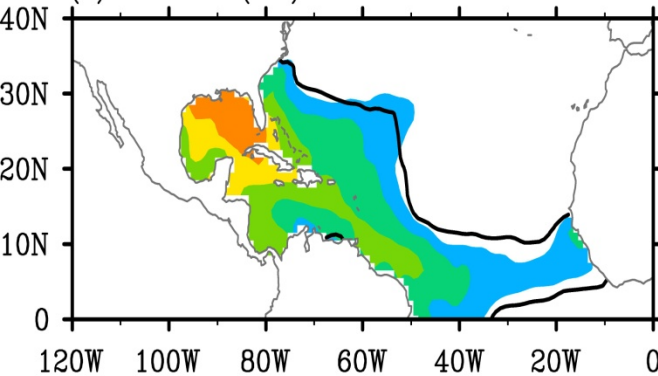
- ➡ Configuration details:
- 1) Levitus data is used for initial and boundary conditions
 - 2) North and South boundaries are relaxed toward Levitus data
 - 3) SSS is relaxed toward Levitus data
 - 4) Land regions must be tiled for AML model

EXP-1: AML-HYCOM_NCEP1_CORE2

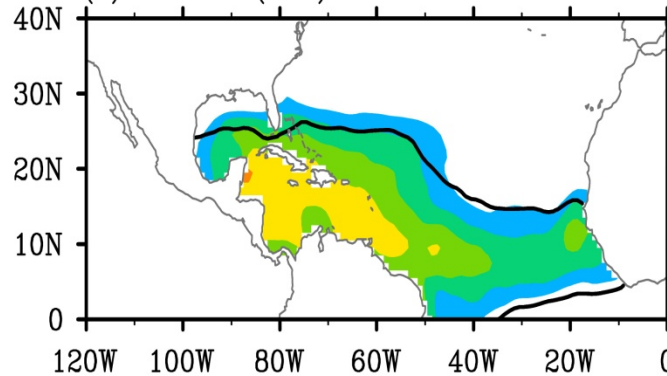
EXP-1: AWP SST is colder than observation by more than 2degC

Atlantic Warm Pool SST in 2009

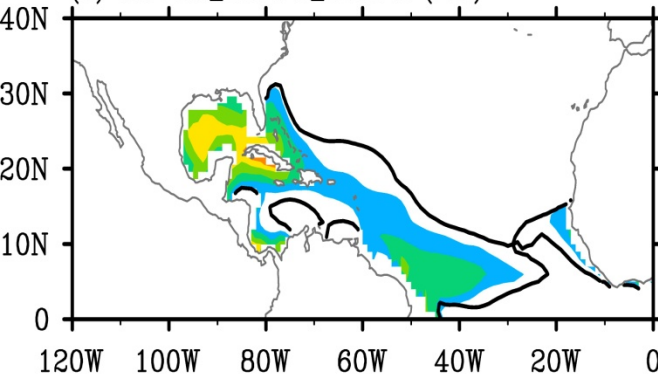
(a) HADISST (JJA)



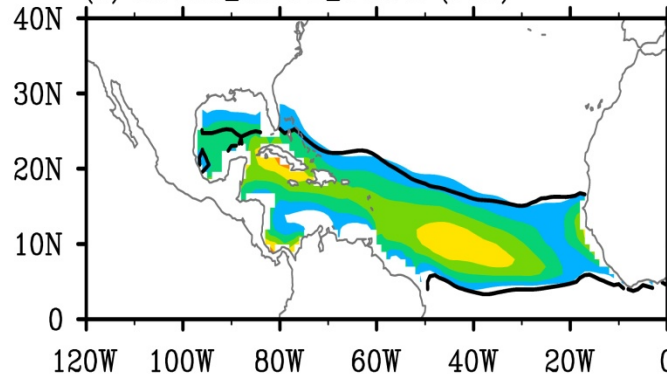
(b) HADISST (SON)



(c) HYCOM_NCEP1_CORE2 (JJA)



(d) HYCOM_NCEP1_CORE2 (SON)



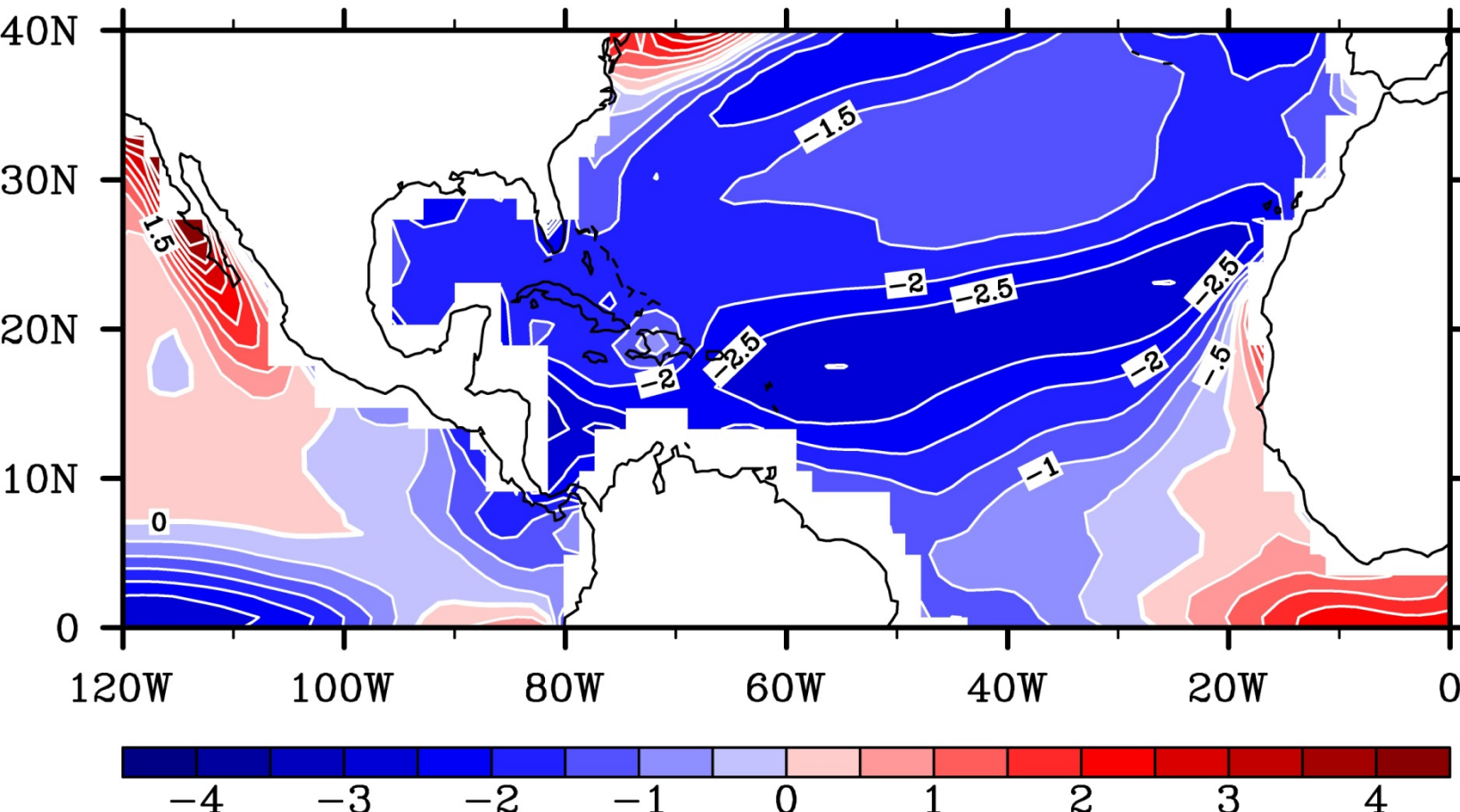
👉 When AML-HYCOM is forced with an optimal surface heat flux dataset, AWP is colder by 2degC

👉 Thus, the cold AWP bias is likely due to model deficiency inherent in HYCOM

EXP-1: AML-HYCOM_NCEP1_CORE2

It is not just HYCOM issue: Cold AWP SST bias is a known problem in fully coupled climate models

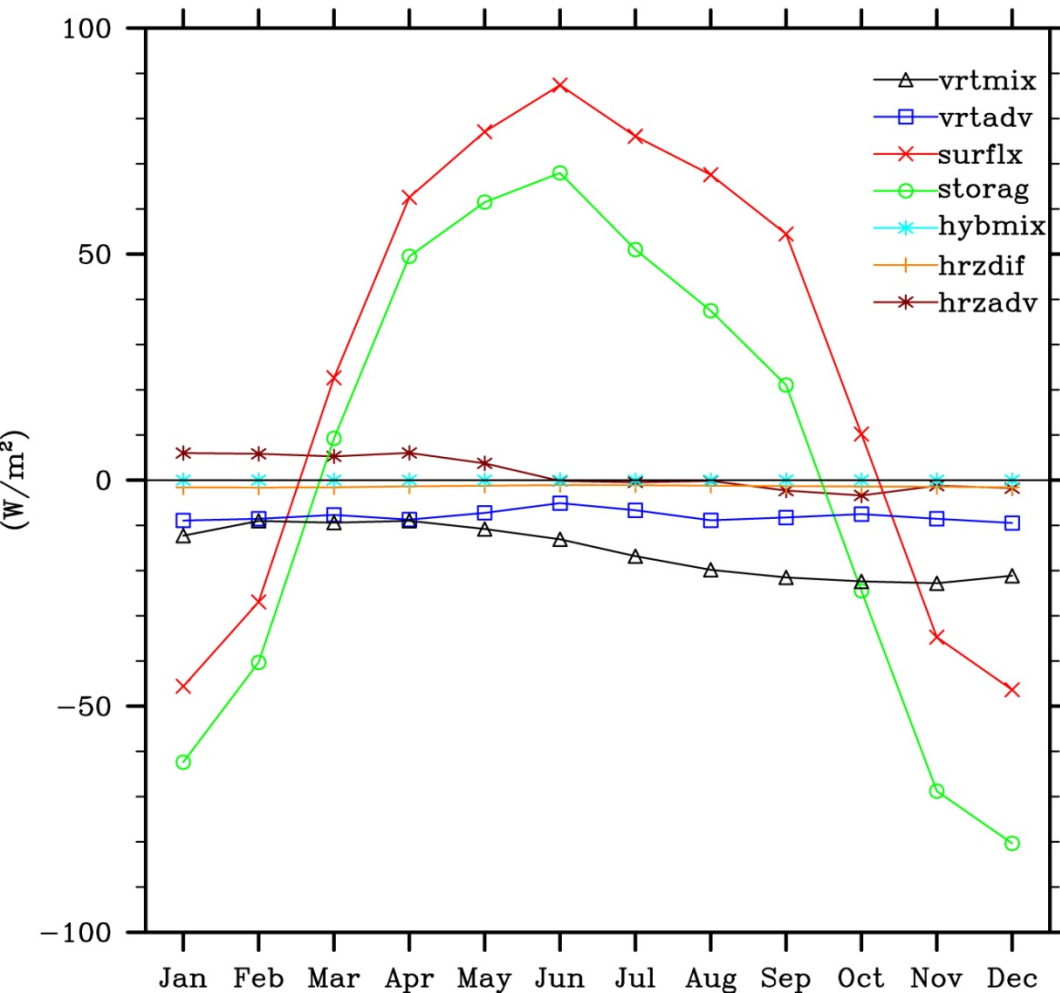
SST Bias in CCSM3 (JJA)



EXP-1: AML-HYCOM_NCEP1_CORE2

AWP mixed layer (upper 40m) heat budget for 2009

AWP Heat Budget for 2009



Heat budget terms are averaged over the AWP region (100W-40W; 5N-30N)

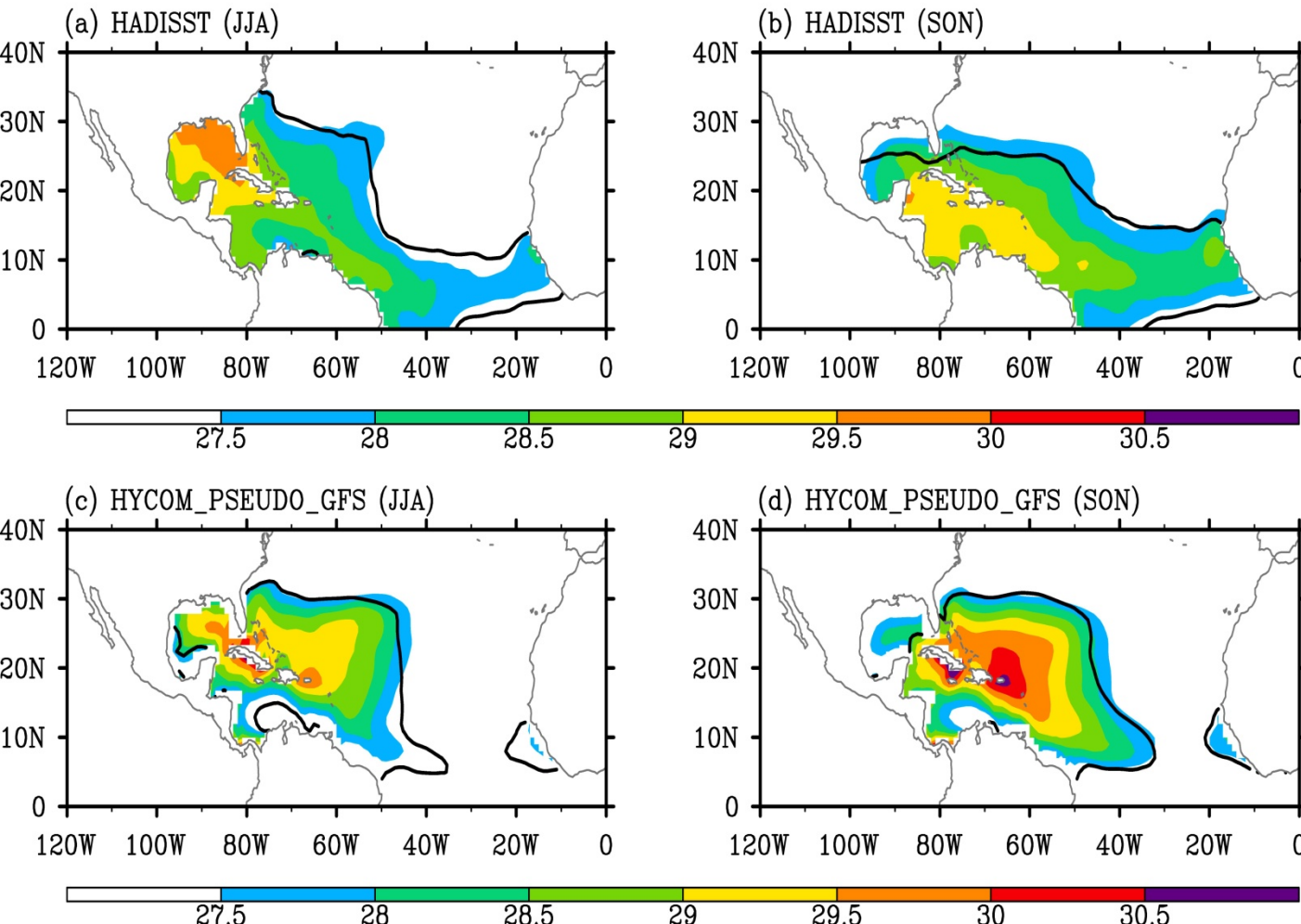
Vertical mixing and vertical advective heat flux are the only major cooling mechanisms

Thus, we can conclude that vertical mixing and vertical advective heat flux are too large in HYCOM

EXP-3: AML-HYCOM_PSEUDO_GFS

EXP-3: AWP SST is slightly warmer than observation

Atlantic Warm Pool SST in 2009



👉 GFS is very different from CORE2 surface flux dataset

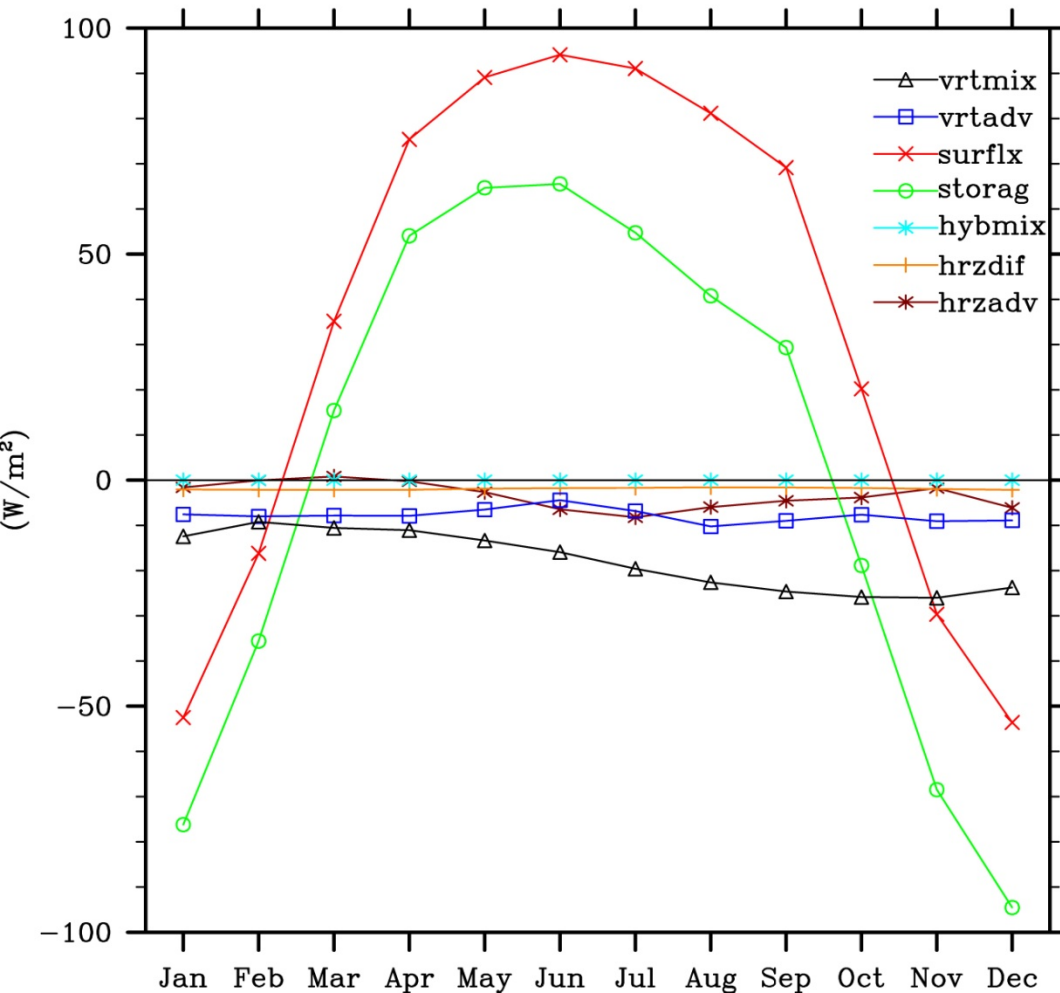
👉 This suggest a large bias in GFS surface flux dataset

👉 We are currently evaluating this case

EXP-3: AML-HYCOM_PSEUDO_GFS

AWP mixed layer (upper 40m) heat budget for 2009

AWP Heat Budget for 2009



Heat budget terms are averaged over the AWP region (100W-40W; 5N-30N)

Vertical mixing is even larger than in EXP-1

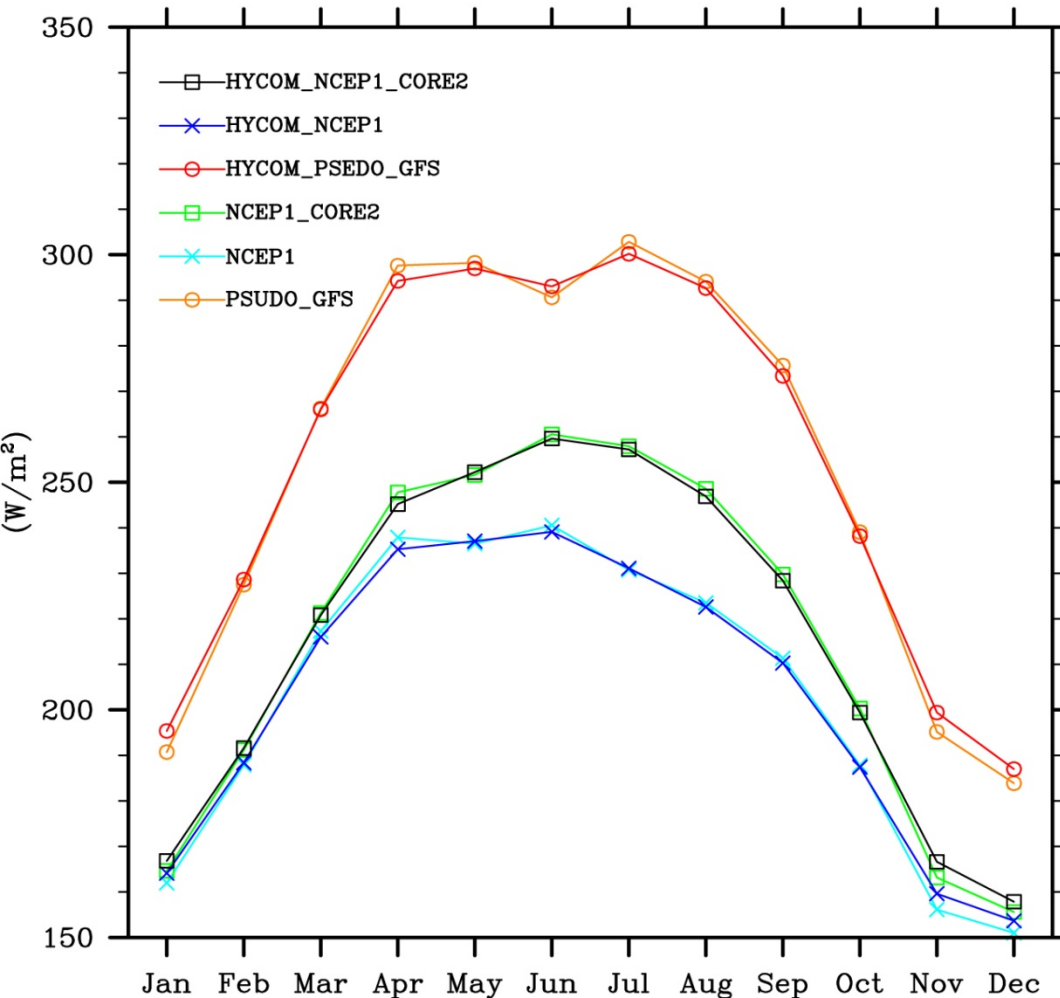
Q_{NET} is the only heating term

Thus, Q_{NET} is too large

Surface heat flux bias in GFS

AWP surface shortwave heat flux for 2009 suggests that GFS is not OK

AWP Surface Shortwave Heat Flux for 2009



➔ When compared to CORE2, GFS add up to $50\text{W}\cdot\text{m}^{-2}$ of extra shortwave radiative heat into the AWP region

➔ This means that Q_{SWR} is the main cause of the warm bias in EXP-3

➔ Excessive Q_{SWR} overcompensates the excessive cooling inherent in HYCOM associated with vertical mixing

Accomplishments, conclusions and future works

👉 Accomplishments:

- 1) HYCOM is coupled to AML to properly diagnose and improve AWP simulation in HYCOM-based RTOFS at NCEP/EMC
- 2) Three sets of surface flux datasets were prepared and used to carry out preliminary low-resolution AML-HYCOM experiments

👉 Preliminary Conclusions:

- 1) When forced with an optimized surface flux dataset, AML-HYCOM produces a cold AWP SST bias of $\sim 2\text{degC}$ due to excessive vertical mixing, which is a bias inherent in HYCOM
- 2) It appears that GFS surface flux datasets put excessive shortwave heat flux into the AWP region of AML-HYCOM (We are currently evaluating this case)

👉 Future works:

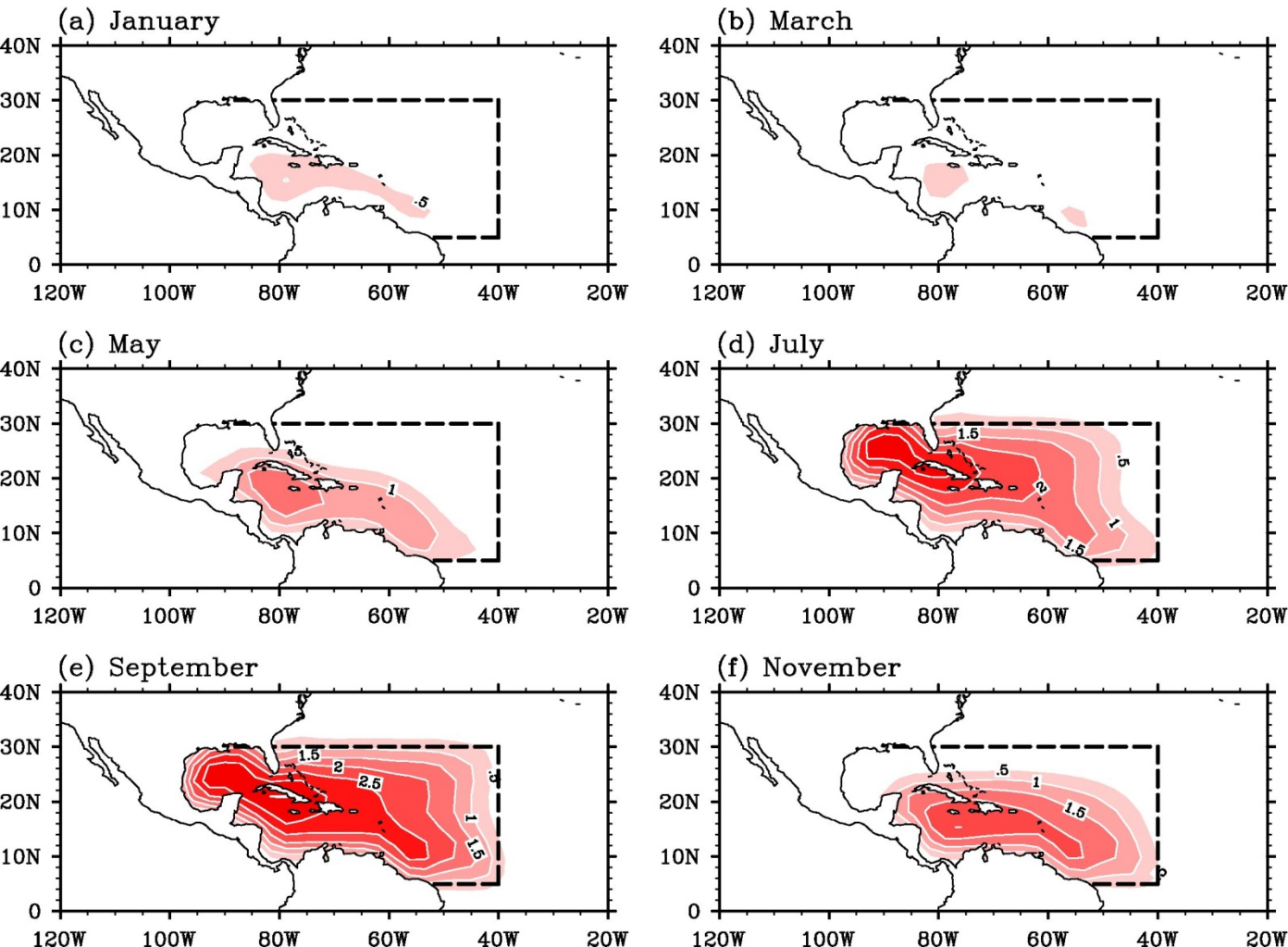
- 1) All three preliminary experiments will be repeated with RTOFS using NCEP/EMC computer resources
- 2) AML will be fine-tuned
- 3) Bias correction strategy will be explored

Supplementary Materials

Why is AWP Important for Atlantic hurricanes?

NCAR Community Atmospheric Model (CAM3) Experiment

SST forcing difference (CTRL - NO_AWP)



➡ Performed two ensemble experiments using CAM3

➡ CTRL run: CAM3 is forced using observed SST

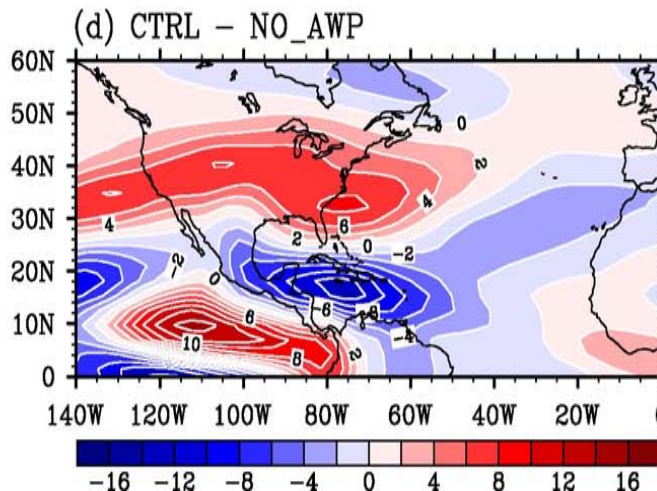
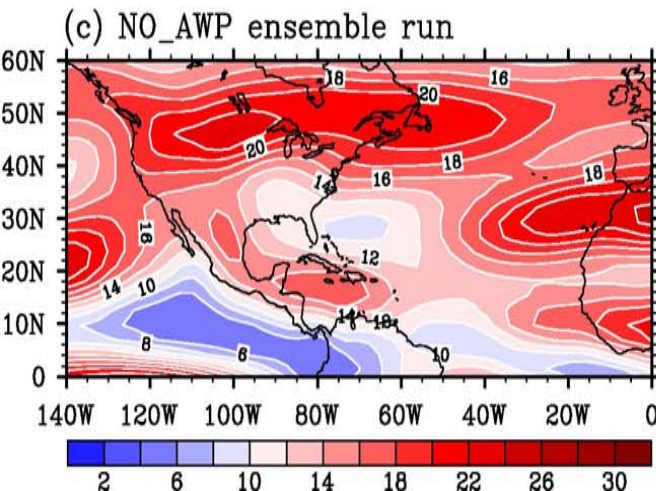
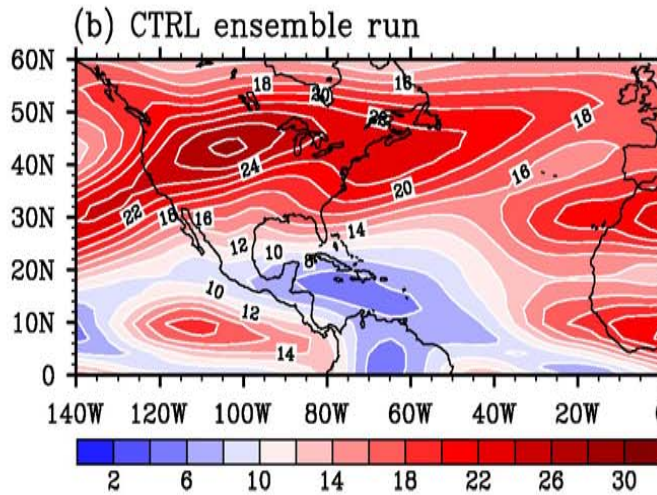
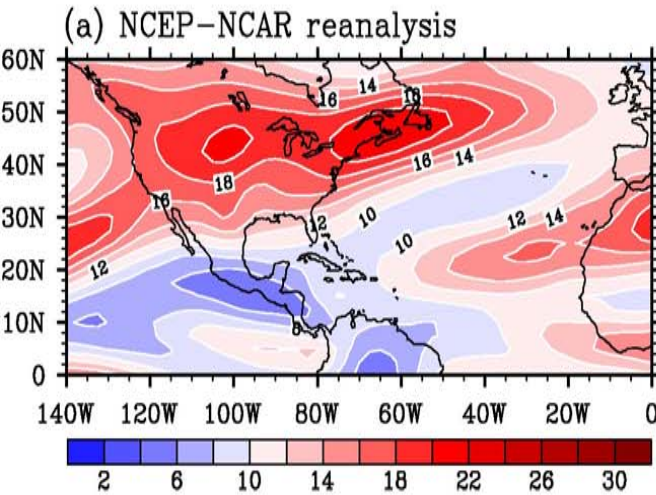
➡ NO_AWP run: AWP is removed from SST data (max SST = 26degC)

➡ Wang and Lee (2007 GRL); Wang, Enfield and Lee (2007 JCL)

What is Atlantic Warm Pool (AWP)?

NCAR Community Atmospheric Model (CAM3) Experiment

Vertical Wind Shear (ASO)



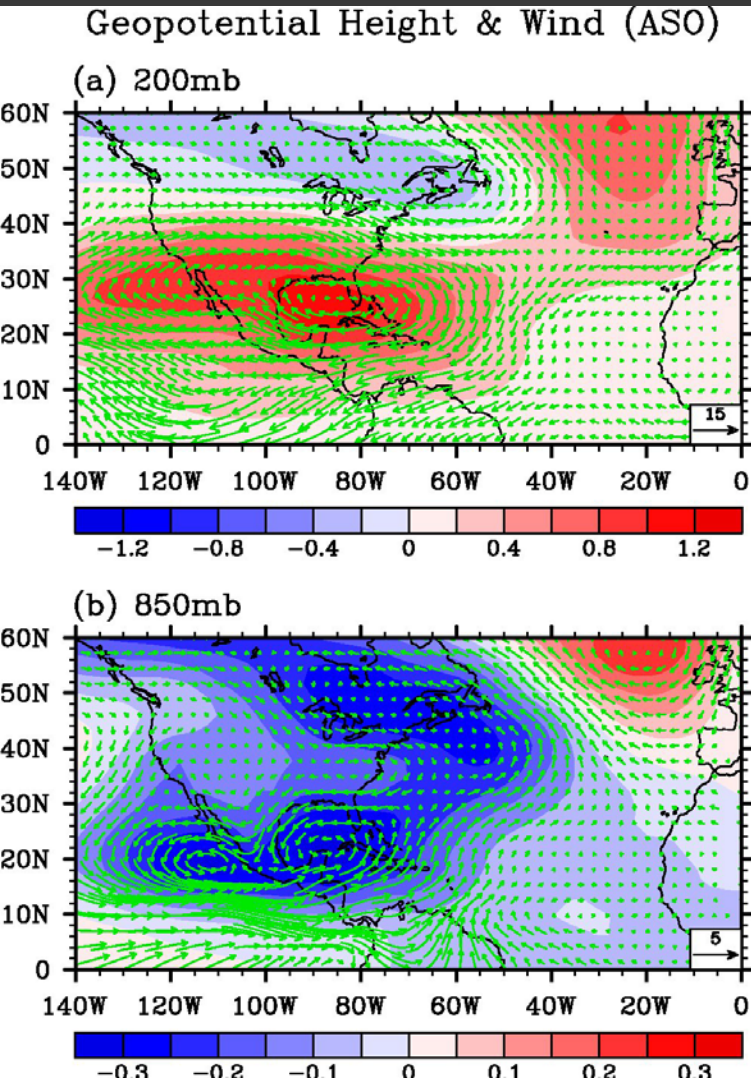
➡ AWP reduces vertical wind shear (200 minus 850mb)

➡ Thus, AWP increases tropical storm formation & intensification

➡ Why?

What is Atlantic Warm Pool (AWP)?

NCAR Community Atmospheric Model (CAM3) Experiment

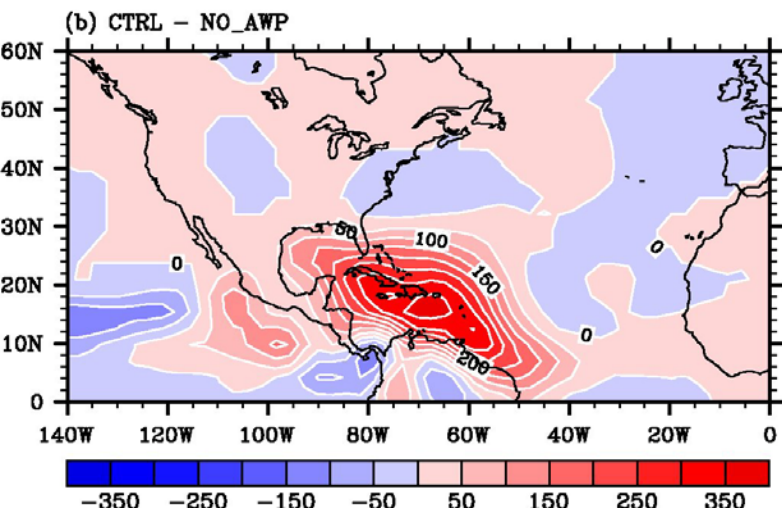
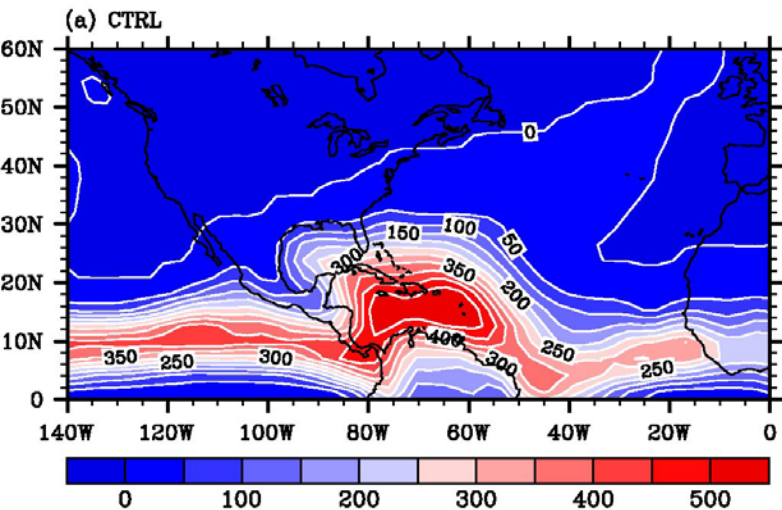


- ➔ AWP induces an anti-cyclone in the upper troposphere and a cyclone in the lower troposphere
- ➔ The atmospheric wind anomalies reduce the zonal wind in both the upper and lower troposphere over the MDR
- ➔ MDR vertical wind shear is reduced as a result
- ➔ AWP-induced wind changes can be explained by using the simple model of Gill (1980)

What is Atlantic Warm Pool (AWP)?

NCAR Community Atmospheric Model (CAM3) Experiment

Convective Available Potential Energy (JJASON)



- ☞ Convective Available Potential Energy (CAPE) is a measure of the static instability of the troposphere
- ☞ CAPE is related to the maximum intensity of which a tropical storm can achieve
- ☞ AWP increases the CAPE in MDR thus more intense storms can form and develop

How do we measure the performance of HYCOM in simulating AWP?

☞ **Surface flux datasets: how reliable are they?**

1) Taylor (2000): “There is currently no one flux climatology which does not exhibit significant errors in one region or another in each of the various flux components”

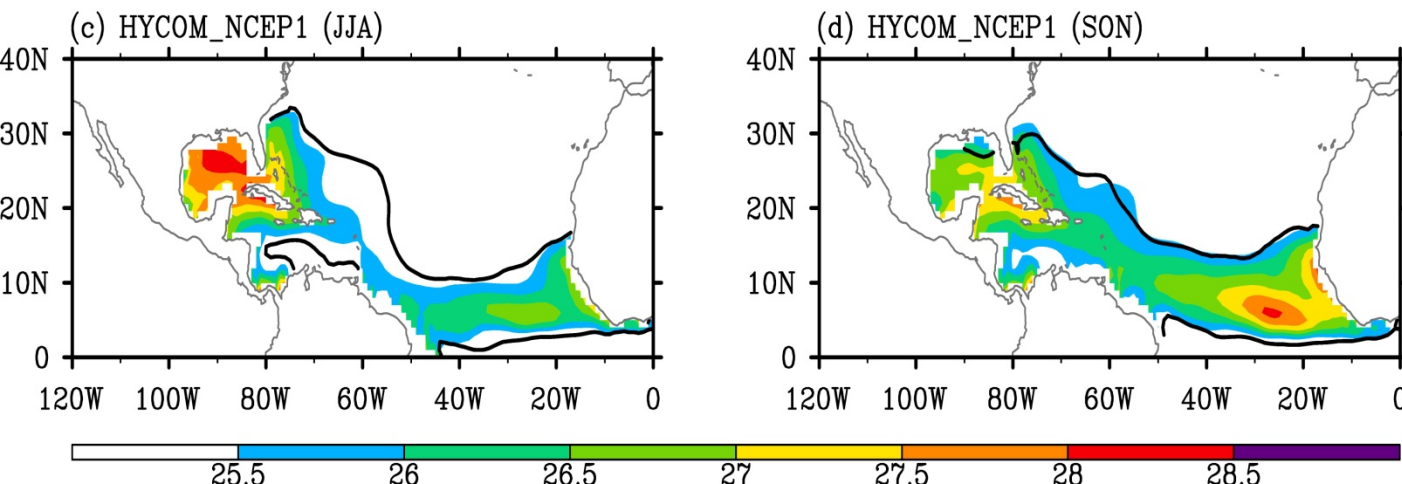
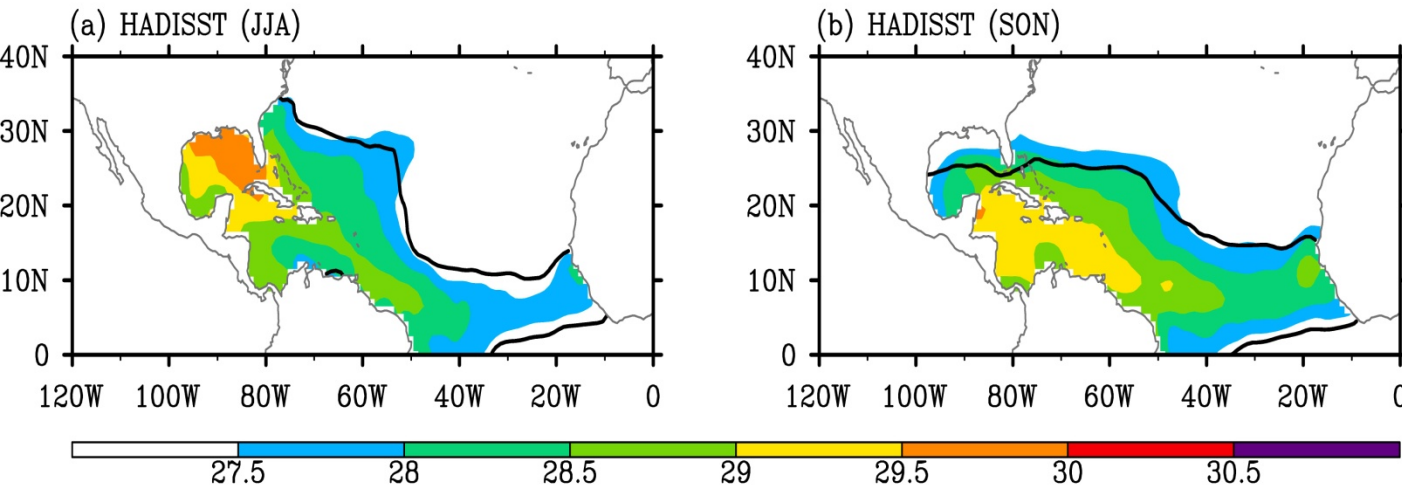
2) Enfield and Lee (2005) : “The magnitude of surface net heat flux into the AWP varies by as much as $100 \text{ W}\cdot\text{m}^{-2}$ among eight commonly used surface flux climatologies”

3) Lee, Enfield and Wang (2005): HYCOM simulated AWP SST varies by 2degC when HYCOM is forced with the eight surface flux climatologies

EXPERIMENT-2: AML-HYCOM_NCEP1

EXP-2 (AML-HYCOM_NCEP1): AWP SST is colder than observation by 2degC

Atlantic Warm Pool SST in 2009



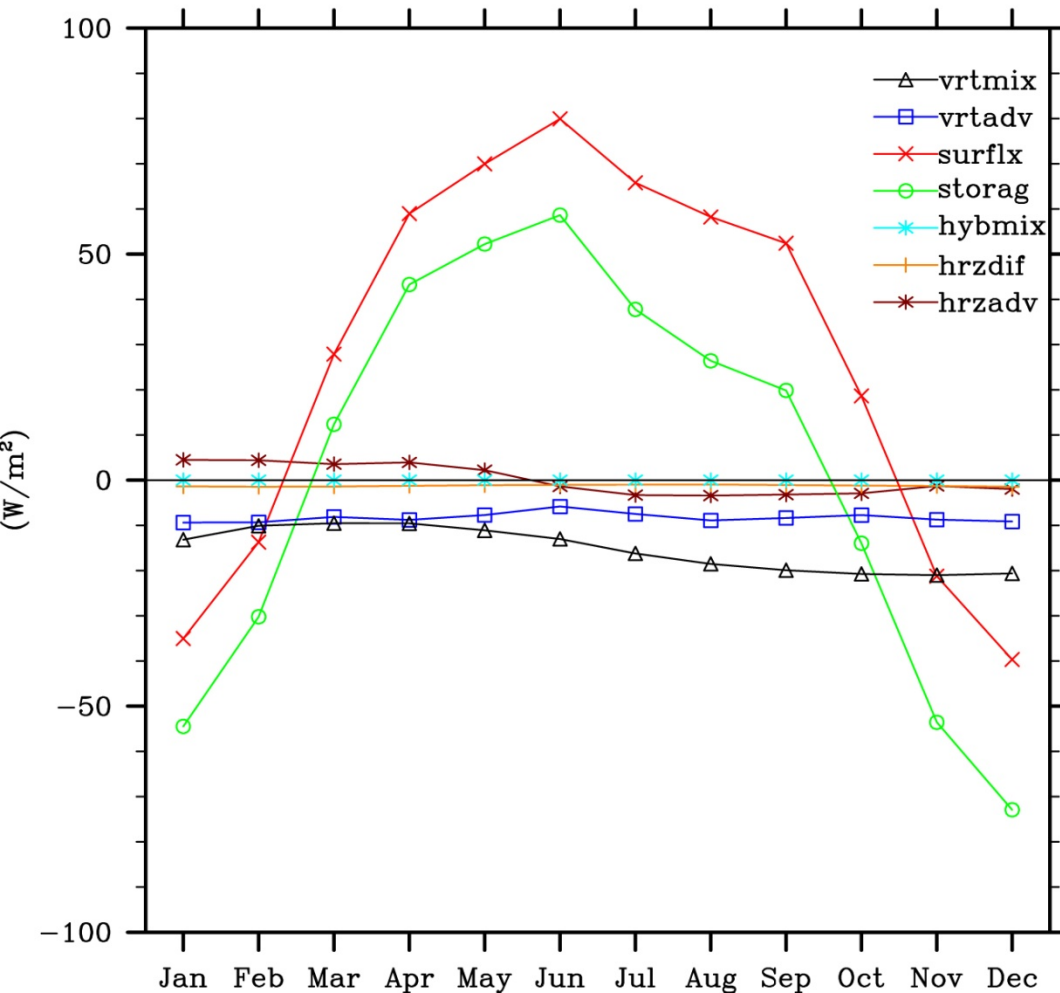
☞ **Advective cooling related to coastal upwelling in the Southern Caribbean Sea is too large**

☞ **In SON, AWP center is shifted too far east**

EXPERIMENT-2: AML-HYCOM_NCEP1

AWP mixed layer (upper 40m) heat budget for 2009

AWP Heat Budget for 2009



➡ Heat budget terms are averaged over the AWP region (100W-40W; 5N-30N)

➡ Vertical mixing may be too large

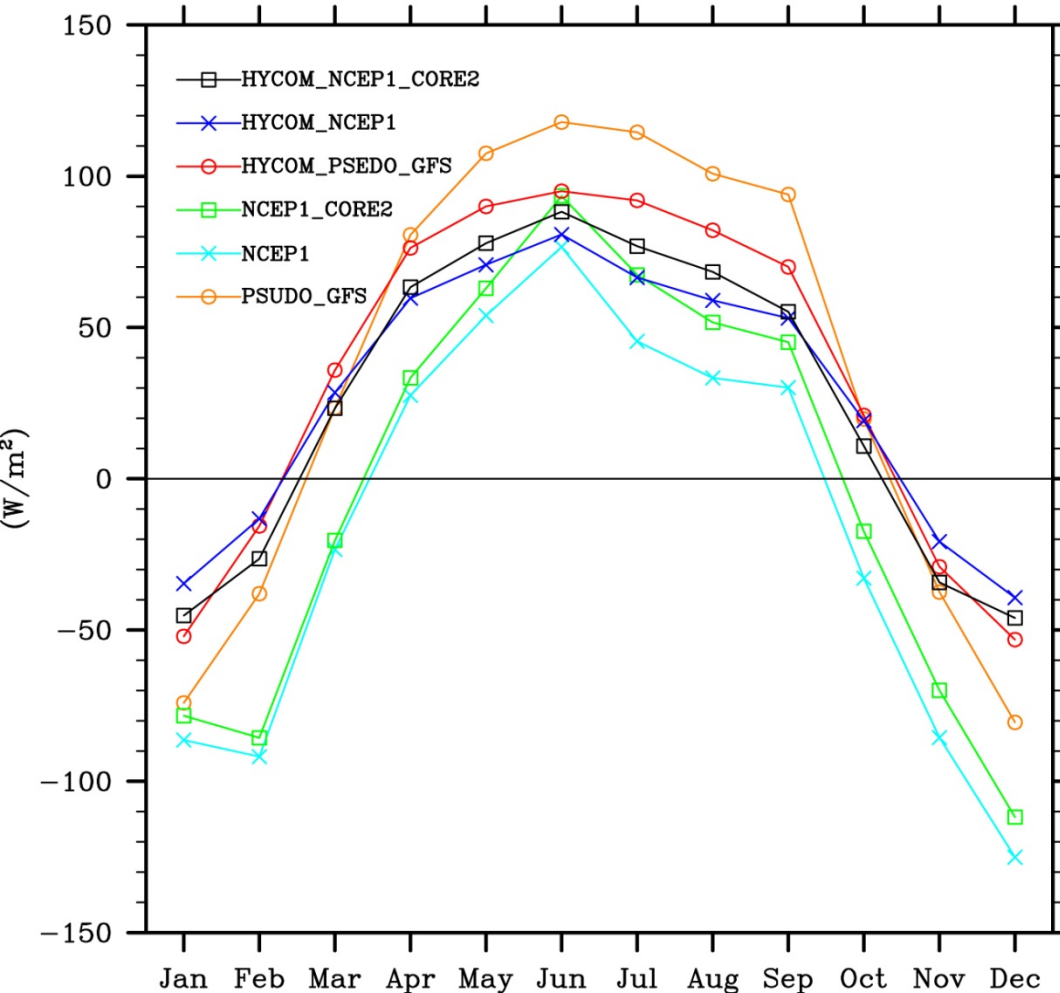
➡ Vertical advective heat flux divergence may be too large

➡ Perhaps, KPP mixing scheme is not effective over AWP region?

Surface heat flux bias in GFS

AWP surface net heat flux for 2009 suggests that GFS is biased

AWP Surface Net Heat Flux for 2009



➔ When compared to CORE2, GFS add up to $50\text{W}\cdot\text{m}^{-2}$ of extra heat into the AWP region

➔ In all three experiments, the surface net heat flux into AWP is too high

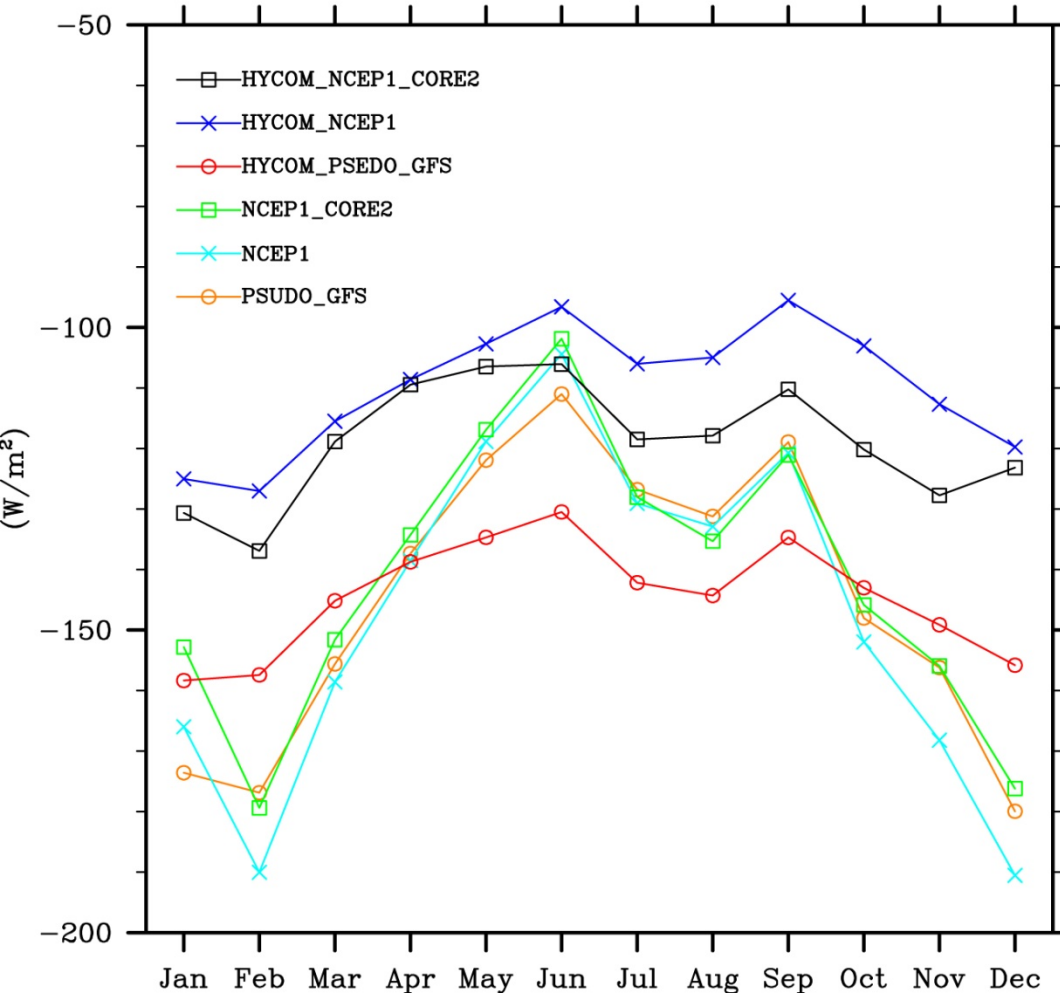
➔ In EXP-1 and -2, it is due to the cold bias and associated reduction in model Q_{LHF}

➔ Fixing HYCOM will cure this problem, but not for EXP-3

Surface heat flux bias in GFS

AWP surface latent heat flux for 2009 suggests that GFS is OK

AWP Surface Latent Heat Flux for 2009



➡ Q_{LHF} of GFS is very close to CORE2

➡ In EXP-1 and -2, Q_{LHF} is too small

➡ This is caused by the cold bias inherent in HYCOM

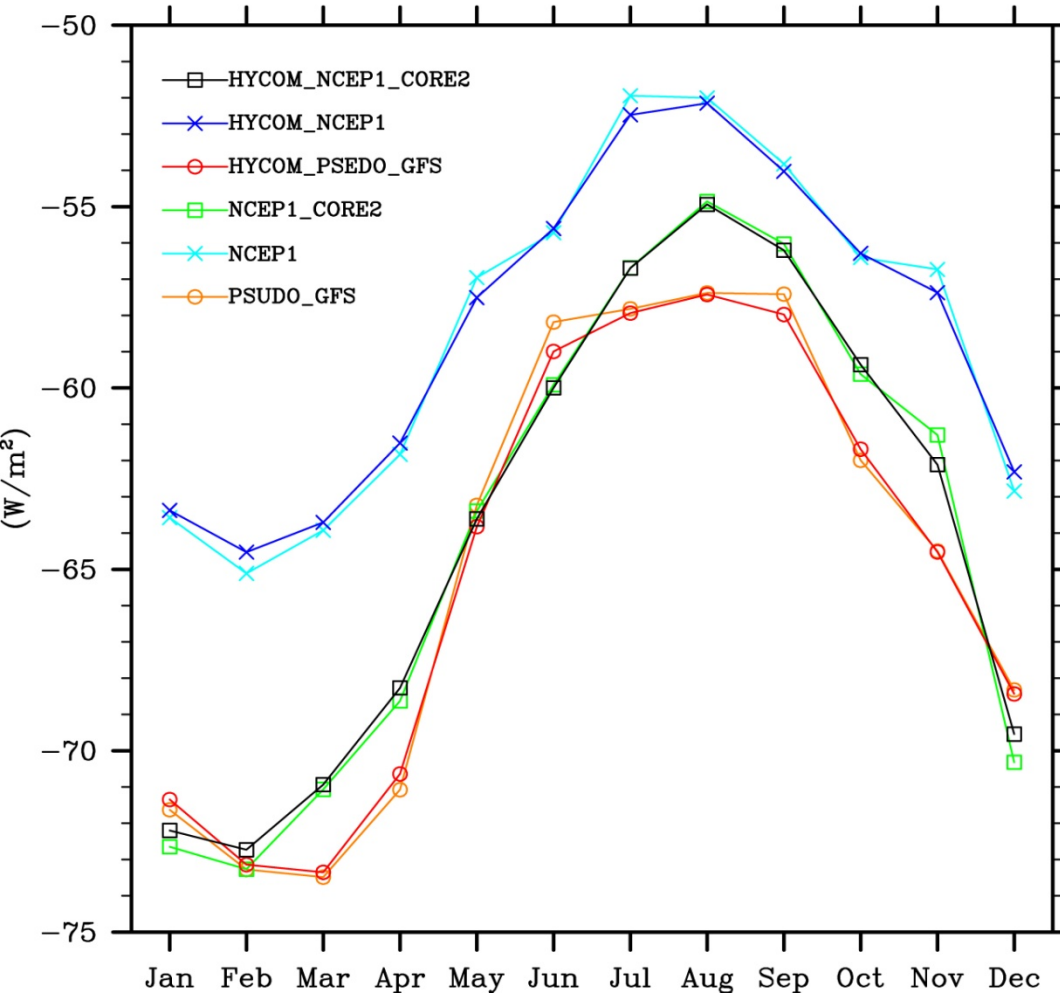
➡ Q_{LHF} of EXP-3 is too large because the warm bias

➡ This means that Q_{LHF} does not cause the warm bias in EXP-3

Surface heat flux bias in GFS

AWP surface longwave heat flux for 2009 suggests that GFS is OK

AWP Surface Longwave Heat Flux for 2009



☞ Q_{LWR} of GFS is very close to CORE2

☞ This means that Q_{LWR} does not cause the warm bias in EXP-3