Simulation of the Atlantic Warm Pool in the Hybrid-Coordinate Ocean Model (HYCOM)

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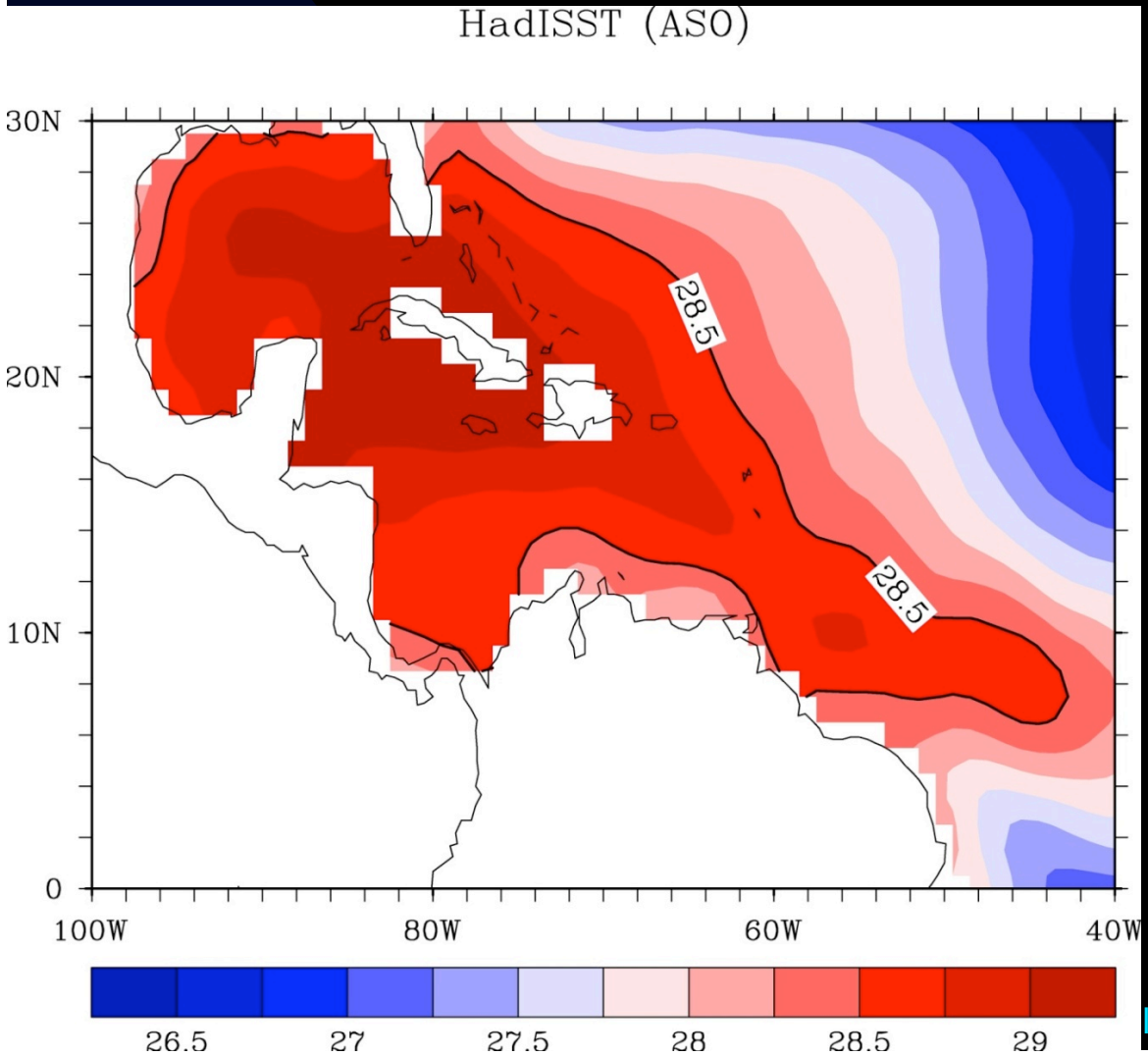
National Oceanic & Atmospheric Administration

Outline

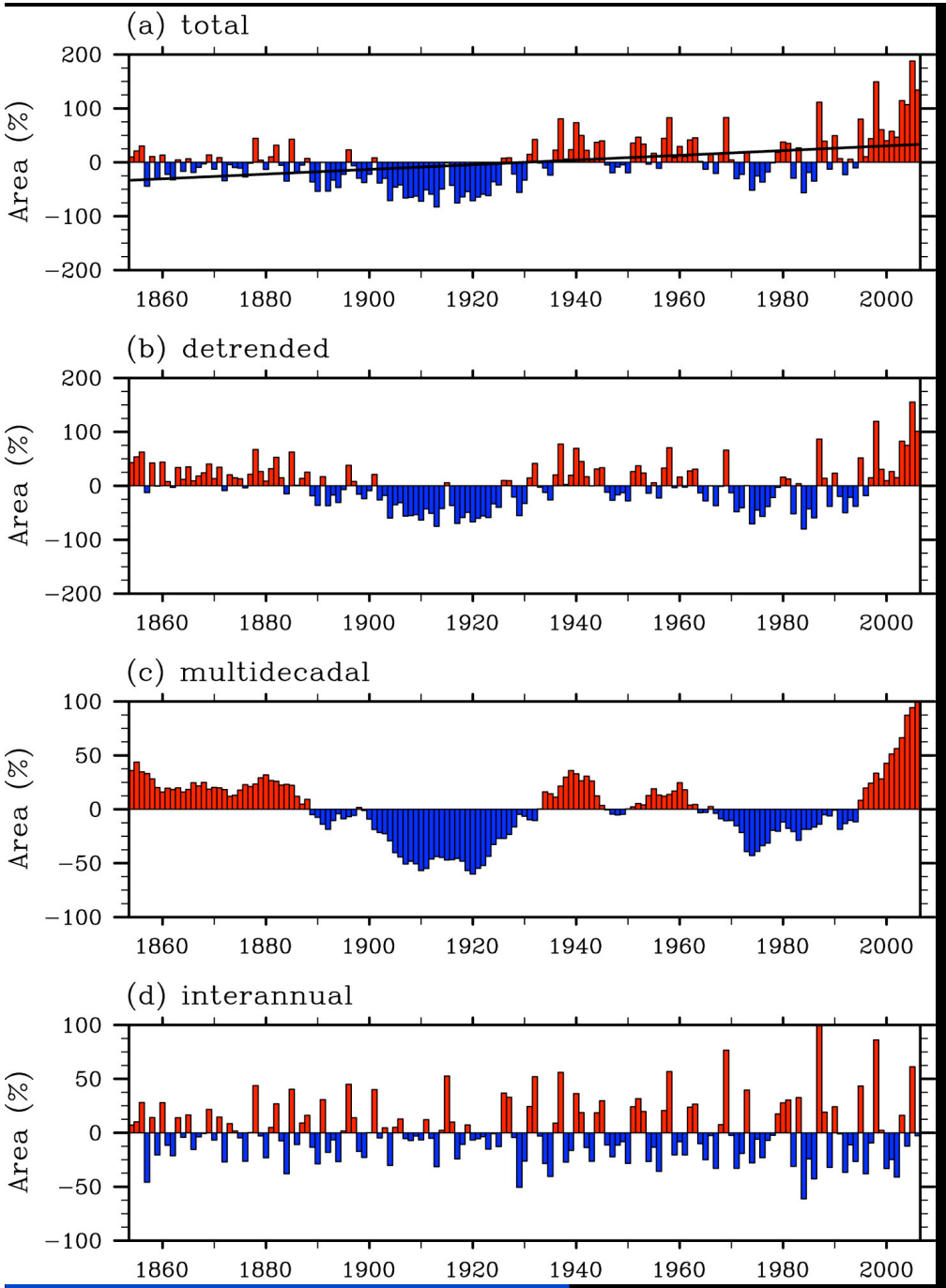
- What is the Atlantic warm pool (AWP).
- Why is AWP important (hurricanes, flood/drought & tornado)?
- JHT project: diagnose and improve AWP simulation in HYCOM-based RTOFS (Real-Time Ocean Forecasting System) at NCEP/EMC.
- How do we measure the performance of HYCOM in simulating the AWP?
- AWP bias inherent in HYCOM.
- AWP bias associated with GFS (Global Forecast System) surface flux fields.
- Accomplishments, conclusions and future work.

What is the Atlantic Warm Pool (AWP)?

AWP SST during August-September-October



- AWP is a body of warm water (≥28.5°C) in the Gulf of Mexico, the Caribbean Sea, and the western TNA.
- AWP appears in boreal summer and fall, and disappears in other seasons.
- AWP is the path of or a birthplace of TCs.
- Wang and Enfield (2001, *GRL*).

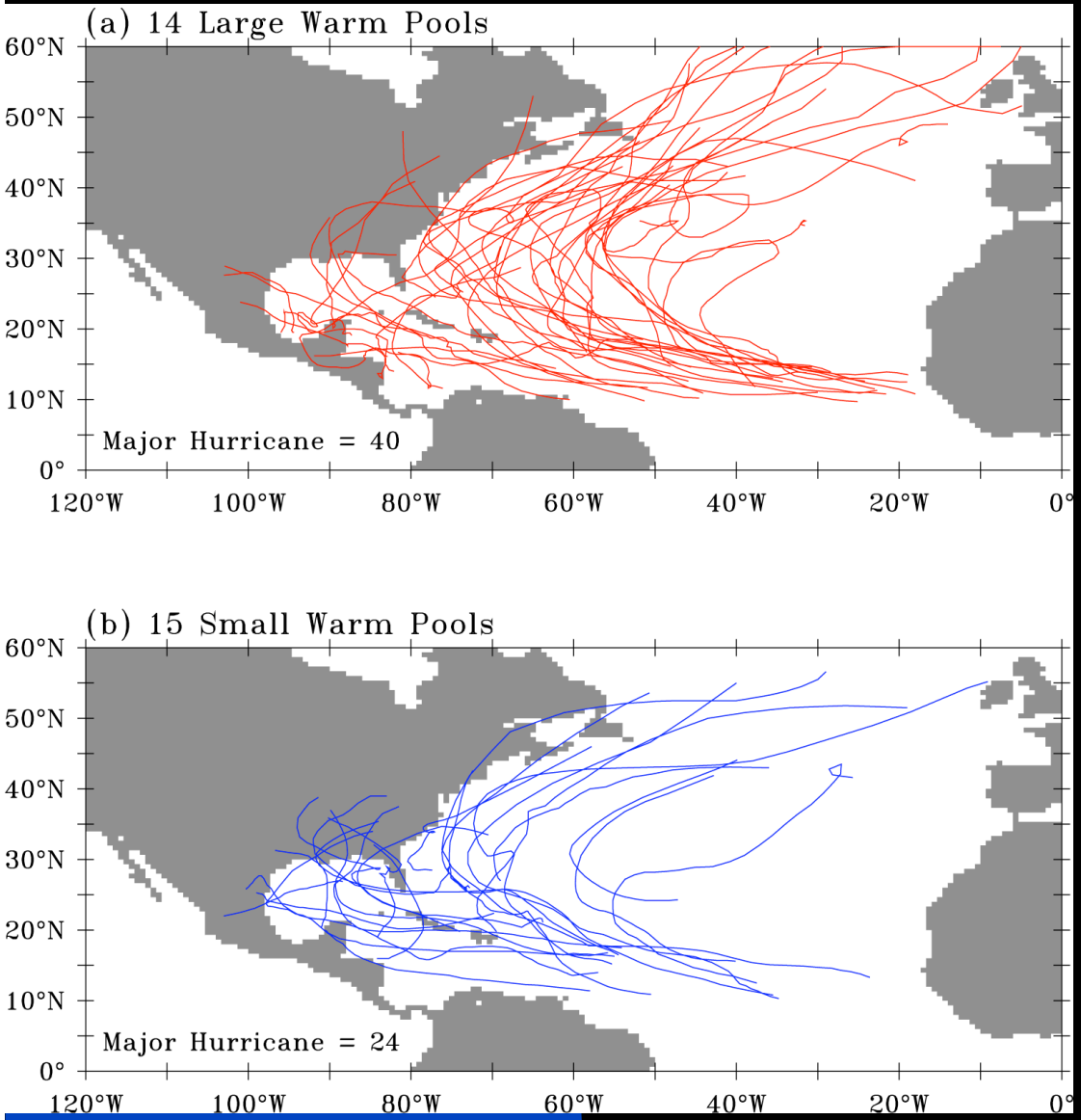


AWP (SST ≥ 28.5°C) area anomaly indices during June-November

In additional to seasonal cycle, AWP also shows multiscale variability: interannual, multidecadal, and linear warming trend variations.

Wang et al. (2008, G^3)

Why is the AWP important for Atlantic hurricanes?

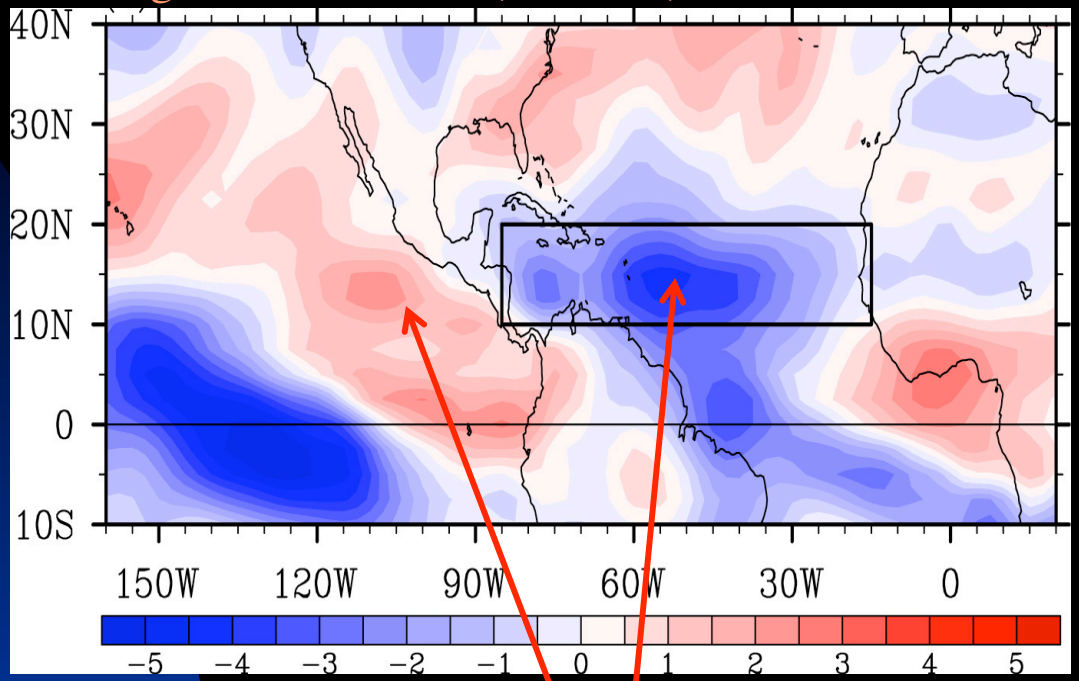


- AWP is significantly correlated with TC indices: COR(TC, AWP) = 0.51.
- Large AWPs provide favorable environment for TC formation & intensification by reducing vertical wind shear and increasing the convective available potential energy in the MDR.
- AWP also affects North Atlantic subtropical high, thus it may influence TC tracks.
- Thus, it is important to properly simulate AWP in hurricane forecast models.

Wang, Enfield, Lee & Landsea (2006, *JCL*)

AWP variability can induce the opposite vertical wind shear (VWS) in N. Atlantic (NA) and eastern North Pacific (ENP).

Regression of VWS (Jun-Nov) onto AWP index

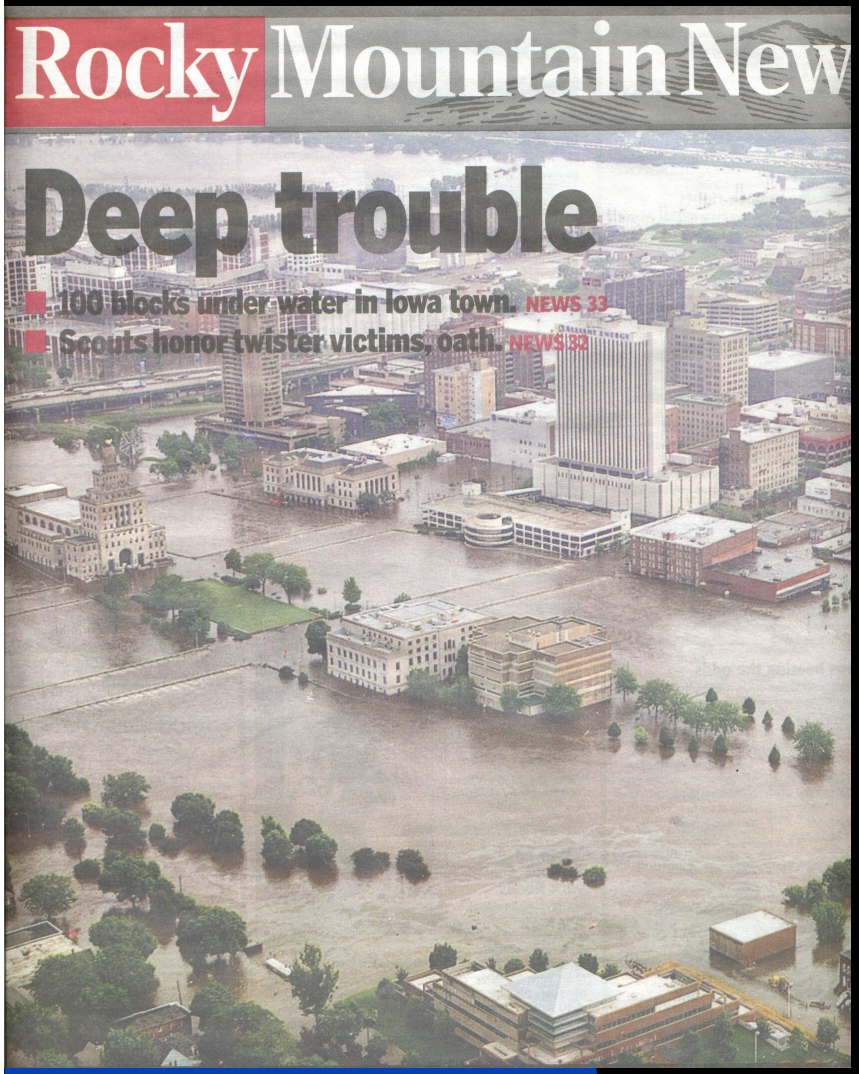


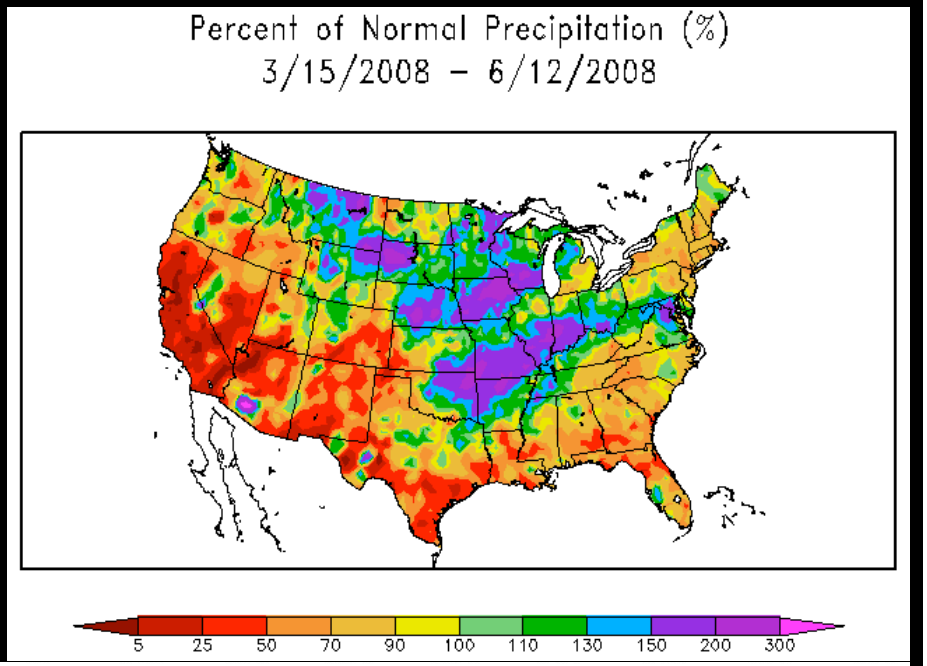
Opposite VWS in NA and ENP

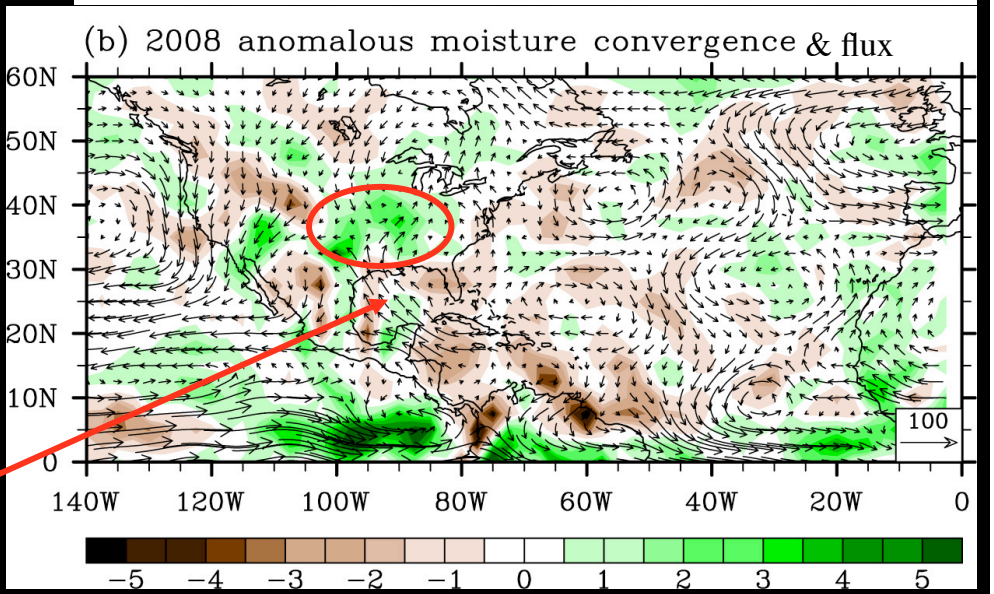
Large (small) AWPs => Low (high) shear in NA => More (less) NA TCs.

Large (small) AWPs => High (low) shear in ENP => Less (more) ENP TCs.

Midwest Extreme Flood in Spring 2008 & Moisture Transport from AWP





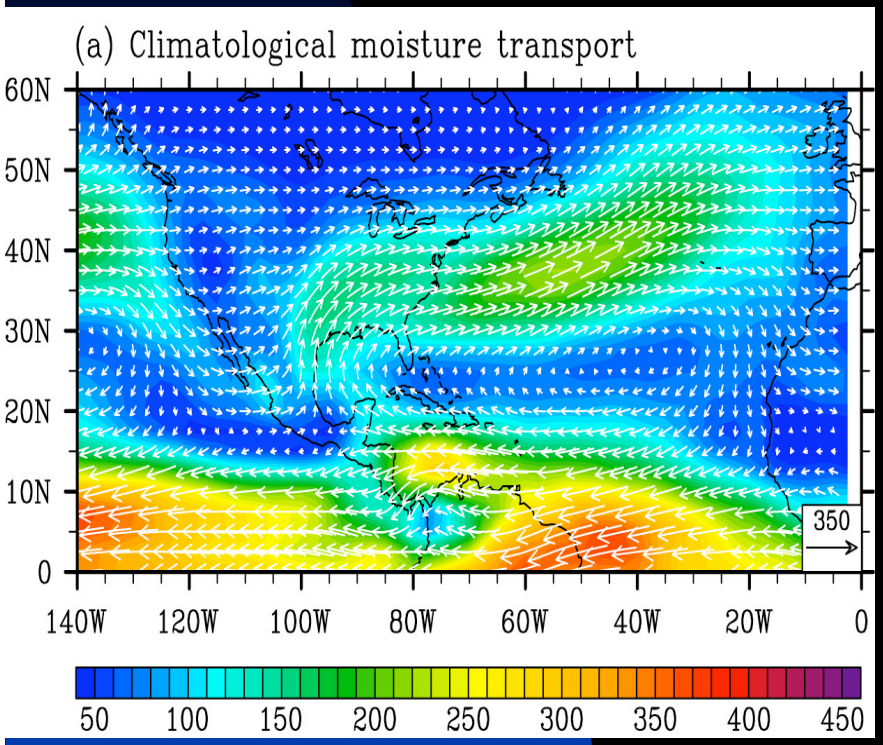


Moisture transport from the AWP

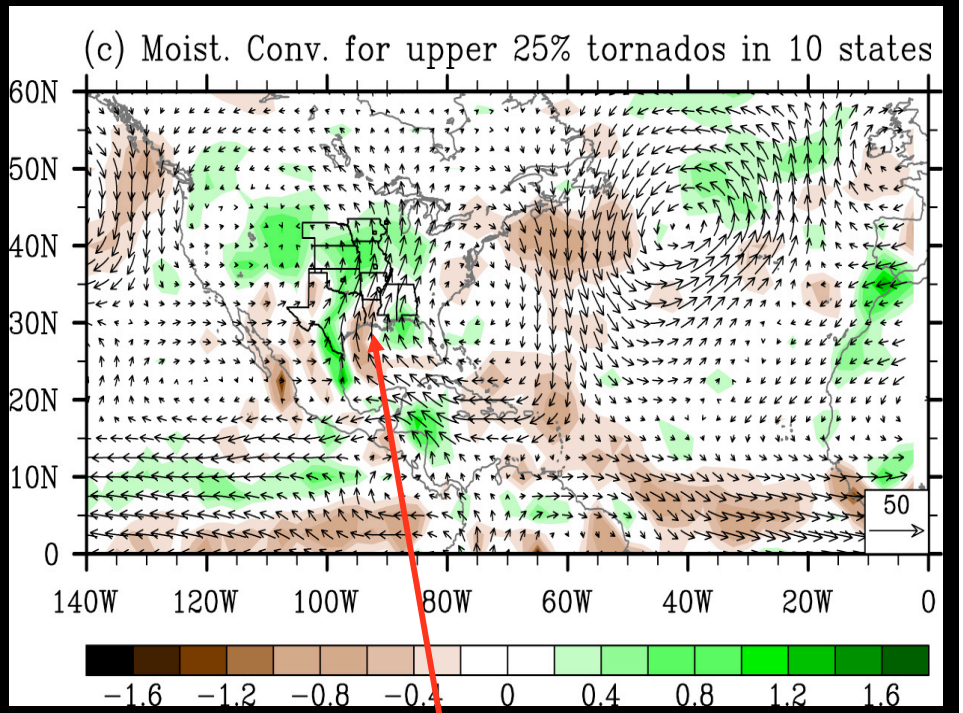
NOAA Atlantic Oceanographic & Meteorological Laboratory

Tornado Activity in Midwest & Moisture Transport from the AWP

March to May (MAM) of 1950-2007



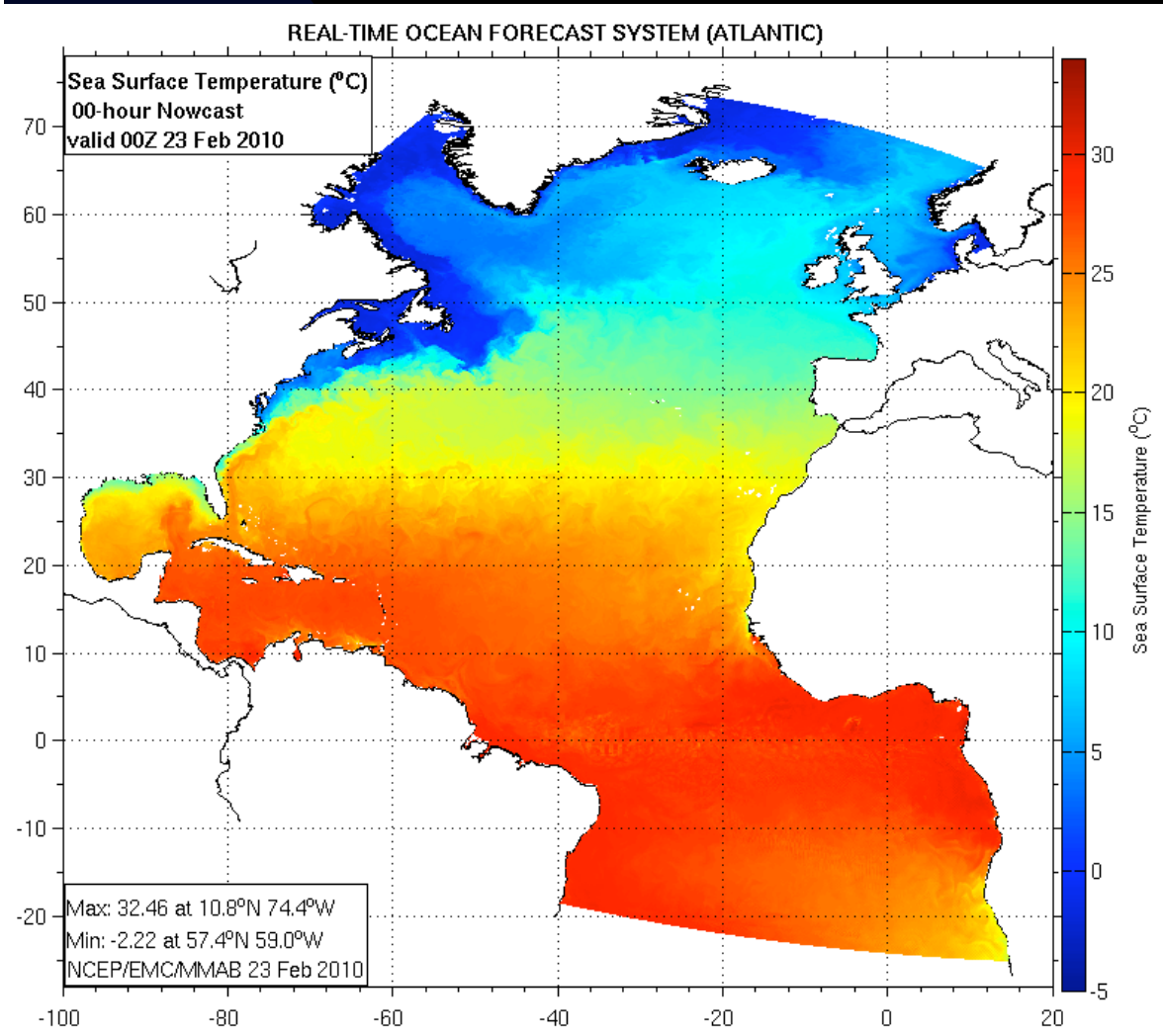
Composites of anomalous moisture transport & conv.
for upper quartile of March-June tornados in Midwest



Moisture transport from the AWP

JHT project: diagnose and improve AWP simulation in RTOFS

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



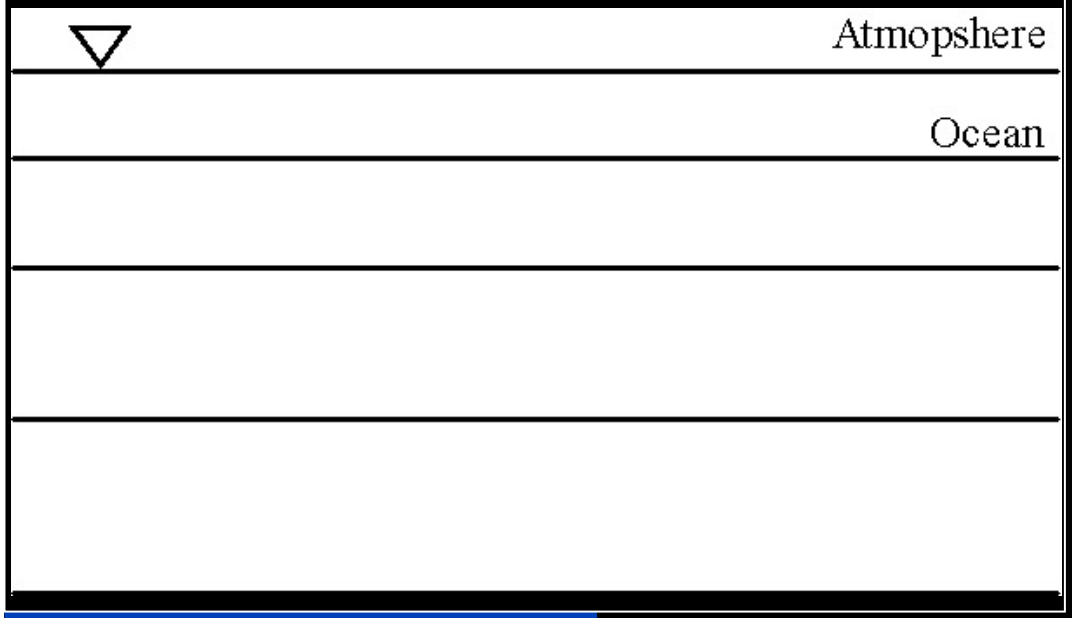
- RTOFS provides initial and boundary conditions for HWRF-HYCOM, which is an experimental hurricane forecast system at NCEP/EMC.
- Both RTOFS and HWRF-HYCOM are based on HYCOM.
- Thus, it is important to evaluate how well HYCOM simulates the AWP.

gical Laboratory

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

HYCOM uses a conventional bulk formula at the air-sea interface (latent & sensible flux)

q_{10}, T_{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 SST error is dumped into Q_{LHF} and Q_{SHF}.
- Thermodynamic inconsistency at the air-sea interface may cause problems if HYCOM is coupled to HWRF.

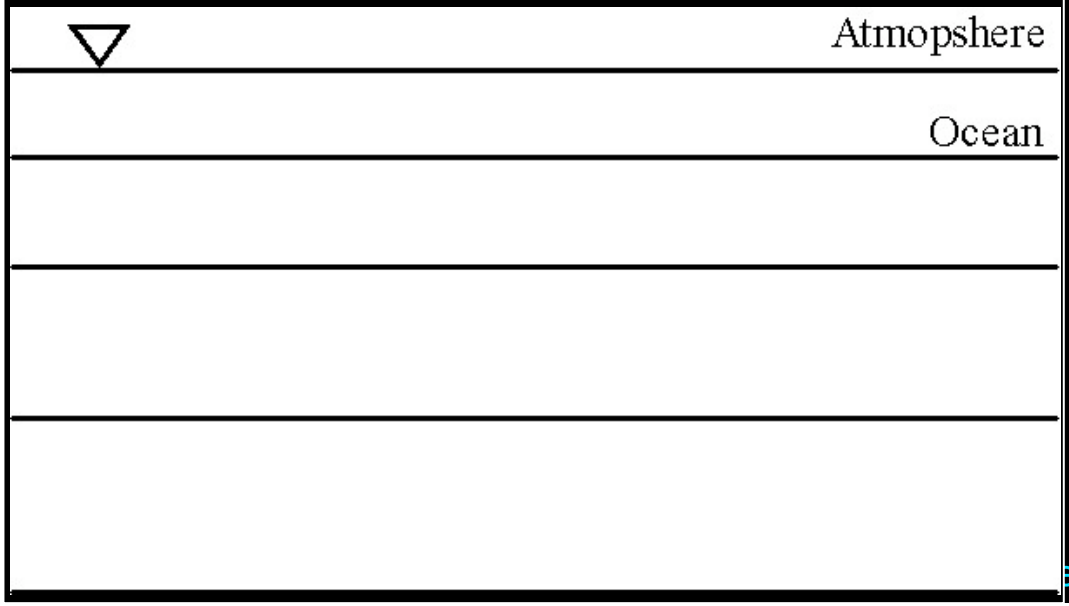
How do we measure the performance of HYCOM in simulating the AWP?

Atmospheric mixed layer (AML) model is coupled to HYCOM

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

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

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



- 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 the AWP?

Optimal surface flux dataset:

- Global flux dataset of Large and Yeager (2008) provides a complete set of bias-corrected surface flux for CORE2 (Coordinated Ocean Research Experiments version 2) program.

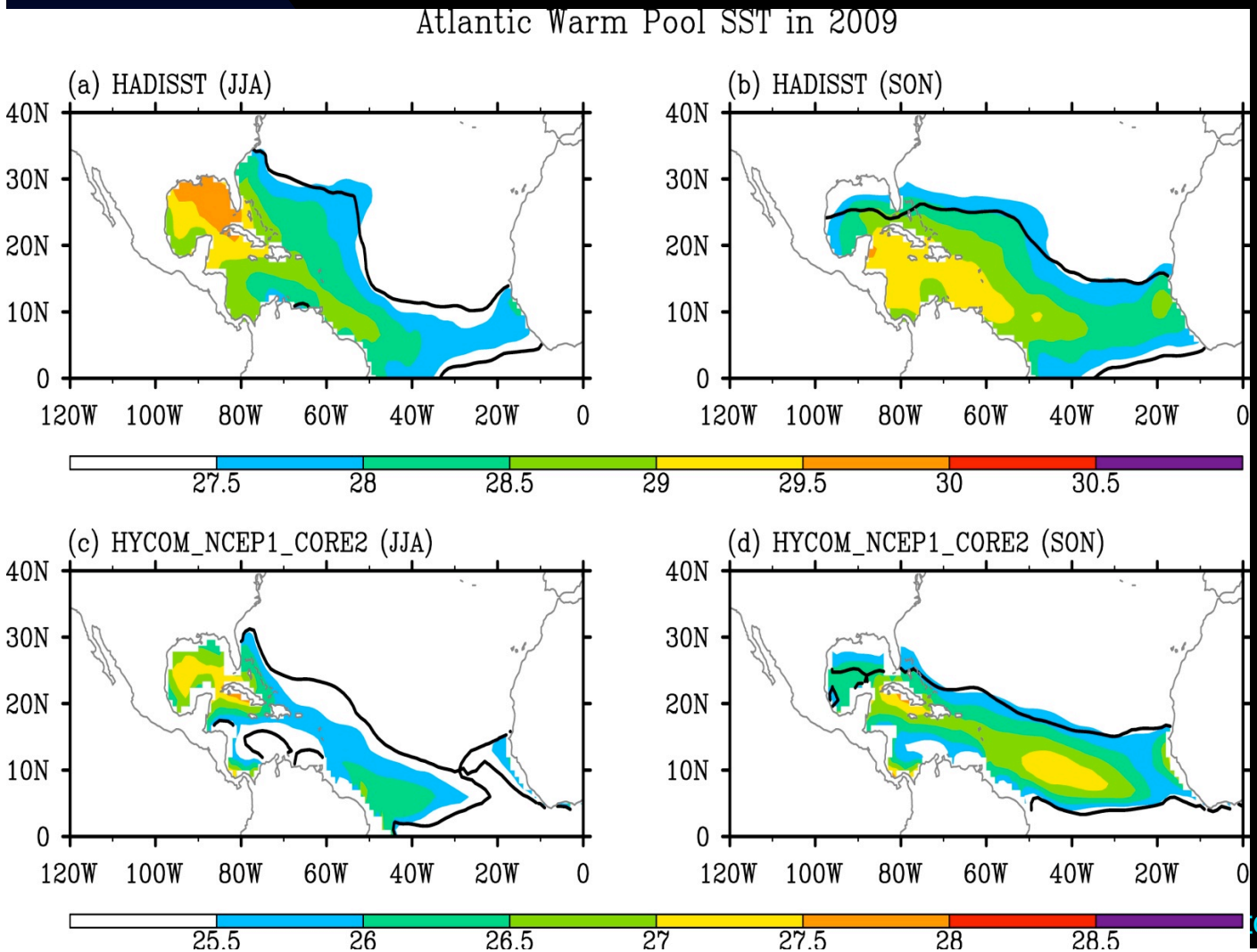
- CORE2 flux dataset is used as the optimal flux dataset to force HYCOM in this study.

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 dataset 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).

EXP-1: AML-HYCOM_NCEP1_CORE2

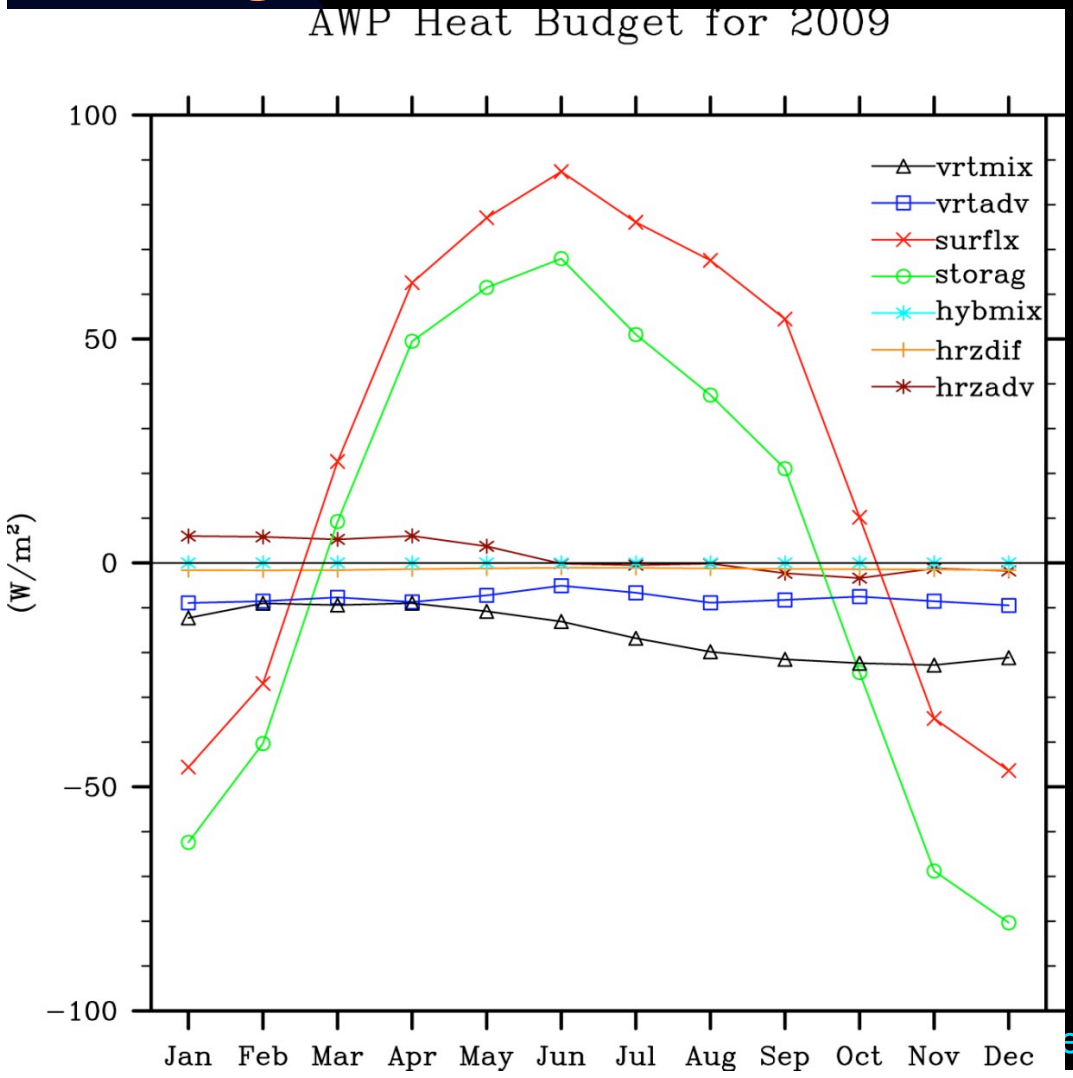
EXP-1: AWP SST is colder than observation by more than 2°C.



- When AML-HYCOM is forced with an optimal surface heat flux dataset, AWP is colder by 2°C.
- Thus, the cold AWP bias is likely due to model deficiency inherent in HYCOM.
- Black contours: 2008 isotherms.

EXP-1: AML-HYCOM_NCEP1_CORE2

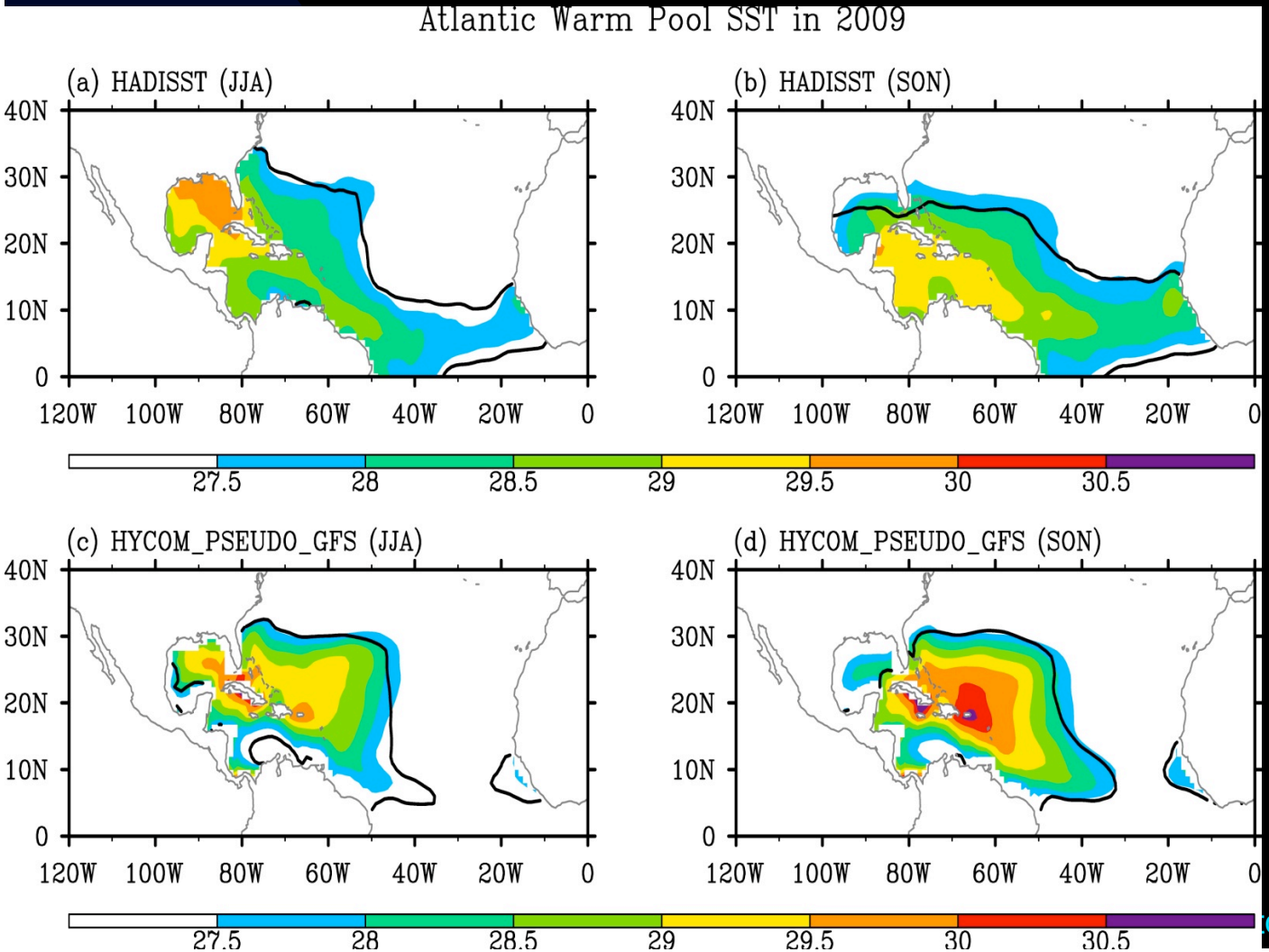
AWP mixed layer (upper 40m) ocean heat budget for 2009



- Heat budget terms are averaged over the AWP region (100°W-40°W, 5°N-30°N).
- Vertical mixing and vertical advective heat flux are the only major cooling mechanisms.
- We can conclude that vertical mixing and vertical advective heat flux are too large in HYCOM.

EXP-3: AML-HYCOM_PSEUDO_GFS

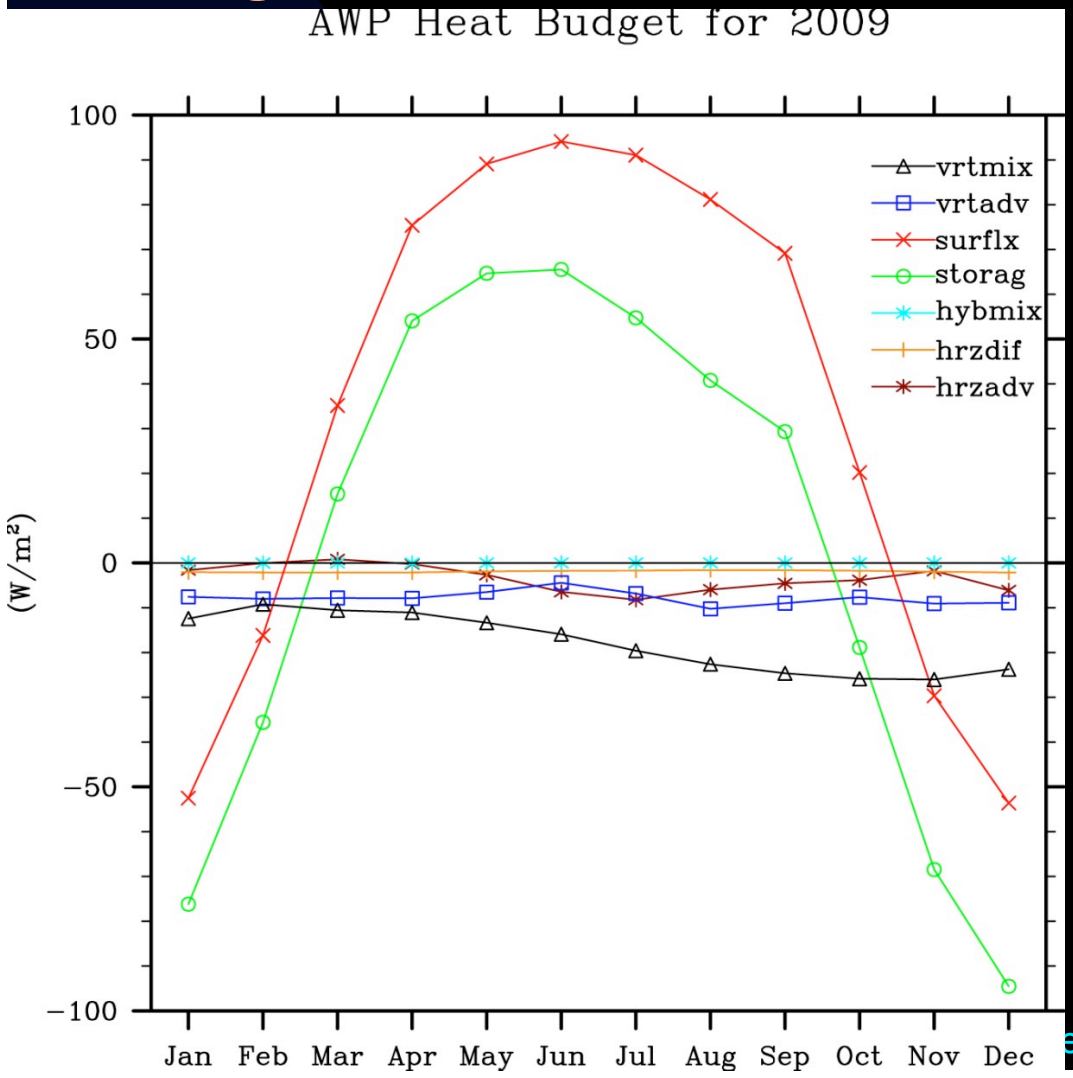
EXP-3: AWP SST is slightly warmer than observation



- GFS surface flux is very different from CORE2 flux dataset.
- This suggests a large bias in GFS surface flux dataset.
- We are currently evaluating this case.

EXP-3: AML-HYCOM_PSEUDO_GFS

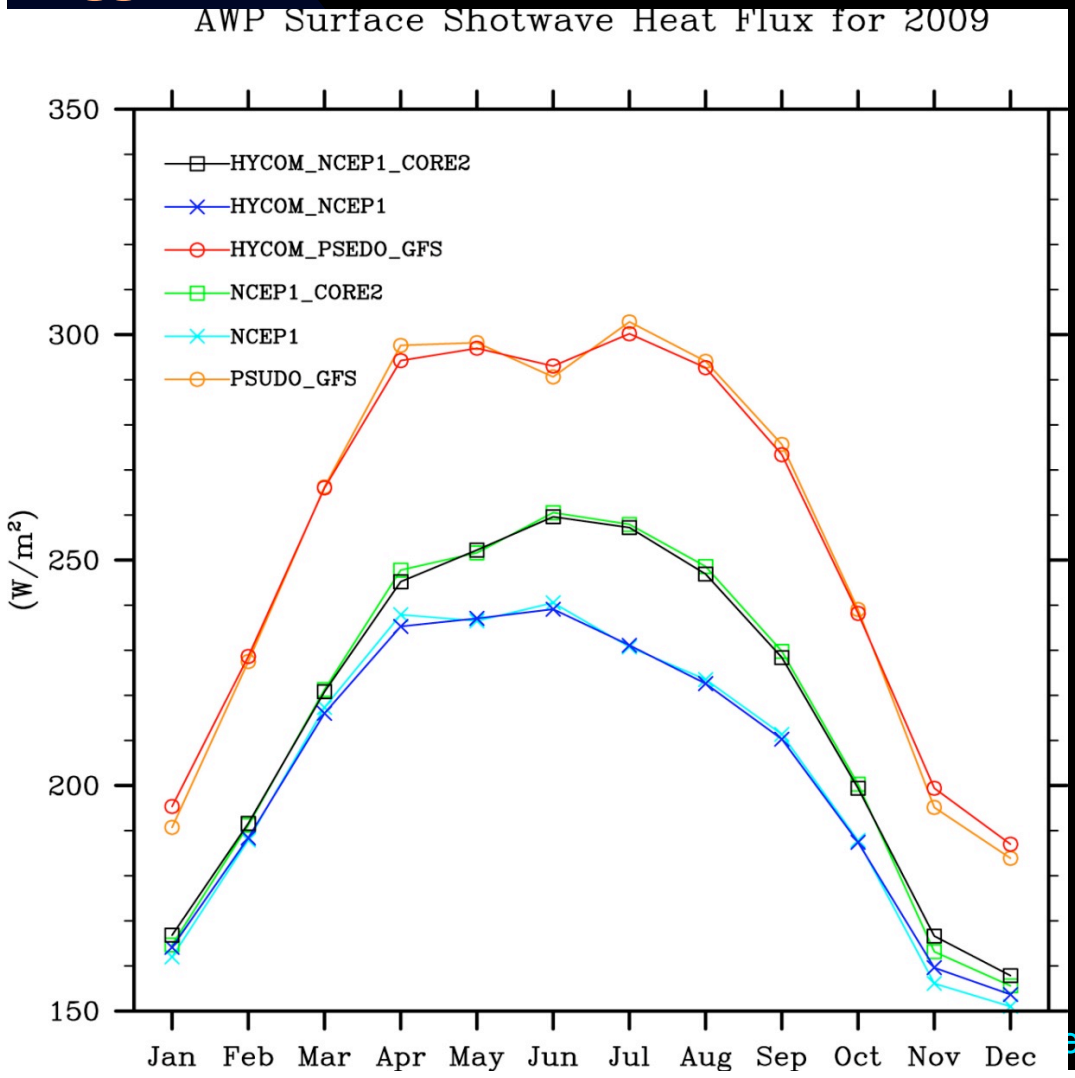
AWP mixed layer (upper 40m) ocean heat budget for 2009



- Heat budget terms are averaged over the AWP region (100°W-40°W, 5°N-30°N).
- Vertical mixing is even larger than in EXP-1.
- Q_{NET} is the only heating term.
- Q_{NET} is too large.

Surface heat flux bias in GFS

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



- When compared to CORE2, GFS add up to 50 Wm^{-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 in inherent in HYCOM associated with vertical mixing.

Accomplishments

- HYCOM is coupled to AML to properly diagnose and improve AWP simulation in HYCOM-based RTOFS at NCEP/EMC.

- Three sets of surface flux datasets were prepared and used to carry out preliminary low-resolution (1°×1°) AML-HYCOM experiments.

Preliminary Conclusions

- When forced with an optimized surface flux dataset, AML-HYCOM produces a cold AWP SST bias of ~2°C due to excessive vertical mixing, which is a bias inherent in HYCOM.

- GFS surface flux datasets put excessive shortwave heat flux into the AWP region of AML-HYCOM (We are currently evaluating this case).

Future work

- All three preliminary experiments will be repeated with RTOFS-Atlantic using NCEP/EMC computer resources.
- AML will be fine-tuned.
- Bias correction strategy will be explored.
- Diagnosis of AWP evolutions during 42 hurricanes in 2004-2008 simulated by the RTOFS-Atlantic.
- Implementing and transferring the improved RTOFS-Atlantic to NCEP/EMC.

Flooding in Nashville, Tennessee on Saturday

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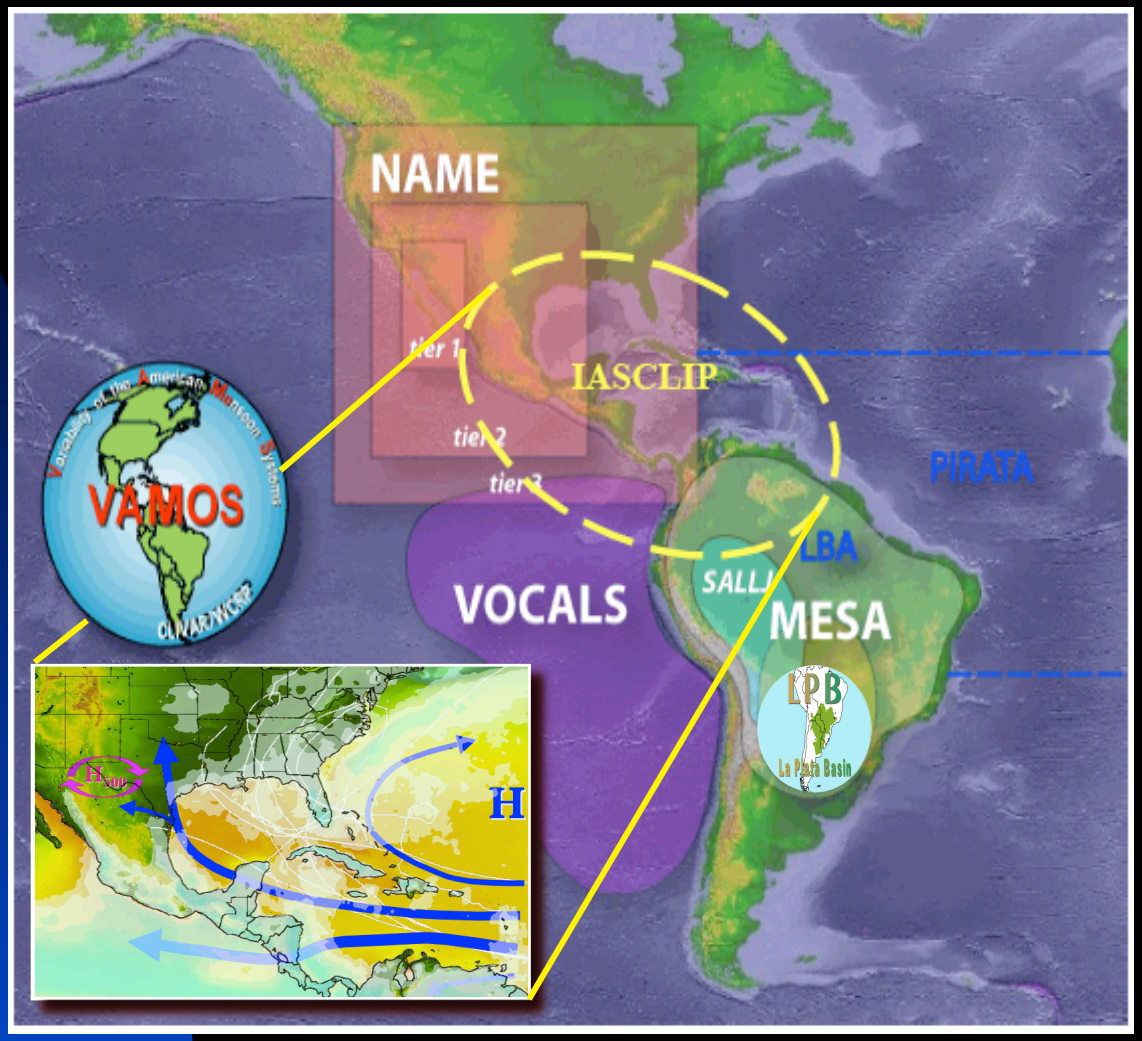
IASCLIP = Intra Americas Study of Climate Processes

A CLIVAR-VAMOS Monsoons Program (FY09 - FY14)

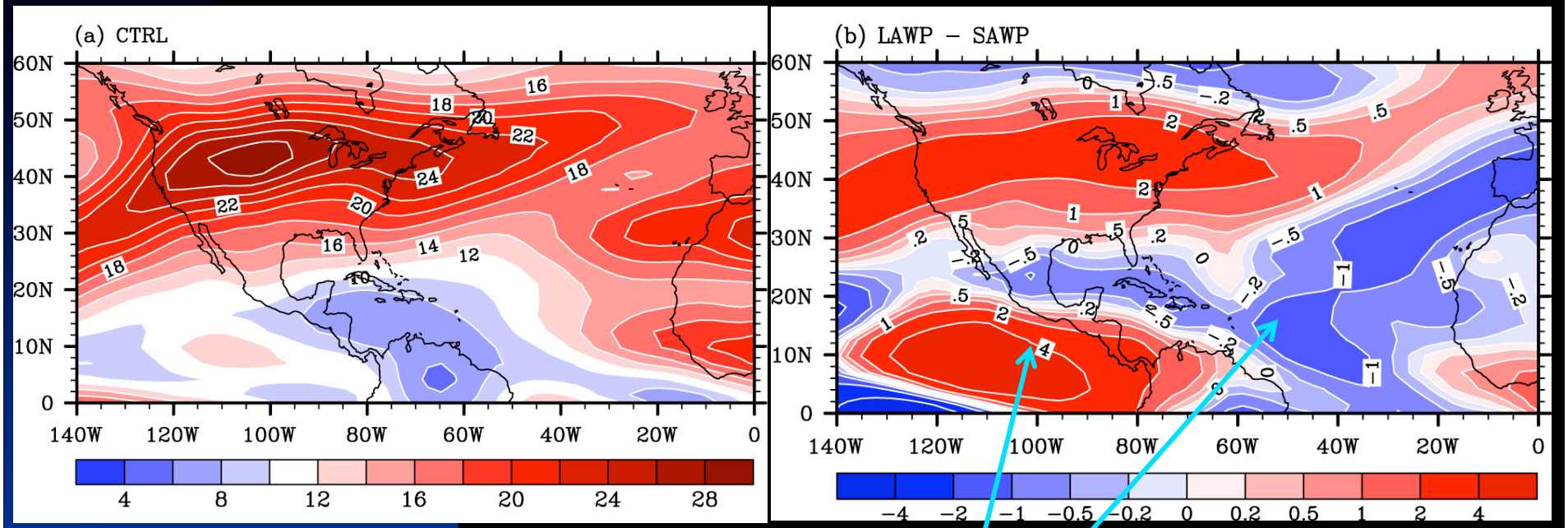
Warm Pool is the centerpiece of the IASCLIP Science/Implementation Plan



The Science and Implementation Plan is available from ftp://ftp.aoml.noaa.gov/phod/pub/wang/IASCLIP_S&Iplan_spr08_v2.pdf

Impact of AWP on Hurricanes: via Wind Shear (CAM3.1)

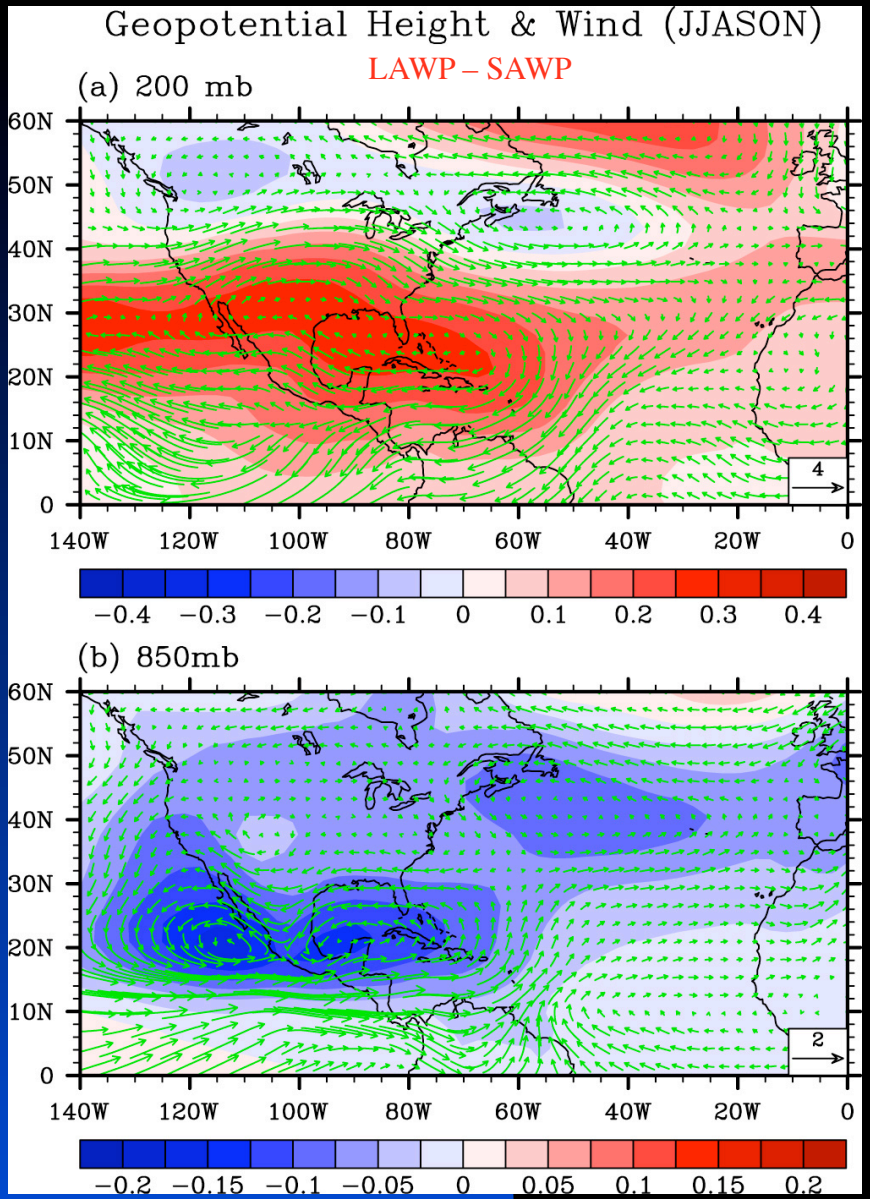
Vertical Wind Shear (JJASON): $VWS = \sqrt{(U_{200} - U_{850})^2 + (V_{200} - V_{850})^2}$



Wang et al. (2008, *JC*)

AWP reduces lower-level easterly flow and upper-level westerly flow, resulting in a reduction of VWS in the NA MDR that favors Atlantic hurricanes. The opposite result occurs in the ENP.

How/Why does AWP reduce (enhance) VWS in the NA (ENP) MDR?



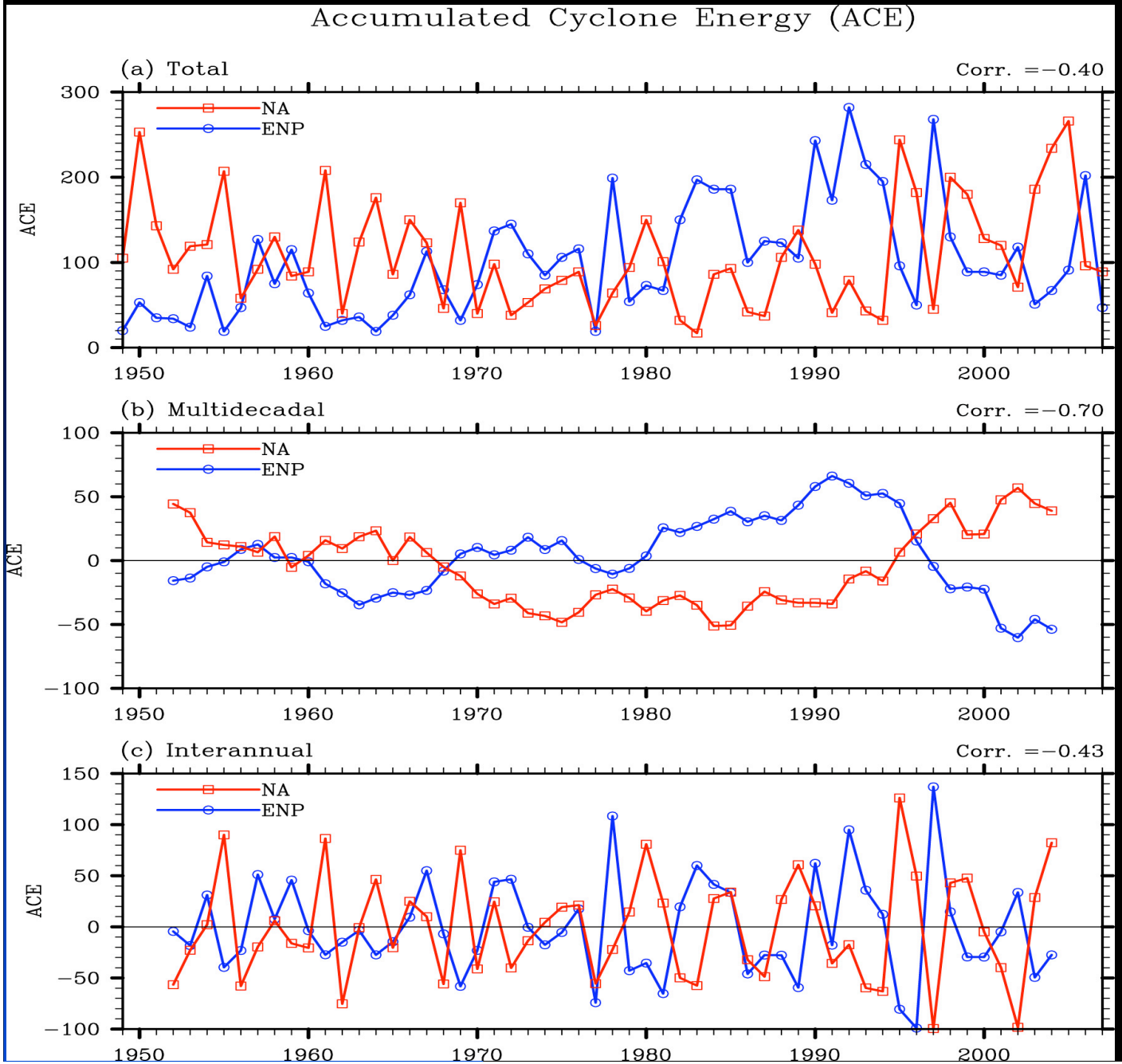
Gill's (1980) physics: Baroclinic response to a heating

Anomalous anticyclone at 200-mb

Anomalous cyclone at 850-mb

Wang et al. (2008, *JC*)

TC Variability in North Atlantic (NA) and eastern North Pacific (ENP)



ACE index is one of common indices to measure TC activity, which takes into account the number, strength and duration of all TCs in a season.

Wang & Lee (2010, EOS)

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.