The Tropical Atlantic Warm Pool (AWP)

Chunzai Wang
NOAA/AOML
Miami, Florida

VAMOS Panel Meeting
Miami, Florida
March 25-26, 2011
The 2010 Hurricane Season in NA and ENP

An active season in NA:
- Number of TCs: 19
- Climatology: 10

An inactive season in ENP:
- Number of TCs: 7
- Climatology: 14

2010 TC activity in NA and ENP was also out-of-phase, consistent with long-term observations (Wang & Lee 2009 & 2010).
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.

\[ ACE = 10^{-4} \sum V_{Max}^2 \]

Wang & Lee (2010, *Eos*)

Other indices also show the out-of-phase relationship.
AWP variability can induce the opposite vertical wind shear (VWS) in North 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.
All TCs in 2010

All TCs in 2010 that formed in the main development region (MDR). No hurricanes made landfall. Why???
North Atlantic subtropical high (NASH) plays an important role for the hurricane track; but what controls the NASH?

Dr. Neil Frank, former director of NHC, used the analogy that the movement of hurricanes is like a leaf being steered by the currents in the stream, except that for a hurricane the stream has no set boundaries.
Impact of AWP on the North Atlantic Subtropical High (NASH): CAM3.1 model runs

SLP’s response to AWP variability in JJA

AWP weakens the NASH (especially at its southwestern edge) and pushes the NASH northeastward.
An extremely large AWP in 2010 shrinks the NASH and induces the northward and northeastward steering flow anomalies which steered hurricanes away from U.S.
AWP-induced steering flow: AGCM results
Climate Model Biases:
Is it possible for model bias in the AWP to affect model error over the S. E. Pacific?

CFS Model Bias

Atlantic warm pool (AWP)
Regional Hadley circulation links the AWP with SE Pacific (Observations)

Large (small) AWPs are associated with a strong (weak) regional Hadley cell emanating from the warm pool into the SE Pacific which strengthens (weakens) subsidence over the SE Pacific. This will change the stratus cloud and rainfall (drizzle) over the SE Pacific.

Wang et al. (2006, *J. Climate*)
AWP has an inter-hemispheric influence on the SE Pacific (GCM runs)

(a) CTRL

(b) LAW - SAW

Velocity Potential and Divergent Wind at 200 mb during JJA
AWP has an inter-hemispheric influence on the SE Pacific (GCM runs)

Vertical Pressure Velocity at 500 mb during JJA

Anomalous subsidence
Simple model response to heating anomaly in the AWP

Wang et al. (2010, JC)

- Baroclinic stream function shows a pair of cyclones straddled in NE & SE Pacific, consistent with Gill’s model (1980).

- Barotropic stream function shows an alternatively high and low pattern that emanates from the AWP and transmits to high latitudes.

- In particular, the AWP heat-induced stream function transmits and crosses the equator into high latitudes of the Southern Hemisphere.
The importance of mean background zonal-wind over the Southern Hemisphere

\( \hat{U} = 0 \)

- Local baroclinic response to the AWP heating is largely independent of the mean background winds.
- In contrast, the mean background winds play a key role for barotropic stream function to be transmitted to the Southern Hemisphere.
- AWP-induced baroclinic anomalies cannot interact with the mean background wind (specified to be zero) to produce barotropic motion in the Southern Hemisphere.
Why do the warm pool and part of U.S. become drier? What role does the warm pool play for the drought condition?

Hypothesis: As the AMOC weakens under global warming, a cooling effect will cause the North Atlantic to warm more slowly than other oceans and thus environment behaves like a small AWP which reduces rainfall.
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
During spring, extreme events (tornados & floods) in Midwest are related to moisture transport from the AWP region.

<table>
<thead>
<tr>
<th>Climate response</th>
<th>Large AWP</th>
<th>Small AWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gill (850 mb)</td>
<td>cyclonic</td>
<td>anticyclonic</td>
</tr>
<tr>
<td>Gill (200 mb)</td>
<td>anticyclonic</td>
<td>cyclonic</td>
</tr>
<tr>
<td>SLP (IAS, N.Am.)</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>NASH</td>
<td>weak, small</td>
<td>strong, large</td>
</tr>
<tr>
<td>Low-level jets</td>
<td>weaker</td>
<td>stronger</td>
</tr>
<tr>
<td>IAS precip</td>
<td>rainy</td>
<td>dry</td>
</tr>
<tr>
<td>Midwest precip</td>
<td>dry</td>
<td>rainy</td>
</tr>
<tr>
<td>MDR shear</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>MDR CAPE</td>
<td>high</td>
<td>low</td>
</tr>
</tbody>
</table>
Summary

- AWP affects rainfall in the United States via the change of moisture transport associated with the Caribbean Low-Level Jet (CLLJ) and Great Plains Low-Level Jet (G PLLJ).

- Repeated large (small) AWPs can induce drought (pluvial) in the United States.

- A large (small) AWP strengthens (weakens) the summer Hadley circulation and thus enhances (suppresses) the subsidence over the SE Pacific.

- It implies that numerical models need to correctly simulate AWP variability in order to reduce model biases in the SE Pacific.
WHWP (Amazonia) is boreal summer (winter) heat source of divergent circulation in the Western Hemisphere.
A WP acts as a link between the AMO and Atlantic TCs/climate

- About 80%, large (small) AWPs occur during warm (cool) phases of AMO; Other 20% occurs in transition phases.

- Climate response to NA SST is primarily forced at low latitude (Sutton & Hodson 2007, *JC*; Wang et al 2008, *JC*); the latter is forcing the former (e.g., Hoerling et al. 2001, *Science*).

- AWP is the path of or a birthplace for Atlantic TCs.
Impact of AWP on Hurricanes via Wind Shear: AGCM Runs

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

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. This is why NA and ENP TCs vary out-of-phase (Wang & Lee 2009, GRL).
How/Why does AWP reduce (enhance) VWS in the NA (ENP) MDR?

Gill’s (1980) physics: Baroclinic response to an AWP heating.

Anomalous anticyclone at 200-mb

Anomalous cyclone at 850-mb

Wang et al. (2008, JC)
Wang & Enfield (2001, *GRL*) named the Western Hemisphere warm pool (WHWP) \(\text{SST} \geq 28.5^\circ\text{C}\).

We focus on the Atlantic side of WHWP (AWP).
AWP (SST $\geq 28.5^\circ$ C) area anomaly indices during June-November

In addition to seasonal cycle, AWP also shows interannual, multidecadal, and linear warming trend variations.

Wang et al. (2008, $G^3$)