First Annual Project Report to NSF

Collaborative Research: The Southern Subtropical Anticyclones

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1. Goals, objectives and progress

The present project aims to reconcile different ideas on the generation and maintenance of the southern Atlantic and Pacific highs, gain a better understanding of these important climate features and their variability, and contribute to improve their simulation by CGCMs through identification of reasons for systematic model errors in the tropics. With these goals in mind, the work performed concentrates on four questions in the framework of the coupled atmosphere-ocean system:

- How is the South Atlantic anticyclone during the southern winter connected with the West African and Asian monsoons?
- How significant are the interhemispheric influences of the Atlantic Warm Pool on the southeastern Pacific and Atlantic?
- In the Southern Hemisphere, do atmospheric-ocean interactions contribute significantly to the links between monsoons and subtropical highs?
- Has the recently reported change in the relationship between Atlantic and Pacific Niños affected the variability of the southern subtropical highs?

In the first year of this project (January 1 2011 – December 31 2011), we focused on the first two questions.

Our methodology for research in this project is based on the performance and analysis of GCM sesitivity experiments. So far we have completed several ensemble simulations using the NCAR community climate system model (CCSM) and UCLA CGCM, as summarized in Table 1. We are currently analyzing these model results. Preliminary results from our on-going analysis are briefly described below.

Table 1. Ensemble model experiments performed during Year-1 of the project. All AGCM (e.g., AGCM experiments with prescribed SSTs) simulations, except AGCM_SYNC, are performed using both CCSM and UCLA model. AGCM-SLAB (i.e., AGCM is thermally coupled to a slab mixed layer ocean model) coupled model experiments are carried out with CCSM, while two partially coupled experiments are performed only with UCLA CGCM. In Year-2, all of the model experiments listed here will be completed.

Experiments	**Models**	**Descriptions**
AGCM_CTRL	CCSM UCLA	The model’s monthly SSTs are prescribed using the climatological global SSTs obtained from Hadley Center SST for 1971-2000.
AGCM_SYNC	CCSM	The run is designed to minimize interhemispheric influences from the NH to the South Atlantic and South Pacific anticyclones during the southern winter. The experiment is identical to CCSM_AGCM_CTRL except that the downward solar radiation at the top of the atmosphere (TOA) and the SSTs are time-shifted by 6 months only in the NH.
AGCM_NAWP	CCSM UCLA	This experiment is identical to CCSM_AGCM_CTRL except that the seasonal onset of the Atlantic warm pool (AWP) is removed by keeping the AWP SST in the Atlantic region of 5^oN-30^oN and 100^oW-40^oW below 26^oC in all months.
AGCM_LAWP	UCLA	This experiment is identical to AGCM_CTRL, except that the prescribed SSTs correspond to years with the larger extent of the observed Atlantic Warm pool, as in Wang et al. [2008]. The experiment had been already performed with the CCSM.
AGCM_SAWP	UCLA	This experiment is identical to AGCM_CTRL, except that the prescribed SSTs correspond to years with the smaller extent of the observed Atlantic Warm pool, as in Wang et al. [2008]. The experiment had been already performed with the CCSM
SLAB_CTRL	CCSM	This experiment is identical to AGCM_CTRL except that the atmospheric model is thermally coupled to a slab ocean model outside of the Atlantic warm pool region (5^oN-30^oN and 100^oW-40^oW).
SLAB_NAWP	CCSM	This experiment is identical to SLAB_CTRL except that the seasonal onset of the Atlantic warm pool (AWP) is removed by keeping the AWP SST in the Atlantic region of 5^oN-30^oN and 100^oW-40^oW below 26^oC in all months.
PCPL_CTRL	UCLA	This is a partially coupled UCLA model simulation. The model is fully coupled (atmosphere-land-ocean) except in the Atlantic basin where the climatological SST is prescribed to force the atmospheric model component.
PCPL_LAWP	UCLA	This is identical to UCLA_PCPL_CTRL except that the AWP SSTs in the Atlantic region of 5^oN-30^oN and 100^oW-40^oW are obtained from the composite SST of large AWP years following Wang et al. [2008].

2. Synchronized Interhemipsheric Seasonal Cycle Model Experiment

Richter et al. [2008] studied the configuration of the South Atlantic anticyclone by means of comparisons between simulations with two versions of the AGCM that reproduce climate feature with significantly different success. Their results suggest the existence of links between intensity and structure of the wintertime South Atlantic anticyclone and the major summer monsoons in the Northern Hemisphere (NH). Here, we revisit this hypothesis by means of control simulations and sensitivity experiments as in Richter et al. [2008], but with a different AGCM and in a more idealized framework.

Our strategy is to clearly isolate and quantify the interhemispheric influence on the South Atlantic anticyclone from other known mechanisms, especially the role of orography [Seager et al. 2003] and monsoon heating-induced circulations [Rodwell and Hoskins 2001; Chen 2003]. To achieve this goal, we minimize interhemispheric exchanges of mass, heat and moisture in the seasonal time scales by synchronizing the seasonal cycles of the external and boundary forcing in both hemispheres. This is achieved by shifting the top of the atmosphere (TOA) downward solar radiation and the global SSTs in the NH by 6 months. Figure 1 shows the TOA clearsky net solar radiation in the control experiment (AGCM_CTRL), the synchronized interhemispheric seasonal cycle model experiment (AGCM_SYNC) and the difference between the two experiments. As shown, the TOA external forcing in the NH is synchronized to that of the Southern Hemisphere (SH) in AGCM_SYNC. It is important to note that the TOA external forcing and the boundary forcing at the sea surface in the SH are unchanged from the control model experiment, thus the difference in the SH between the two model experiment (i.e., AGCM_CTRL - AGCM_SYNC) represents the net effect of major interhemipsheric influence of the NH summer on the SH winter.

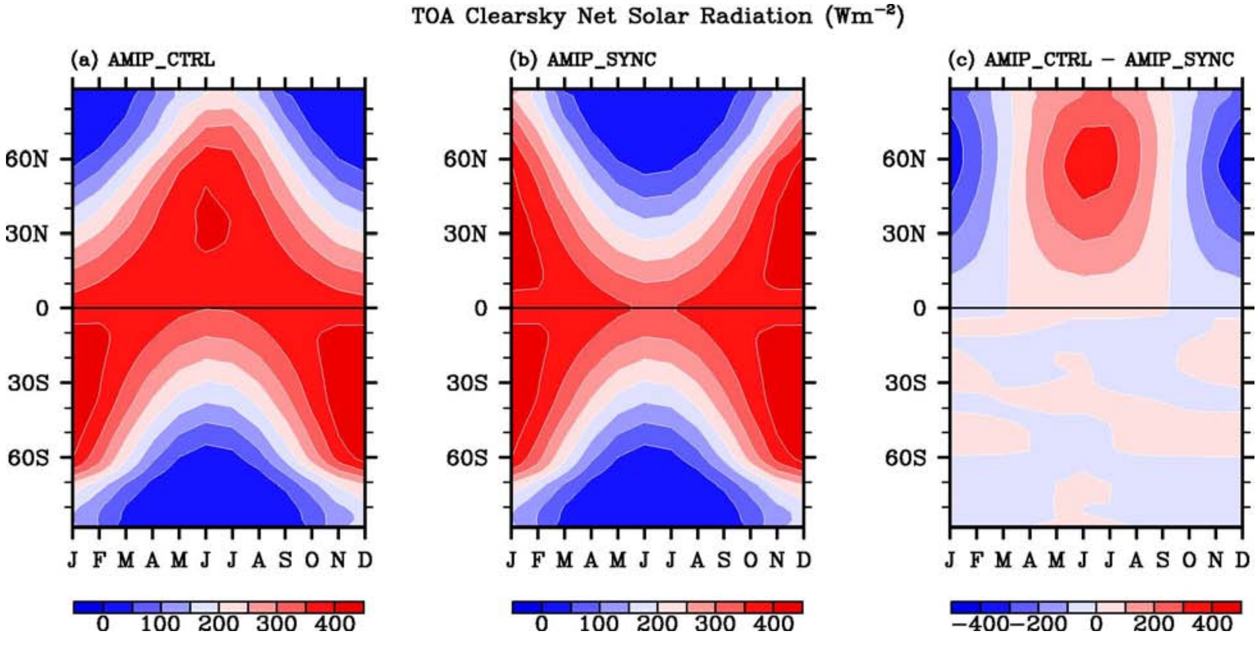


Figure 1. TOA clearsky net solar radiation in (a) the control experiment (AGCM_CTRL), (b) synchronized interhemispheric model experiment (AGCMM_SYNC) and (c) the difference between the two experiments.

Figure 2 shows the velocity potential and divergent winds at 200mb obtained from AGCM_CTRL, AGCM_SYNC and AGCM_CTRL – AGCM_SYNC averaged for June-August (JJA) and ASO. In AGCM_CTRL, the rising motion is centered over the India and over the Caribbean Sea. The sinking motion splits into one centered over the South Atlantic and the other over the Southeastern Pacific. The geographic separation of the two sinking centers is much more clear in ASO compared to that in JJA.

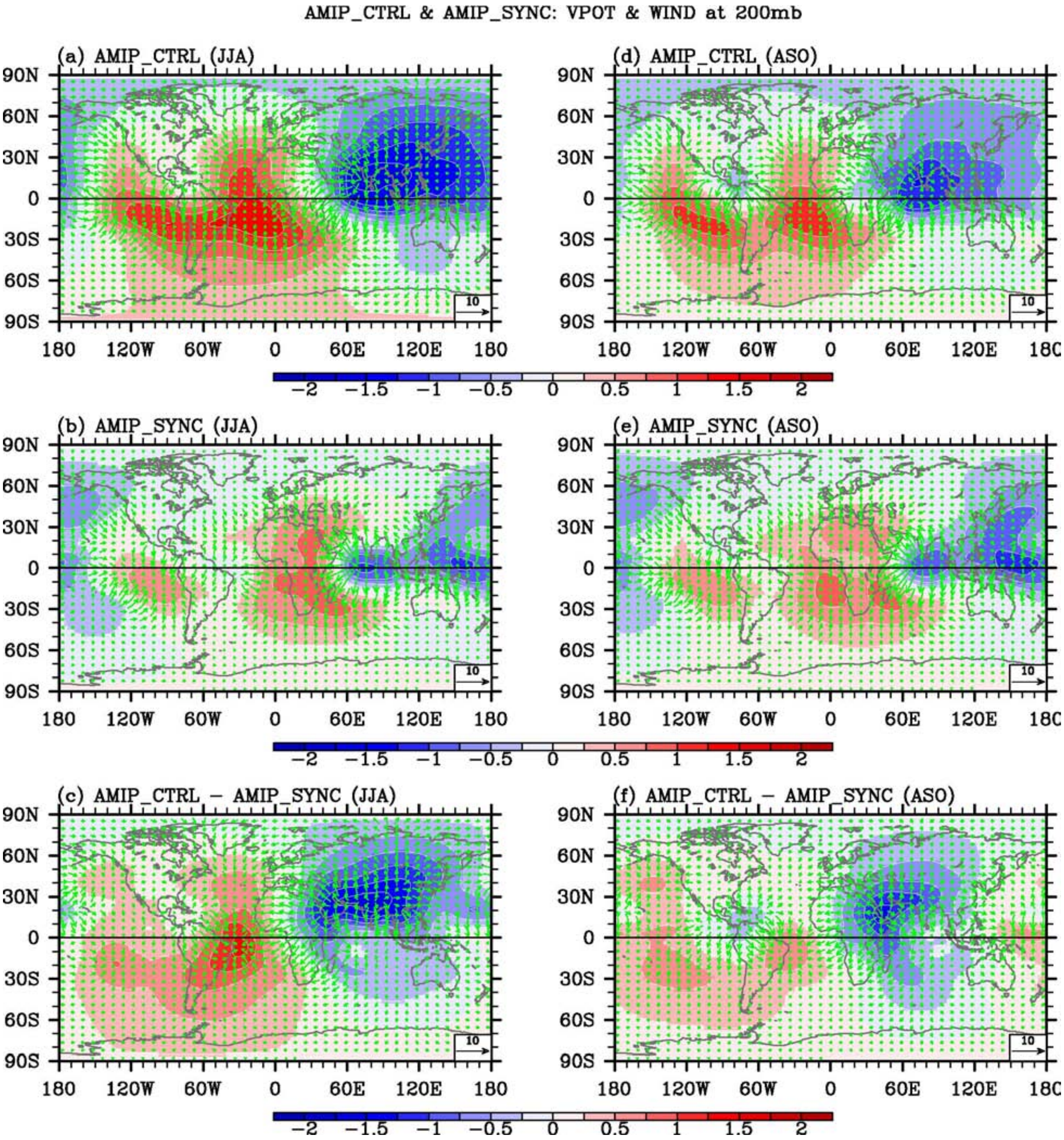
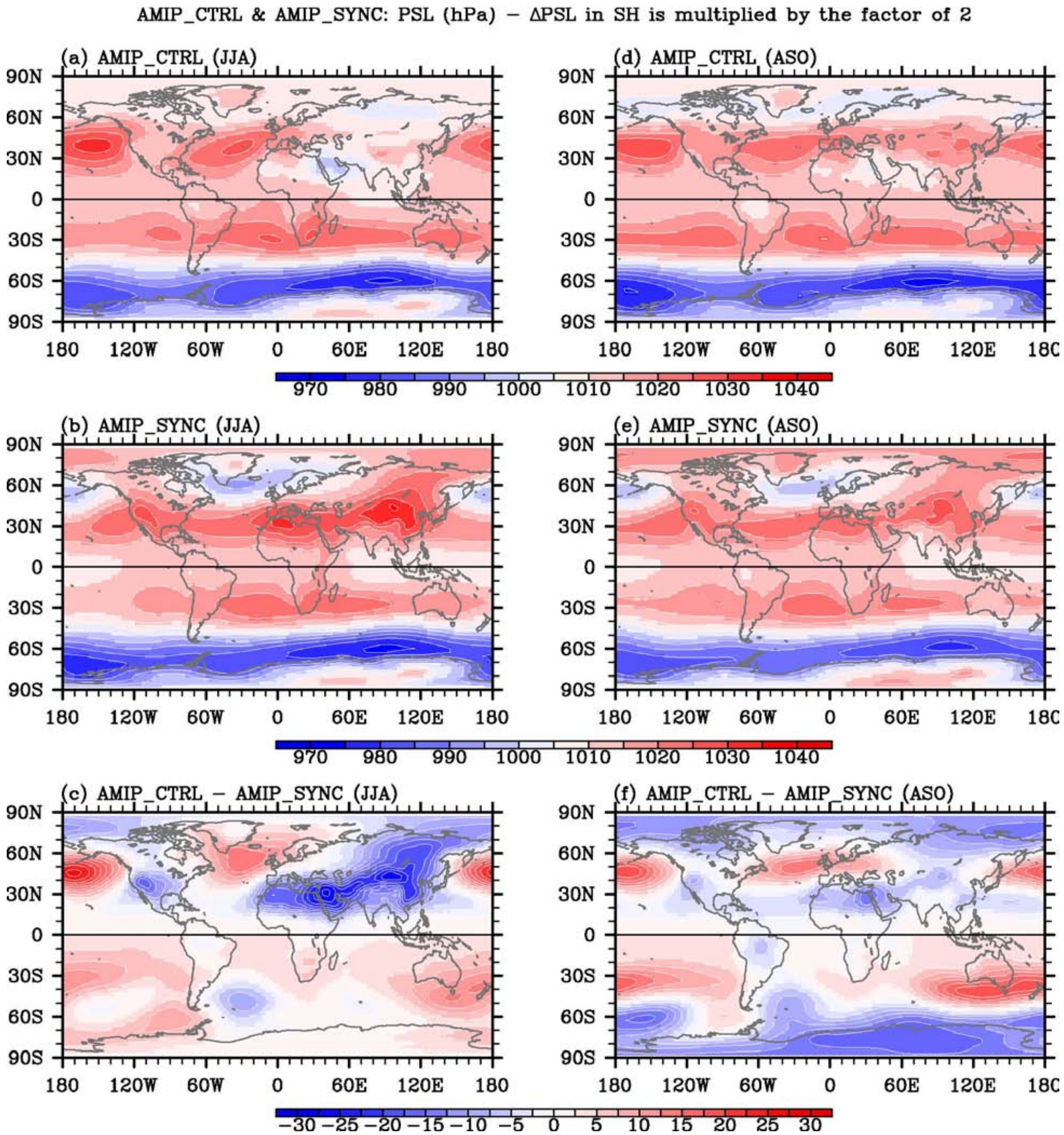


Figure 2. Velocity potential and divergent winds at 200mb obtained from AGCM_CTRL, AGCM_SYNC and AGCM_CTRL – AGCM_SYNC for JJA and ASO.

In AGCM_SYNC, the rising motion is much weaker and confined to the equatorial Indian and Western Pacific Ocean where seasonal cycle of the underlying SST is relatively weak. The sinking motions over the Southeastern Pacific and South Atlantic are also much weaker. Interestingly, the center of the sinking motion over the South Atlantic is shifted to the east. The difference in velocity potential between the two experiments further shows that the sinking motion over the Southwestern Atlantic region is strongly influenced by the rising motion over the Caribbean Sea. Therefore, it appears that the lack of diabatic heating aloft the Caribbean Sea in AGCM_SYNC aids in the reduced sinking motion over the Southwestern Atlantic and thus pushes the center of the South Atlantic sinking motion to the east in AGCM_SYNC.

Consistent with the reduced subsidence over the Southwest Atlantic, the South Atlantic sea level pressure is generally weakened in AGCM_SYNC during JJA (Figure 3). In other words, the interhemispheric influences associated with the monsoon in the NH increase the subsidence over the Southwest Atlantic and thus contributes to the South Atlantic anticyclone.

Obviously, an important question is why the African-Asian monsoon enhances subsidence over the Southwest Atlantic. A preliminary analysis suggests that the seasonal onset of the West African monsoon help reduce the moisture transport and convergence onto the Southwest Atlantic, thus reduces deep tropical convection there (Figure 4). Further diagnosis of the CCSM model experiments and similar experiments with UCLA model are planned in the Year-2 of the project.


AMIP_CTRL & AMIP_SYNC: PSL (hPa) – ΔPSL in SH is multiplied by the factor of 2

(a) AMIP_CTRL (JJA)

(d) AMIP_CTRL (ASO)

(b) AMIP_SYNC (JJA)

(e) AMIP_SYNC (ASO)

(c) AMIP_CTRL – AMIP_SYNC (JJA)

(f) AMIP_CTRL – AMIP_SYNC (ASO)

Figure 3. Sea level pressure obtained from AGCM_CTRL, AGCM_SYNC and AGCM_CTRL – AGCM_SYNC for JJA and ASO.

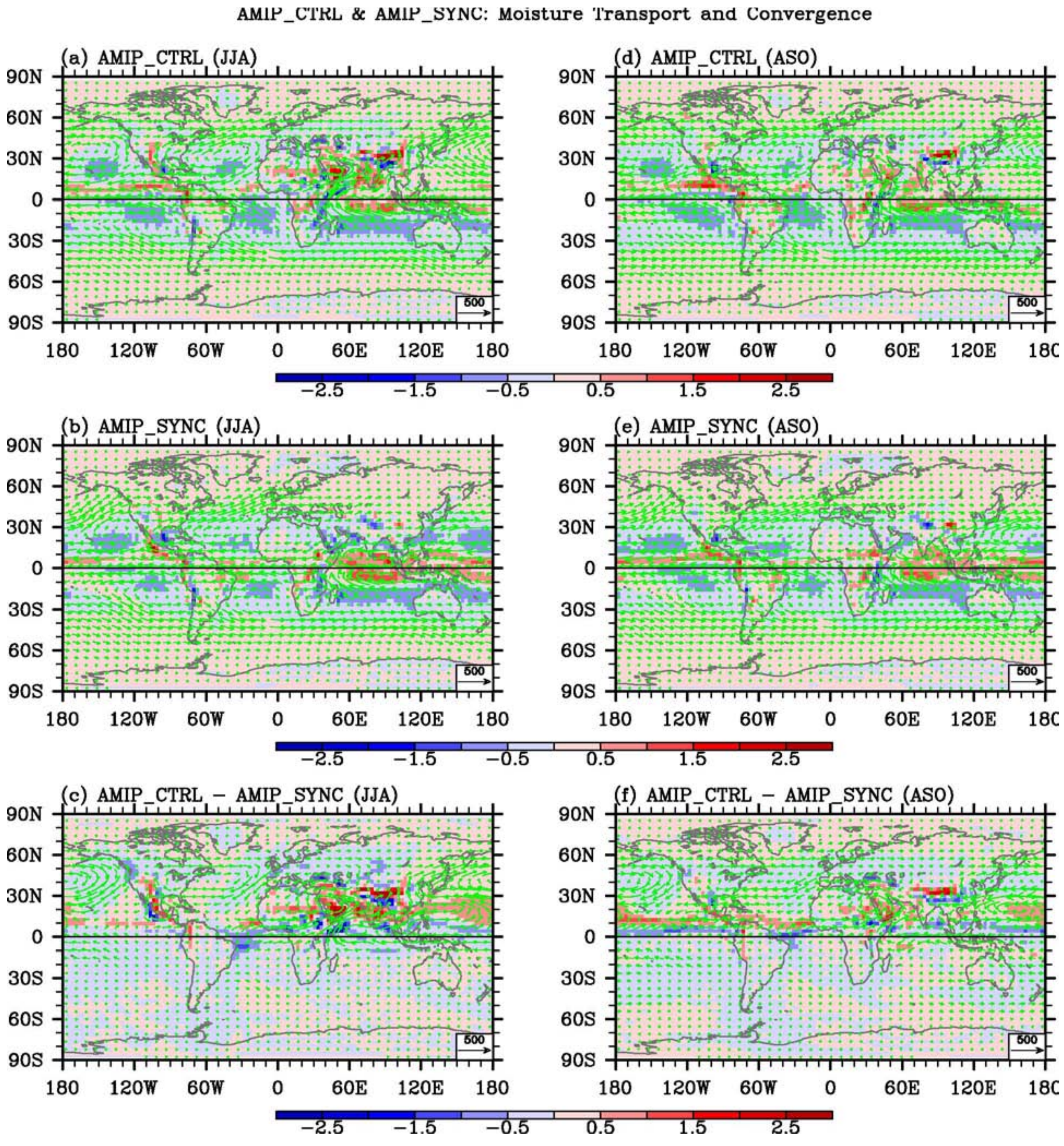


Figure 4. Vertically integrated moisture transport and convergence obtained from AGCM_CTRL, AGCM_SYNC and AGCM_CTRL – AGCM_SYNC for JJA and ASO.

3. How significant are the interhemispheric influences of the seasonal Atlantic Warm Pool onset on the southeastern Pacific?

A recent work by Wang et al. [2010] emphasized connections between the South Pacific subtropical high and convection over the Atlantic Warm Pool (AWP; warm surface water in regions comprising the Gulf of Mexico, Caribbean Sea, and the western tropical North Atlantic). This paper demonstrated the establishment of interhemispheric connections through a regional Hadley circulation emanating from the AWP and sinking over the subtropical southeastern Pacific. Such Hadley circulation is strengthened (weakened) by anomalously large (small) AWPs. The interhemispheric connection helps explain why stratus clouds in the southeastern Pacific peak in the southern spring and not in the summer, when the South American monsoon system is in full strength.

We are further investigating the AWP-Southeastern Pacific connection, proposed in Wang et al. [2010], in seasonal, interannual and multidecadal times scales by using thermally coupled and fully coupled GCMs. Here, we will briefly summarize our findings on the seasonal AWP-Southeastern Pacific connection in a thermally coupled GCM. As summarized in Table 1, we performed two experiments using the CCSM coupled to a slab mixed layer ocean model. In the control simulation (SLAB_CTRL), the atmospheric model is thermally coupled to a slab ocean model outside of the AWP region (5^oN-30^oN and 100^oW-40^oW), whereas SSTs over the AWP region are prescribed using the climatological global SSTs obtained from Hadley Center SST during 1971-2000. The second experiment is identical to SLAB_CTRL except that the seasonal onset of the AWP is removed by keeping the AWP SST in the Atlantic region of 5^oN-30^oN and 100^oW-40^oW below 26^oC in all months (SLAB_NAWP).

Figure 5 clearly shows that the sea level pressure in the Southeastern Pacific is reduced in SLAB_NAWP, consistent with Wang et al. [2010]. As shown in Figure 6c, the seasonal onset of the AWP induces rising motions over the Caribbean Sea and sinking motions in the tropical Pacific. It is clear that the AWP-induced sinking motion over the South Pacific is th edirect cause of the increased sea level pressure in the Southeastern Pacific as concluded in Wang et al. [2010]. Therefore, it appears that the AWP-Southeastern Pacific connection also exists in seasonal time scale. We also find that SST is reduced and the low-level cloud fraction is increased over the Southeastern Pacific in response to the AWP-Southeastern Pacific connection (not shown). This suggests that the AWP-Southeastern Pacific connection is strengthened by SST-low-level cloud positive feedback on seasonal time scale. Further diagnosis and comparison with AGCM_CTRL and AGCM_NAWP simulations are planned in the Year-2 of the project to explore the importance of the local feedback.

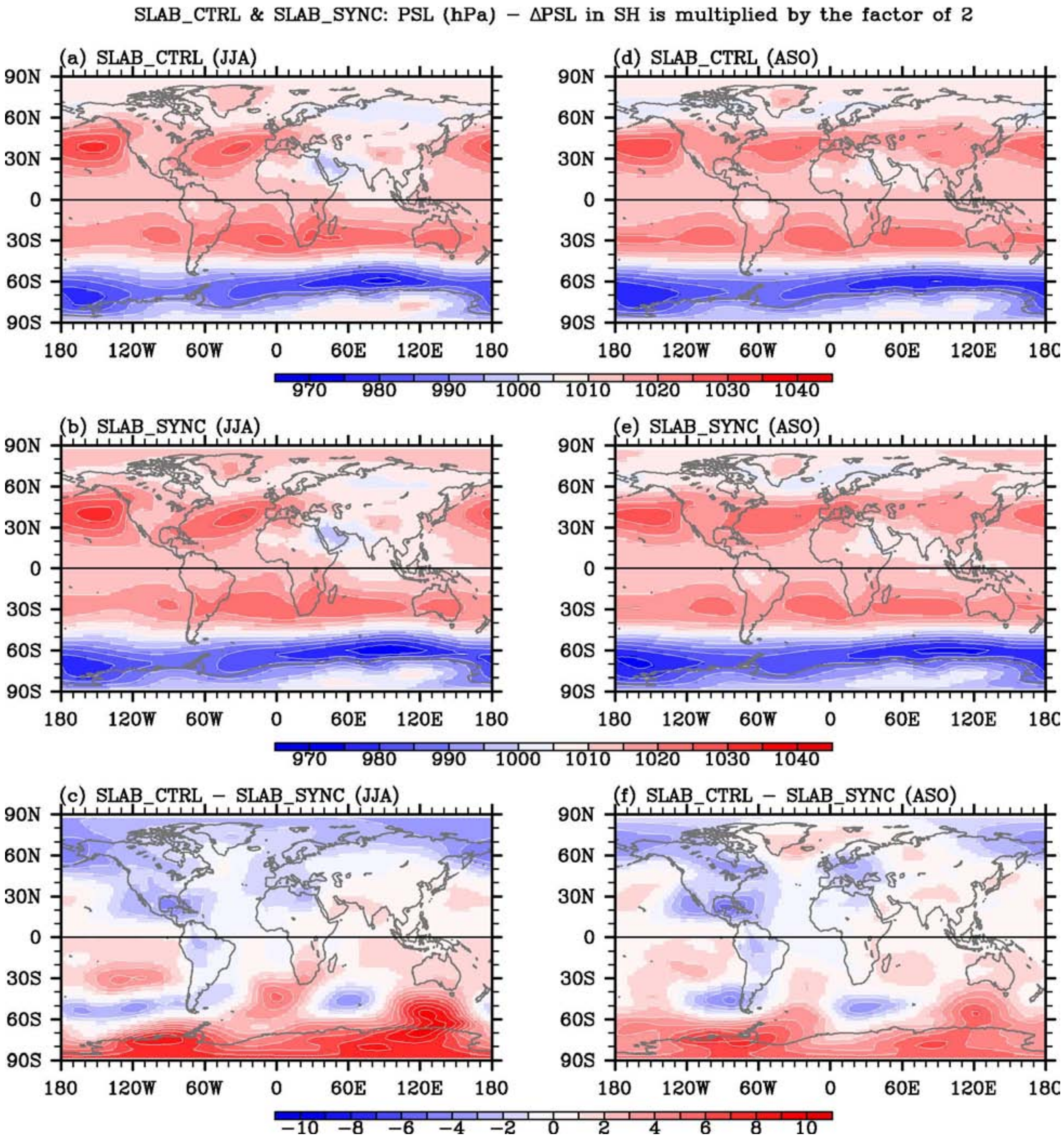


Figure 5. Sea level pressure obtained from SLAB_CTRL, SLAB_NAWP and SLAB_CTRL – SLAB_NAWP for JJA and ASO.

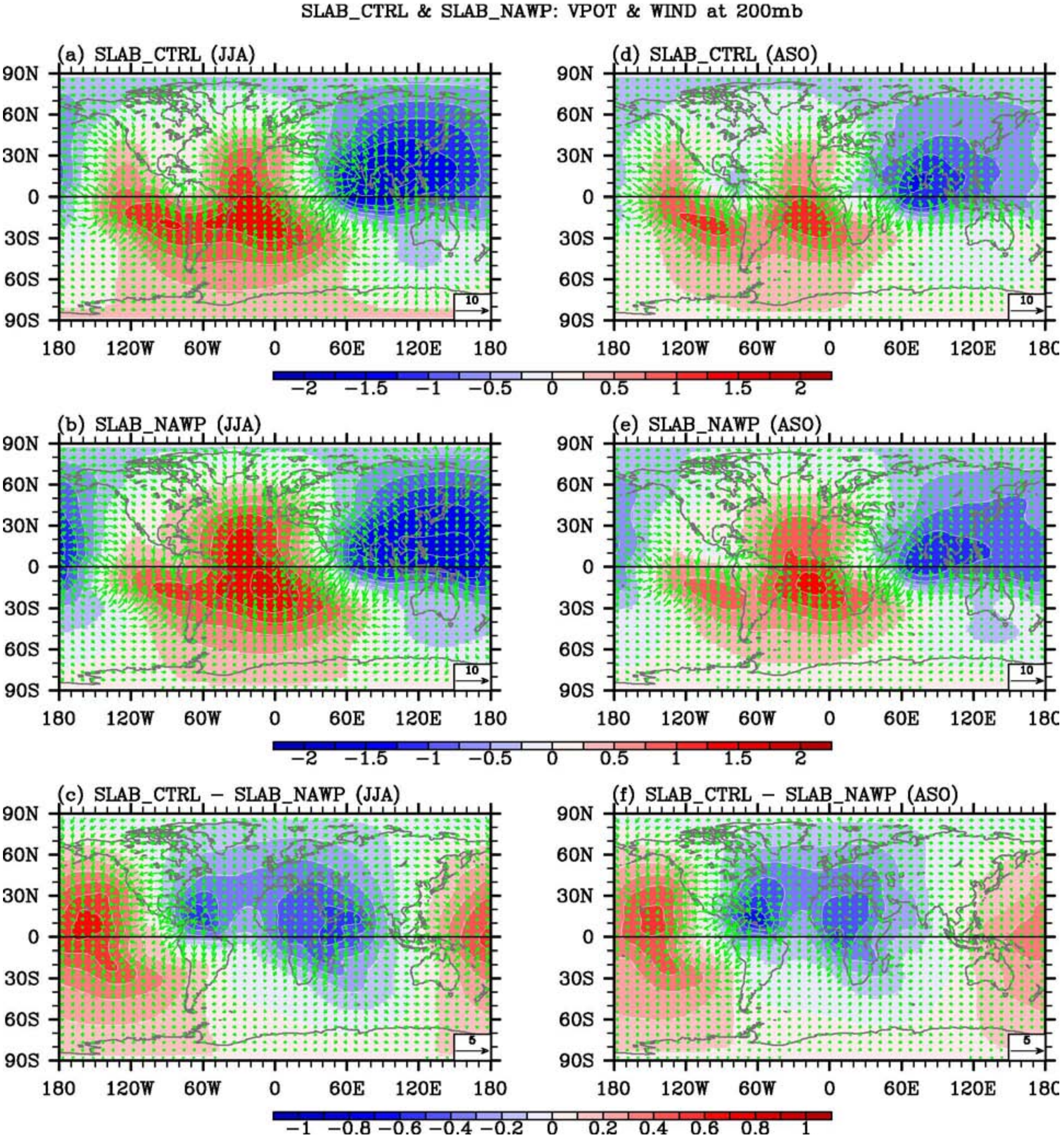


Figure 6. Velocity potential and divergent winds at 200mb obtained from SLAB_CTRL, SLAB_NAWP and SLAB_CTRL – SLAB_NAWP for JJA and ASO.

4. Interhemipsheric influence of large and small Atlantic Warm Pool in two AGCMs

Four experiments, AGCM_CTRL, AGCM_NAWP, AGCM_LAWP, and AGCM_SAWP with the UCLA model have just completed. We are currently comparing these model results with those with CCSM.

5. What is the role of atmospheric-ocean interactions in the interhemipsheric influence of Atlantic Warm Pool on the Southeastern Pacific?

To explore this questions we have completed PCPL_CTRL, and PCPL_LAWP. These are all 50-year long simulations. Figure 7 shows that a larger AWP encourages the formation of stratocumulus in the southeastern Pacific. Preliminary analysis, however, has suggested that the average climate with this models has unrealistic features. Currently, we are exploring ways to overcome this problem, such as using the so-called anomaly coupling technique.

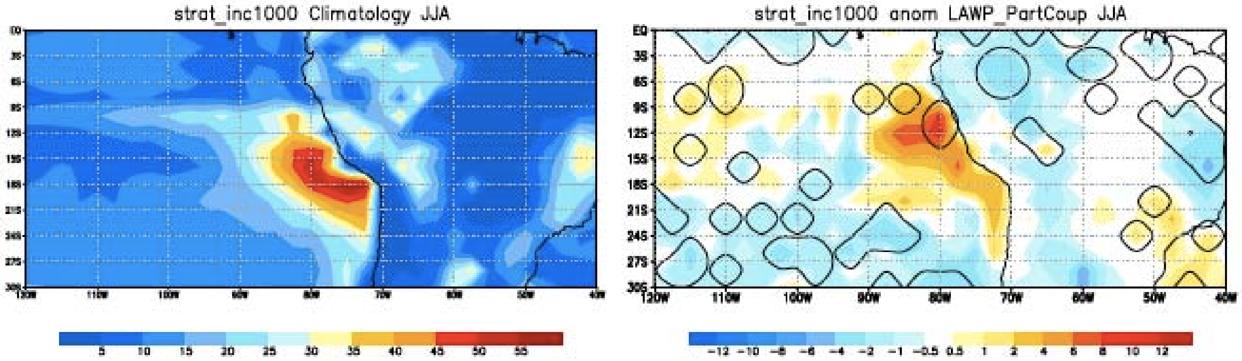


Figure 7. Stratocumulus obtained in PCPL_CTRL (left) and PCLA_LAWP_ (right).

6. Interhemispheric teleconnections using a simple two-level model

We are exploring the interhemispheric teleconnection with the simple two-level model of Lee et al. (2009). The effects of surface drag in forcing the Rossby wave response by modifying the two-layer in the following way: remove the damping term $-r\nabla^2\psi$ in the vorticity equation at 250mb, and replace the same term at 750mb with $-r_s\nabla^2\psi$, where $r_s = (g/p_T)\rho_a C_D V_s$, where $p_T = 500\ hPa$. In this way, the barotropic vorticity equation will have an additional forcing term $r_0\nabla^2\hat{\psi}$, and similarly, the baroclinic vorticity equation will have a term $r_1\nabla^2\bar{\psi}$, where $r_0 = r_1 = r_s/2$.

Figure 8 shows the response of the model when a Gaussian shaped heating in the Atlantic Warm Pool area is prescribed. Fig. 8a shows the result in the original model, where the barotropic response can only be forced by shear forcing, the barotropic stream function (upper panel) is relatively small; the effects of surface drag in forcing the barotropic response can be seen in Fig. 8b. Note that the contour interval for the barotropic stream function in Fig. 8a is twice that in Fig. 8b, thus we can see that the barotropic response is more significant than in the shear forcing case; the total barotropic response when both forcing are present (Fig. 8c) shows how the added surface drag effects enhance enhances the barotropic response and the cross equatorial Rossby wave response to the thermal forcing.

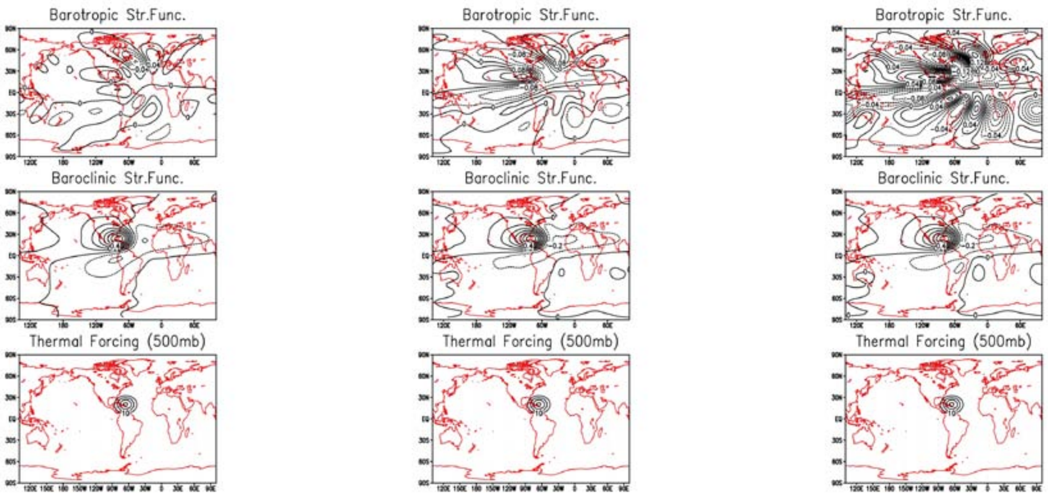

(a) Shear only **(b) Surface drag only** **(c) Both forcing**

Figure 8. Simple two-layer model solutions with (a) shear forcing only; (b) surface drag forcing only and (c) both forcing. The contour intervals for the upper panels are: (a) $0.2 \times 10^6 m^2 s^{-1}$; (b) $0.4 \times 10^6 m^2 s^{-1}$; (c) $0.2 \times 10^6 m^2 s^{-1}$. The contour interval for the middle panels is $1.0 \times 10^6 m^2 s^{-1}$. The lower panels indicate the heating prescribed in the three experiments.

7. Summary and future plan

During the Year-1, we focused on two main questions: (1) how is the South Atlantic anticyclone during the southern winter connected with the West African and Asian monsoons?; and (2) how significant are the interhemispheric influences of the Atlantic Warm Pool on the southeastern Pacific and Atlantic? We have completed several ensemble simulations using the CCSM and UCLA CGCM, as summarized in Table 1. A preliminary conclusion from our on-going analysis is that both the African-Asian summer monsoon and the summer onset of the AWP contribute to the subsidence over the Southwestern Atlantic during austral winter, and thus contribute to the seasonal intensification of the South Atlantic anticyclone. Further analysis and more experiments are planned in the Year-2 to better understand the physical mechanisms that make such interhemispheric connections possible. In particular, the synchronized interhemispheric seasonal cycle model experiment will be repeated by using UCLA AGCM to explore model-to-model differences in the interhemispheric connections. The CCSM coupled to a slab ocean mixed layer model will be also used to better understand the potential involvement of air-sea coupling in the interhemispheric connections.

Another interesting finding in the Year-1 is that the positive SST-low level cloud feedback plays a role in the amplification and localization of the AWP's interhemispheric influence on the Southeastern Pacific region. Fully coupled UCLA CGCM simulations are planed in the Year-2 to further explore the air-sea interaction in the Southeastern Pacific in response to the AWP's interhemispheric influence. In the Year-2, we will also explore the NCAR's Community Earth System Model (CESM), which is the latest version of the CCSM, to take advantage of the much improved stratocumulous parameterizations in that model.

8. Publications

We were quite productive in term of publication in 2011. The following is the list of 17 publications by the PIs of the project (R. Mechoso, S.-K. Lee, and C. Wang) on the subject of Pacific and Atlantic climate and modeling during 2011.

Published or In Press in 2011:

1) **Lee S.-K**., W. Park, E. van Sebille, M. O. Baringer, **C. Wang**, D. B. Enfield, S. Yeager, and B. P. Kirtman, 2011. What Caused the Significant Increase in Atlantic Ocean Heat Content Since the mid-20th Century? Geophysical Research Letters, doi:10.1029/2011GL048856. [highlighted in Oct. 6, 2011 issue of Nature as Community Choice]
2) **Lee, S.-K**., D. B. Enfield and **C. Wang**, 2011. Future Impact of Differential Inter-Basin Ocean Warming on Atlantic Hurricanes. Journal of Climate, 24, 1264-1275.
3) Liebmann, B., and **C.R. Mechoso**, 2011: The South American Monsoon System. The Global Monsoon System: Research and Forecast, 2nd Edition. Chang, C. -P., Y. Ding, N.-C. Lau, R. H. Johnson, B. Wang, and T. Yasunari, Eds., World Scientific Series on Asia-Pacific Weather and Climate, Vol. 5, World Scientific Publication Company, 608 pp.
4) Ling, Z., G. Wang, **C. Wang**, and Z.-S. Fan, 2011: Different effects of tropical cyclones generated in the South China Sea and the northwest Pacific on the summer South China Sea circulation. Journal of Oceanography, 67:347-355.
5) Ma, H.-Y., X. Ji, J. D. Neelin, and **C. R. Mechoso**, 2011: Mechanisms for Precipitation Variability of the Eastern Brazil/SACZ Convective Margin. J. Climate, doi: 10.1175/2011JCLI4070.1.
6) Mohino, E., B. Rodriguez-Fonseca, **C.R. Mechoso**, S. Gervois, P. Ruti, and F. Chauvin, 2011: Impacts of the Tropical Pacific/Indian Oceans on the Seasonal Cycle of the West African Monsoon. J. Climate doi: 10.1175/2011JCLI3988.1.
7) Shu, Q., F. Qiao, Z. Song, and **C. Wang**, 2011: Sea ice trends in the Antarctic and their relationship to surface air temperature during 1979 to 2009. Climate Dynamics, in press.
8) Song, Z., F. Qiao, and **C. Wang**, 2011: The correctness to the spuriously simulated semi-annual cycle of the sea surface temperature in the equatorial eastern Pacific. Science China Earth Sciences, 54:438-444, doi:10.1007/s11430-011-4176-3.
9) Stammer, D., N. Agarwal, P. Hermann, A. Kohl, and **C. R. Mechoso**, 2011 Response of a Coupled Ocean-Atmosphere Model to Greenland Ice Melting. Surveys of Geophysics. In Press.
10) Teixeira, J., S. Cardoso, M. Bonazzola, J. Cole, A. DelGenio, C. DeMott, C. Franklin, C. Hannay, C. Jakob, Y. Jiao, J. Karlsson, H. Kitagawa, M. Kohler, A. Kuwano-Yoshida, C. LeDrian, J. Li, A. Lock, M. J. Miller, P. Marquet, J. Martins, **C. R. Mechoso**, E. v. Meijgaard, I. Meinke, P. M. A. Miranda, D. Mironov, R. Neggers, H. L. Pan, D. A. Randall, P. J. Rasch, B. Rockel, W. B. Rossow, B. Ritter, A. P. Siebesma, P. M. M. Soares, F. J. Turk, P. A. Vaillancourt, A. Von Engeln, and M. Zhao, 2011: Tropical and sub-tropical cloud transitions in weather and climate prediction models: the GCSS/WGNE Pacific Cross-section Intercomparison (GPCI). J. Climate. doi: 10.1175/2011JCLI3672.1.
11) Toniazzo, T., S. J. Abel, R. Wood, **C. R. Mechoso**, G. Allen, and L. C. Shaffrey, 2011: Large-scale and synoptic meteorology in the south-east Pacific during the observations campaign VOCALS-REx in austral Spring 2008. Atmos. Chem. Phys., 11, 4977-5009.
12) Turner, A., K. Sperber, J. Slingo, G. Meehl, **C.R. Mechoso**, M. Kimoto, and A. Giannini, 2011: Modeling Monsoons: Understanding and predicting current and future behavior. The Global Monsoon System: Research and Forecast, 2nd Edition. . Chang, C. -P., Y. Ding, N.-

C. Lau, R. H. Johnson, B. Wang, and T. Yasunari, Eds., World Scientific Series on Asia-Pacific Weather and Climate, Vol. 5, World Scientific Publication Company, 608 pp. April 2011.

13) **Wang, C**., 2011: Atlantic multidecadal oscillation (AMO). In "State of the Climate in 2010". Bulletin of the American Meteorological Society, 92(6):S137-S138.
14) **Wang, C**., H. Liu, **S.-K. Lee** and R. Atlas, 2011. Impact of the Atlantic Warm Pool on United States Landfalling Hurricanes. Geophysical Research Letters, doi:10.1029/2011GL049265. [highlighted in Oct. 21, 2011 issue of Science as Editor's Choice]
15) Wang, X., **C. Wang**, W. Zhou, D. Wang, and J. Song, 2011: Teleconnected influence of North Atlantic sea surface temperature on the El Niño onset. Climate Dynamics,37:663-676, doi:10.1007/s00382-010-0833-z.
16) Wood, R., **C. R. Mechoso**, C. S. Bretherton, R. A. Weller, B. Huebert, F. Straneo, B. A. Albrecht, H. Coe, G. Allen, G. Vaughan, P. Daum, C. Fairall, D. Chand, L. Gallardo Klenner, R. Garreaud, C. Grados, D. S. Covert, T. S. Bates, R. Krejci, L. M. Russell, S. de Szoeke, A. Brewer, S. E. Yuter, S. R. Springston, A. Chaigneau, T. Toniazzo, P. Minnis, R. Palikonda, S. J. Abel, W. O. J. Brown, S. Williams, J. Fochesatto, J. Brioude, and K. N. Bower, 2011: The VAMOS Ocean-Cloud-Atmosphere-Land Study Regional Experiment (VOCALS-REx): Goals, platforms, and field operations. Atmos. Chem. Phys.,11, 627-654.
17) Zamboni, L., F. Kucharski, and **C. Mechoso**, 2011: Seasonal variations of the links between the interannual variability over South America and the South Pacific. Clim. Dyn., Published online, 22 June 2011.