Wind-Mixed layer-SST modes in the tropical Atlantic

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The tropical Atlantic Ocean hosts a “meridional mode”, which is accompanied by cross-equatorial sea surface temperature (SST) anomaly gradient. It is thought that this mode is destabilized due to thermodynamic coupling between the wind speed, evaporation, and SST (WES feedback). Using a simple linear coupled model, we show that two additional ocean-atmosphere coupled feedback, which contribute to a cross-equatorial SST anomaly gradient, are possible in the tropical Atlantic, by taking mixed layer depth (MLD) variations into account. It is found that those feedback processes are stronger than the canonical WES feedback in our simple model framework. In the presence of damping effects, however, they exist either as a weakly unstable mode or a least damped mode. The SST and MLD structures in the simple model bear a resemblance to those of observed Atlantic meridional modes.

The importance of cloud feedback for inter-hemispheric tropical Atlantic climate variability

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Over the tropical Atlantic during boreal spring, typical inter-hemispheric differences in sea-surface temperature (SST) coincide with a coherent pattern of interannual to interdecadal climate variability resembling that associated with the Atlantic Meridional Mode. This includes anomalous dipoles of SST and sea-level pressure roughly symmetric about the equator, as well as anomalous cross-equatorial surface winds. Over the regions of maximum marine boundary layer cloudiness in both hemispheres, enhanced cloudiness associated with this variability is co-located with cool SST, and reduced cloudiness is associated with warm SST -- indicative a positive cloud feedback that reinforces the underlying SST anomalies. The simulation of this feedback varies widely among models participating in phase 5 of the Coupled Model Intercomparison Project. Models that simulate a cloud feedback magnitude that is approximately three-to-four times weaker than that observed in nature substantially underestimate the amplitudes of typical inter-hemispheric tropical Atlantic variability in SST, cloudiness, and atmospheric circulation. Models with a realistic feedback magnitude generally produce higher and more realistic amplitudes of variability. Marine boundary layer clouds therefore appear to be a key element of springtime coupled atmosphere-ocean variability over the tropical Atlantic. The simulation of this variability in climate models may be improved by better representing boundary layer cloud processes.

Keywords: cloud feedback, Atlantic Meridional Mode, atmosphere-ocean interactions

Seasonal predictability of the Atlantic Meridional Mode and its link with the Guinea Dome

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Seasonal predictability of the Atlantic Meridional Mode is investigated by use of the SINTEX-F climate model from the viewpoint of the preconditioning role of the Guinea Dome. The 2009 strong negative event is successfully predicted a few months ahead when the model is initialized using a three-dimensional variational ocean data assimilation (3DVAR) method. However, nudging the sea surface temperature (SST) only for the initialization fails to predict the event. It is shown that the mixed-layer depth in the Guinea Dome region is unrealistically deep in the latter. Denying even one ocean mooring array data at 12ºN, 23ºW in the 3DVAR initialization clearly demonstrates that monitoring the Guinea Dome is very important for predicting the Atlantic Meridional Mode.

Keywords: Atlantic Meridonal Mode, Seasonal prediction, Guinea Dome

On the predictability of tropical Atlantic surface winds

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The potential predictability of tropical Atlantic surface winds is examined in a set of AMIP-like experiments with the SINTEX-F coupled general circulation model (GCM). In the control experiment, sea-surface temperatures (SSTs) are strongly restored to observed values for the period 1982-2014. In the sensitivity tests, SSTs are restored to climatological rather than observed values in selected regions including the global oceans, the equatorial Atlantic (5S-5N), the southeastern tropical Atlantic (10W-20E, 20-10S), the northern tropical Atlantic (90W-20E, 5-15N), and the equatorial Pacific (10S-10N).
Observed surface zonal wind variability over the western equatorial Atlantic displays pronounced seasonality with a distinct peak in April. The SINTEX-F control simulation is able to reproduce this seasonality though the peak is delayed by one month relative to observations. The sensitivity tests suggest that, during May and June, about 80% of this variability is due to local and remote SST anomalies, while internal atmospheric processes contribute 20%. The contribution from internal variability is substantially larger in other months. Equatorial Atlantic SSTs control about 75% of the equatorial surface wind variability in June but only about 20% in boreal spring. Likewise, remote influences associated with equatorial Pacific SST anomalies contribute about 20% of equatorial Atlantic surface wind variability in spring.
The results suggest that a large portion of equatorial Atlantic wind variability in boreal spring is due to internal atmospheric processes and therefore not predictable. This may also limit the predictability of equatorial Atlantic SST variability.

Keywords: tropical Atlantic, predictability, seasonal prediction, interannual variability

Skillful multi-year predictions of tropical Atlantic-Pacific interaction

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Tropical sea surface temperature (SST) anomalies have large impacts on global climate variability through atmospheric teleconnections. Although reliable predictions of tropical SST variability are useful to assess the future climate variability, the predictability of tropical climate conditions is typically limited to the El Niño Southern Oscillation (ENSO) predictive skills for several seasons. Here we present observational and modelling evidence for multi-year predictability of coherent trans-basin climate variations that are characterized by a zonal seesaw in tropical sea surface temperature and sea-level pressure between the Atlantic and Pacific basins. State-of-the-art climate model forecasts initialized from a realistic ocean state show that the low-frequency trans-basin climate variability, which explains part of the ENSO flavors, can be predicted up to 3 years ahead, far beyond the predictable limit of ENSO. This low-frequency variability emerges from the synchronization of ocean anomalies in the Atlantic and Pacific basins via global reorganizations of the atmospheric Walker Circulation. Through this trans-basin connection, the Atlantic SST impacts on the atmospheric circulation can be detected in the decadal sea level pressure trends in the entire Pacific and western North American drought conditions.

Keywords: Climate variability, Climate prediction, ENSO, Atlantic, Trans-basin variability

Role of the Tropical Atlantic in the mid-70’ s ENSO shift

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A number of recent studies have argued that tropical Atlantic variability (TAV) can influence variability in the Indo-Pacific, and may even enhance the predictability of major El Niño events. However, the influence of the Atlantic on the Pacific appears to be non-stationary, being present after the 1970’ s and absent during the period 1930-1970. He we study the impact of TAV on the Indo-Pacific in partial coupled model experiments in which model sea surface temperature (SST) are restored strongly to observation over the tropical Atlantic while elsewhere the model is full coupled. For robustness we perform experiments with a full (ECHAM5/MPIOM) and reduced (SPEEDY-reduced gravity ocean model) complexity coupled models. Both models reproduce the strengthening of Atlantic-Pacific relation after the 70’ s, and this enhances ENSO variability, consistent with observations. The strengthening of the Atlantic-Pacific relation appears related to a warming of the South Atlantic that leads to a southward shift of the ITCZ in the Atlantic and a corresponding enhancement of the atmospheric response to local equatorial SST variability. The Atlantic Nino pattern also extends further to the west after the 70’ s, also favouring a stronger teleconnection. The role of the Atlantic in the 2015/2016 El Niño event will be discussed.

Keywords: Tropical Atlantic variability, ENSO, Climate prediction

Influence of Atlantic and Pacific multidecadal variability on Arctic warming

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We investigate the influence of Atlantic and Pacific multidecadal variability on the Arctic temperature, with a particular focus on the early 20th century Arctic warming (E20CAW). Arctic surface air temperature increased rapidly over the early 20th century, at rates comparable to those of recent decades despite much weaker greenhouse gas forcing. We find that the concurrent phase shift of Atlantic and Pacific multidecadal variability is the major driver for the rapid E20CAW. Atmospheric model simulations reproduce the E20CAW when forced with an improved sea surface temperature (SST) dataset. The E20CAW is associated with the cold-to-warm phase shifts of Atlantic and Pacific multidecadal variability modes. Atmospheric circulation changes are important for the E20CAW. The extratropical North Atlantic and North Pacific SST warming strengthens surface westerly winds over northern Eurasia, intensifying the warming there. The equatorial Pacific warming deepens the Aleutian low, advecting warm air to the North American Arctic. Coupled ocean-atmosphere simulations support the constructive intensification of Arctic warming by a concurrent, negative-to-positive phase shift of the Pacific and Atlantic multidecadal variability. Our results aid attributing the historical Arctic warming and thereby constrain the amplified warming projected for this important region.

Keywords: Atlantic multidecadal variability, Pacific decadal variability, Arctic warming

Attribution of Simulated Atlantic Multidecadal Variability to External Forcing, Internal Coupled Variability, and Weather Noise

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The mechanisms of the Atlantic Multidecadal Variability (AMV) simulated by the CCSM3 CGCM in a 300 year run with constant external forcing and in a 110 year run with 20th century forcing are isolated and compared. The diagnostic procedure employs several auxiliary configurations of the CCSM3 component models:

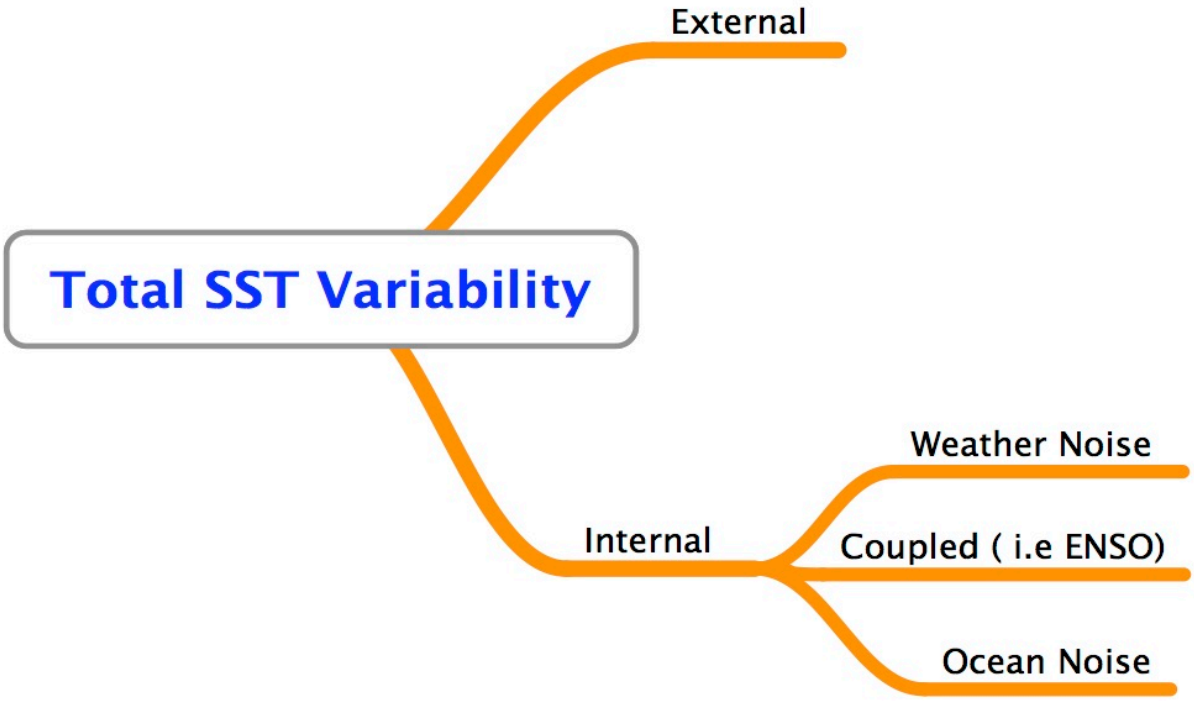
1) Ensemble of CGCM simulations (in the case of 20th century forcing). The externally forced AMV is the AMV of the ensemble mean of the CGCM simulations.

2) Ensemble runs of the AGCM component forced by the SST and external forcing from a CGCM simulation. The ensemble mean of the AGCM simulations diagnoses the SST and externally forced response of the atmosphere for a CGCM simulation (AMIP-type ensembles). Removal of the diagnosed SST and externally forced response from the CGCM simulation leaves the internal atmospheric variability (weather noise) as a residual.

3) The Interactive Ensemble (IE) version of CCSM3 forced by specified weather noise. The IE is a CGCM in which the ensemble mean of an AGCM ensemble is coupled to an OGCM. Each AGCM ensemble member is forced by the same SST, as produced by the OGCM, while the ocean and its SST are simultaneously forced by the ensemble mean of the AGCM surface fluxes. The IE coupling effectively parameterizes the atmospheric transient eddy fluxes, while suppressing the weather noise forcing of the ocean, leaving SST variability due only to external forcing, coupled atmosphere-ocean feedbacks and ocean internal variability. Due to the suppression of the weather noise, the IE responds quasi-deterministically to specified forcing applied to the IE OGCM. We take advantage of this property by forcing the IE with the weather noise surface fluxes diagnosed from original CGCM simulation in step 2. This specified forcing is applied either globally or regionally, and separately by process (surface heat flux, wind stress, salinity flux), to mechanistically attribute the CGCM simulated AMV response to the noise forcing structures. To complete the attribution, AMV not explained by external or weather noise forcing is attributed to internal variability of the ocean or coupled feedbacks between the atmosphere and ocean in the coupled system.

The results show that all of the potential mechanisms are playing a role in the simulated AMV, with:
-A predominant role for NAO-like weather noise forcing, associated especially with heat flux in the eastern North Atlantic and wind stress in the northwest North Atlantic,
-An ocean dynamical response to the weather noise involving the AMOC and gyre circulations that could be acting as a positive coupled feedback,
-A non-trivial role for 20th century external forcing.

Keywords: climate variability, Atlantic Multidecadal Variability, Interactive Ensemble CGCM, climate simulation


External
Total SST Variability
Weather Noise
Internal
Coupled (i.e ENSO)
Ocean Noise

Interbasin effects on subdecadal climate changes relevant to global warming hiatus

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Subdecadal modulation in the upper ocean heat content relevant to global warming hiatus is observed over the tropical Pacific in 2000s, in a different manner from other decades. On the subdecadal timescales, dynamical ocean response to the strong Pacific trade wind works to keep warm and cold tendencies in the western and eastern tropical Pacific Oceans, respectively. Consequently, it can contribute to slow down of global warming. Our decadal hindcasts with initialization insufficiently reproduce this subdecadal modulation a few years in advance, particularly due to low skill in hindcasting the strong trade wind observed in mid-2000s. Sensitivity experiments using a coupled climate model suggest that the strong trade wind can be largely contributed by high sea surface temperature over the tropical Atlantic Ocean in relation to the positive peak of the Atlantic Multidecadal Oscillation.

Keywords: interbasin effects, decadal climate variability, global climate model

A study on the decadal mode of the internally generated Atlantic Multidecadal Variability in CCSM3

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Mechanisms of the decadal mode of the internally generated Atlantic Multidecadal Variability (AMV) are investigated in the Community Climate System Model version 3 with constant external forcing. The AMV index is decomposed into interannual, decadal and multidecadal modes based on the ensemble empirical mode decomposition. The AMV decadal mode (12-year mode) is examined in detail. The interactive ensemble (IE) coupling strategy, with an ensemble of atmospheric GCMs (AGCM) coupled to an ocean model, a sea-ice model and a land model, is used to diagnose the roles of various processes in the coupled GCM (CGCM). The noise components of surface heat flux, momentum flux and fresh water flux of the control simulation, determined from the CGCM surface fluxes by subtracting the SST-forced surface fluxes, estimated as the ensemble mean of AGCM simulations, are applied at the Atlantic Ocean surface of the IE in different combinations.
The North Atlantic Oscillation pattern in the atmosphere, dominated by the noise component, forces the AMV decadal mode through noise heat flux and noise momentum flux. The associated ocean dynamics are connected with both noise heat flux and noise wind stress, but the Atlantic Meridional Overturning Circulation related to the decadal mode is more likely to be forced by noise heat flux. The atmospheric response to SST, including the SST-forced heat flux and SST-forced wind stress, acts as a damping.

Keywords: Atlantic Multidecadal Variability, Decadal mode, Interactive ensemble CGCM

Meridional Shift of the Gulf Stream Front in the Past 34 Years

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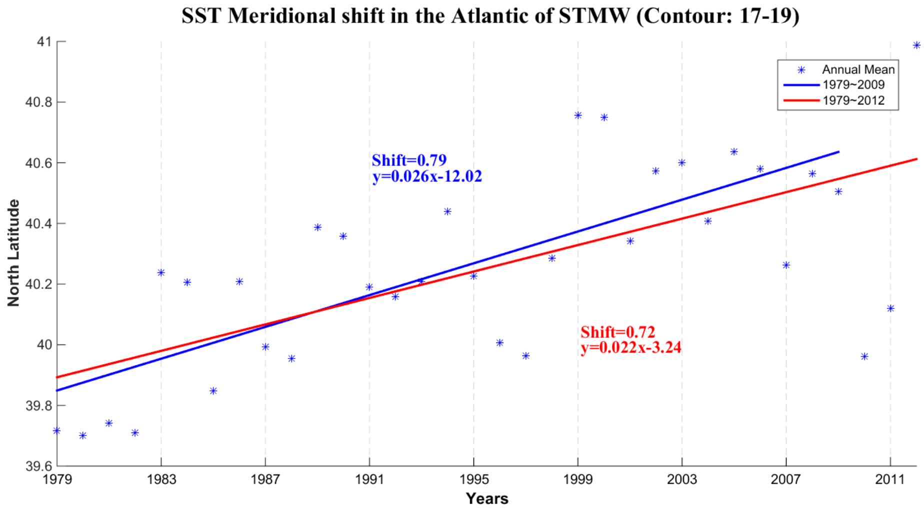
The subtropical sea surface temperature fronts (SSTF) in the Ocean, anchored by the strong western boundary currents, are the key regions in the climate system with huge heat and mass transport, high eddy activities, strong atmospheric storms, as well as major CO2 sink. They are also the most challenge areas in the climate model simulations and projections. Ongoing efforts are seeking to understand their variability, especially associated with climate change.
Here, by focusing on the SSTF in the North Atlantic Ocean along the Gulf Stream and its extension, we analyze its meridional shift in the past 34 years (1979~2012) with the Ishii reanalysis data. It is shown that the SSTF moves northward of 0.72 degree from 1979 to 2012. This pole-ward shift may reflect the extension of Hadley Cell under global warming. Interestingly, the SSTF meridional shift is uneven in the past 34 years among different seasons. In winter SSTF moves further northward with more than 1 degree while in other seasons SSTF only shift to north for about 0.5 degree. Meanwhile, the sea surface temperature gradient in the SSTF increases 50% in winter but decreases 10% in summer during that period. Besides the long-term trend of SSTF shift, there are strong decadal and interannual variability. Before 1999, the SSTF shift northward for more than 1 degree, from 39.6N to 40.8N. After 1999, the SSTF stops to move northward and turns to move southward for about 0.5 degree. This decadal change is consistent with the global warming Hiatus, when the global mean SST does not increase remarkably during 1999~2012, and may be partly related with the Atlantic Multi-decadal Variability. There is an extreme southward shift event of SSTF in 2010. It moves from about 38N in 2009 winter to about 36.5N in 2010 winter. It is reported that the observed transport of Atlantic Meridional Overturning Circulation (AMOC) has a dramatic drop in 2010 and the North Atlantic Oscillation also reaches a peak value of its negative phase. Weakening of the westerly wind and shrinking of subtropical ocean circulation will make the SSTF move southward and decrease the transport of AMOC.
Our study highlights the multi-scale variability and their interactions of SSTF. The short-term variability may affect the long-term trend of SSTF shift. For example, the strong southward shift occurred in the 2010 winter reduces the annual mean northward trend from 0.79 degree (1979-2009) to 0.72 degree (1979-2012). Since the Hadley cell will continue to expend pole-ward under the increasing of green-house gas, as predicted by climate models, we could expect the similar meridional shift of the SSTF. But the increasing of extreme events in the warming scenario may cause the SSTF to be more unstable and this needs further study with intense observations and high resolution climate models.

Keywords: Subtropical Sea Surface Temperature Front, Meridional Shift, Multi-scale variability, Gulf Stream


SST Meridional shift in the Atlantic of STMW (Contour: 17-19)
Annual Mean
1979~2009
1979~2012
Shift=0.79
y=0.026x-12.02
Shift=0.72
y=0.022x-3.24
North Latitude
Years
41
40.8
40.6
40.4
40.2
40
39.8
39.6
1979
1983
1987
1991
1995
1999
2003
2007
2011

The Effects of Explicit versus Parameterized Convection on Extratropical Air Sea Interactions: A Case Study of the Gulf Stream System using a High-Resolution Coupled Regional Climate Model

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Evidence is mounting that the atmosphere and ocean are tightly coupled along extratropical oceanic fronts, such as the Gulf Stream and Kuroshio. Unlike the coupling in the tropics that operates on large scales, the intense extratropical ocean-atmosphere interaction occurs at frontal-and meso-scales, which is not explicitly resolved by the current generation of climate models. This raises the question whether the unresolved air-sea interactions may contribute to large model biases over the oceanic frontal zones. To shed light on this issue, we conducted a set of eddy-resolving coupled regional climate model simulations of North Atlantic winter climate, where we systematically increase the resolution of the atmospheric model –the Weather Research & Forecast (WRF) –from 27 km to 9 km and finally to 3 km, while keeping the resolution of the ocean model –Regional Ocean Modeling System (ROMS) –at 9 km. At 3 km resolution, the atmosphere model begins to explicitly resolve convection, allowing us to simulate frontal- and meso-scale air-sea interactions without using parameterized convection in the coupled integrations. Inter-comparison among these numerical experiments provides some insight into how atmospheric model resolution and parameterized convection can have an impact on extratropical air-sea interactions and, consequently, on the simulation of the Gulf Stream system. The preliminary analysis shows that the simulation of the Gulf Stream system is sensitive to both atmospheric model resolution and convective parameterization. At 27 km resolution with parameterized convection, the simulated Gulf Stream shows a tendency to overshoot Cape Hatteras and separate too far north. As a result, the sea-surface temperature north of the Gulf Stream is significantly warmer in the 27 km simulations than in the 9 km simulations. Interestingly, when explicit convection is used at 3 km resolution, surface warming also occurs north of the Gulf Stream. However, this warming does not seem to be associated with the Gulf Stream overshoot, rather caused by changes in surface fluxes produced by explicit vs. parameterized convection.

Keywords: gulf stream, air-sea interaction, ocean eddies

