CLIVAR TROPICAL ATLANTIC MEETING, PARIS, November 2006

	CLIVAR TROPICAL ATLANTIC MEETING PROGRAM
WEDNESDAY November 18	
9:00	Welcome by Peter Koltermann, Intergovernmental Oceanographic Commission
Tropical Basin I	
9:10	Lothar Stramma - IFM-GEOMAR "The oxygen minimum zone south of the Cape Verde Islands"
9:35	Fritz Schott - IFM-GEOMAR "Mean circulation and variability of the tropical Atlantic during 1952-2001 in the ECCO assimilation fields"
10:00	Bill Johns - RSMAS "North Brazil Current Rings: Remaining Puzzles""
10:25	Regina Rodrigues - NOAA "Tropical Atlantic Decadal Variability Associated with Shallow Overturning Cells"
10:50	BREAK
11:15	Tropical basin I. Discussion - Synthesis/chairperson : Bill Johns
Equatorial Waves and Currents	
11:40	Marcus Dengler - IFM-GEOMAR "Upper ocean mixing processes in the tropical Atlantic during monsoon onset in 2006."
12:05	Gabriela Athie - IRD-Brest "Variability of intra-seasonal waves in the equatorial Atlantic"
12:30	Hyodae Seo - Univ. California San Diego "Effect of Coupling of Wind and Current on Tropical Instability Waves in the Atlantic Ocean"
12:55	LUNCH
14:20	J. Fisher/F. Schott. "SEUC analysis"
14:45	Irene Polo - Univ. Sci. Madrid "Kelvin wave activity in the tropical Atlantic"
15:10	Eq waves and currents. Discussion - Synthesis/chairperson: Marcus Dengler
15:35	BREAK
Equatorial SST and currents	
16:00	Verena Hormann - IFM-GEOMAR "Seasonal to interannual variability of the equatorial Atlantic cold tongue"
16:25	Peter Brandt - IFM-GEOMAR "Zonal flow in the equatorial Atlantic and its relation to the cold tongue"
16:50	Anne Charlotte Peter - LEGOS "Interannual variability of the equatorial SST"
17:15	Nicolas Kolodziejcjziyk - IRD-Brest "Equatorial Undercurrent analysis at 10°W"
THURSDAY November 19	
Equatorial SST and currents (continued)	
9:00	Bernard Bourlès (presented by Yves du Penhoat)- IRD-Brest "In situ observations in the eastern tropical Atlantic: status and perspectives in the framework of EGEE/AMMA and PIRATA".
9:25	Equatorial SST and currents. Discussion - Synthesis/chairperson: Peter Brandt
Upper Ocean Processes	
9:50	Juliette Mignot - LOCEAN-IPSL "Barrier Layer mechanisms"
10:15	Hervé Giordani - CNRM "How to catch the real dynamics of the near surface layers?"
10:40	BREAK
10:55	Jacques Servain - LOCEAN-IPSL "Oceanic Contribution to the SST seasonal cycle: regional balances in the tropical Atlantic"
11:20	Audine Laurian - LOCEAN-IPSL "Generation of subsurface salinity anomalies nearby the northern salinity maximum"
11:45	Upper Ocean Processes. Discussion - Synthesis/chairperson: Juliette Mignot
12:10	LUNCH
Air-sea coupling	
13:30	Ping Chang - Texas A&M "The effect of "weather noise" on seasonal climate prediction in the tropical Atlantic"

13:55	Mojib Latif - IFM-GEOMAR “Tropical Atlantic variability and hurricane activity”
14:20	Noel Keenlyside - IFM-GEOMAR “Understanding equatorial Atlantic Interannual variability”
14:45	Rein Haarsma - KNMI “The extra-tropical atmospheric response to equatorial Atlantic cold tongue anomalies”
15:10	Alban Lazar - LOCEAN-IPSL “Local processes involved in the seasonal migration of the AMITCZ”
15:35	BREAK
16:00	Alessandro Dell Aquila - ENEA “Variability in the north African summer circulation: a global perspective”
16:25	Air-sea coupling. Discussion – Synthesis/chairperson: Noel Keenlyside
16:50	GENERAL DISCUSSION I: Needs in observations and modeling
FRIDAY November 20	
Tropical basin II	
9:00	Christian Mertens – Univ. Bremen “Variability of the inflow to the Caribbean Sea”
9:25	Kerstin Kirchner - Univ. Bremen “Observed and modeled MOC related flow into the Caribbean”
9:50	Karina v. Schuckmann - IFM-GEOMAR “Intraseasonal variability in the southwestern tropical Atlantic”
10:15	Cyril Lathuilière - LOCEAN-IPSL “Surface chlorophyll variability along the northwest African coast”
10:40	Gregory Foltz - NOAA-PMEL “Unusually warm SST in the tropical North Atlantic during 2005”
10:55	BREAK
11:20	Tropical basin II. Discussion - Synthesis/chairperson: G. Foltz
11:45	GENERAL DISCUSSION II: Needs in observations/modelling (continued); the next and multidisciplinary tropical Atlantic meeting; other topics…
13:00	AJOURN

Session summaries:

Tropical basin I (Bill Johns)

Stramma reviewed observations the oxygen minimum zone of NW Africa – the focus of a new multi-year German SFB program. - and discussed issues relevant to the oxygen budget. A key issue in this problem is the role of ocean advection in bringing relatively high dissolved O2 waters into the region from the western tropics. Evidence for a significant NEUC source was presented.

Schott discussed progress in ocean reanalyses (ECCO and SODA-POP) efforts in the tropical Atlantic. Strong correlation was seen in ECCO between the Ekman transport divergence, STC convergence, and EUC transport on interannual time scales with a range of about 5 Sv and an apparent increasing trend over the past 20 years. The strength of the MOC in ECCO also increased which was reflected in the NBC transport at 10S. In a later session he also showed new evidence from shallow profiling floats that suggest the SEUC may terminate well east of the African coast, leading to doubts about its role in ventilation of the coastal upwelling zones there (i.e. Angola Dome).

Johns reviewed the status of knowledge on North Brazil Current rings and emphasized several key puzzles that remain about their dynamics and overall importance, specifically: (i) models still seem to suggest a lesser quantitative role of NBC rings in the MOC than indicated by observations, (ii) the process of formation of thermocline rings from the EUC retroflection is still not understood and has been paid little attention, and (iii) the year-round formation of surface rings at the NBC retroflection still needs to be satisfactorily explained.

Rodrigues presented new analyses of the SST meridional gradient mode and discussed issues regarding its persistence into the next year and what feedback processes may be involved. Given the fact that the meridional mode anomalies typically dissipate rapidly in the second half of the year it remains an important question how a decadal signal is sustained. She showed a seesaw between western boundary and

interior STC pathways with changes in the strength of the NE trades. A strong correlation was also shown between meridional flow convergence associated with the STCs and the variability of the meridional mode, with the positive SST pattern apparently leading the STC convergence by about 6 months.

Main Issues/questions:

Issue 1: Pathways of the MOC through the tropics
Questions:

1. What is the partitioning between western boundary (including rings) and interior pathways?
2. MOC Interaction with the STC's:
   - How does STC variability influence the MOC pathways (and vice-versa)?

Issue 2: Influence of STC variability on TAV
Questions:

1. Where does the memory of a boreal spring meridional mode event into the following spring reside ?
2. Is there a positive feedback between the ocean circulation in the tropics (e.g. STC convergence) and the meridional mode?

Issue 3: Role of zonal equatorial currents (and other circulation features) in supplying waters to the eastern upwelling zones
Questions:

1. What are the climatological transports and seasonal cycles of the EUC, SEUC, NEUC, and where/how do they terminate?
2. How do they vary interannually in relation to TAV (e.g., does the EUC's transport and eastward penetration vary systematically during Atlantic Nino events?)
3. Ventilation (and export) from the oxygen minimum zone?

Observation and modelling: what could be improved?

On the subject of MOC pathways through the tropics it would be useful to establish the degree to which models have reached a consensus on this or how greatly they differ among themselves and from observations. For example, the role of NBC rings versus interior pathways in various models has only been quantified in certain models. A coordinated model intercomparison project may be desirable for this.

Observations and modelling studies focused on determining the persistence mechanism of the SST gradient mode, and particularly the NTA SST anomaly pattern, should be encouraged.

The comparison of ocean reanalyses results provided by Schott indicates that SODA-POP suffers from unrealistically large transients when certain data are assimilated and ECCO/GECCO shows a prolonged sensitivity to initial conditions. This suggests that work remains to be done on improving data assimilation techniques in both OI and adjoint approaches and that considerable caution needs to be exercised in physical interpretations based on available reanalyses.

Further observational and modelling studies on the dynamics, structure, and termination of the currents feeding the eastern upwelling zones need to be undertaken as well as their interannual variability in relation to TAV. Observational enhancements from moorings to be deployed during TACE will help to improve the data coverage in the east but targeted programs involving floats and drifters would also be very useful.

Tropical basin II (Gregory Foltz)

1. Main progresses
The Caribbean route for meridional overturning circulation (MOC) return flow is important (>60% of surface layer return flow and >40% of intermediate water passes through Caribbean), but other routes (i.e. interior Atlantic) cannot be neglected (based on FLAME model simulations). There is strong variability of inflow into the Caribbean on time scales of 1-4 months that is likely associated with North Brazil Current rings (based on mooring data).

Eddy kinetic energy (EKE) in the equatorial North Atlantic is generated by a combination of barotropic and baroclinic instability; in the South Atlantic baroclinic instability dominates (based on model simulations).

The primary driver of intraseasonal to seasonal chlorophyll variability in the north-eastern tropical Atlantic is wind stress variability (based on satellite data). However, there is significant variability not related to changes in wind stress that may be associated with changes in wind stress curl and oceanic circulation.

On interannual time scales, SST in the tropical North Atlantic is driven primarily by changes in latent heat loss. However, contributions from horizontal oceanic heat advection and shortwave radiation are also important, especially during the record-breaking warm event of 2005 (based on PIRATA and satellite data).

2. Questions for future research
Besides the Caribbean pathway, what are the other routes for MOC return flow? What happens to NBC rings north of 15N?
What is the role of tropical instability waves (TIW) in oceanic heat transport (both horizontal and vertical)?

What are the roles of oceanic heat advection, shortwave radiation, and barrier layer formation in the mixed layer heat balance of the tropical North Atlantic?

3. Research projects
Argo will be helpful for evaluating the pathways of MOC return flow.

Measurements of currents, temperature, and salinity at the 0, 23W PIRATA site, as well as additional velocity measurements planned within a few degrees of the equator at 23W, will help to quantify the role of TIW in the mixed layer heat balance.

Satellite measurements and possibly the new PIRATA mooring at 12N, 23W, will help to quantify the roles of wind stress curl and oceanic circulation in driving surface chlorophyll variability.

Continued measurements at the PIRATA sites along 38W and at the NTA site at 15N, 51W will help to diagnose SST variability in the tropical North Atlantic. Additional current meter(s) (one at 30-60 m depth for example) and salinity measurements (at ~80 m) on the 15N PIRATA mooring would help to better quantify the roles of horizontal heat transport, entrainment, and barrier layer formation in the mixed layer heat balance.

Equatorial Sessions (Marckus Dengler and Peter Brandt)

Equatorial SST and Currents

The main topic of the session was the equatorial current system, its mean and seasonal to interannual variability, with focus on its relation to the mixed layer heat budget in the cold tongue region. New moored and shipboard observations particularly regarding the eastward EUC and the westward flow below were presented that yield better estimates of the mean flow and its variability needed as reference for numerical models. The heat budget of the mixed layer in the eastern tropical Atlantic and its relation to the equatorial flow field are analysed by high-resolution numerical models to obtain a better understanding of the interannual cold tongue variability and its possible predictability.

Hormann et al. analysed a high-resolution numerical model with respect to EUC variability associated with cold tongue SST variability. It was found that during boreal summer the EUC transport anomaly is anticorrelated with the SST anomaly of the cold tongue region, i.e. large EUC thermocline transports during cold events.

Brandt et al. showed from moored observations at 23°W that the EUC core as well as isotherms at the EUC core depth deepens during years with anomalous cold SSTs in the cold tongue region. From several ship sections and moored observations Brandt et al. also showed the existence of a mean Equatorial Intermediate Current at 35°W and 23°W flowing westward below the EUC. This current that consists of an upper and a lower core with an eastward core in between may have an impact of the flow of AAIW across the equator and its contribution to the MOC.

Peter et al. analysed the heat budget in the cold tongue region using a high-resolution numerical model. At a first order, the seasonal mixed layer temperature balance in the equatorial band results from cooling by vertical processes and heating by atmospheric heat fluxes and eddies (mainly tropical instability waves). At interannual timescale also dynamic, basin-scale processes, in particular horizontal advection, play an important role.

Kolodziejcjziyk et al. presented observational results regarding the flow variability at 10°W. The mean EUC transport was estimated to be about 9.2 Sv (Eulerian mean) representing a substantial reduction compared to the central equatorial Atlantic (14 Sv at 26°W). The EUC transport and stratification show a semi-annual cycle that is related to equatorial Kelvin and Rossby beams.

Bourles et al. (presented by du Penhoat) reported on the status of the observational programs in the eastern tropical Atlantic. Within the French EGEE program, 3 cruises were completed and another three cruises are planned (2006- 2007) substantially increasing the current and hydrographic data set from the eastern tropical Atlantic. The combination atmospheric flux measurements and microstructure measurements (G. Caniaux and M. Dengler) during EGEE cruises appear to be a challenging tool for identifying main biases in simulated mixed layer heat budgets of the region.

Equatorial Waves and Currents

Recent advances in the role of intraseasonal variability and its effect on the tropical Atlantic Climate system as well as new circulation schemes and measured diapycnal heat fluxes were presented.

G. Athie et al. analyzed state-of-the-art SST and SSH products that suggest a different dynamical behaviour of Tropical Instability Waves (TIWs) in the Gulf of Guinea compared to the central equatorial region.

A regionally coupled ocean-atmosphere model study presented by H. Seo et al. showed the atmospheric responds to TIW induced SST variability to have a negative feedback (damping) onto the TIW currents with a magnitude of about 10% of the barotropic conversion term.

An SSH and OGCM (ORCA05 model) analysis by I. Polo suggests a remote forcing of SSH anomalies in the Benguela and northwest African upwelling regions by equatorial Kelvin waves. Furthermore, phase and amplitudes of Kelvin waves exhibit significant interannual variability in the cold tongue region.

An analysis of recent drifter trajectories and CTD data by F. Schott et al. demonstrated the feeding of NECC and NEUC waters into the Guinea dome and showed a standing wave pattern in the western SEUC region.

Analysis of new microstructure measurements collected during the development of the cold tongue in June 2006 presented by M. Dengler et al. suggest large diapycnal heat fluxes of ~200 Wm^{-2} out of the mixed layer in the region of the EUC. Simultaneous shipboard turbulent atmospheric flux measurements showed a warming of 50 Wm^{-2} for the same region.

Part of the discussion focused on errors of atmospheric fluxes from bulk formula. Recent comparisons between measured turbulent atmospheric fluxes and bulk estimates showed large discrepancies. The question on how models could benefit from the results of microstructure data was raised. The suggested approach was to use one-dimensional models tuned to observed background conditions to validate the use of different model parameterizations for vertical mixing processes. The discussion suggested that the

impact of TIWs and Kelvin waves as well as their interannual variability on the mixed layer heat budget is one of the main issues to be addressed in future research.

What has been achieved?

- better heat budget at the PIRATA position in the Northwestern Tropical Atlantic
- barrier layer may play an important role for seasonal cycle
- knowledge about the mean thermocline and intermediate water circulation has advanced
- Ideas on diapycnal fluxes in the ocean and atmosphere have started to emerge from new combined atmospheric flux and oceanic microstructure measurements

Observations: what is missing?

- There are still large gaps in surface drifter, profiling float coverage in the Eastern Tropical Atlantic. It is important to enhance this coverage in the future.
- Observations regarding the wave-guide toward the south-eastern Atlantic are important to understand the dynamics and thermodynamics of Benguela Ninos.
- Possible cooperation between German, French and US groups to install turbulence measurements in north-eastern Tropical Atlantic (Cape Verde time series station?)

Largest variability in the cold tongue region was found to be related to the monsoon onset in June. Accordingly, a discussion addressed the coordination of a special observing period in 2009. In this period, equatorial current meter arrays at 23°W, 10°W and 0°W will be installed. Several research vessels (US, French and German) will be in the region. A combined coordination of the individual field programs will lead to an optimum coverage of surface drifters, floats and gliders to obtain a better understanding of the cold tongue heat content variability and the role of intraseasonal waves. A mooring at 2°N is important for understanding of TIW (will be deployed at 23°W in April 2008, Brandt et al.). Equatorial current meter moorings in the eastern equatorial Atlantic will address the termination of the EUC (Johns et al.). The combination of atmospheric flux and oceanic microstructure measurements should be still one of the main foci of the observational program to close the mixed layer heat budget in the cold tongue region.

Numerical modelling: what could be improved?

- necessity of regional modelling of the tropical Atlantic (regional coupled ocean-atmosphere models)
- need of better representation of mixed layer processes (increased mixed layer resolution to account for very shallow mixed layer depths)
- is the diurnal cycle important, how can it be modelled?
- possible role of EIC and intermediate currents for NBC ring generation and flow into the Caribbean, the MOC and oxygen minimum zones.

Upper Ocean processes (Juliette Mignot)

The understanding of upper ocean processes progressed in two directions. First, the recent observational data bases allow a global and seasonal mapping of the upper ocean structure such as the difference between the temperature and the salinity stratification. Seasonality of the barrier layer phenomenon was therefore assessed in greater detail and a wide area of subsurface temperature maximum was identified in the western tropical Atlantic.

Progress was also made in understanding the mechanisms responsible for these different stratifications. In particular, modeling work proposes a new method to predict the subsurface salinity anomalies subducting in the subtropical basin along isopycnals. Another direction of progress concerns the understanding of the upper heat budget. The oceanic contribution to the SST seasonal cycle could be investigated and quantified in an ocean general circulation model. Various regional regimes were identified. The role of the vertical mixing was emphasized, especially during summer everywhere in the basin, when the surface warms.

Questions that remain concern essentially the validation of the modelling results, as well as impacts at interannual to decadal scales. For the validation, more observations are of course needed, in particular

regarding the subsurface salinity, vertical mixing impact on SST, and density compensated anomalies below the thermocline. The ARGO data set is promising. Further analysis of the heat budgets at interannual frequency is planned.

Recent findings on mixing processes and upper-layer dynamics from the POMME programme in the midlatitudes could be applied to the tropical area in the framework of the AMMA/EGEE observation campaign. Strong vertical movements in the upper ocean in response to the wind forcing were also shed into light by using diagnostic tools, which helps to unravel the w-sources.

Air-Sea coupling (Noel Keenlyside)

1. Main progresses

Current tropical equatorial and South Atlantic predictability is low, and lower than levels suggested by perfect predictability studies. Understanding the reasons for this poor predictability and improving skill is a main area of research. Broadly speaking two approaches towards this were raised during the meeting.

First, it was shown that enhancing the signal to noise ratio (via statistical filtering) improves skill in the South Atlantic, while it had little or no affect on the cold tongue region.

The second involved understanding seasonality of the equatorial Atlantic, its affect on local variability, and on associated teleconnections.

The seasonal heat budget of the north west Africa warm pool was quantified in term of meridional migration forcing terms. It was shown to be controlled by latent heat losses, but largely also by horizontal advection and vertical mixing, depending on season and location.

The SST changes in this region are important for the seasonal migration of the ITCZ. This in turn, via changes in atmospheric and oceanic sensitivity, strongly modulates the positive Bjerknes feedback in the Atlantic that is responsible for the Atlantic Nino and explains its seasonality.

The position of the ITCZ is also very important for the teleconnections from the equatorial cold tongue and North Africa to the extra-tropics. For example, in November equatorial SST anomalies can influence deep convection, as the ITCZ is close to the equator, and hence have a large impact on the atmosphere.

Hurricane activity is also tied to ITCZ movements, through among other things the associated changes in wind shear. Understanding what modulates this from the seasonal to decadal timescale is thus important. It was pointed out that remote SST fluctuations in the Indo-Pacific need also to be considered.

2. Main questions

Three main questions were raised by the results of this session. The first is related to the mean climate and its seasonality. We know from previous studies and work presented here, that correctly representing these features is critical to simulating variability of the region and the associated teleconnections. Yet, almost all climate models simulate these features very poorly.
First question is thus, what are the principal reasons behind these tropical Atlantic biases, and how can they be improved? Only then can we start to trust in these models and expect improvements in prediction skill.

A second question is motivated by the prediction skill improvements demonstrated by noise filtering. This technique clearly demonstrated the utility of statistical methods to improve forecast skill. The question is thus, what statistical method (e.g., noise filtering and bias correction) may be useful for improving predictability of the region, at least in the shorter term.

A third question was motivated by results presented in other sessions on regionally coupled models. Through regional coupling, errors in other regions are excluded from the problem. Thus, to what extent can these models be used to understand and improve biases, understand equatorial variability, and improve prediction skill?

3. Main research projects

- Noel, Marcus, Mojib : Will work on an appraisal of the flux errors and their sensitivities in the ocean and atmospheric components of coupled models.
- Quantification of the biases in forced and coupled models in terms of migration of the ITCZ, which are in such context important through their meridional gradients, and not only their absolute value.