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Project Acronym: **PREFACE**

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Deliverable Reference Number and Title:

D 6.1

" Assessment of bias development in s2d integrations "

Lead work package[1] for this deliverable: WP6

Lead contractor[1] for this deliverable: MF-CNRM

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Actual submission date:

Project co-funded by the European Commission within the Seven Framework Programme (2007-2013)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	

[1] Name of beneficiary (=institute/organisation/university)

Contribution to project objectives – with this deliverable, the project has contributed to the achievement of the following objectives (see Annex I / DOW, Section B1.1.):

N.º	Objective	Yes	No
1	Reduce uncertainties in our knowledge of the functioning of Tropical Atlantic (TA) climate, particularly climate-related ocean processes (including stratification) and dynamics, coupled ocean, atmosphere, and land interactions; and internal and externally forced climate variability.	x	
2	Better understand the impact of model systematic error and its reduction on seasonal-to-decadal climate predictions and on climate change projections.	x	
3	Improve the simulation and prediction TA climate on seasonal and longer time scales, and contribute to better quantification of climate change impacts in the region.		x
4	Improve understanding of the cumulative effects of the multiple stressors of climate variability, greenhouse-gas induced climate change (including warming and deoxygenation), and fisheries on marine ecosystems, functional diversity, and ecosystem services (e.g., fisheries) in the TA.		x
5	Assess the socio-economic vulnerabilities and evaluate the resilience of the welfare of West African fishing communities to climate-driven ecosystem shifts and global markets.		x

Authors of this deliverable: A. Voldoire

Deviation from planned efforts for this deliverable:

(PLEASE ONLY COMMENT IF THERE WERE DEVIATIONS FROM THE ORIGINAL PLAN[2] IN PERSON-MONTHS PER BENEFICIARY[1] AND/OR WORK PACKAGE OR OTHER RESOURCE USE FOR ACHIEVEMENT OF THIS DELIVERABLE)

Report on the deliverable:

Report Summary

Several partners of the project have analysed the initial drift in existing seasonal forecasts as planned at the start of the project but several groups have also performed new simulations and already made some sensitivity experiments. UREAD has investigated the timing of the SST bias settlement in the tropical Pacific in the ECMWF seasonal forecasts. They have pointed out the role of easterly wind stress pulses in driving a cold SST bias along the equator which would be responsible for the northward shift of the ITCZ in the western Pacific. This thorough analysis put forward a method on how to investigate a causal chain of mechanisms and find the initial driver of a tropical bias similar to what happens in the tropical Atlantic. Their study clearly pictures the benefit of analysing initialised simulation both in forced and coupled mode. A draft paper of this work is in preparation.

CERFACS and MF-CNRM have collaborated to compare the drift in their respective version of the CNRM-CM model, that differ mainly by the resolution. BSC has performed a very similar analysis with the EC-EARTH model. In both cases, the role of the initialisation product used for the ocean has

[2] See List of person-months, nature and dissemination level of deliverable

been tested as well as the role of the model resolution. The problem of the initialisation product arises naturally when comparing different ocean resolution since high resolution models with ORCA025 are initialised using GLORYS which is produced using NEMO at the same resolution whereas low-resolution models are more easily initialised with ORAS4 done using the ORCA1 grid. The results of the 2 groups are not totally in agreement. In CNRM-CM, the increase of resolution clearly reduces the SST biases in most cases whereas it is much less clear in EC-Earth. Conversely, the ocean product used to initialize the low resolution model has a larger impact in the EC-Earth model than in the MF-CNRM model. However, the analysis has been conducted on experiments that do not span exactly the same period. This problem should be avoided in future simulations done in the context of the coordinated experiments to be performed as part of task 6.2. Nevertheless, in both models, the role of the wind stress curl and vorticity along the coast in the south-eastern Atlantic is clearly shown.

UiB and UniRes have collaborated to perform an analysis on the biases of the NorESM model in the Angola-Benguela region. Their study also points out the role of the wind curl in driving the SST bias. Interestingly, they show that there is no positive feedback between the SST bias and the wind stress bias since the wind stress bias is not amplified in the forced model using the biased SSTs. Along the coast, the role of the solar radiation errors of the atmospheric model are clearly modest compared to the thermodynamical adjustment of the atmosphere to the SST biases. This study is to be submitted soon.

Additionally, 5 partners have already started to run their coupled control simulation for the intercomparison exercise planned as part of task 6.2 of the project. A very preliminary analysis of these control simulations starting in February and May has been performed. This analysis confirms that all models drift toward a warm bias in the southeastern Atlantic. On the contrary, the drift is much more model dependent along the equator. The speed of the drift for the different surface fluxes is not similar in all models and for the 2 start dates. The mechanisms at play are thus probably model dependent consistently with what was shown for CMIP5 decadal hindcasts in Toniazzo and Woolnough (2013).

Several conclusions can be drawn from these studies:

- The great interest of analysing the drift in initialised simulations.
- Two regions of interests are to be considered : the equatorial region and the Benguela-Angola regions.
- The impact of the model resolution appears as model dependent, as is the role of the initialisation product.
- The role of the wind errors in driving the SSTs biases in both regions.
- The less important role of the solar radiation errors.

1 Bias development in the EC-Earth model, impact of resolution and of ocean initialisation

E. Exarchou (BSC)

We investigate the mechanisms explaining the development of the SST biases in the Tropical Atlantic in three sets of seasonal forecasts performed with EC-Earth3.0, which are four-month long and are initialized every first of May and November over 1993-2009 (Table 1.1). The bias here is defined as the difference between model SSTs and observational estimates of SSTs from HadISST dataset (Rayner et al., 2003). We use the experiment EXP-GLORYS (Table 1.1) as a baseline experiment. The two main differences between the other two experiments, namely the reanalysis product used to initialize the ocean (experiment EXP-GLORYS versus EXP-ORAS4), and the horizontal resolution in both the ocean and the atmosphere (experiment EXP-GLORYS versus EXP-GLORYS-high) allow an assessment of the impact of both the initialization product and the resolution on the SST biases in the Tropical Atlantic. When we compare EXP-GLORYS to EXP-ORAS4 we exclude years 1997, 2001 and 2002, because of a strong subsurface and surface temperature bias in GLORYS2V1 in the Tropical Atlantic. This bias has been reported in Milestone 21.

Exp	EXP-GLORYS	EXP-ORAS4	EXP-GLORYS-high
Resolution	T255L91-ORCA1L46-LIM2	T255L91-ORCA1L46-LIM2	T511L91-ORCA025L75-LIM2
Ocean initialization	GLORYS2V1	ORAS4	GLORYS2V1
Ice initialization	GLORYS2V1	GLORYS2V1	GLORYS2V1

Table 1.1*: Summary of experiments used in this study. GLORYS2V1 is discussed in Ferry et al., 2012, and ORAS4 in Balmaseda et al., 2013.*

The experiment EXP-GLORYS has a strong warm bias over the Angola-Benguela Area (ABA hereinafter, defined as the region between 8-15^o East and 10-20^o South) in all forecast months, and it is particularly strong during JJA (Figure 1.1). There is also a strong cold bias over the ATL3 box (defined as the box between 20^o-0 West and 3^o South and 3^o North), which is particularly strong during DJF (Figure 1.1). Since we do not compare with a historical simulation of the same model, we cannot assess at this point whether the biases are stronger during JJA and DJF because of longer lead times or because the model tends to have stronger biases at these particular seasons.

Changing the reanalysis product that is used to initialize the ocean results in a reduction of the warm bias over ABA during July and August, and in the cold bias during June, January and February (Figure 1.2). The fact that the ORAS4 is a better initialization product than GLORYS might be partly due to the fact that ORAS4 has been generated at the resolution used in these experiments while GLORYS has been performed at higher resolution so it has been interpolated to a lower resolution here.

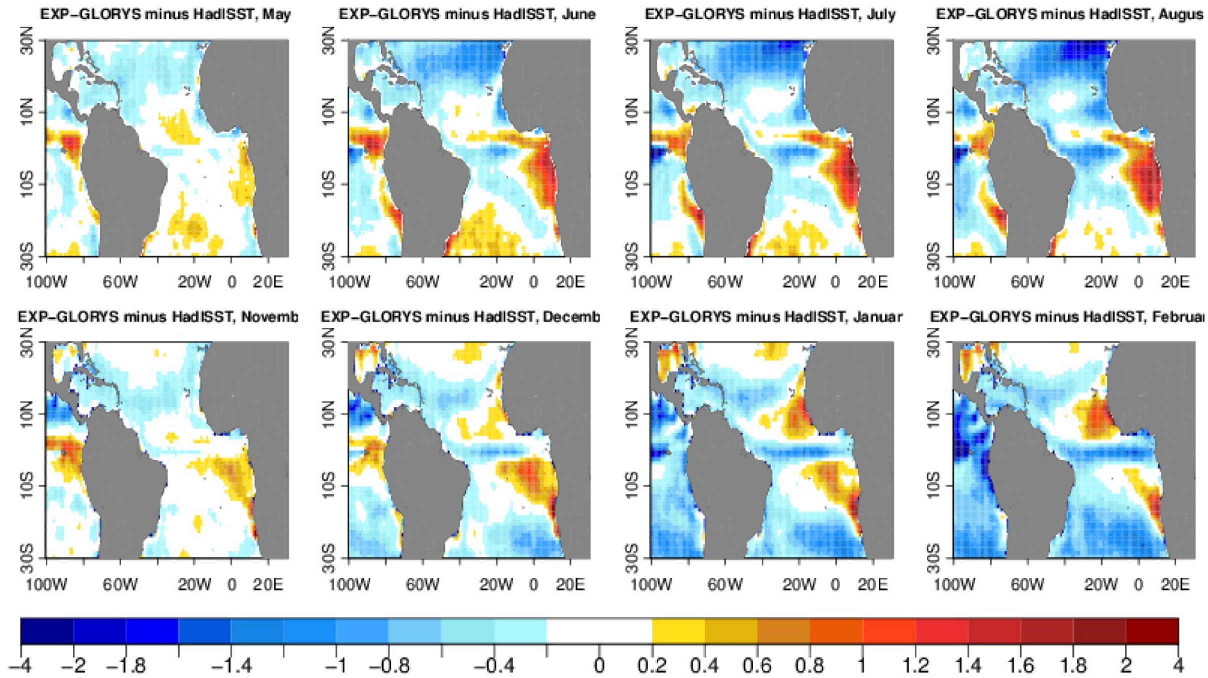

Figure 1.1: *Bias in SST for experiment EXP-GLORYS (Table 1.1) with respect to HadISST (Rayner et al., 2003) for the forecasts initialized in May (top row) and November (bottom row), for each forecast month.*

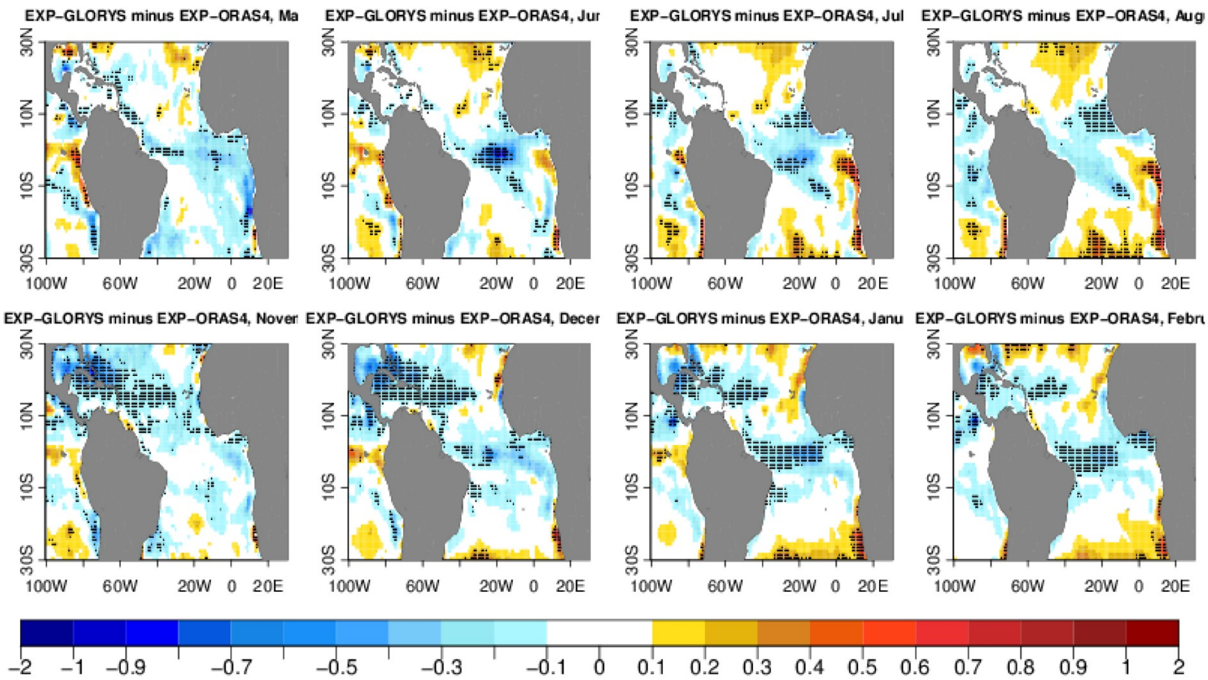

Fig 1.2: *Difference in SST biases between experiments EXP-GLORYS and EXP-ORAS4 (Table 1.1). Dotted areas indicate regions where the EXP-ORAS4 experiment has significantly smaller bias (at a 90% confidence level) compared to EXP-GLORYS.*

Increasing the model resolution results in a reduction of the cold equatorial bias during July and August, and of the warm bias in a very confined region close to the coast between 15-30^{0} South in January and February (Figure 1.3). These results imply that changing the model resolution has a relatively weak impact on the tropical Atlantic SST biases compared to changing the ocean initialization dataset. This point can also be illustrated when averaging the SSTs over the ABA and ATL3 region (Figure 1.4). Increasing the model resolution (EXP-GLORYS-high, bottom row of Figure 1.4) does not generally improve the bias, and in some cases it makes it worse (Figure 1.4).

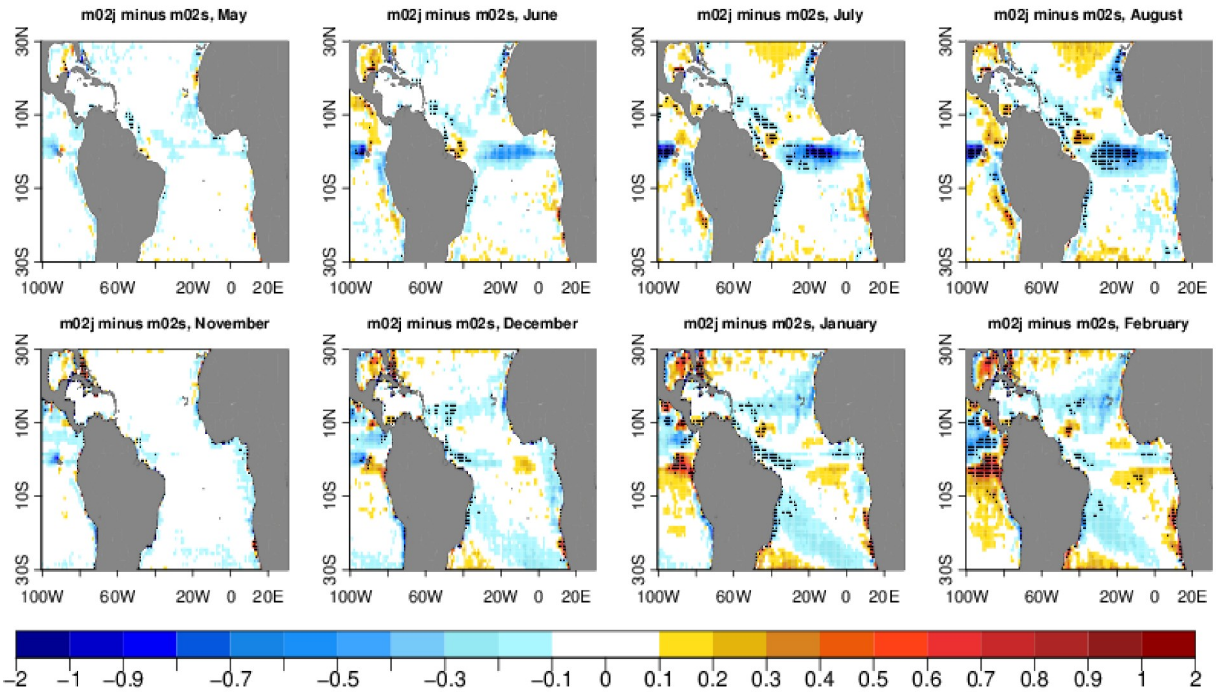

Fig 1.3: *Difference in SST biases between experiments EXP-GLORYS and EXP-GLORYS-high (Table 1). Dotted areas indicate regions where the EXP-GLORYS-high experiment has significantly smaller bias (at a 90% confidence level) compared to EXP-GLORYS.*

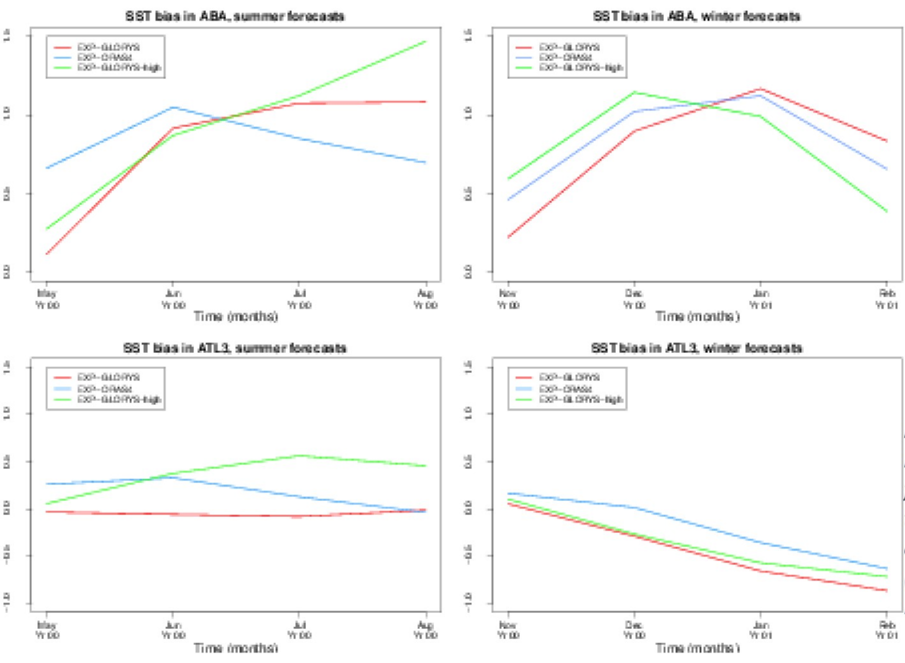

Fig 1.4*: SST biases for ABA (top row) and ATL3 (bottom row) for the three experiments, for the summer forecasts (left column) and winter forecasts (right column), with respect to HadISST.*

Focusing on the two experiments, EXP-GLORYS and EXP-ORAS4, which exhibit the largest differences among the three simulations in terms of SST biases in the Tropical Atlantic, we investigate to what measure an initial fast drift in the surface fluxes, occurring in the first days of the forecasts, could be responsible for the warm bias over ABA and the cold bias over ATL3. Systematic initial error growth in surface fluxes has been previously found to be responsible for warm SST biases over Southeastern Tropical Atlantic in different initialised decadal hindcast integrations of CMIP5 models (Toniazzo et al., 2014). We use here ERAint as a reference dataset for the fluxes, but ERAint fluxes have weaknesses over the Tropical regions, which were addressed in ERAint-derived products, such as the Tropflux (Praveen et al., 2012). We plan in the future to evaluate the uncertainty in the ERAint fluxes over the Tropical Atlantic. We find that in both EXP-GLORYS and EXP-ORAS4 the daily climatologies reveal that the model has weaker downward net heat fluxes than ERAint over ABA (Figure 1.5), therefore dumping the SST bias, rather than enhancing or generating it. The SST biases, therefore, do not seem to have an atmospheric origin. The model bias in the net fluxes is mainly dominated by the negative biases in latent heat fluxes during the forecasts initialized in May and negative biases in solar fluxes (therefore, too much cloud cover in the model) during the forecasts initialized in November. The bias in the latent heat fluxes indicate that it is likely a response, rather than a driver, of the SST warm bias. Over ATL3, on the other hand, there is also a negative bias in the surface net heat fluxes in May and November (Figure 1.5), which implies that erroneous surface fluxes in the model could be partly responsible for the cold bias in NDJF over the ATL3 region.

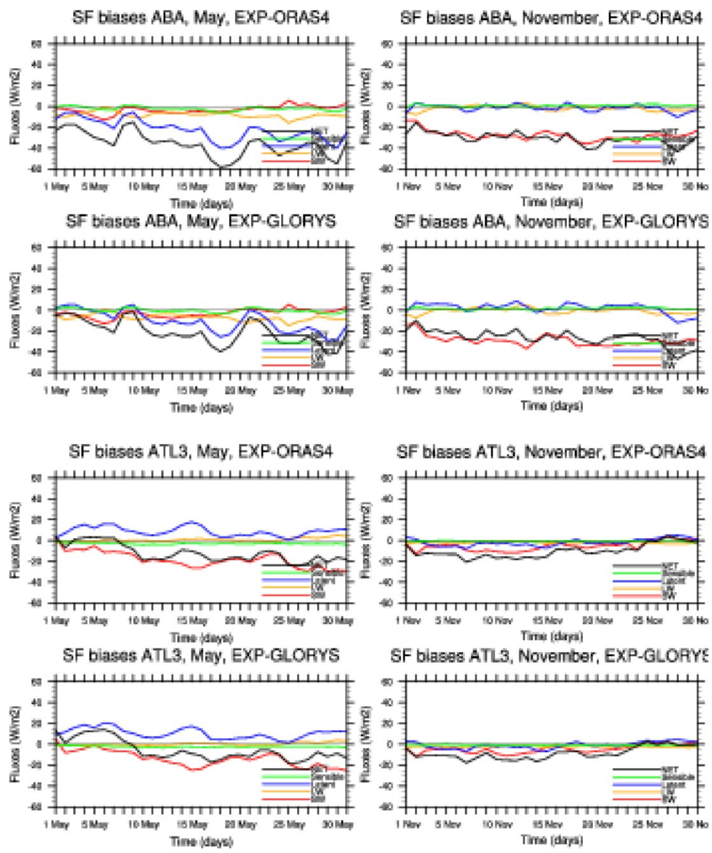

Fig 1.5: Biases in the four components of the surface heat fluxes with respect to ERAint: sensible (green), latent (blue), longwave (orange), shortwave (red) and net (black), where positive is downwards. The daily climatologies (where by "climatology" here we refer to the quantities averaged over every May and November between 1993-2009, excluding 1997, 2001 and 2002 for the ATL3 region) for May (left column) and November (right column), for ABA (top two rows) and ATL3 (bottom two rows) are shown, for EXP-GLORYS and EXP-ORAS4.

The lack of excessive downward surface fluxes over the ABA region, where there is the warm SST bias, indicate that the SST bias has likely an oceanic origin. A possible mechanism can be related to weaker wind curls, that would reduce the Ekman-driven upwelling in the coastal region, therefore resulting in weaker mass transport of colder water to the surface and a warm SST bias. We investigate such a hypothesis for the first few days of the summer forecast (Figure 1.6). The wind curl (and the wind vorticity) in the ABA region is negative (as in ERAint climatology, top plot of Figure 1.6), which denotes a clockwise circulation and an upwelling of water masses in the Southern hemisphere. A reduction in the negative vorticity in the coastal region of ABA, evident in both EXP-GLORYS and EXP-ORAS4, can result in weaker Ekman upwelling, and can generate or contribute to a warm SST bias.

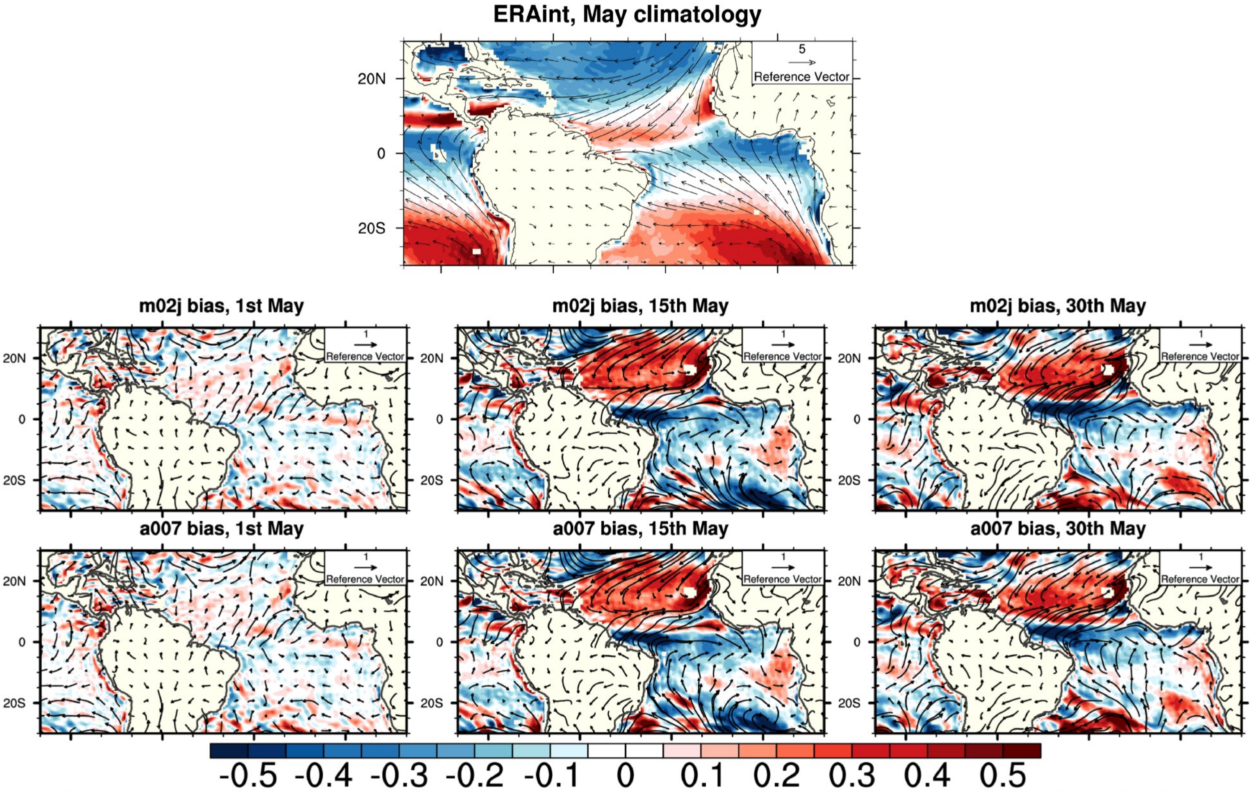

Fig 1.6*: Biases in surface wind (vectors, in m/s) and wind vorticity (colors, in m/s per 100km) with respect to ERAint for the forecasts that are initialized on 1st May. Results are shown for the climatologies of 1st May, 15th May and 30th May (EXP-GLORYS in the top row and EXP-ORAS4 in the bottom row). The May climatology for wind and wind vorticity in the ERAint dataset is also shown on the top. Positive (negative) vorticity corresponds to a counterclockwise (clockwise) circulation that is a downwelling (upwelling) in the Southern Hemisphere.*

2 Development of the systematic bias in the tropical Atlantic in seasonal hindcast experiments with CNRM-CM: Role of model resolution and ocean initialisation

C. Frauen (MF-CNRM), K. Goubanova (CERFACS)

To study the role of the model resolution on the development of the systematic bias in the tropical Atlantic an initial analysis is performed on existing seasonal hindcast experiments based on the CNRM-CM model. Two hindcast ensembles exist with the atmospheric model ARPEGE coupled to the ocean model NEMO at different resolutions. The model setups only differ in the sea ice and land surface models used. However, for this initial analysis these differences are of minor importance. The first ensemble (LR-ORAS4) is performed with CNRM-CM5.2 (Voldoire et al., 2013) and has an atmospheric resolution of T127 (1.4°) and 31 vertical levels. The ocean model uses an ORCA-1° grid with 42 vertical levels. The high resolution ensemble (HR-GLORYS) was performed in the framework of the SPRUCE project (Maisonnave et al., 2012) and has an atmospheric resolution of T359 (0.5°) and 31 vertical levels. The ocean model has an ORCA-0.25° grid and also an increased vertical resolution with 75 levels. In both cases the atmosphere model is initialised from ERA-Interim (Dee et al., 2011). However, the ocean model in the LR-ORAS4 case is initialised from ORAS4 (Balmaseda et al., 2013) while in the HR-GLORYS case from GLORYS (Ferry et al., 2012). The LR-ORAS4 ensemble was performed from 1993-2011 with start dates twice a year on the first of May and the first of November. The ensemble consists of 12 members with slightly perturbed atmospheric initial conditions and each experiment is run for 7 months. The HR-GLORYS ensemble was performed from 1998-2009 with the same start dates on the first of May and the first of November. However, the ensemble only consists of 3 members. Due to a problem with the GLORYS dataset, the years 2001-2003 are not considered in this analysis. To study the influence of the different ocean initialisation datasets an additional ensemble (LR-GLORYS) was performed with the low resolution model setup but also initialised from GLORYS. However, these experiments were only performed for selected years (2005, 2006, 2009), ran for 3 months and consisted of 5 ensemble members. An overview of the experiments can be found in Table 2.1.

	Resolution	Initialisation	Years	Members
LR-ORAS4	Atmos: T127 (1.4°), 31 levels Ocean: ORCA-1°, 42 levels	Atmos: ERA-Interim Ocean: ORAS4	1993-2011	12 members 7 months
LR-GLORYS	Atmos: T127 (1.4°), 31 levels Ocean: ORCA-1°, 42 levels	Atmos: ERA-Interim Ocean: GLORYS	2005, 2006, 2009	5 members 3 months
HR-GLORYS	Atmos: T359 (0.5°), 31 levels Ocean: ORCA-0.25°, 75 levels	Atmos: ERA-Interim Ocean: GLORYS	1998-2009 used only: 1998-2000 2004-2009	3 members 7 months

***Table 2.1**: Overview of the experiments setup.*

For both model resolutions also climatological runs were performed. Figure 2.1 shows the climatological mean sea surface temperature (SST) bias with respect to HadISST SSTs (Rayner et al.,

2003) from 30 year long control simulations with both model resolutions. Strong differences can be seen in the SST bias between the two model resolutions. The low resolution model has a much stronger bias along the coast in the South-East tropical Atlantic. However, in the high resolution model the bias extends further towards the West and is also stronger in the ATL3 (20W-0W,3S-3N) region. In the following the focus will be on the development of the SST bias in the ATL3 and the SETA (5E-12.5E,25S-5S) regions in the seasonal hindcast experiments.

a) b)

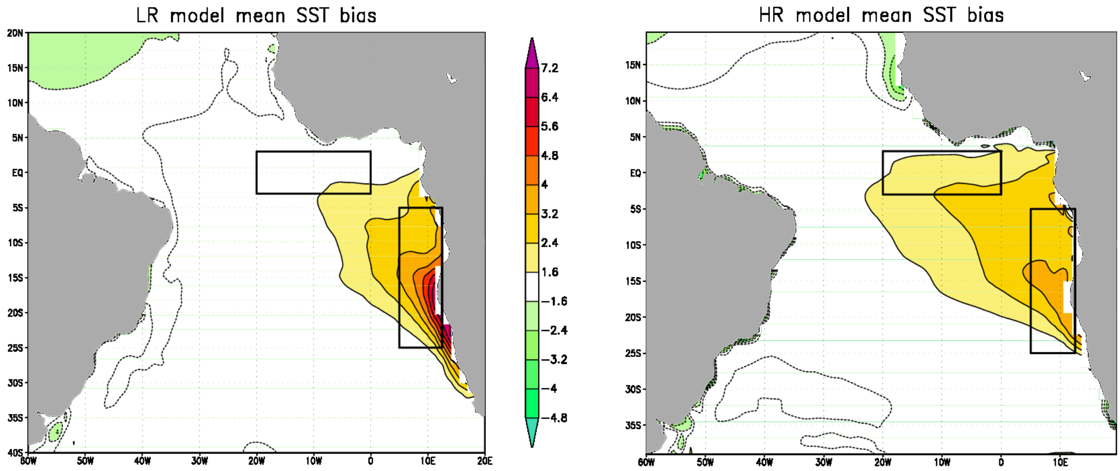

***Fig 2.1**: Climatological mean SST bias with respect to HadISST SSTs from 30 year long control runs with a) the low resolution model and b) the high resolution model. The boxes indicate the ATL3 and the SETA regions. Units are in [K].*

Figure 2.2 shows the evolution of monthly mean ATL3 and SETA SSTs in the different experiments in comparison to HadISST SSTs. Between the LR-ORAS4 and LR-GLORYS experiments there is little difference in the bias development. There is only a slight indication that the bias in the first month might be smaller in the experiments initialized from GLORYS compared to the experiments initialized from ORAS4. However, with only 3 years the LR-GLORYS ensemble is too small to draw any definite conclusion. In the framework of the PREFACE WP6 coordinated experiments two full sets of control hindcast experiments will be performed with the low resolution model initialized from both ORAS4 and GLORYS to allow a more detailed analysis of the role of the ocean initialisation dataset. As for the role of the model resolution, the differences in the bias development vary strongly depending on the region and the season. In the ATL3 no significant differences are found in the bias development between the low and high resolution models for the first months in the experiments initialized in November. Only after three months a slightly stronger bias seems to develop in the high resolution model. However, for the May start dates there are strong differences. While the low resolution model is not able to reproduce the strength of the spring cooling, the high resolution even overestimates the cooling. However, the reason for this is unclear and will be further analysed in the complete ensembles for the coordinated experiments. As for the SETA region for both the May and November start dates the bias is much stronger in the low resolution ensembles than in the high resolution ensemble from the first month. This is in good agreement with the much stronger climatological bias in the control simulation in the low resolution model in this region.

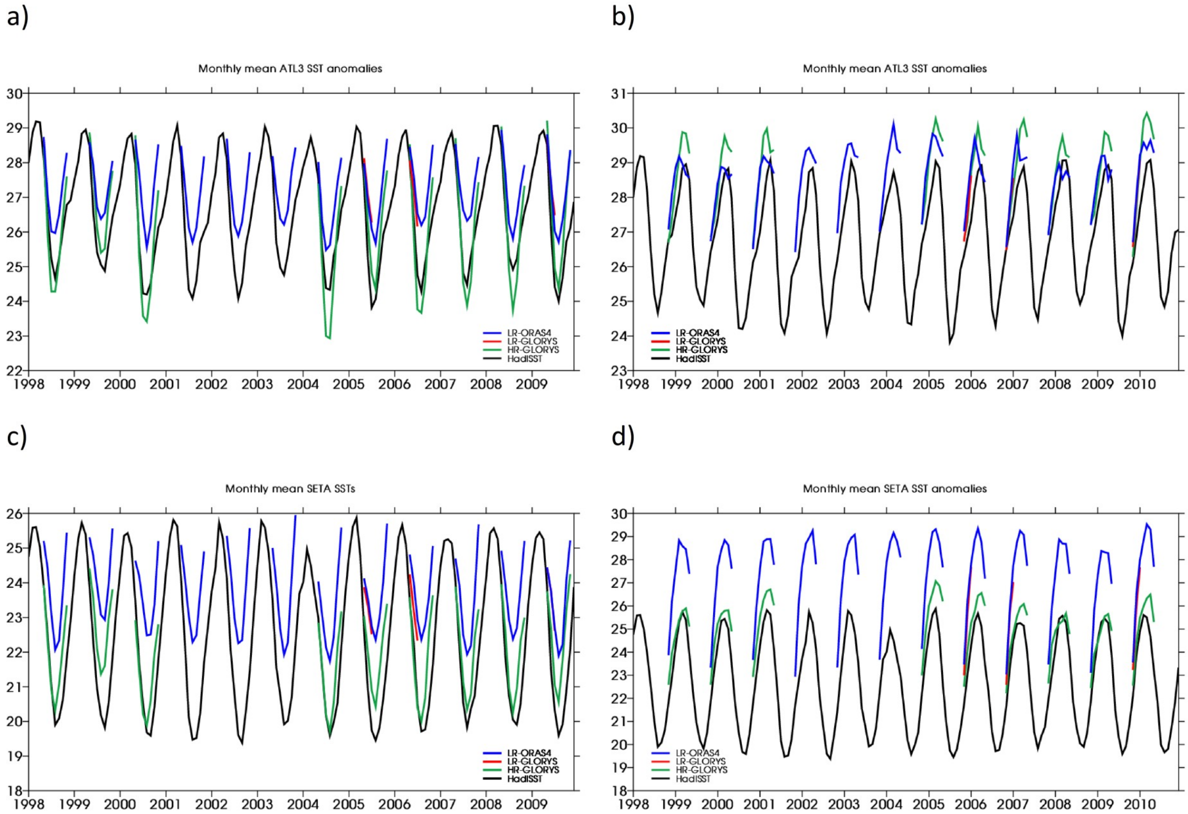

***Fig 2.2**: Monthly mean SST evolution in the ATL3 (top row) and SETA (bottom row) regions for the hindcast experiments initialized in May (left column) and November (right column). Black indicates the HadISST SSTs, blue LR-ORAS4, red LR-GLORYS, and green HR-GLORYS. Units are in [°C].*

A more detailed analysis of the daily evolution of the bias in the SETA region is performed based on the hindcasts starting in November for the years 2005, 2006 and 2009, for which the LR-GLORYS experiments were performed. Figure 2.3 shows the daily evolution of biases in SST and surface heat fluxes for the HR-GLORYS and LR-GLORYS experiments with respect to TropFlux (Praveen Kumar et al., 2012). In both experiment setups one finds a fast initial growth of the SST bias. While the bias in the HR-GLORYS case stabilises at around 1K after 2-3 weeks, the bias in the LR-GLORYS case continues to grow for at least the first 2 months and reaches values of around 3K. Both models show strong biases in the solar heat flux from the first day of the simulation, which are mostly compensated by biases in the longwave and latent heat fluxes. However, since these biases are of the same order of magnitude in both experiment setups they can't explain the difference in the bias evolution between them.

A comparison of the daily meridional wind stress and the evolution of the meridional wind stress bias with respect to TropFlux (Praveen Kumar et al., 2013) again shows no significant differences between the two ensembles (Fig. 2.4, upper row). However, this is not the case for the wind stress curl (Fig. 2.4, lower row). While the HR-GLORYS ensemble represents the magnitude of the wind stress curl in the SETA region relatively well, it is strongly underestimated in the LR-GLORYS ensemble. The negative curl seen in the observations and the HR-GLORYS model produces cyclonic circulation, which is favourable for the coastal upwelling of colder sub-surface waters. The weaker curl in the LR-GLORYS model thus diminishes the coastal upwelling, consequently leading to warm SST biases. Thus, a sufficiently high resolution of the atmospheric model is necessary to resolve the spatial structure of the wind stress near the coast and to realistically model the coastal upwelling.

This is in agreement with a study by Small et al. (2015), in which they analysed the role of model resolution and the coastal wind representation in the Community Climate System Model.

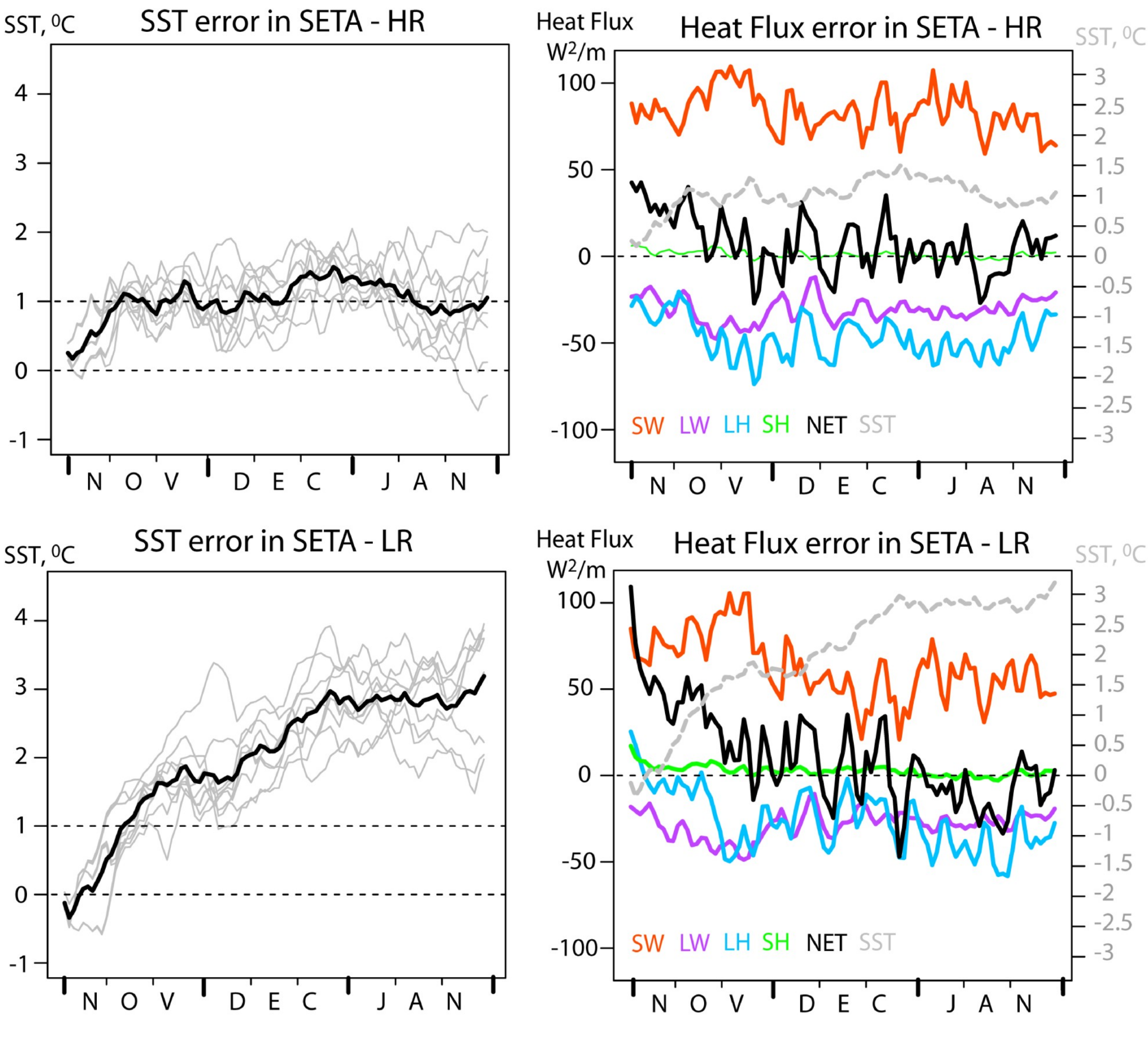

Fig 2.3*: Evolution of daily SST (left) and surface heat flux (right) biases in the SETA region averaged over the years 2005, 2006 and 2009 for the November restarts. The top (bottom) row shows the bias for the HR-GLORYS (LR-GLORYS) experiments. On the left the black line indicates the hindcast mean and grey lines mark the ensemble members. On the right positive fluxes correspond to ocean heat gain.*

Comparing the bias development in hindcast experiments performed with the same model only at different resolutions allows us to learn a lot about the development of systematic biases in the tropical Atlantic region. While this initial analysis already points out the important role of the model resolution in the SETA region, it also clearly shows that insufficient model resolution is not the only reason for systematic biases in the tropical Atlantic. Especially the differences between the two model resolutions in the simulation of the spring cooling in the ATL3 region need further analysis. The control hindcast experiments in the framework of the PREFACE WP6 coordinated experiments offer a good base for this. It will be especially interesting to analyse the bias development in the ATL3 region for the experiments initialized in February, which is the month when in the experiments initialized in November the high resolution model starts to develop a stronger bias than the low resolution model.

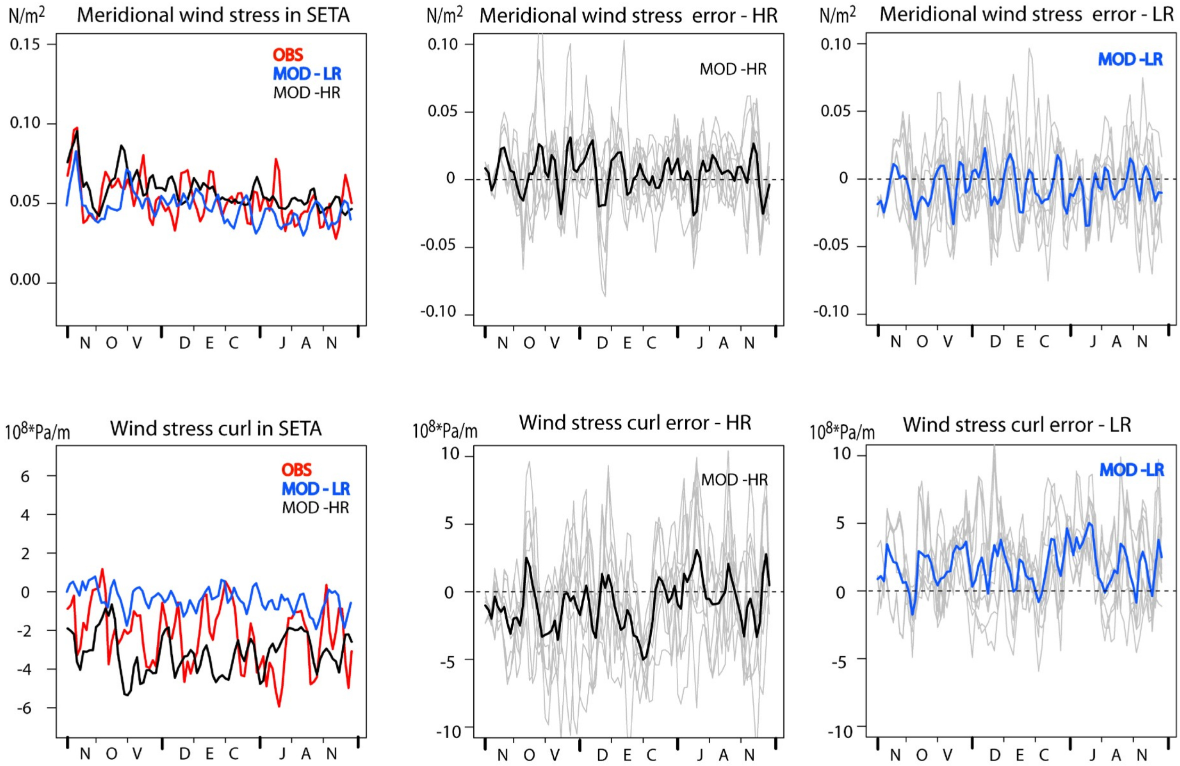

***Fig 2.4**: (Top) Evolution of daily-mean (left) observed (red line) and modeled (black – HR model, blue – LR model) meridional wind stress and corresponding errors for the (middle) HR and (right) LR models. Plain lines indicates hindcast or observed mean over 2005, 2006 and 2009; grey lines show the individual ensemble members. (Bottom) as in Top but for the wind stress curl. Negative curl corresponds to the cyclonic circulation favoring the coastal upwelling.*

3 Identifying Causes of ITCZ Drift in ECMWF System 4 Hindcasts

J. Shonk (UREAD) S. Woolnough (UREAD), T. Toniazzo (UniRes), E. Guilyardi (UREAD, UPMC),T. Stockdale(ECMWF)

We study the development of systematic biases in the ECMWF System 4 model, used operationally for long-range forecasting. We analyse seasonal hindcasts for the period 1996 to 2009. With a view on the global scale, we focus on the tropical Pacific.

We use two sets of hindcast:

- “coupled” hindcasts, which use the full operational configuration, with atmosphere and ocean coupled together;
- “uncoupled” hindcasts, which use the same model version, but with prescribed sea-surface temperatures (SSTs) from observations.

The time evolution of ensemble-average, forecast-average, systematic model errors with respect to observations is documented in terms of monthly and daily averages. Our reference observational datasets consist of OISSTv2 for SSTs, TRMM and CMAP for precipitation, OAFlux and TropFlux for surface fluxes and radiances; and ERA-Interim for winds and atmospheric temperature, humidity and geopotential on pressure levels.

3.1Northward Drift of the ITCZ

In the ECMWF System 4 model, the intertropical convergence zone (ITCZ) drifts to the north from the observed location during the first three months of forecast. Here, “observed location” is defined as the latitude of the precipitation centroid averaged over latitudes containing more than half of the rainfall at the latitude with the highest rainfall. This drift is most pronounced in the tropical western Pacific. Figure 3.1 shows the deviations of the latitude of the ITCZ in the hindcasts (coloured lines) compared with the observed one (solid black line). Over the course of a seven-month hindcast, the erroneous shift is between 1° and 3° northwards.

This drift appears to follow from a cooling of the SSTs over the equatorial ocean. The cooling over the equator suppresses convection on the equator; the local meridional temperature gradient pushes rainfall to the north. The coupled error appears nearly saturated at four months lead time, but a spurious cooling tendency over the equatorial Pacific is apparent at one month lead time already (Fig 3.2).

We exploit daily-mean data to analyse the chronology in which systematic biases develop and infer a possible chain of causality. A summary of the main results so far is exemplified in Figure 3.2, which shows longitude—time plots of the zonal component of the surface wind stress averaged with a 2° latitude band straddling the equator. A pulse of excess easterly wind stress appears in the West Pacific, peaking in intensity after about ten days. This pulse develops almost identically in the coupled and uncoupled hindcasts, implying that the error originates in the atmosphere model component. The wind cools the surface, at least initially, by evaporative cooling. This process can be confirmed by comparing the rate of model cooling with a predicted cooling using latent heat error derived from the wind tress error and the model mixed-layer depth.

The wind error is seen to develop rapidly from day one, starting as an easterly error at the surface over the central Pacific, then building until, after ten days, an error pattern suggesting a strengthened Walker circulation is seen (fig 2c).

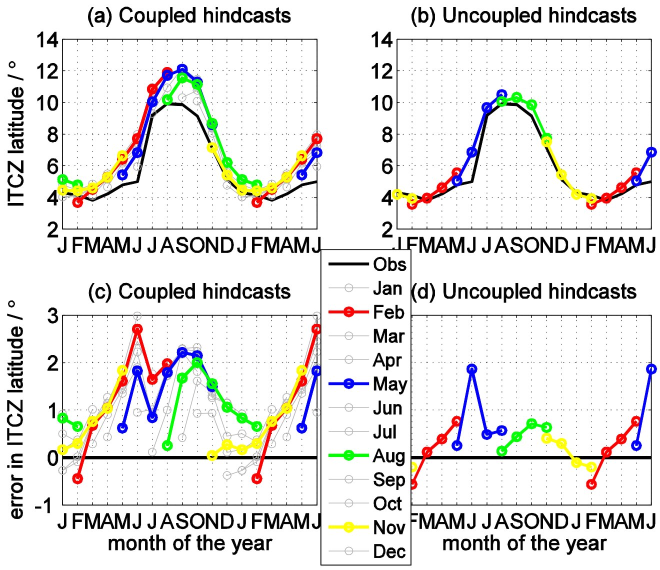

Fig 3.1: *"Worm plots" showing the location of the ITCZ in the western Pacific, both for observed rainfall data from TRMM (black line) and ECMWF System 4 (grey and coloured lines). Each of the latter shows evolution of ITCZ location for each start month for which data is available. The top row shows the absolute location of the ITCZ; the bottom row shows biases with respect to the observed location.*

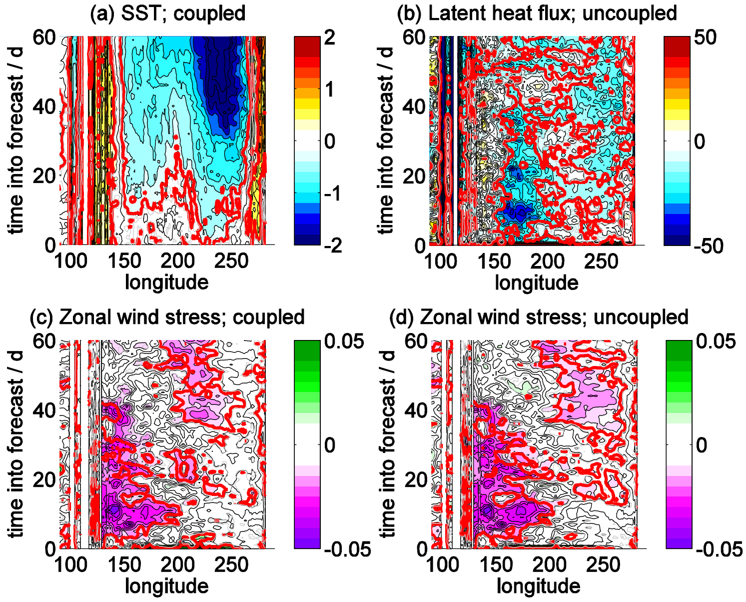

Fig 3.2: *Longitude—time plots, showing model bias growth in (a) sea-surface temperature in °C; (b) latent heat flux in W m^{-2}; (c, d) zonal wind stress in N m^{-2}, averaged over the latitudE2 boxes. For observations, we use OISSTv2 for sea-surface temperature, OAFlux for latent heat and TropFlux for wind stress. Hindcasts starting on February are shown, wih statistics over years 1996 to 2009. Significance is indicated by the red contour.*

3.2 Next Steps

Having identified the driver of the northward drift of the ITCZ in the ECMWF System 4 as an easterly error in the atmospheric wind fields, we wish to determine the cause of the wind error itself. So far, we have observed a tendency for the entire pattern in the divergent component of the tropical atmospheric circulation to shift to the west in the first few days of hindcast.

Ultimately, once we have found a process that contributes to this error in the early stages, we can test that this is the case by performing model simulations that correct for this wind error and see if this ITCZ drift still occurs.

4 Causes of the large warm-bias in the Angola-Benguela Frontal Zone in the Norwegian Earth System Model

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We have investigated the causes of warm sea surface temperature (SST) bias in the southeastern Atlantic Ocean, the Angola-Benguela Frontal Zone (ABFZ) arising in the Norwegian Earth System Model (NorESM) simulation. Similar to other coupled-models, NorESM bears the warm SST bias in the ABFZ of up to 8K in the annual mean (in JJA, this warm SST bias is the largest). Our analyses on results of NorESM reveal that an erroneously local low pressure (-3hPa) and clockwise surface wind around the ABFZ drives the anomalous southward Angola Current and displaces the ABFZ southward. The location of the clockwise surface circulation is approximately with that of the warm SST bias in the ABFZ.

The demonstration of standalone experiments of atmosphere and ocean (O1) with control configuration (AMIP5/COREv2-Internanual forcing) shows that both of the uncoupled models have basic errors around the ABFZ: the atmospheric model exhibits a similar erroneously strong local clockwise surface circulation anomaly and the ocean model has the warm SST bias that is a half of NorESM full bias in the ABFZ. The same experiment of the ocean model with higher horizontal resolution also has the warm SST bias of about 4K in the ABFZ. The sensitivity experiment (in which the COREv2-IAF climatology is replaced with the climatological surface wind of atmospheric model over the ABFZ, O2) shows that the local clockwise surface wind error generates the anomalously strong Angola Current and consequently, the warm SST bias in the ABFZ is amplified by 2K (equal to a quarter of NorESM full bias). However, the enhanced warm SST bias does not amplify the atmospheric primal error of local low pressure and clockwise surface circulation, revealed by another sensitivity experiment with the forced atmospheric model. This result indicates that there is no positive feedback among warm SST and low pressure-negative wind stress curl in the ABFZ.

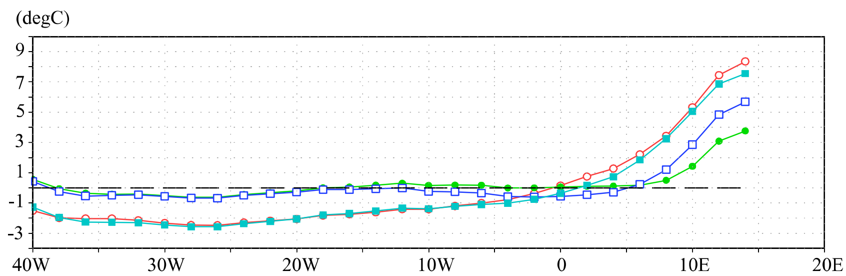

Fig 4.1:. Longitudal section of climatological annual-mean SST difference for each experiment with respect to the observation; NorESM(red), O1(green), O2(blue), and O5(light blue). Each line is averaged between 17S and 22S

To investigate the rest of causing chain of the warm SST bias, we have conducted a sensitivity experiment (O5) in which the climatological errors of 2m temperature and specific humidity are added on the COREv2-IAF as well as surface wind error. This experiment showed that the warm SST bias in the ABFZ is approximately consistent with that in NorESM. The thermodunamically-adjusted atmosphere contributes to reduce the ocean surface fluxes and enhances the warm SST bias in this experiment. In NorESM and our sensitivity experiments, remote effect via equatorial and coastal Kelvin Waves does not appear to be exposed in the ocean surface, but only the ocean subsurface. Additionally, a sensitivity experiment is performed in which the climatological solar radiation error is added into COREv2-IAF. This correction conterbalances the underestimation of low-level cloud over the subtropical southern Atlantic in NorESM in JJA, but its impact on SST is negligibly small compared to surface wind and atmospheric dumping.

5 Analysis of the drift in the coordinated control experiments of task 6.2

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Dedicated simulations have started to be performed as part of task 6.2. These experiments are initialized experiments starting in February and May. 5 groups have started to run the control experiments. The list of models involved is indicated in table 5.1. These experiments are considered as control simulations for the sensitivity experiments to be performed in intercomparison mode. For the time being, all groups have not performed the simulations for all start dates and years planned see table 5.1). The results presented here are thus based on heterogeneous ensemble sizes and need to be considered as preliminary results.

Model Name	Institute	Years simulated	Start Dates
CNRM-CM-BR v5.2	MF-CNRM	1993-2009	Feb and May
CNRM-CM-LR v5.1	CERFACS	2001-2004 2006-2008	Feb
ECMWFS4	UREAD, ECMWF	1996-2009	Feb and May
EC-Earth v3.1	WU, BSC	2000-2009	May
Nor-ESM	UniRes, UiB	1981-2000	Feb and May

Table 5.1: *Models used in the coordinated experiment analysis.*

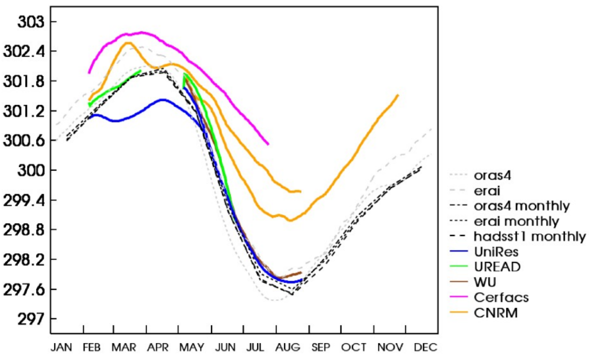
It can be seen that the WU and UREAD models are able to represent reasonably well the equatorial cold tongue development seen on the ATL3 region (fig 5.1), whereas the MF-CNRM and CERFACS models underestimate largely the cooling whatever start date is considered. However, the timing of the drift depends on start dates. In both cases, the SSTs become warmer than observations in June, that corresponds to five months lead time for February starts and one month lead time for May starts. On the contrary, the UniRes model is colder than observation products and weakly overestimate the spring cooling. On figures 5.1 and 5.2 several observationally derived data set have been added in black for monthly data or in grey for daily data so as to estimate the uncertainty in the reference. Over ATL3 and consistently with the SST biases, only the MF-CNRM and CERFACS models have large biases in momentum and surface heat fluxes (fig 5.1b-d). The latent heat flux is largely overestimated, but this acts to cool the ocean, thus this error is probably a feedback of the warm SST bias rather than the source of the bias. Similarly, the solar heat flux is underestimated and can not explain a warm bias. On the contrary the surface zonal wind stress drift very quickly and becomes positive within a month. The momentum flux is thus more probably the driver of the SST bias in these two models.

From this preliminary analysis, two groups of models can be formed, one without large biases over the ATL3 region and one with a strong warm bias associated to surface momentum biases. These models will probably behave very differently in the sensitivity experiments.

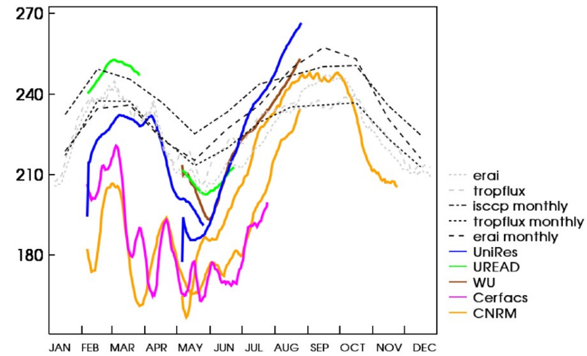
Over the south-eastern region (0E-10E, 20S-5S), all the models tend to have a warm bias that settle rather smoothly(fig 5.2). The MF-CNRM model still drift more quickly than the others for February starts. In many cases, the timing of the error development of the solar heat flux is not consistent with the SST bias development (Fig 5.2a-b). In the UniRes model, the solar heat flux drifts very quickly within a few days whereas the SST errors develop smoothly. On the contrary, for the MF-CNRM model, the SST bias develops faster for February starts whereas the solar radiation error is remains weak for several months. In this region, all the models tends to overestimate the latent heat flux loss but this can not be considered as the driver of the initial drift.

Generally speaking, the biases in the region are similar for all models but the speed of the drift is quite different which may indicate that the processes at play are not exactly similar. To better understand the mechanisms at play, the partners of the intercomparison experiments will perform a thorough analysis of the drift in their respective models as been done by UREAD for the tropical Pacific. For this preliminary analysis, all the groups have not been able to provide their respective initialisation product to clearly picture the bias development taking the proper reference dataset for each model. This will have to be done in future analysis. Given the diversity of the models behaviour in their initial drift, the response in the sensitivity experiments to be performed will probably be model dependent.

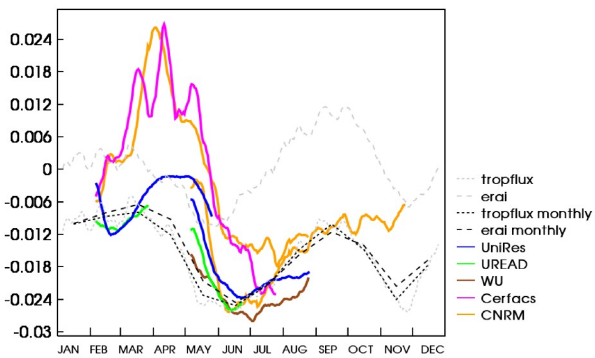
a) SST (K)



b) Net surface solar flux (W/m^2)



c) Surface zonal wind stress (N/m^{-2})



d) Surface latent heat flux (W/m^2)(positive downward)

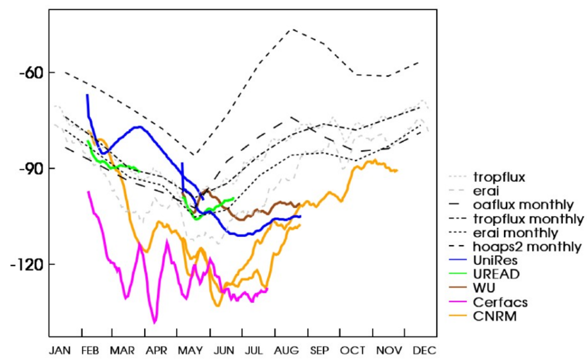
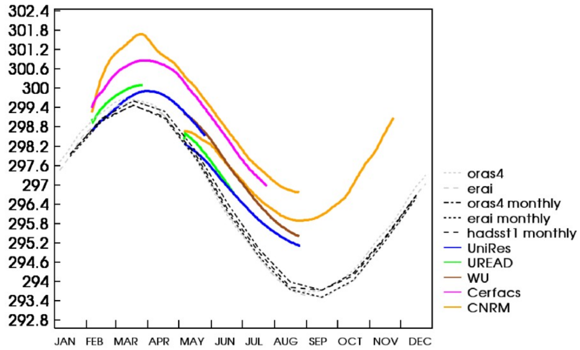
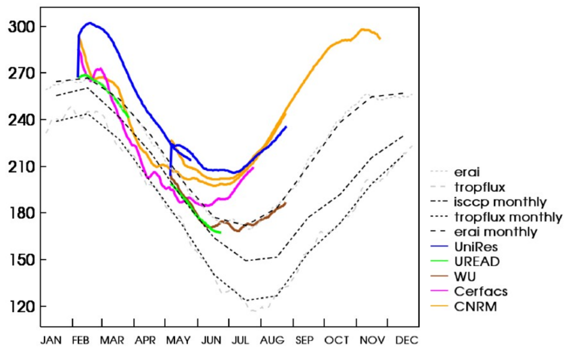


Fig 5.1: *Time evolution of a) SST, b) net solar flux, c) zonal wind stress and d) latent heat flux over the ATL3 box (20W-0E,3S-3N). The different models are in color, and daily observational data are in grey, black lines are for monthly data. A 11 day running mean average has been applied on daily data series. Time series are ensemble mean averaged over the period simulated by each model.*

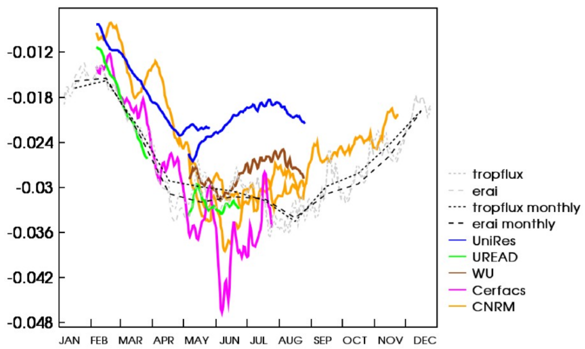
a) SST (K)



b) Net surface solar flux (W/m^2)



c) Surface zonal wind stress (N/m^{-2})



d) Surface latent heat flux (W/m^2) (positive downward)

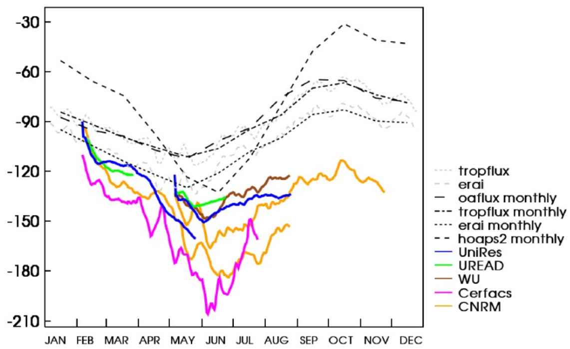


Fig 5.2: *As figure 5.1 for a box over the south eastern tropical Atlantic open ocean (0E-10E, 20S-5S).*

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