Coupled errors of CMIP5 GMCs in the South-eastern tropical Atlantic

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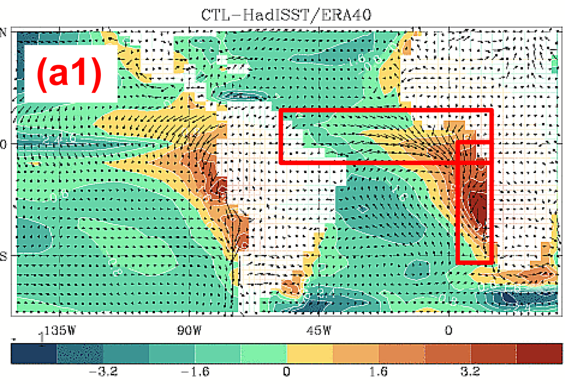
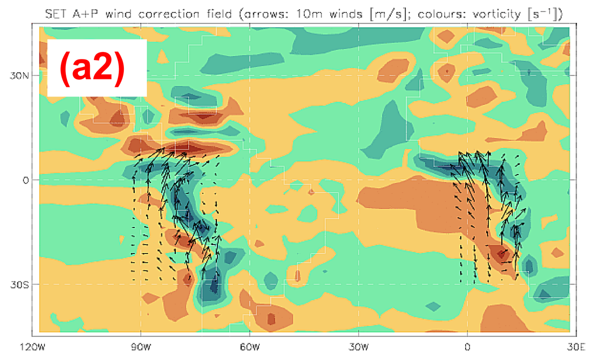
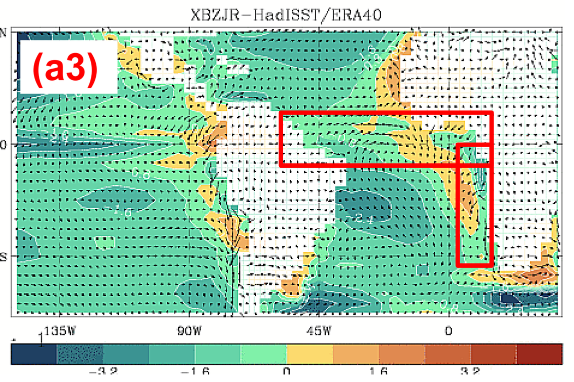
1. Wind, SST, and ocean errors in tropical coastal upwelling systems

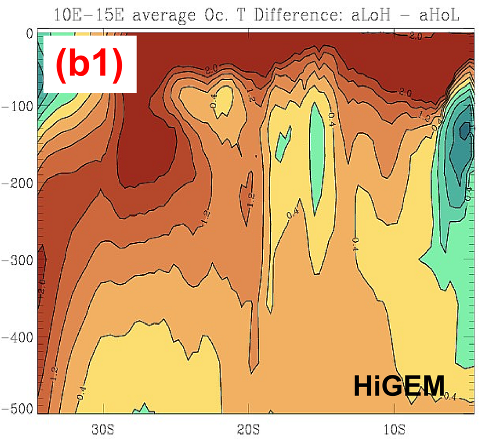


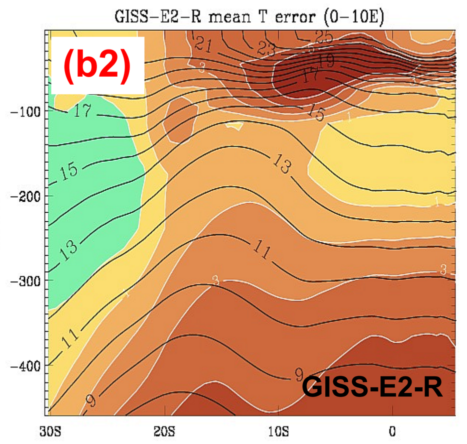




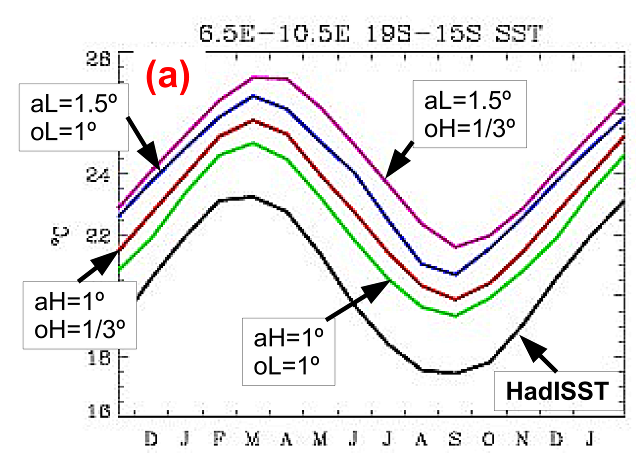
The marine area of the south-eastern tropical Atlantic (SEA) is associated with warm SST biases in GCM, linked with the equatorial region and impairing the simulated climate in climatically critical land areas s.a. the Amazon basin. Due to the presence of coastal and equatorial upwelling, the errors are sensitive to wind-stress errors, Figures (a1-3), but equally to misrepresentation of the subsurface ocean waters, Figures (b1-2).

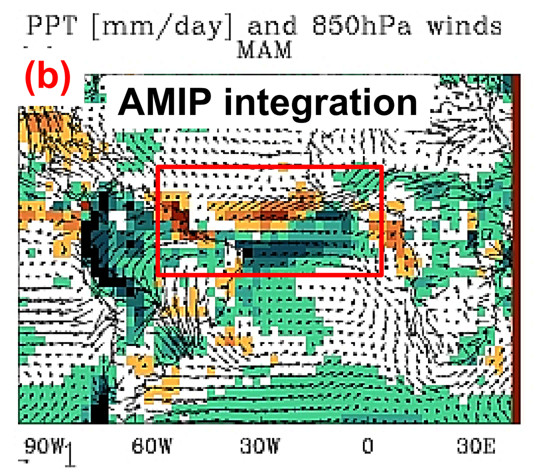
- In the HadCM3 model (above and left), correcting wind biases eliminates the warm coastal SST errors (Toniazzo 2010)
- In the SEA, SSTs feed back on the winds (not in the SEP)
- In some CMIP5 models (right), subsurface warm errors exist that may be of remote origin



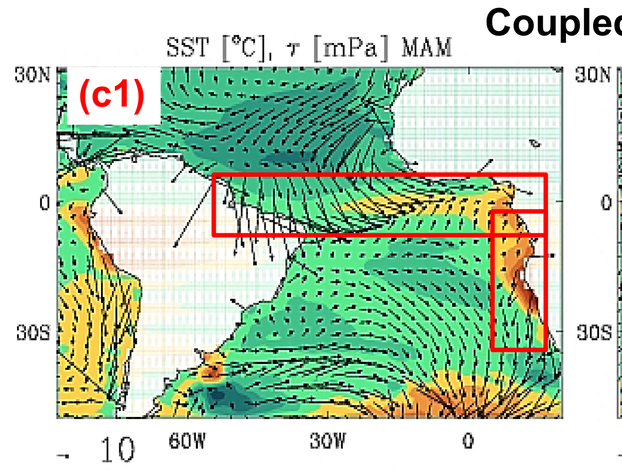


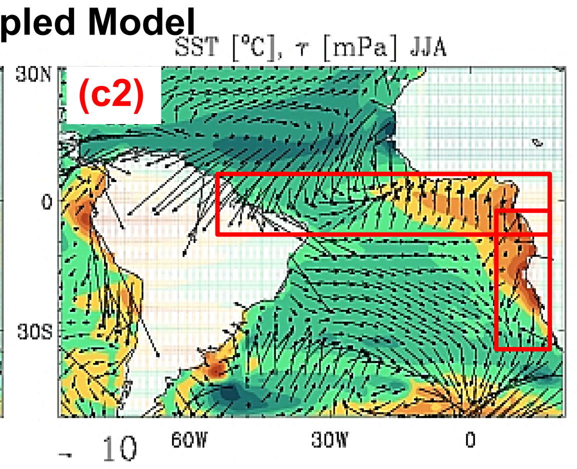
2. Robustness and resolution (in)dependence of errors





Coupled Model

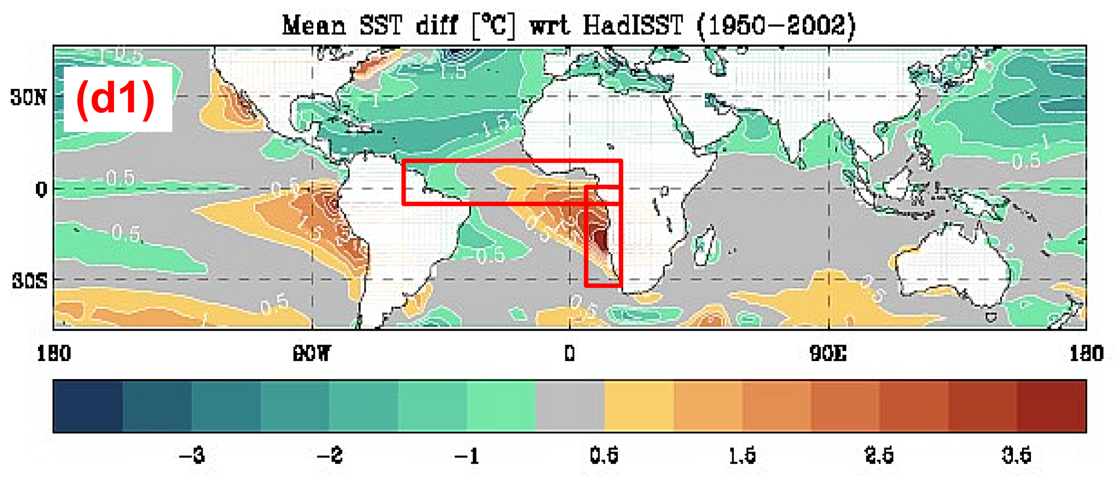


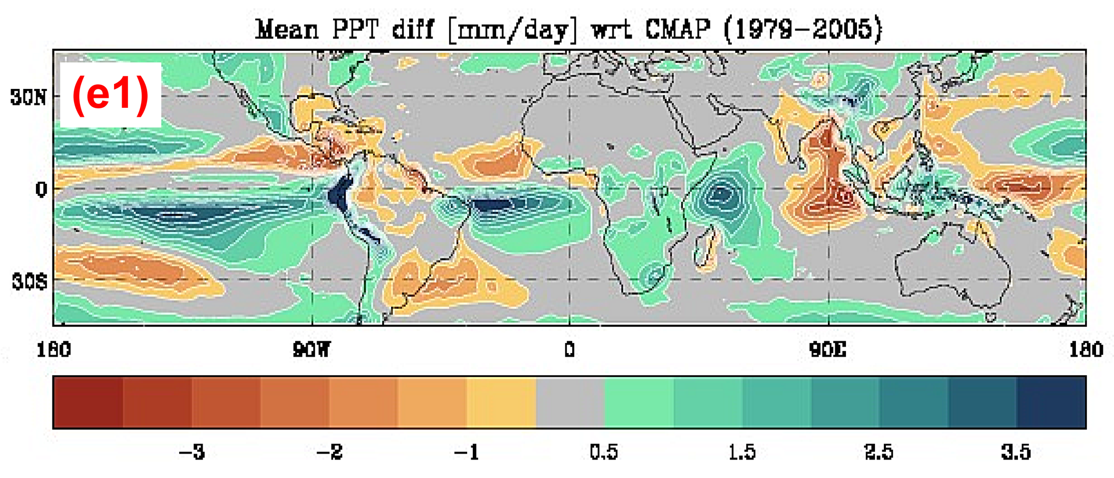


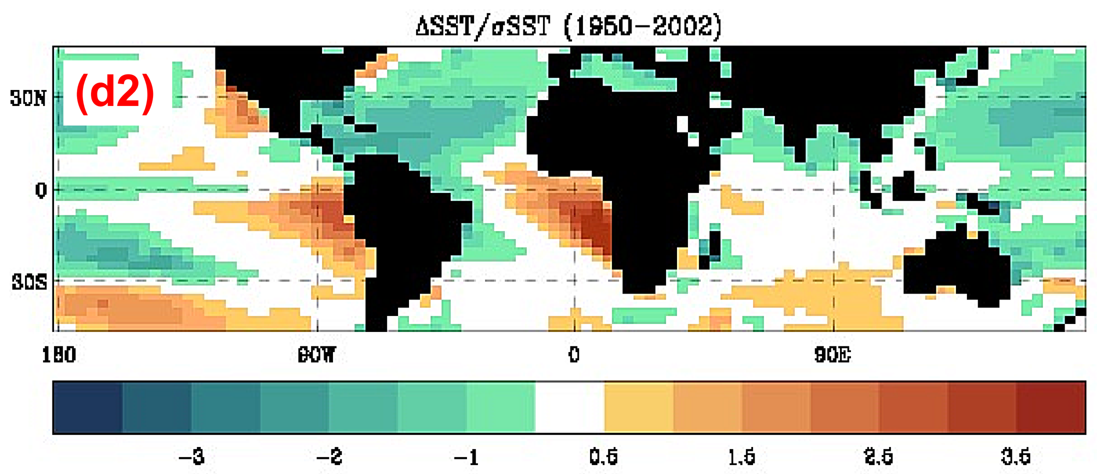
Higher-resolution GCMS, such as HiGEM (Shaffrey et al. 2009), while improving on the eastern-Pacific SST errors, still perform poorly in the Atlantic. The effect of resolution alone has been explored with HiGEM, Figure (a), by varying separately the atmosphere and the ocean resolution. Higher atmospheric resolution tends to improve SSTs, while improving oceanic resolution alone appears detrimental. Error compensation at low resolutions however is likely.

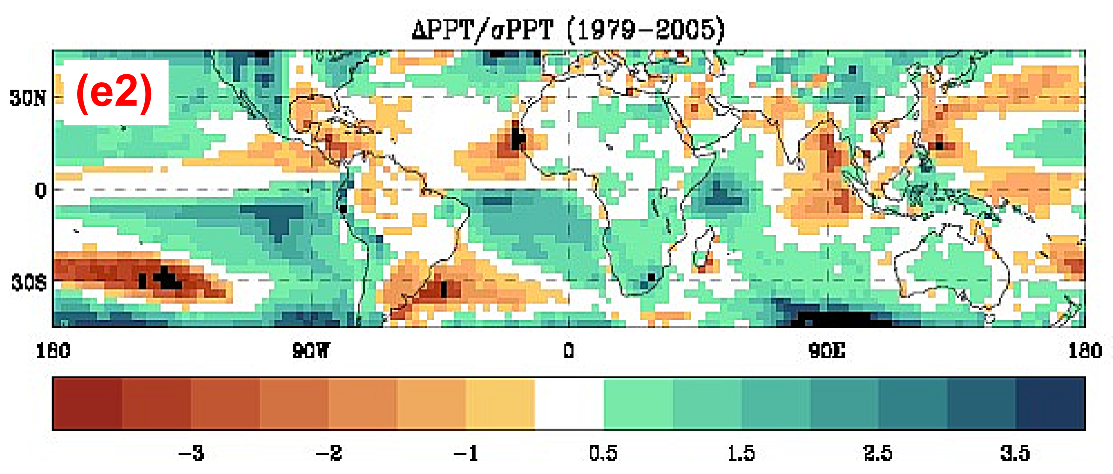
The seasonal amplification mechanism described by Richter et al. (2006) appears to be operating in HiGEM, at all resolutions. In MAM, atmospheric zonal wind errors over the Equator, coupled with an erroneous southward shift of the ITCZ, Figure (b), are amplified by equatorial ocean dynamics and lead to a spread of the warm errors in JJA, Figures (c1), (c2).

Within the CMIP5 set, similar errors appear in all models, with qualitatively identical pattern (including SST gradient reversal), irrespective of formulation, grid type, and resolution. The CMIP5 ensemble-mean SST error is shown in Figure (d1) and for precipitation in Figure (e1). The same mean errors normalised by the respective ensemble standard deviations are shown in Figures (d2), (e2), respectively.

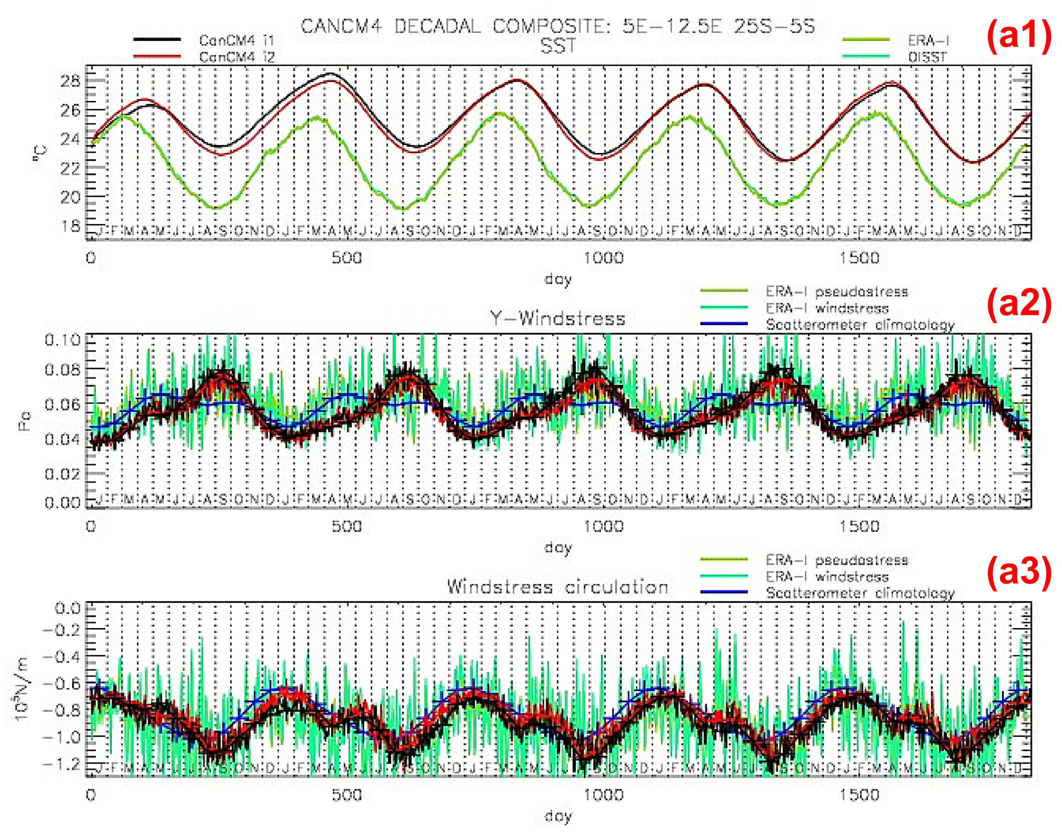


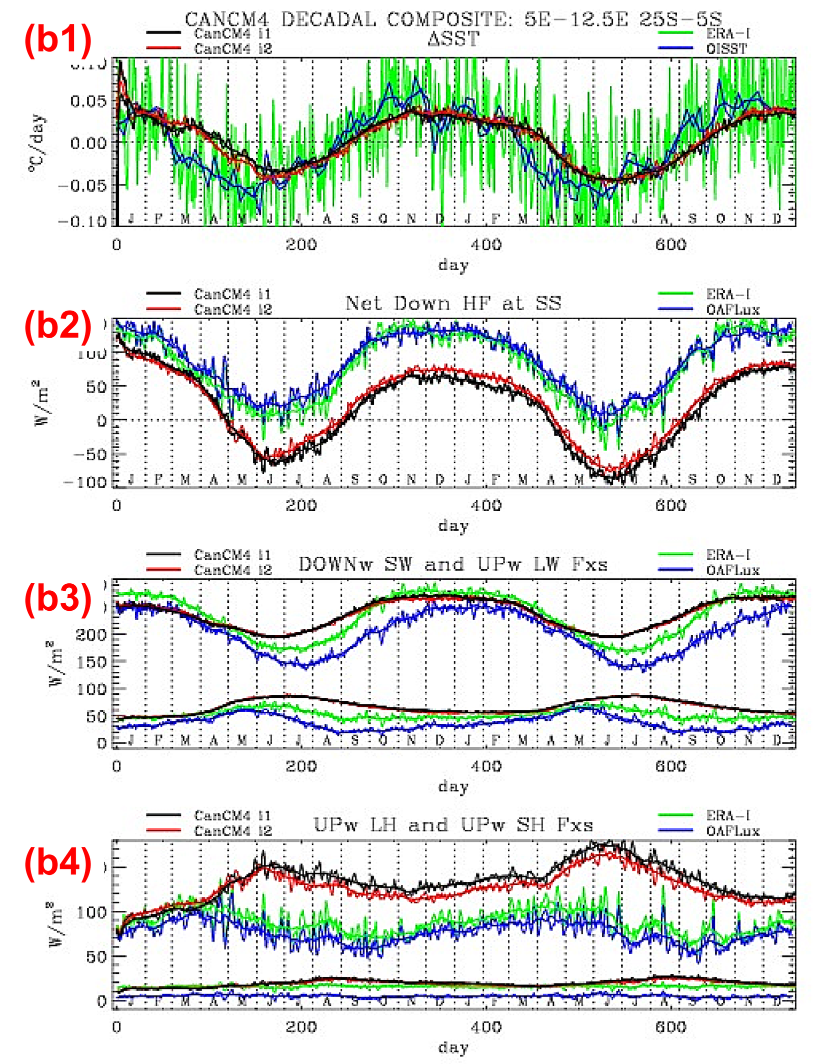






3. An analysis of error growth in initialised decadal forecasts: the case of CanCM4



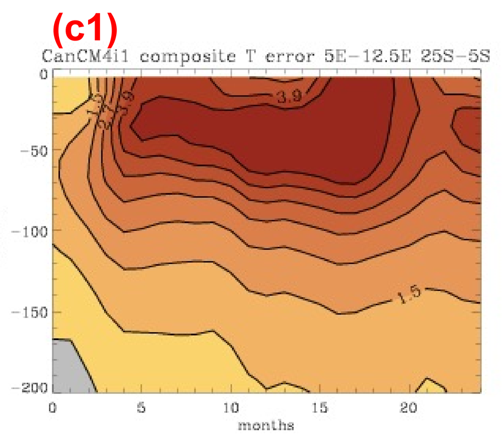


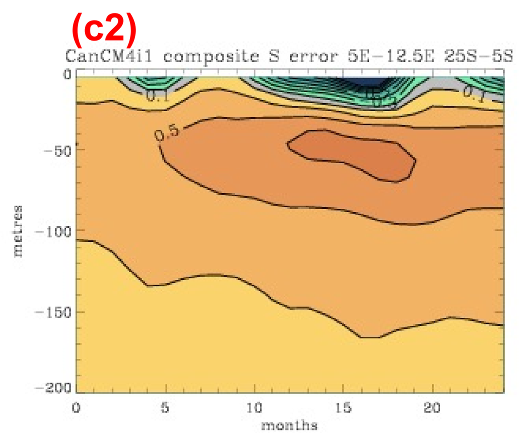
The initialised decadal hindcast integrations in CMIP5 provide the opportunity to document initial errors growth in the simulations and attempt to disentangle cause-effect relationships linking the coupled atmospheric and oceanic errors.

We focus on the CanCM4 model, which has a large ensemble of full-field initialised hindcasts, to discuss the generation of SST errors in the marine coastal region of the SEA, Figure (a1), using composites over 5 hindcasts (starting in 1 Jan 2001, 2003, 2004, 2005 and 2006) averaged over all 10 members of the „i1" ensemble.

SEA SSTs remain close to observations for about 3 months, after which the errors grow quickly. Within 6-7 months, they reach their climatology. Meridional wind-stress, Figure (a2), is marginally weak but the integrated wind-stress curl, Figure (a3), is accurate, implying a correct oceanic upwelling mass-flux (account is taken of zero effective stress -i.e. no Ekman flow- along the coast). This is initially effective in counter-acting the heating by surface fluxes, Figure (b2).

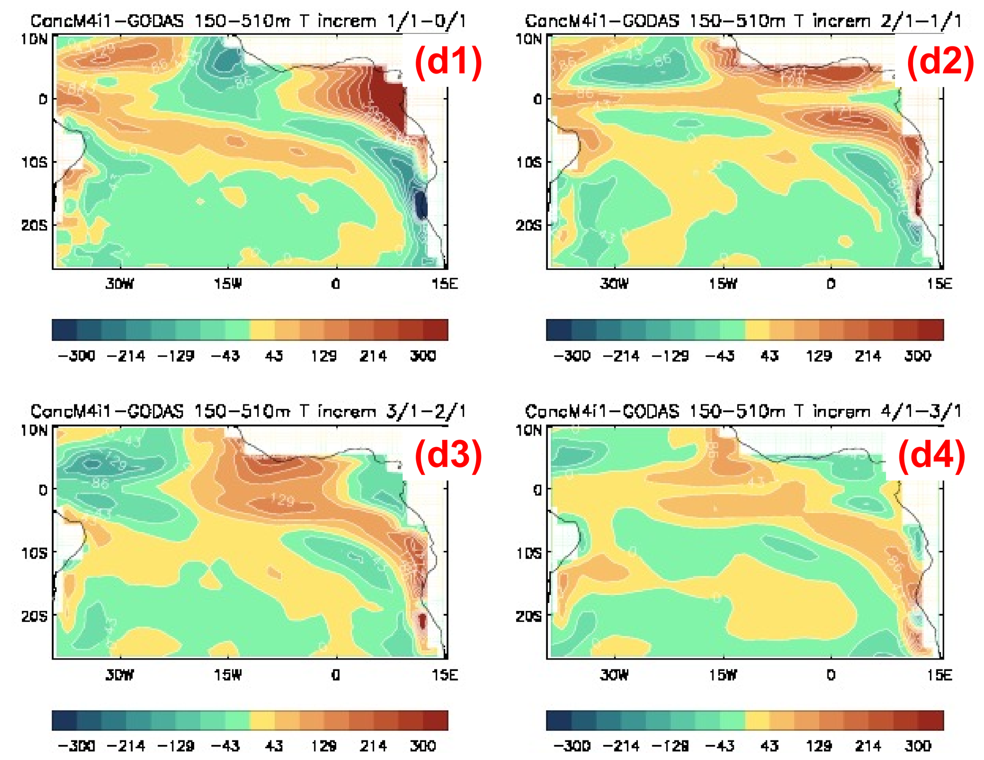
Apart from minor adjustments the initial tendencies, Figure (b1), are correct during the first 2 months. In March, SST fail to cool, and LW losses, Figure (b4), grow until the net heat gain becomes negative in JJA, leading to a zero average over the annual cycle. This implies that cooling by oceanic advection has stopped.

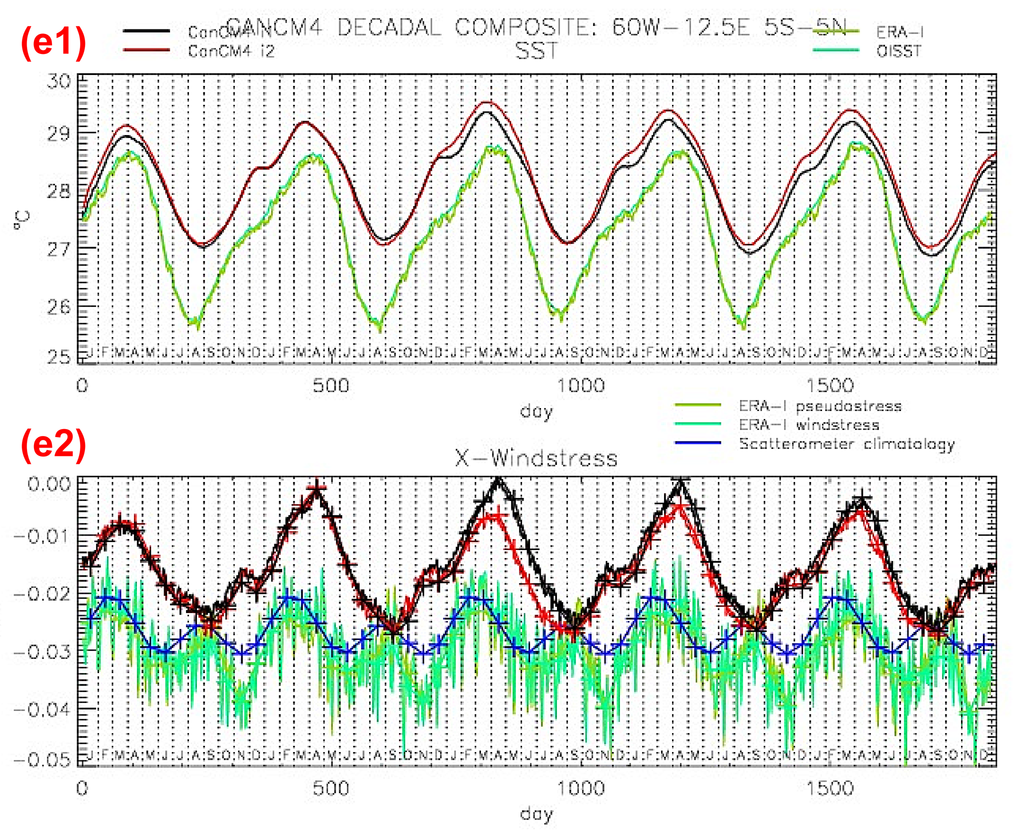




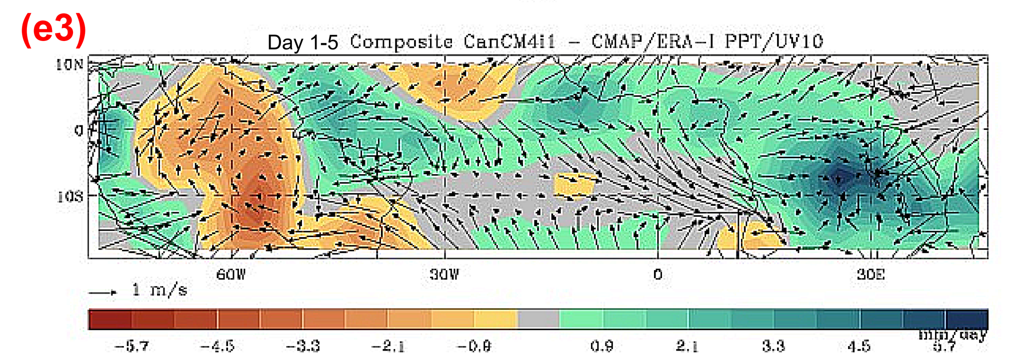
Indeed in the same month the sub-surface ocean temperature rapidly grows a large positive error, Figure (c1). It is partly salinity-compensated, Figure (c2), indicating a geostrophic advection error.

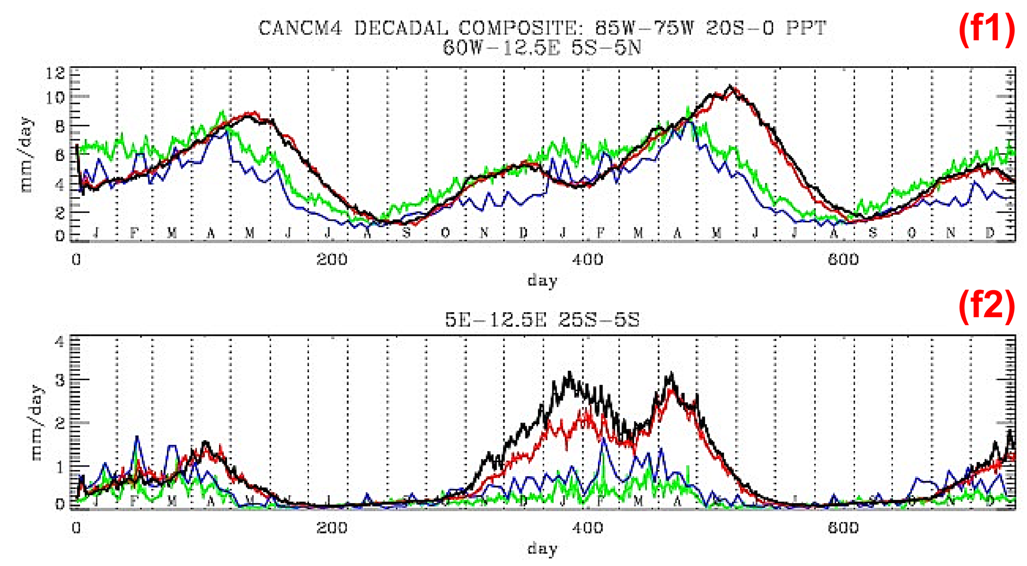
The origin of the sub-surface anomaly is traced in the monthly-mean tendencies of the vertically averaged ocean temperature in Figures (d1-4). It first develops in the Gulf of Guinea, and spreads from there as a mixed coastal-Kelvin/equatorial-Rossby wave to the west, and as a coastal Kelvin wave to the south.



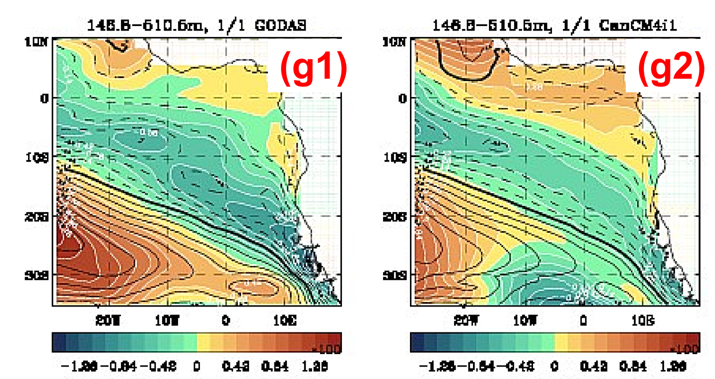


High-frequency 3-D ocean diagnostics are unavailable and the initial evolution in the first month cannot be traced, but the surface diagnostics over the Equator clearly show the cause. The zonal wind-stress, Figure (e2), has nearly its full climatological error from day 1, unbalancing the equatorial thermocline. Equatorial upwelling is slowed and equatorial SSTs rise, Figure (e1). The positive zonal wind error is associated with precipitation errors that also appear immediately over the African and South-American continents, Figure (e3). This type of error growth mechanism is consistent with the results of Richter et al. (2011).

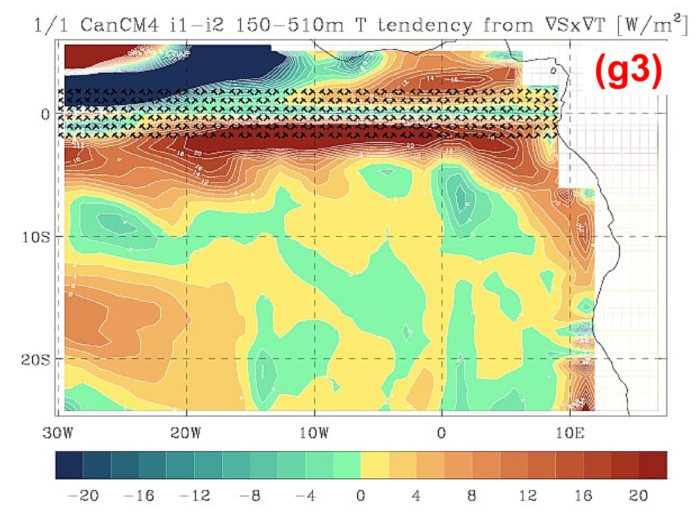




As with the surface heat fluxes, precipitation errors subsequently respond to the changed distribution of SSTs, with a wet error appearing from May over the Equator, Figure (f1). Over the SEA, a small wet error first occurs in April, but it represents a positive feedback on the warm SST error. While the surface heat flux is little affected, the surface freshening, first seen in month 5 in Figure (c2), stabilises the upper ocean and reduces vertical mixing. This allows SSTs to warm even further with the arrival of the second warm season in September, reaching a peak above 28°C the following April which fuels further heavy precipitation, Figure (f2). Stabilisation is reached by an additional increase in LW cooling, Figure (b4).



While warm sub-surface oceanic anomalies are initially generated at the Equator, they appear to significantly grow in amplitude as they approach the SEA. Horizontal, geostrophic advection anomalies represent a possible mechanism. These can be approximated by the perturbation in -(g/ρf)∇S×∇T, scaled by β for temperature, and by -α for salinity (Toniazzo et al 2010). In the region around the salinity front in the south-eastern Atlantic, similar to the stronger one in the south-eastern Pacific, such anomalies can be large. The time-average fields over the first month of ensemble „i1", Figures (g1), (g2), show small T,S errors that imply warm advection in the SEA by this mechanism, Figure (g3). These are exacerbated as the error grows. Initial errors of this kind may arise when relaxation is performed on T and S separately without reference to the density field.



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