Reproducibility of Precipitation Variability over the Gulf of Guinea and the Western Sahel Associated with "Realistic" Subsurface Soil Moisture Prescriptions

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INTRODUCTION

The Sahel Africa is one of the most densely-populated regions in African continent, is meteorologically characterized as the monsoon region. The monsoon season abruptly begins in June to July from the southern region originated from the Gulf of Guinea (Sultan and Janicot 2000; Le Barbe et al. 2002). Management of water resources in the monsoon season is inevitable for agricultural activities. On the other hand, WAM is well known as malaria-infested season in a world and about 1 million deaths a year is reported (Greenwood et al. 2005). Therefore the accurate simulation of the WAM onset is a very important issue for better prediction The ITCZ abruptly shift northward from a quasi-stationary location at 5N (Gulf of Guinea) in May-June (MJ) to another quasi-stationary location at 10N in July-August (Sultan and Janicot 2003). Predictability in sub-seasonal to seasonal scale is limited by the atmospheric chaos. Atmospheric initialization cannot improve the forecast skill beyond about a week (Lorenz, 1963; Yamada et al. 2007). SSTs are main contributors for sub-seasonal to seasonal forecast by its slowing varying characteristics such as the El Nino and La Nina cycles (Shukla et al. 2000). A number of studies have pointed out the importance of SSTs on WAM by using observational based SSTs data (e.g., Rowell 1995).

Scientific based rumors are around that subsurface soil moisture is another contributor by water and heat fluxes associated with its slow varying characteristics (Koster and Suarez, 2001). Previous studies have investigated the potential impact of soil moisture and suggested that soil moisture can influence seasonal weather evolutions (Koster et al. 2000; Douville et al. 2000). Due to lack of temporally-spatially dense soil moisture data in global scale, "realistic" soil moisture data has been produced based on a land surface off-line simulation using observed precipitation and re-analyzed atmosphere data (Hirabayashi et al. 2005; Dirmeyer et al. 2006), and some AGCM studies pointed out realistic soil moisture data could influence to seasonal precipitation in the boreal summer of the Sahel Africa (Douville et al. 2001, Kanae et al. 2006). The Sahel was also suggested one of the three major strong land-atmosphere coupling regions (named hot spots) as a dozen of AGCM result (Koster et al. 2004). This allows a multimodel estimation of the regions on Earth where precipitation is affected by soil moisture anomalies. However their studies investigated the soil moisture impact in relative comparison among different framework of experiments in seasonal scale, any of them has not discussed the reproducibility of the WAM associated with meteorological processes such as the northward shift of the ITCZ. One of the reasons are the properly simulation of the ITCZ is one of the most difficultly for global models especially in middle to low resolved models (Biasutti et al. 2006). This suggests a question: Are the reproducibility of the WAM associated with the northward shift of the ITCZ reproduced by the combination of realistic soil moisture anomalies and high-resolved AGCM? The African easterly jet (AEJ) is a prominent feature of the zonal wind structure in the WAM season and the AEJ forms over the Sahel in summer as a result of strong meridional soil moisture gradients (Cook 1999). Thus the reproducibility of the WAM onset must be discussed with also the reproducibility of the ITCZ over the Gulf of Guinea in MJ.

METHODOLOGY

Our study is based on two types of eight ensemble simulations in 1998 carried out with an Atmospheric General Circulation for the Earth Simulator (AFES) (Ohfuchi et al. 2004). The model we used has a framework of Center for Climate System Research in the University of Tokyo and the National Institute for Environmental Studies (CCSR/NIES) AGCM (Numaguti et al. 1997). As parameterization schemes, the Minimal Advanced Treatments and Surface RunOff (MATSIRO) land surface parameterization (Takata et al. 2003) and the Emanuel convective parameterization scheme are used (Emanuel and Živkovic-Rothman 1999). We adopted T239 (about 50km) triangle truncation grid scales which contrary to about 1/5 smaller resolutions in comparison with previous studies in this research field. The basic model simulations will be referred to as the CTRL-T239 runs based on observed pentad SSTs. The runs differ only in their initial atmospheric conditions. Another type of simulations named SOIL-T239 were also carried out using same type of atmospheric initial conditions as in CTRL-T239. Only one difference among the two types of experiment is the treatment of subsurface soil moisture. In CTRL-T239, subsurface soil moisture is determined by modeled precipitation and atmosphere conditions. In SOIL-T239 on the other hand, global fields of realistic subsurface soil moisture are prescribed at every time step which are produced by simulating an off-line land surface model with the Global Precipitation Climatology Project (GPCP) and re-analyzed atmospheric forcing data (Hirabayashi et al. 2005) (called OFFL-LINE run). Note that the subsurface soil moisture is in 5cm below depth from land surface in our definition.

SUBSEASONAL MEAN STATE

Figure 1 shows geographical distributions of precipitation and horizontal wind vectors at 925hPa height for GPCP, CTRL-T239, and SOIL-T239 in MJ and July. As shown in Fig. 2-a, GPCP shows that precipitation is much increased at the beginning of July over the Sahel (8N-15N and 10W-5E). In Fig.1-a, wind vectors are plotted by the ERA-40. GPCP has the ITCZ over the Gulf of Guinea from the eastern Atlantic Ocean. Over the Sahel, southerly wind vectors are weakened by the convergence over the Gulf of Guinea. CTRL-T239, however does not simulate the ITCZ over the same region. Precipitation is about 3.3 mm/day against 7.6 mm/day in GPCP over the Gulf of Guinea (2N-5N and 10W-5E). Southerly wind vectors are not converged but blows through the Sahel to the interfrontal zone around 15N. In SOIL-T239, large precipitation (about 6.1mm/day) is simulated and southerly winds are also converged. See Table 1 for references. Difference of these MJ mean daily precipitation between SOIL-T239 (Fig.1-c) and CTRL-T239 (Fig.1-b) satisfy 95% statistical significance level by the student-t test in and around the Gulf of Guinea. Here we note again that the reproducibility of SOIL-T239 is brought by realistic subsurface soil moistures in addition to solar radiations and SSTs which are the driving forcing in CTRL-T239. Previous papers have suggested that the influence of soil moistures is local. Our results suggest the geographical pattern and strength of the ITCZ in the vicinity of coastal line would potentially be improved by realistic soil moisture in high-resolved AGCMs.

Does the reproduced ITCZ of MJ in SOIL-T239 contribute to the WAM in subsequent months? Figure 1-d to f show for July. Comparing with CTRL-T239, SOIL-T239 has larger precipitation over many regions of the Sahel and geographical patterns of precipitation are more similar as GPCP (Fig.1-d).

NORTHWARD SHIFT OF THE ITCZ

Here we discuss subseasonal evolution of the WAM from the pre-monsoon to the onset stage. Figure 2-a to –c show 10-day mean precipitation averaged between 10W and 5E. As expressed in Fig.-1a, GPCP has large precipitation in and around the Gulf of Guinea through MJ. In the first half of July, however large precipitation abruptly shifts northward to 10N and this brings the onset of the WAM. CTRL-T239 shows weak ITCZ over the Gulf of Guinea in MJ. Relative large precipitation is simulated over the Sahel of July, however its northward shift is quite weaker in comparison with GPCP. In Fig.2-c, SOIL-T239 has large precipitation over the Gulf of Guinea in MJ and the northward shift of the ITCZ is clearly simulated to the Sahel. Note that Fig.2-c is averaged result among 8 ensemble mean and this makes smoother latitudinal shift than GPCP (Each ensemble member represents the northward shift of the ITCZ abruptly). As a result, the reproducibility of the ITCZ activity over the Gulf of Guinea in MJ is significantly linked to the behavior of the ITCZ's northward shift.

Meridional circulation at lower troposphere and the African Easterly Jet (AEJ) at 600-700hPa height are main driving forces for the northward shift of the ITCZ (e.g., Sultan and Janicot 2003). Figure 2-d to e show latitudinal diagrams of 10-day mean horizontal wind convergences at 925hPa height for ERA-40, CTRL-T239 and SOIL-T239. Figure 2-g to i are for relative vorticities at 700hPa height. All values are averaged between 10W and 5E. ERA-40 indicates strong convergence region (warm colors) over 2N to 6N in MJ and shifts northward to 8N to 12N in the first half of July. Relative vorticities also show same northward shift of cyclonic vorticities (cooler colors) in Fig.2-g. These would correspond to the African Wave Disturbance (AWD) which is brought by the horizontal shear of the AEJ (Burpee 1972; Norquist et al. 1977). In CTRL-T239, wind fields at 925hPa are not converged but diverged over the Gulf of Guinea and southern Sahel up to 8N. On 700hPa height, the AWD is not active until the middle of July. Thus the combination of poor simulation skill of the lower troposphere convergence and the AWD bring also poor reproducibility of the WAM onset. SOIL-T239 simulates both wind the convergence and the AWD over the Gulf of Guinea in MJ and northward shift in the first half of July.

Fig.2-f clearly shows that the wind convergence zones abruptly propagate northward despite of ensemble mean result. CTRL-T239 and SOIL-T239 have similar distributions both for the lower wind convergence and the AWD from the latter half of July. However both experiments have quite different atmosphere processes for the onset of WAM association with the northward shift of the ITCZ by global fields of realistic subsurface soil moisture. Here we investigate the horizontal resolution dependency by using a lower resolution (T39; approximately 300km grid scale) which are same order as previous studies used. MJ mean precipitation over the Gulf of Guinea. SOIL-T39 has 3.6mm/day contrary to 2.7mm/day in CTRL-T39 and thus the ITCZ is not reproduced in the lower horizontal resolution. In evidence, lower convergence at 925hPa (Fig.3-a and b) and the AWD at 700hPa (Fig.-3 c and d) are not reproduced over the Gulf of Guinea in MJ even though global distributions of realistic subsurface soil moisture are prescribed. Thus the northward shift of the ITCZ is not reproduced without a combination of higher resolutions and realistic subsurface soil moistures.

SUMMARY

We suggested a new role of geographical distributions of "realistic" subsurface soil moisture for the reproducibility of WAM associated with northward shift of the ITCZ in a high-resolved AGCM. Now it has gradually been able to use high-resolved model by the development of computer technology and its environment and re-analysis products and seasonal forecast will be performed by the high-resolved models as same as we used in this study. Initializations of soil moistures may enhance better prediction of WAM associated with the northward shift of the ITCZ also in high-resolved models.

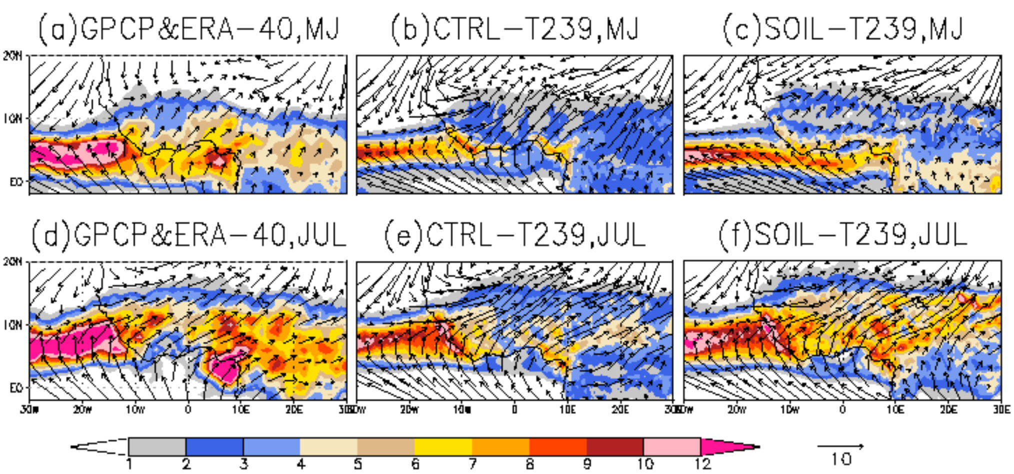

Figure 1: Geographical distributions of subseasonal mean precipitation and horizontal wind vectors at 925hPa for GPCP&ERA-40, CTRL-T239, and SOIL-T239. Upper figures are for May and June (MJ) and lowers for July.

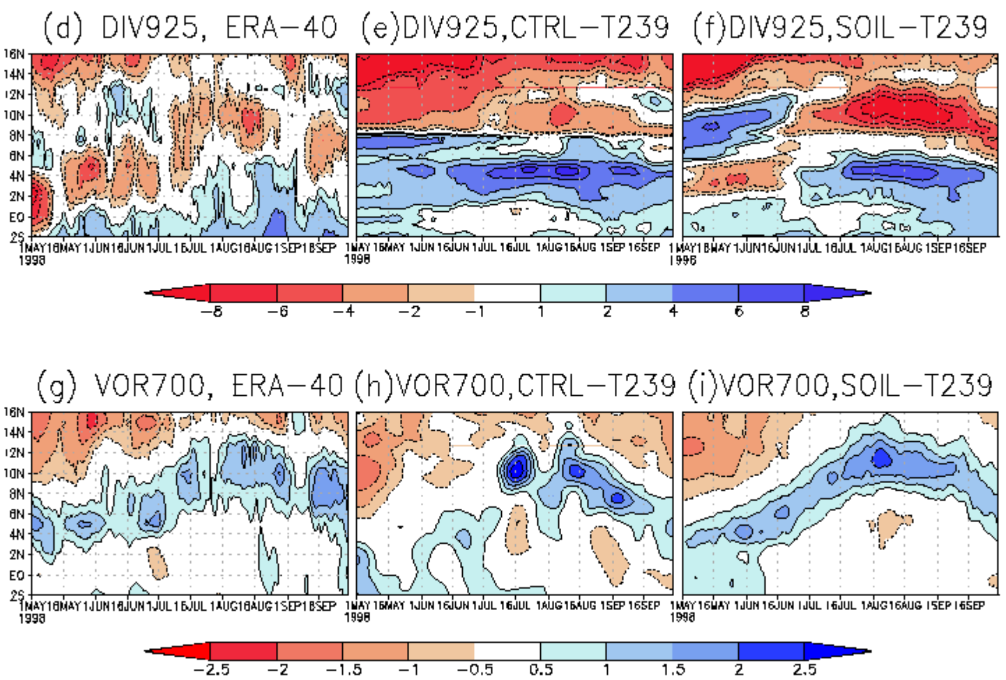

Figure 2: Latitudinal time series of 10-day mean precipitation (upper figures), horizontal wind convergence at 925hPa (middle figures) and relative vorticity at 700hPa (lower figures) averaged between 10W and 5E for GPCP, ERA-40, CTRL-T239 and SOIL-T239. In the middle figures, values are multiplied by 10^6. Warmer (cooler) colors indicate convergences (divergences). In the lower figures, values are multiplied by 10^5. Cooler (warmer) colors indicate cyclonic (anticyclonic) disturbances.

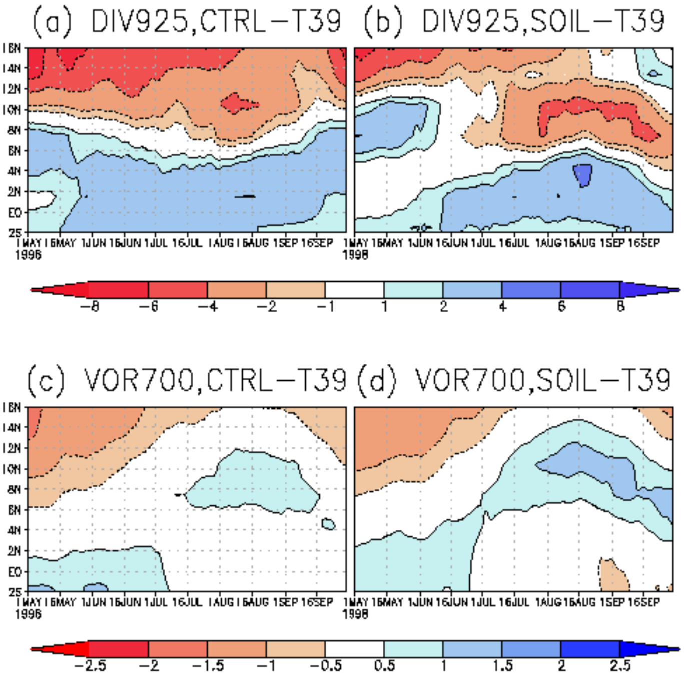

Figure 3: Latitudinal time series of 10-day mean horizontal wind convergence at 925hPa (upper figures) and relative vorticity at 700hPa (lower figures) averaged between 10W and 5E for CTRL-T39 and SOIL-T39. Details of these figures are described in Fig.2.

Table 1: May-June mean precipitation over the Gulf of Guinea (2N-5N and 10W-5E)

GPCP	CTRL-T239	SOIL-T239	CTRL-T39	SOIL-T39
7.8	3.3	6.1	2.7	3.6

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