Effects of the land-atmosphere interaction on the West African monsoon onset

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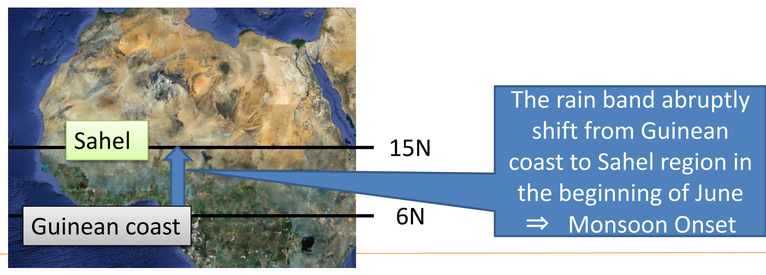
1, Intro

The mechanism of West African monsoon onset, the abrupt latitudinal shift of maximum precipitation from the Guinean coast into Sahel region in summer, has to be investigated in order to improve the water resource management in this region.

However, it is difficult to investigate the terrestrial effects on the West African monsoon onset due to the limitation of the existing climate model simulation capability of the land surface hydrological parameters such as soil moisture and surface fluxes.

Therefore, this study applies an atmospheric meso-scale model coupled with a satellite based land data assimilation which can physically introduce heterogeneities of land surface conditions into models in order to investigate the effects of the land-atmosphere interaction on the monsoon onset in West Africa.



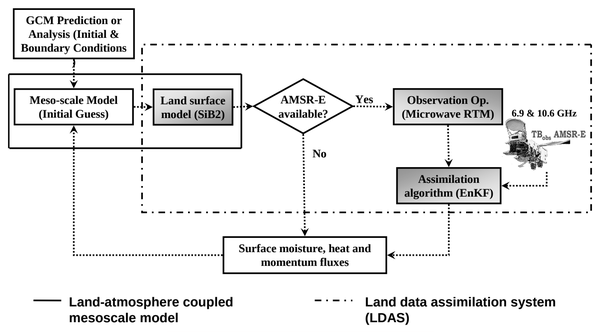
2, Method

LDAS-A (Rasmy (2010)) is an atmospheric meso-scale model coupled with a satellite based land data assimilation system.

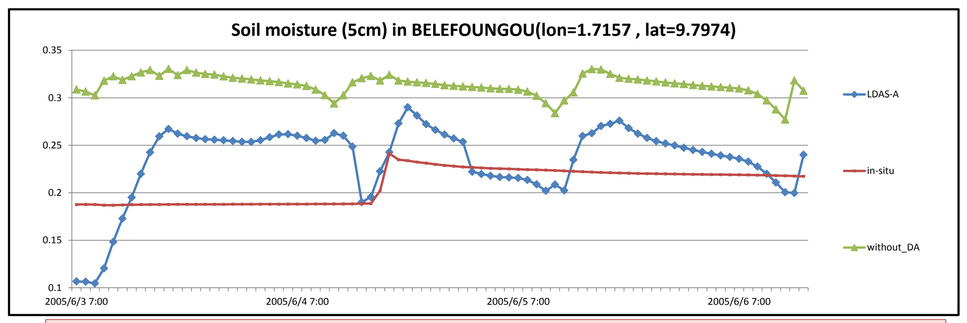
ARPS (Xue et al. (2000)) is used as a meso-scale model. And in LDAS-A, it is coupled with SiB2(Sellers et al. (1995)) as a land surface model.

By using a data assimilation system, LDAS-A can introduce heterogeneities of surface soil moisture, which is the key valuable of the land-atmosphere interaction, into a model.

LDAS-A can investigate the effects of land surface conditions on climate system.



Basic scheme of LDAS-A

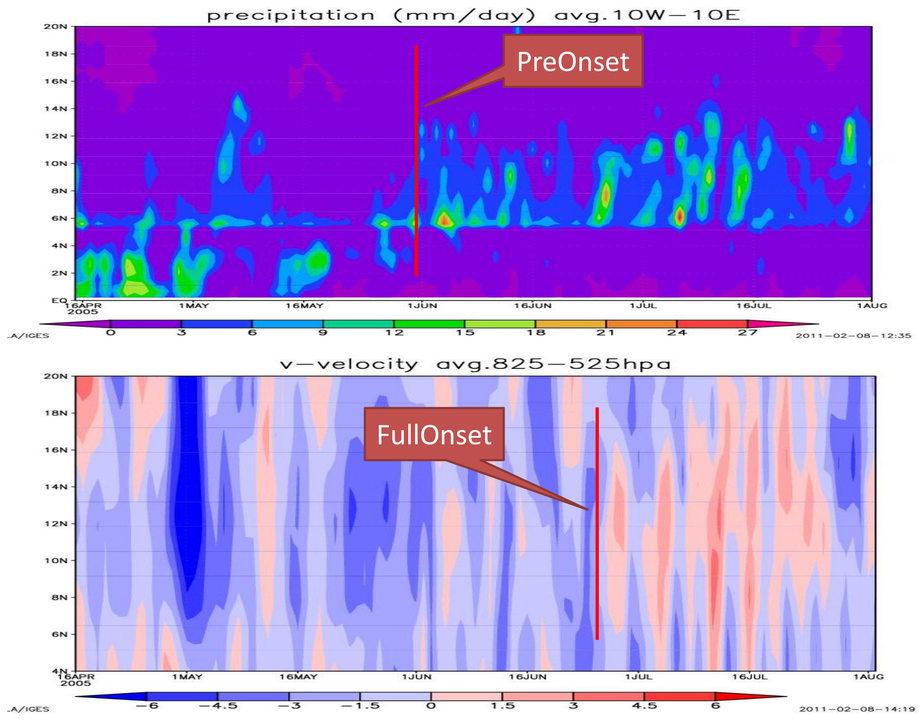


The accuracy of estimation of soil moisture is improved with Data assimilation (DA).

3, Result

➢ When Does Monsoon Onset Occur ?

Precipitation area shifts abruptly from coastline to inland on the beginning of June. But afterwards , northward wind is reinforced on July. So in this study , the abrupt shift of precipitation area is defined as Pre Onset. And the abrupt shift of wind direction is defined as Full Onset.

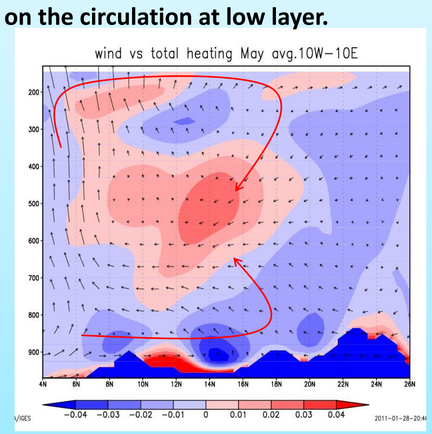


➢ Monsoon Onset and Atmospheric Heating

The latitudinal pressure gradient due to heating of atmosphere introduces an inertial instability. And this process abruptly shifts the midtropospheric meridional wind convergence maximum from the coast into the continental interior at the end of May (Tomas and Webstar (1997) , Hagos and Cook (2007)). We analyze the mechanism of the atmospheric heating both in PreOnset and FullONSET

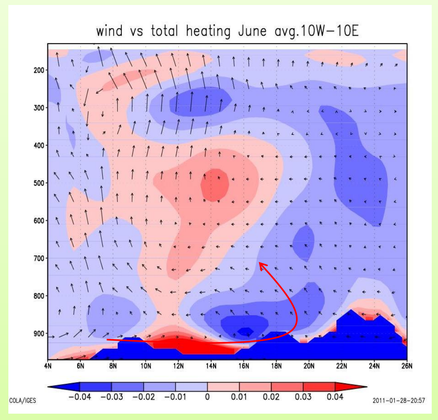
Heating atmosphere in Pre Onset

In May, there are two sources of heating of atmosphere. One is adiabatic heating due to subsidence. Another is diabatic heating due to condensation of moisture which moves on the circulation at low layer.



Heating atmosphere in Full Onset

In June, there is only diabatic heating due to condensation of moisture as heat source. Adiabatic heating disappears in this period.



The shallow surface circulation plays an important role to transport moisture from the ocean to the inland area and to warm the troposphere in both of May and June.

This circulation consists of the northward wind over the Gulf of Guinea and the updraft over the Sahel region. And this updraft is driven by the strong sensible heat flux on Sahel (Hagos and Cook (2010)). And the distribution of sensible heat flux is determined by complicated land-atmosphere interactions.

➢ Energy Budget on Land Surface

The shallow updraft moves northward during summer (Fig.A) because sensible heat flux at northern area on June is bigger than that on May while the sensible heat flux at south part of West Africa reduces during May (Fig.B). From May to June, surface albedo decreases due to the increase of soil moisture (Fig.C), but most of the net radiation is spent as latent heat flux in the south part of West Africa (under 12N) (Fig.D). Therefore, the place of sensible heat maximum shift northward after PreOnset. And the shift of shallow circulation into continent due to the latitudinal shift of maximum sensible heat causes the progress of the atmospheric heating on inland area and of monsoon onset.

Fig.A

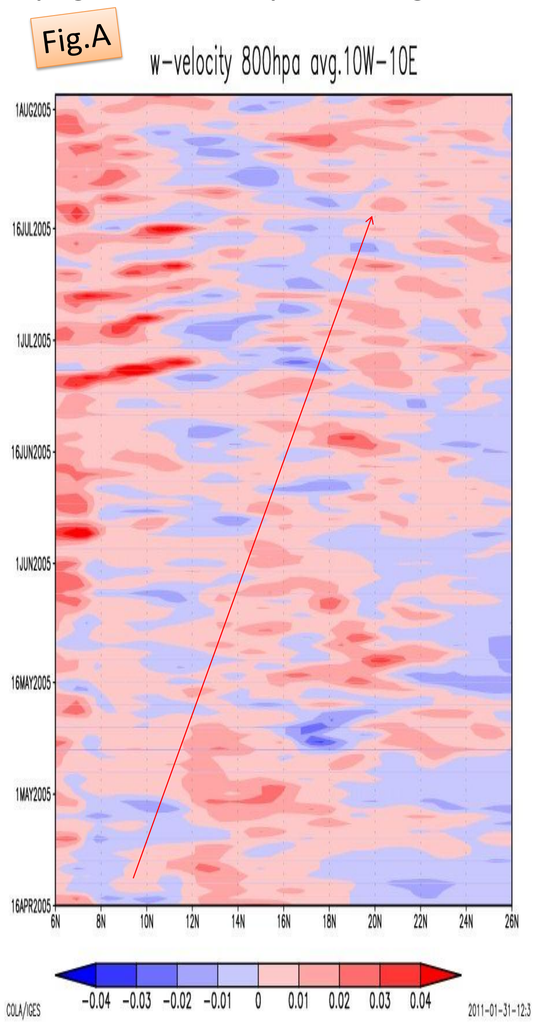


Fig.B

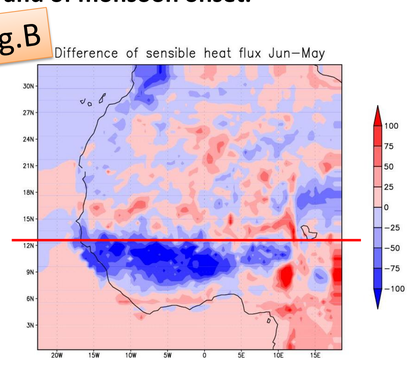


Fig.C

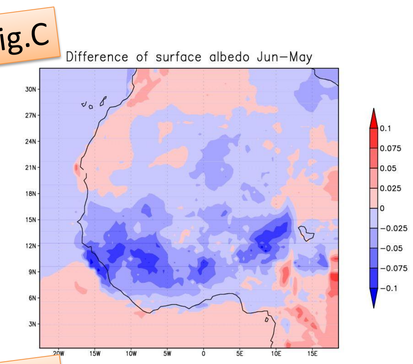
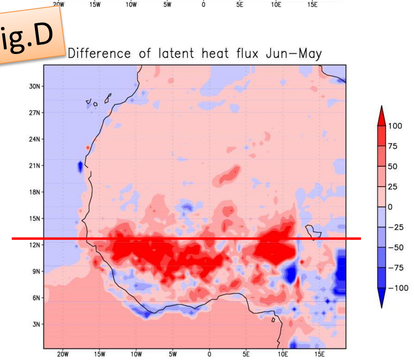


Fig.D



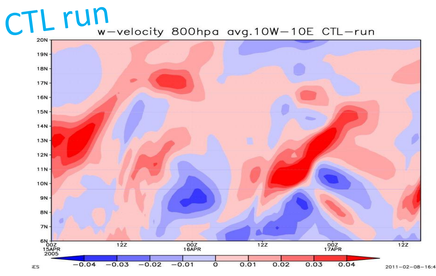
➢ The Effect of Land Condition - Sensitivity Analysis -

The above processes are addressed by using the sensitivity analysis. The weather in Sahel is thought to be controlled by the distribution of vegetation and the change of vegetation (Charney (1974)). We investigate the effect of vegetation on West African Monsoon Onset.

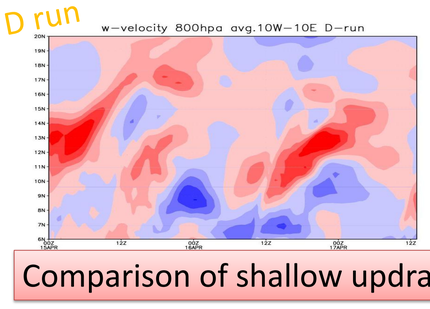
The design of sensitivity analysis

CTL run : control-run
D run : Desertification-run, all of the vegetation in West Africa is defined as desert in D-run
S run : Sensible heat eliminated-run, S run is without the sensible heat on land

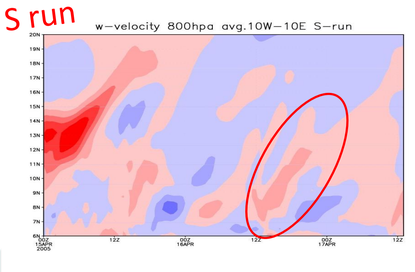
CTL run



D run

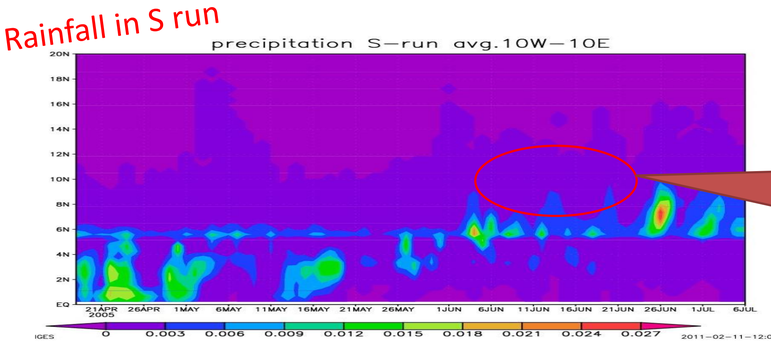


S run



Comparison of shallow updraft

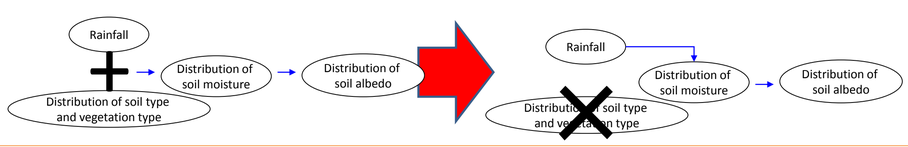
Rainfall in S run



The abruptly shift of maximum precipitation disappears when we eliminate the sensible heat flux on land which drives a shallow circulation.

There are some strong shallow updrafts in the daytime in Sahel (CTL run). But when we eliminate the sensitivity heat flux, these updrafts disappear (S run). In addition, the change of the forest cover doesn't have any big effects on a shallow circulation in this region (D run). D run has both of PreOnset and FullOnset same as CTL run while S run lose both of them (rainfall in D run is not shown).

We can conclude that the forest cover is not a key factor in determining the distribution of soil moisture and surface albedo compared with the amount of light rainfall before the monsoon onset (see a below chart).



4, Conclusion

The West African monsoon onset, which is essential for daily life in this region, is strongly related to land-atmosphere interaction. We clarify that almost all of the distribution of surface albedo, sensible heat, and latent heat are determined by the amount of soil moisture. And the change of the distribution of sensible heat flux has an important role in the seasonal march of the monsoon onset. The latitudinal shift of a shallow updraft driven by sensible heat flux is one of the big factor of heating atmosphere and introduce an inertial instability which makes the shift of the meridional convergence into the continent. On the other hand, the forest cover is not a key factor when we analyze a climate on such a big scale.

The existing climate model simulation capability of the land surface hydrological parameters such as soil moisture and surface fluxes is not sufficient considering how large the effects of soil moisture and heat flux on monsoon onset is. We show one of the solutions to clarify the effects of land-atmosphere interaction on monsoon onset by using land data assimilation system and improving the accuracy of estimating soil moisture in regional climate model.