Towards a realistic simulation of boreal summer tropical rainfall Climatology in global coupled models

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I. Motivation and scientific rationale

❑ State-of-the-art global coupled models (CMIP5 and seasonal forecast coupled models) have unrealistic simulation of boreal summer tropical rainfall climatology (e.g. monsoons, Pacific ITCZ, …)

❑ This has serious implications as it will lead to deficiencies in future monsoon projections as well as seasonal monsoon forecasts.

❑ The dry land monsoon and Pacific double ITCZ biases are commonly attributed to:

➔Too coarse horizontal atmospheric resolution (e.g. Johnson et al. 2016, Prodhomme et al. 2016, Samson et al. 2016, …)

➔Tropical SST and air-sea fluxes errors in state-of-the art coupled models (e.g. Levine et al. 2013, Hourdin et al. 2016, …)

➔Deficiencies to represent sub-grid scale processes (e.g. convection and clouds) in too coarse atmospheric models (e.g. Dai 2006; Stephens et al. 2010, ...)

❑ However, the role of land surface parameters (albedo, emissivity, roughness length, moisture, vegetation, …) on these tropical rainfall biases in coupled models has received less attention.

❑ Hence our primary objective here is to show the pivotal role of land surface albedo (background) and temperature errors in regulating the tropical rainfall biases in current coupled models.

II. Data and Models

❖Observational and reanalysis data sets

➔ERA-interim reanalysis (Dee et al. 2011)

➔GPCP Rainfall (Huffman et al. 2008)

➔CERES-EBAF (Kato et al. 2013) surface and TOA radiative fluxes from Clouds and Earth's Radiant Energy System (CERES); Energy Balance and Filled (EBAF) top-of-the atmosphere and surface fluxes version 2.8; Kato et al. 2013)

➔MODIS MCD43GF-v5 (Schaaf et al. 2011): Moderate Resolution Imaging Spectro-radiometer (MODIS) snow-free gap-filled white-sky (diffuse) albedo product MCD43GF for three different spectral bands: total shortwave (SW, 0.3–5.0 µm), visible (VIS, 0.3–0.7 µm), and near-infrared (NIR, 0.7–5.0 µm)

❖ Coupled models:

➔Historical simulations of 36 CMIP5 models

➔Long control experiments and a large set of sensitivity/upgrade experiments with two high resolution global coupled models: The SINTEX-F2 (Masson et al. 2012) and the CFSv2 (Saha et al. 2014). Both models are extensively used for seasonal forecasts in Japan, India and the US. SINTEX is also included in CMIP5

❖ Configuration of models

➢ CFSv2 (Climate Forecast System version 2) coupled model:

atmosphere: NCEP GFS model	ocean/sea ice: MOM4p0d
T126 (~0.9) L64	(0.25-0.5 × 0.5) L40
360 × 181 × 64	720 × 360 × 40

➢ SINTEX-F2 coupled model:

atmosphere: ECHAM5.3	ocean/sea ice: NEMO v3.2
T106 (~1.125 degree) L31	ORCA05-LIM2(0.5 degree)
320 × 160 × 31	722 × 511 × 31

III. Results and Discussions

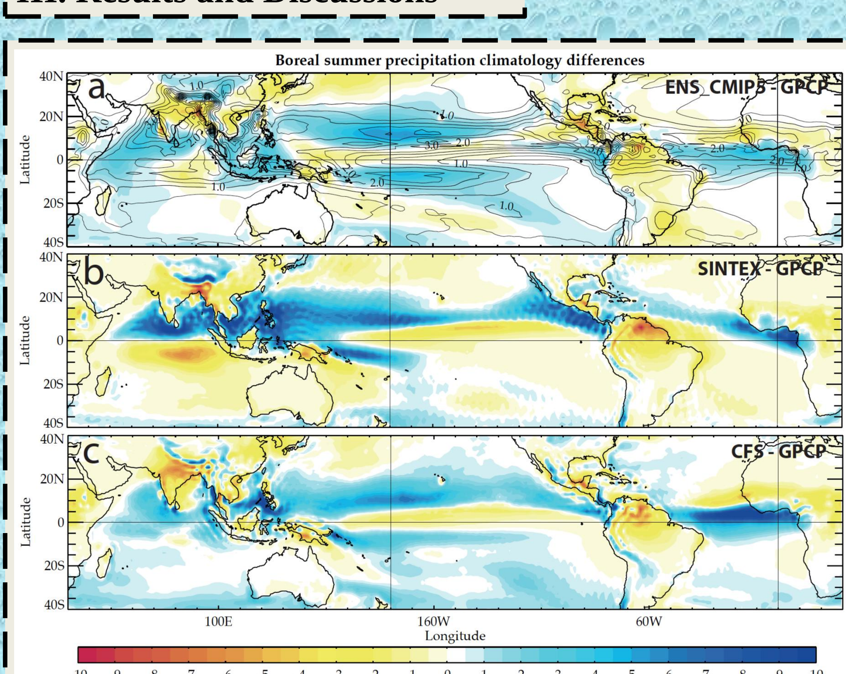


Figure 1: Boreal summer (JJAS) rainfall biases in (a) ensemble-mean from 36 CMIP5, (b) SINTEX-F2 and (c) CFSv2, against precipitation from GPCP over 1979-2010. In (a), rainfall standard deviation is also shown from CMIP5 models.

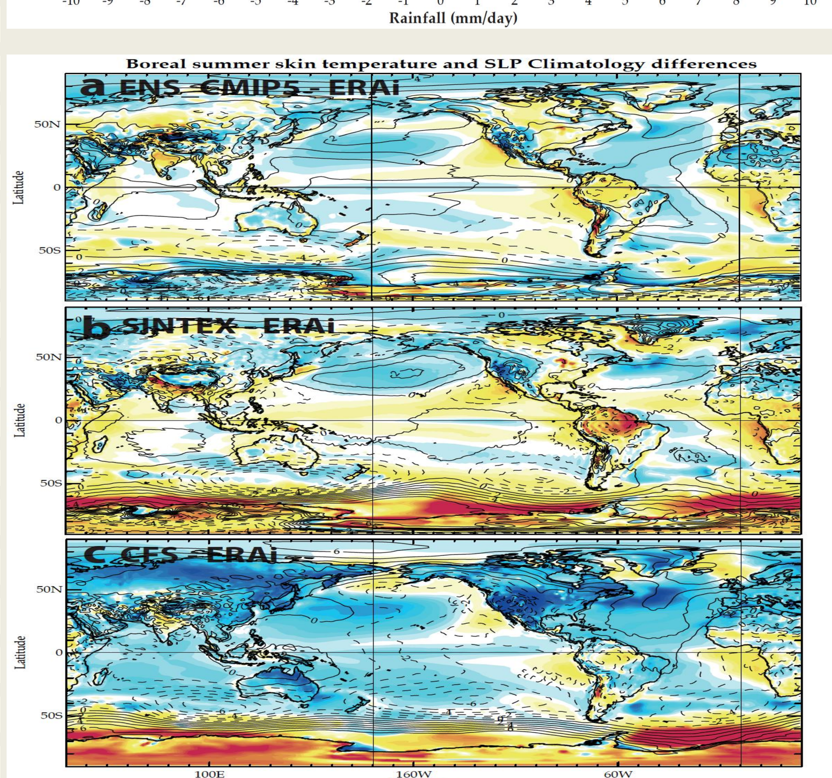


Figure 2: Skin temperature (degree C, shading) and SLP (hPa, contours every 1-hPa) biases, against ERA-Interim during JJAS period of 1979-2014 in (a) ensemble-mean from 36 CMIP5, (b) SINTEX-F2 and (c) CFSv2

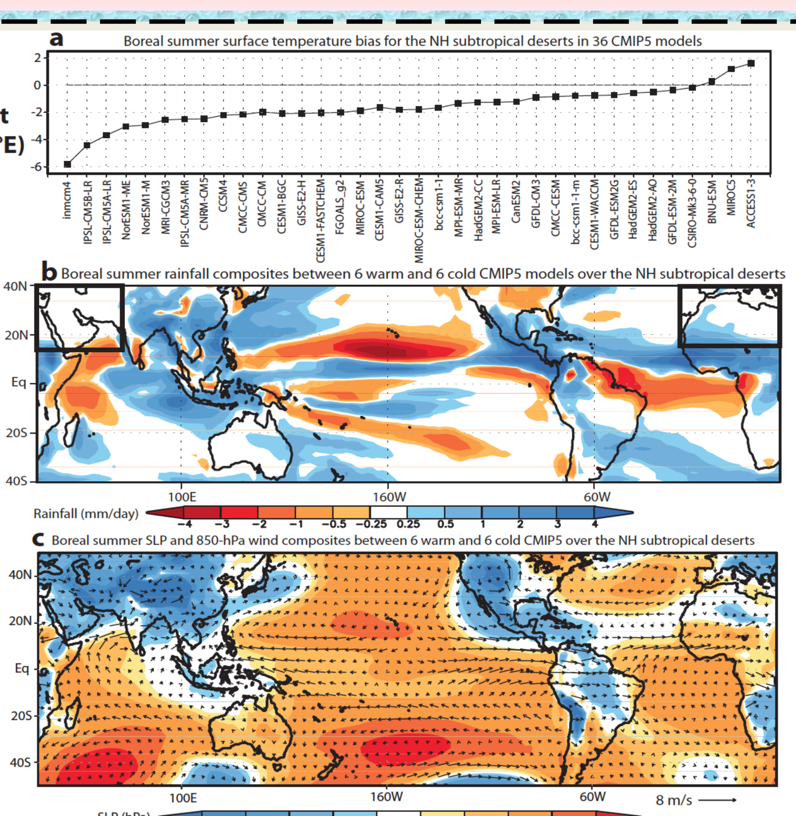
➢Couple models exhibit severe cold bias over northern hemisphere (NH) subtropical deserts that are over Middle East region (Sahara and Arabian deserts)

➔What is the role of SST errors on the rainfall biases ?

➔What is the role of SH mid-latitude cloud and circulation errors ?

➔What is the role of Land Skin temperature and SLP errors?

NH subtropical deserts: Sahara, Arabia, Middle-East (Land : 15°–40°N, 20°W–75°E)



➢Suggest a possible role of the temperature errors over the NH subtropical deserts on the tropical rainfall biases !

Figure 3: (a) Surface temperature bias (degree C, in JJAS period) over NH deserts using CMIP5, (b) Rainfall composite difference between the six warmest and six coldest CMIP5 models for JJAS period, (c) (b), but for SLP (hPa) and 850hPa winds (m/s)

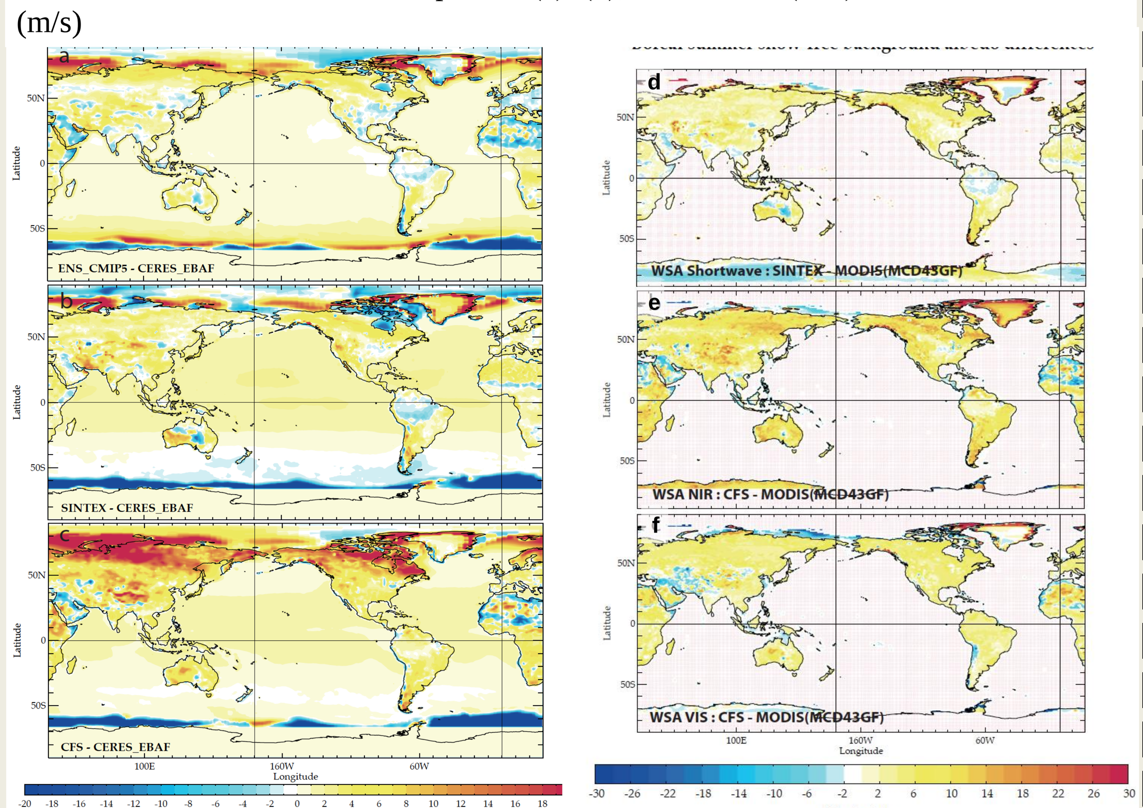


Figure 4: [Left] Surface albedo (%) biases during JJAS period in (a) ensemble-mean from 36 CMIP5, (b) SINTEX-F2 and (c) CFSv2, against CERES flux estimates over 2000-2014. [Right] Background snow free land albedo (%) biases during JJAS period for (d) diffuse broadband SW (0.3-5µm) albedo in SINTEX, (e) diffuse near IR (> 0.7 µm) albedo in CFS and (f) diffuse visible (< 0.7 µm) albedo in CFS, against MODIS estimates.

✓Strong albedo biases (but not always positive) over the NH subtropical deserts !

Acronym	Coupled model	Duration (years)	Setup
SINTEX	SINTEX-F2	210	Control experiment
MODIS_SINTEX	SINTEX-F2	110	Prescribed background snow-free broadband shortwave albedo replaced by MODIS estimates
DESERT_SINTEX	SINTEX-F2	60	Prescribed background snow-free broadband shortwave albedo replaced by MODIS estimates and further decrease by -0.2 over the Sahara, Arabia and Middle-East deserts (land domain: latitude 15°-40°N, longitude 20°W-75°E)
CFS	CFSv2	80	Control experiment
MODIS_CFS	CFSv2	60	Prescribed background snow-free diffuse visible and near-infra-red albedo replaced by MODIS estimates
DESERT_CFS	CFSv2	30	Prescribed background snow-free diffuse visible and near-infra-red albedo replaced by MODIS estimates and further decrease by -0.2 over the Sahara, Arabia and Middle-East deserts (land domain: latitude 15°-40°N, longitude 20°W-75°E)

Table: Coupled experiments performed with CFSv2 and SINTEX-F2 coupled models

• Replace the prescribed snow-free diffuse albedo in the two models by the similar estimates from satellite.

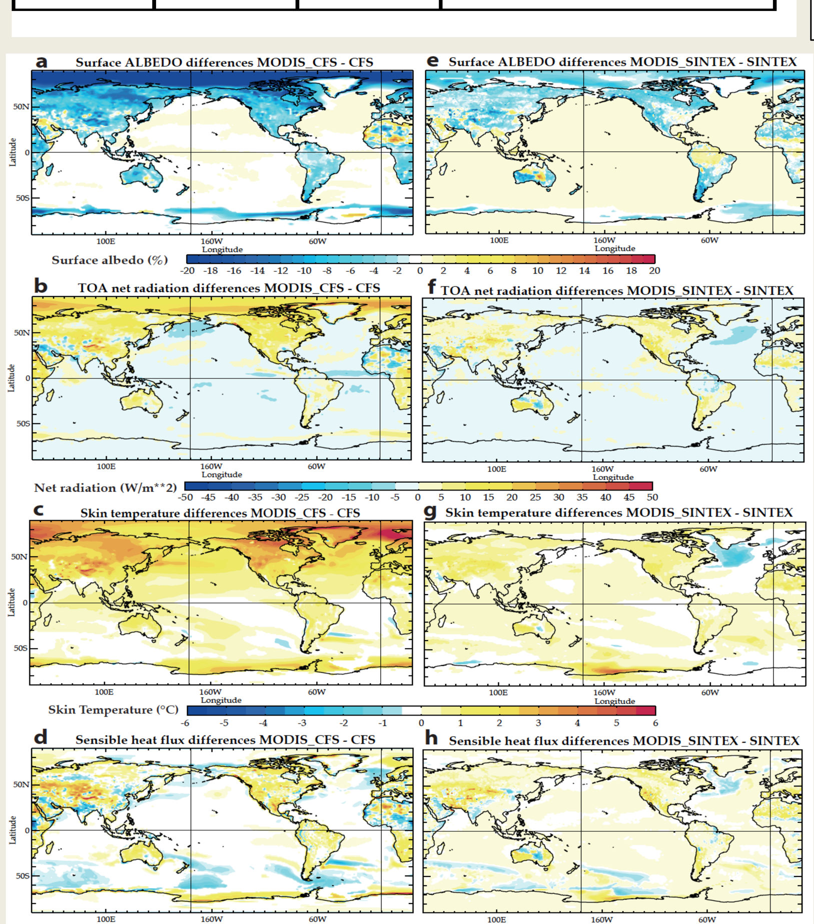


Figure 5: Differences between the MODIS and control runs for (a-d) CFS and (e-h) SINTEX, during JJAS period, for surface albedo (%), TOA net radiation (W/m^2), skin temperature (degree C) and sensible fluxes (W/m^2)

➢More heat and energy in the Northern Hemisphere and sensible heat fluxes over the subtropical NH deserts !

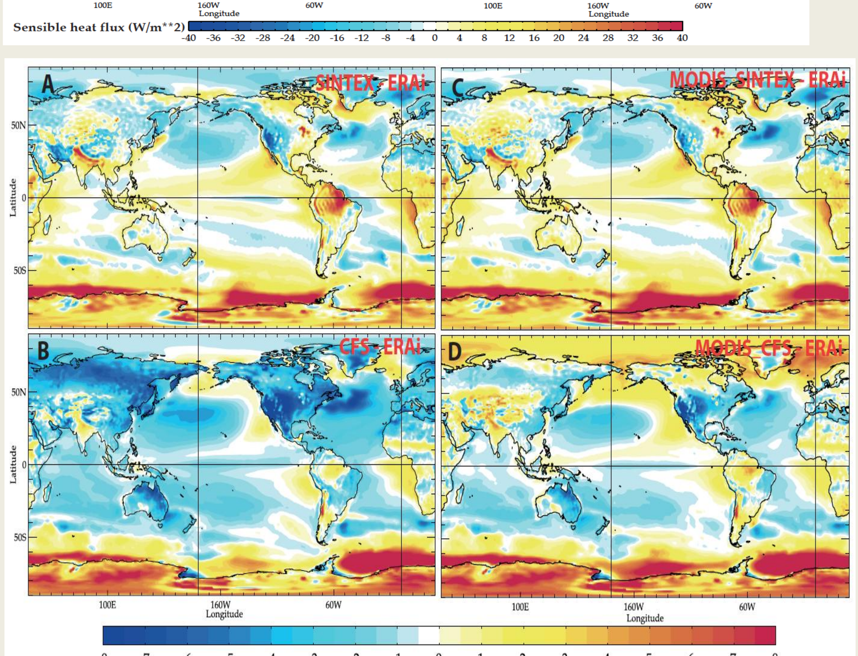


Figure 6: Skin temperature bias (degree C) during JJAS in (A) SINTEX, (B) CFS, (C) MODIS_SINTEX and (D) MODIS_CFS, against ERA Interim

• Reduction of the skin temperature biases

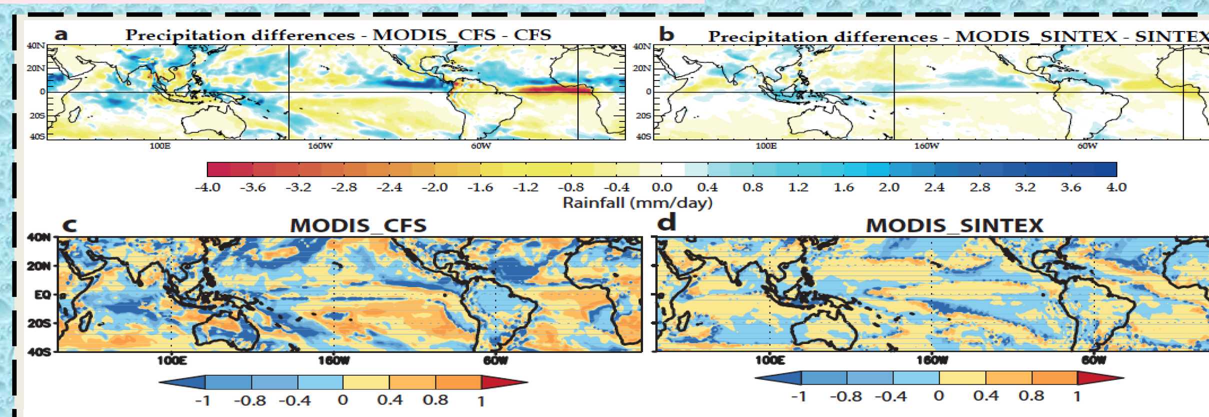


Figure 7: Precipitation differences between the MODIS and control runs for (a) CFS and (b) SINTEX, during JJAS period. Improvement or deterioration of simulated tropical rainfall during boreal summer in the experiments (c) MODIS_CFS and (d) MODIS_SINTEX, compared to the biases in their respective control simulations. Following Haywood et al. (2016), improvement/deterioration is given by 1 – abs((EXP-GPCP)/(CTL-GPCP)), where EXP is for experiments (e.g. MODIS_CFS) and GPCP is the reference rainfall dataset.

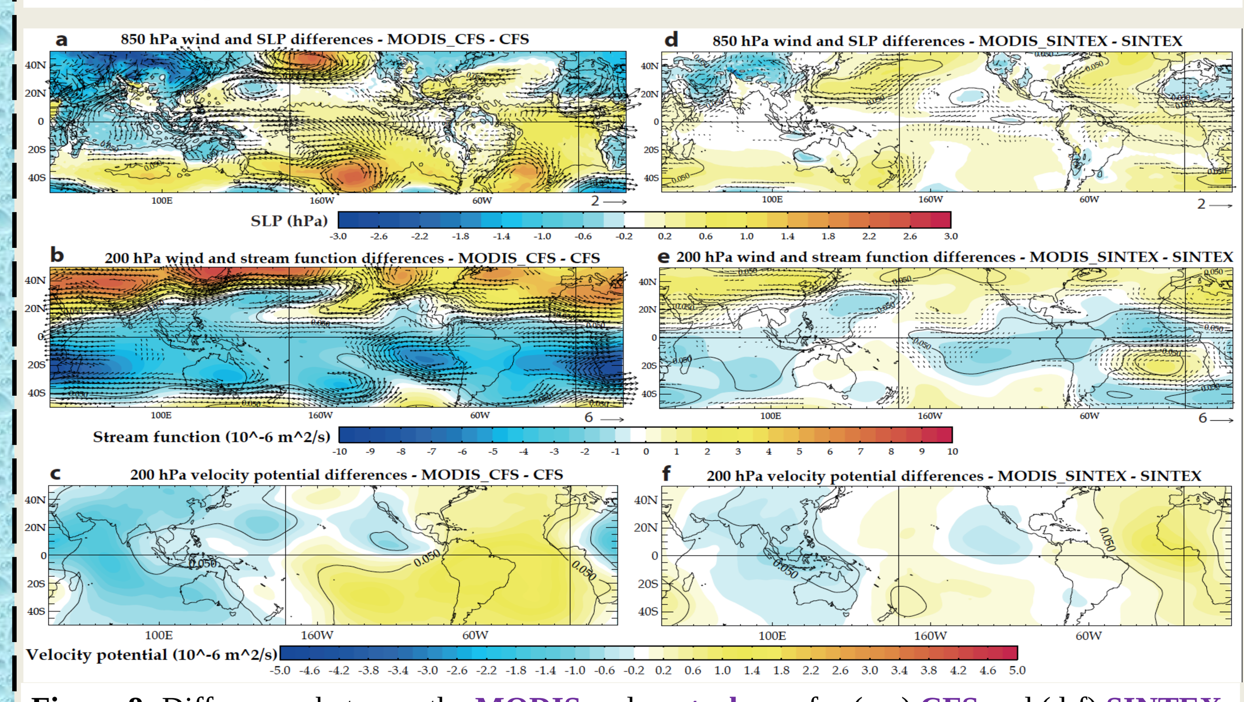


Figure 8: Differences between the MODIS and control runs for (a-c) CFS and (d-f) SINTEX, during JJAS. In (a,d) 850-hPa winds (m/s) and Sea Level Pressure (hPa), (b,e) 200-hPa winds (m/s) and stream function (10^{-6} m^2/s) and (c,f) 200-hPa velocity potential (10^{-6} m^2/s). Positive (negative) values of the stream function denote clockwise (anticlockwise) motions.

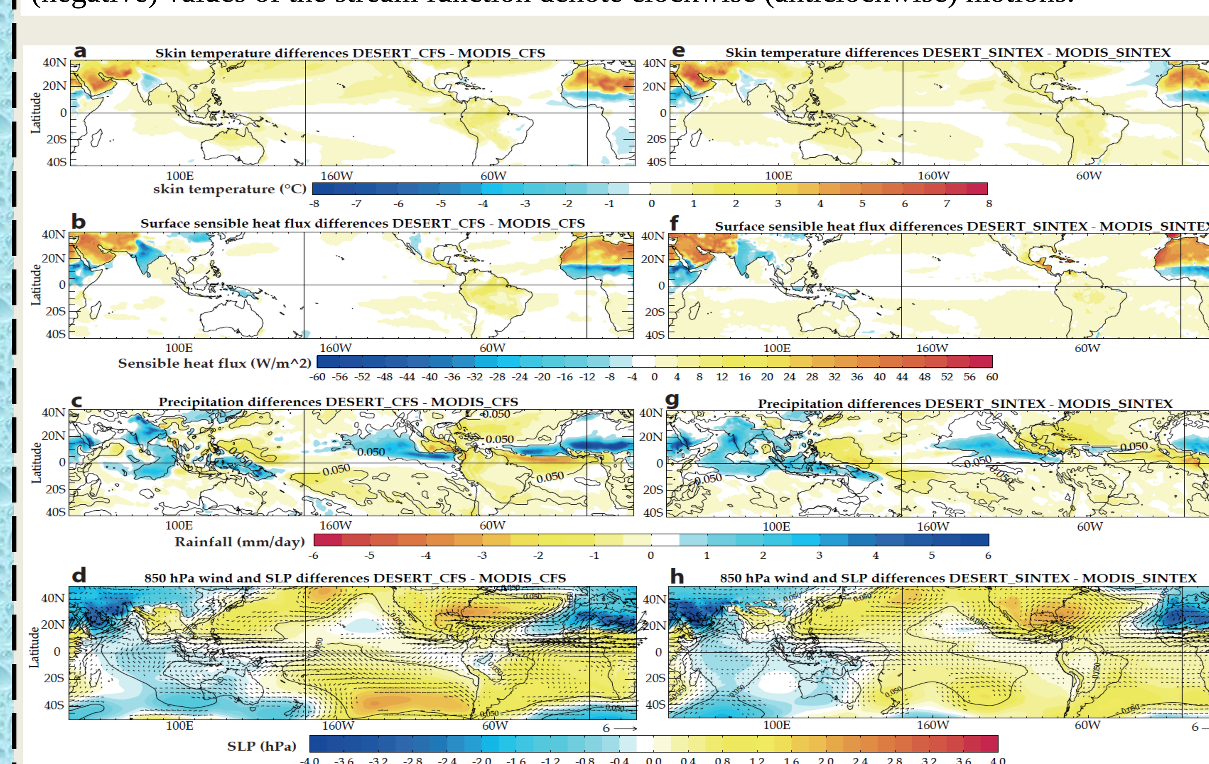


Figure 9: Differences between the DESERT and MODIS runs for (a-d) CFS and (e-h) SINTEX, during JJAS period. In (a,e) skin temperature (degree C), (b,f) sensible flux (W/m^2), (c,g) precipitation (mm/day) and (d,h) 850-hPa winds (m/s) and Sea Level Pressure (hPa)

IV. Summary of the Results

✓ Our modeling efforts demonstrate that a realistic representation of surface albedo can lead to a reduction of the surface land temperature and dry monsoon biases affecting coupled climate models

✓Our study fundamentally show that the tropical rainfall errors are linked to insufficient surface thermal forcing and incorrect representation of the surface albedo over the NH subtropical deserts.

✓ We also demonstrate that the Asian monsoons are, partly, a response to the large-scale pressure gradient between the hot NH subtropical deserts and the relatively cooler oceans to the South.

V. Concluding remarks and perspective

➔ Our study highlights the need to monitor and simulate carefully the surface fluxes (radiation, sensible and latent heat) over the NH monsoon regions and the adjacent deserts in order to reduce the tropical rainfall biases in current CGCMs.

➔It further demonstrates that the role of land surface processes and parameters (albedo, emissivity, roughness length, moisture, vegetation, …) in current CGCMs needs much more attention (as SST and cloud-convection errors).

➔It also shows the surprising possible influence of the NH subtropical deserts on the NH monsoon systems.

Desert amplification, especially over Sahara and Arabia, is one of the main modes of global warming

We may need to revisit the « classic » monsoon-desert paradigm in order to improve monsoon projections !

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For more details, see

Terray et al. (2017) Towards a realistic simulation of boreal summer tropical rainfall climatology in state-of-the art coupled models : role of the background snow-free albedo. *Climate dynamics*, doi:10.1007/s00382-017-3812-9

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