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Impacts of Thermal Roughness Length on Surface Meteorology in IPSL-CM

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Outline

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- **Methods**

  I. The z_{0h} calculation in LMDZ-ORCHIDEE

  II. Experiments design

- **Results and Discussions**

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  II. Impacts of z_{0h} on T_{max}, T_{min}, *DTR* (Diurnal Temperature Range)

  III. Impacts of z_{0h} on combined Temperature-Humidity health effects.

- **Conclusions**

Background

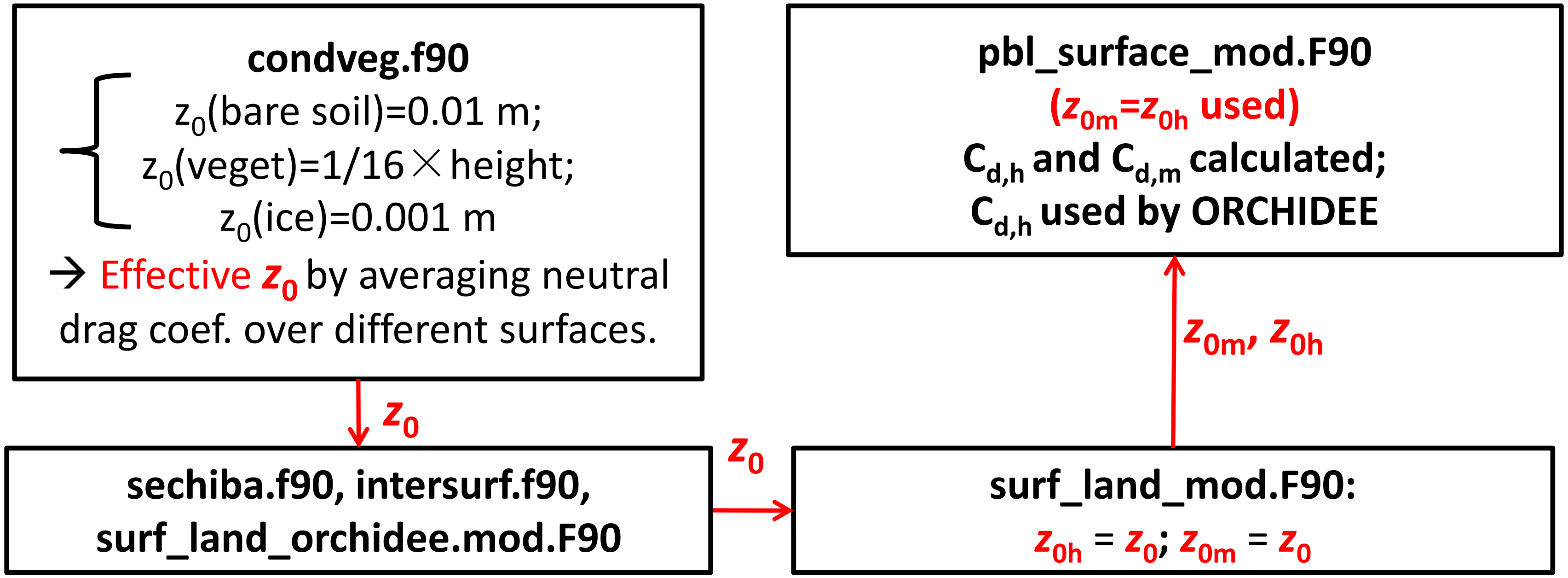
The **roughness length (z_0)** is a crucial parameter to calculate turbulent flux. The transport of scalars (z_{0h}, by molecular diffusion) is considered less efficient than momentum (z_{0m}, by pressure fluctuations) in most cases, owing to the absence of bluff-body forces for scalar exchange. The z_{0h} parameterization (over land) varies with models:

Model	z_{0h}
ECHAM6	$z_{0h}= z_{0m} * e^{(2-86.276z0m)0.375}$
MetUM	$z_{0h}= \alpha * z_{0m}$; α varies with surfaces
ECMWF	$z_{0h}= z_{0m}$ (trees); $z_{0h}= z_{0m}/100$(desert, low vegetations).
JMA	$z_{0h}= z_{0m}/7.4$

In LMDZ-ORCHIDEE: $z_{0h}=z_{0m}$. The ***objective*** of the current work is to test varies z_{0h} formulas in LMDZ-ORCHIDEE model, and to study its effects on surface meteorology.

Method

z_0 in ORCHIDEE-LMDZ



Experiment Design: **CTL**: $z_{0m} = z_{0h}$; **EXP$_{10}$**: $z_{0h} = z_{0m}/10$; **EXP$_{100}$**: $z_{0h} = z_{0m}/100$;

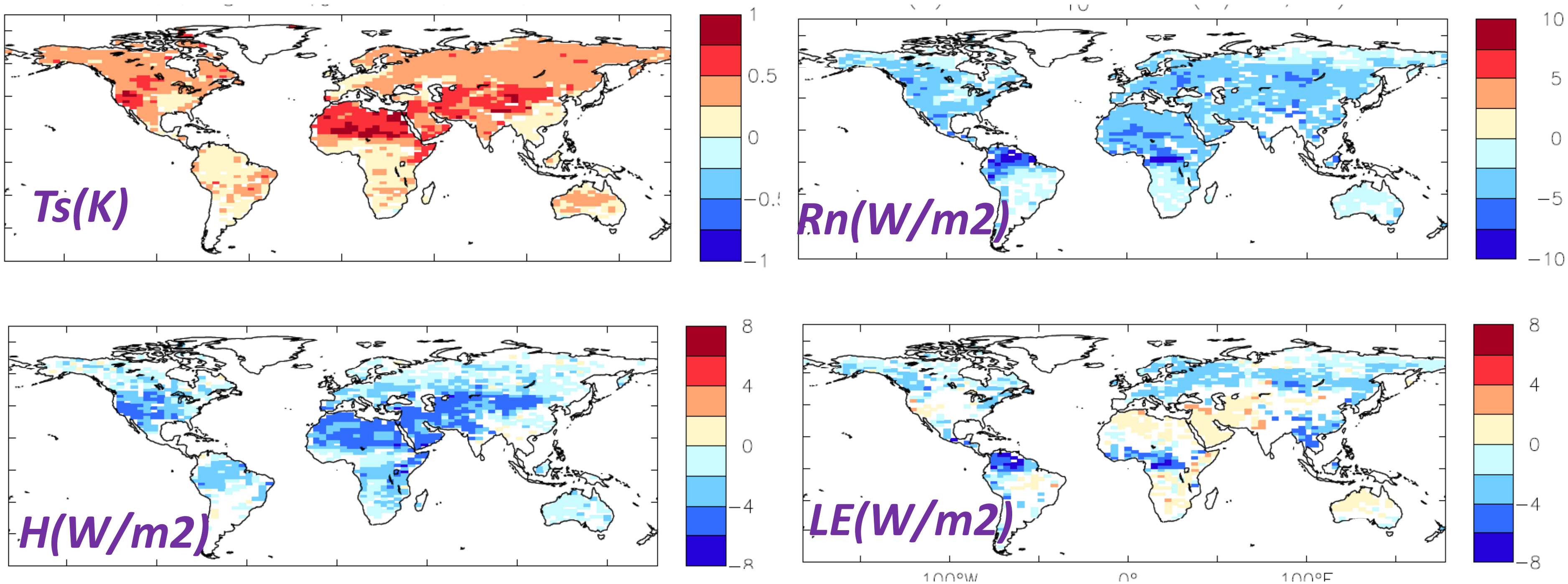
EXP$_{cz09}$: CZ09 ($z_{0h} < z_{0m}$) [*Chen and Zhang*, 2009] $\ln\left(\frac{z_{0m}}{z_{0h}}\right) = 10^{-0.4\times h}\kappa Re_*^{1/2}$

Model: LMDZ-ORCHIDEE (NPv3.2 + CWRR); Resolution: 96×95×39.

Simulation: 5-Year (nudged) after 20 years spin-up; global

Impacts of z_{0h} on *Ts, Rn, H, LE* (JJA)

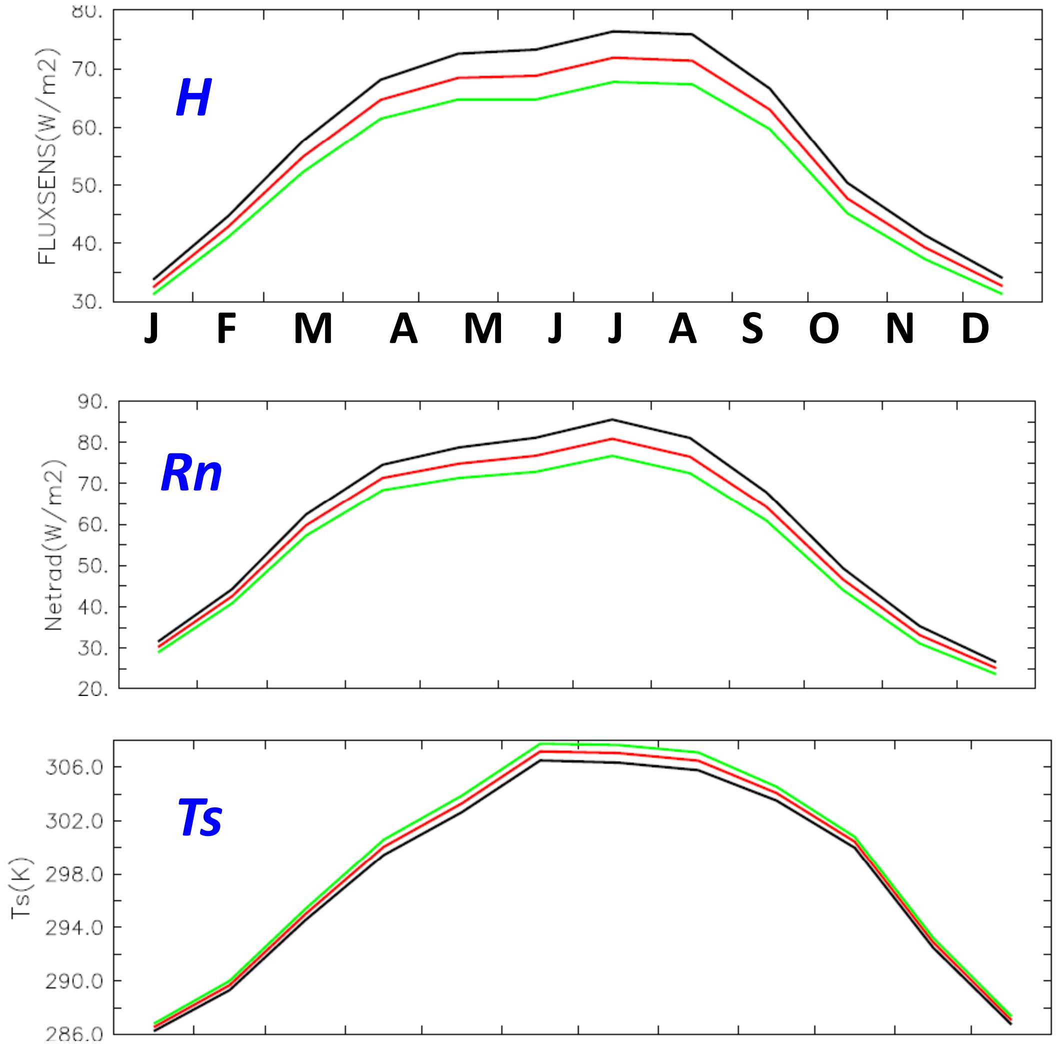
EXP$_{10}$ ($z_{0h} = z_{0m}$ / 10) **- CTL** ($z_{0m} = z_{0h}$)



- **z_{0h} ↓ →drag coeff. ↓ → Turbulent heat flux ↓(weaker turbulent exchange);**
- **T_S ↑ (0.9-1.8 K); larger change over bare soil (lower soil heat capacity);**
- **R_n decreases ↓ (outgoing R_{lw} ↑);**
- **The change for EXP$_{100}$ ($z_{0h} = z_{0m}$ / 100) is even larger (both JJA & DJF).**

Seasonal Cycles

Sahara desert [10W-10E, 20N-25N]



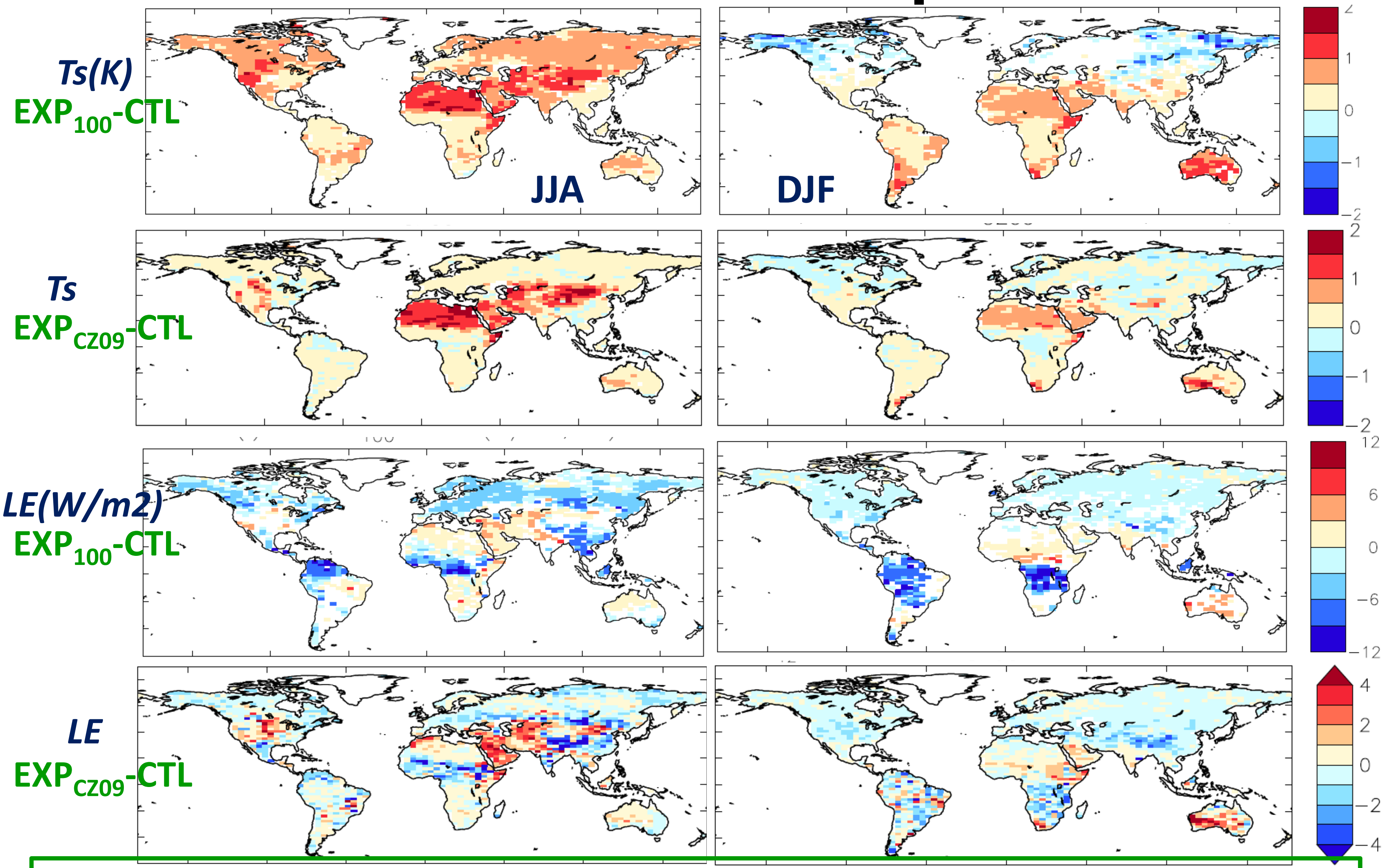
CTL ($z_{0m} = z_{0h}$)

EXP$_{10}$ ($z_{0h} = z_{0m}$ / 10)

EXP$_{100}$ ($z_{0h} = z_{0m}$ / 100)

More significant in warm season (stronger turbulent) than cold season.

Ts & *LE* Diff. in Varies Experiments

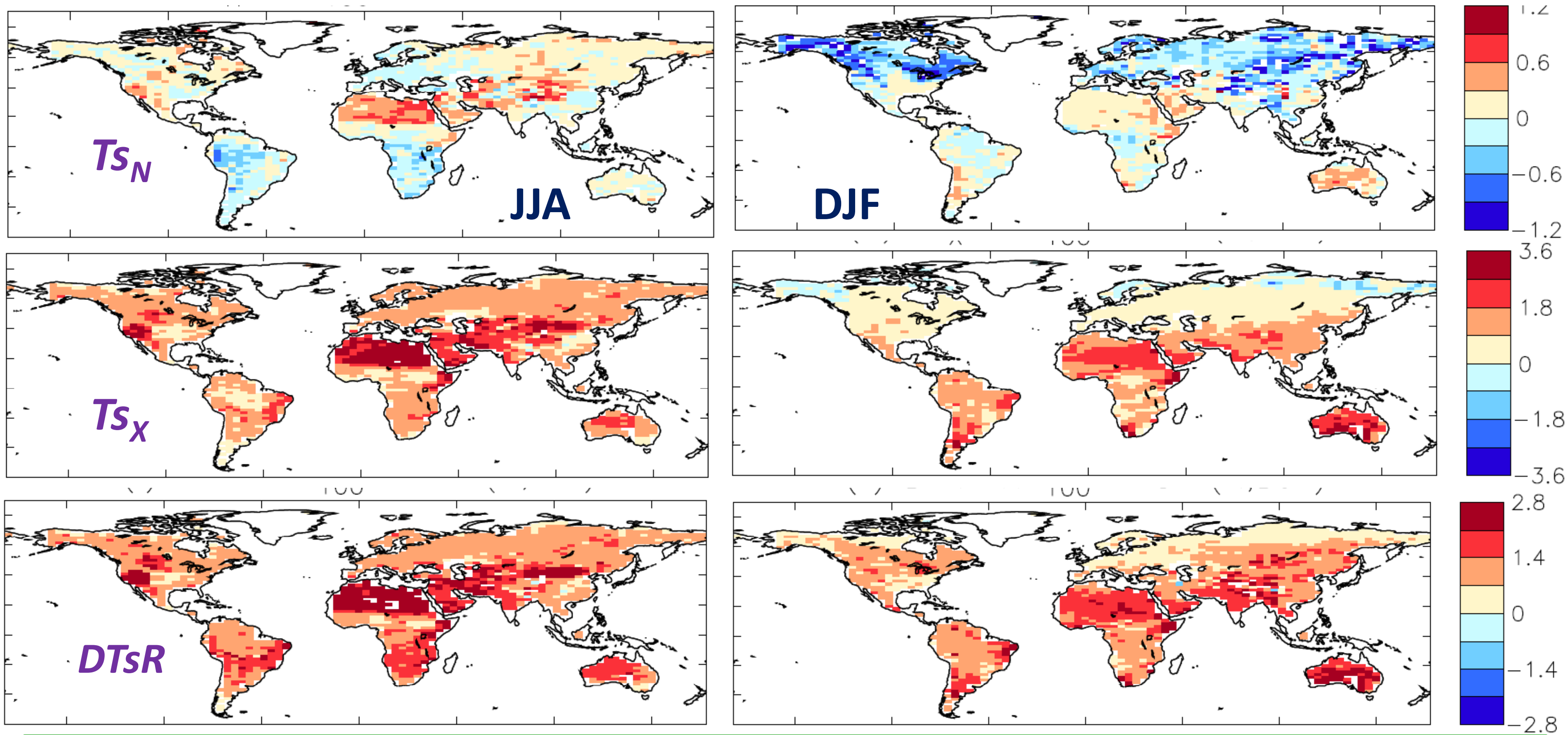


Different z_{0h} formulas have similar change pattern for *Ts*,*LE* (as well as for *H*, *Rn*)

Impacts of z_{0h} on Max. Min. DTsR. of *Ts*

EXP$_{100}$ ($z_{0h} = z_{0m} / 100$) - CTL ($z_{0m} = z_{0h}$)

Unit: K



Ts_X ↑ (during the day, turbulent heat flux ↓, less cooling).

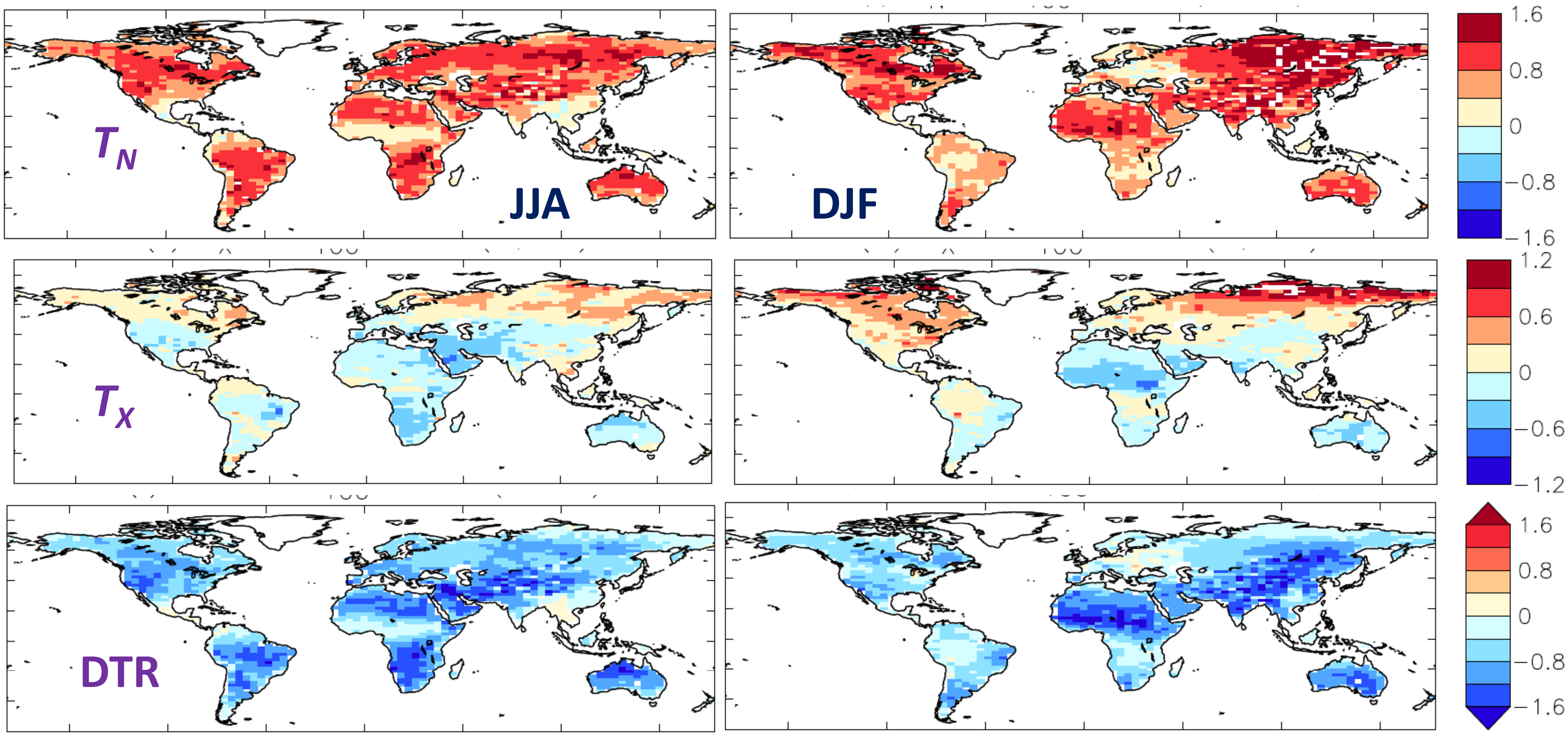
Ts_N small change (weak turbulent heat transfer during night).

DTsR (Diurnal range of Ts = Ts_X - Ts_N) ↑ (most significant over desert).

Impacts of z_{0h} on Max. Min. DTR. of *Tair*

EXP$_{100}$ ($z_{0h} = z_{0m}$ / 100) - CTL ($z_{0m} = z_{0h}$)

Unit: K

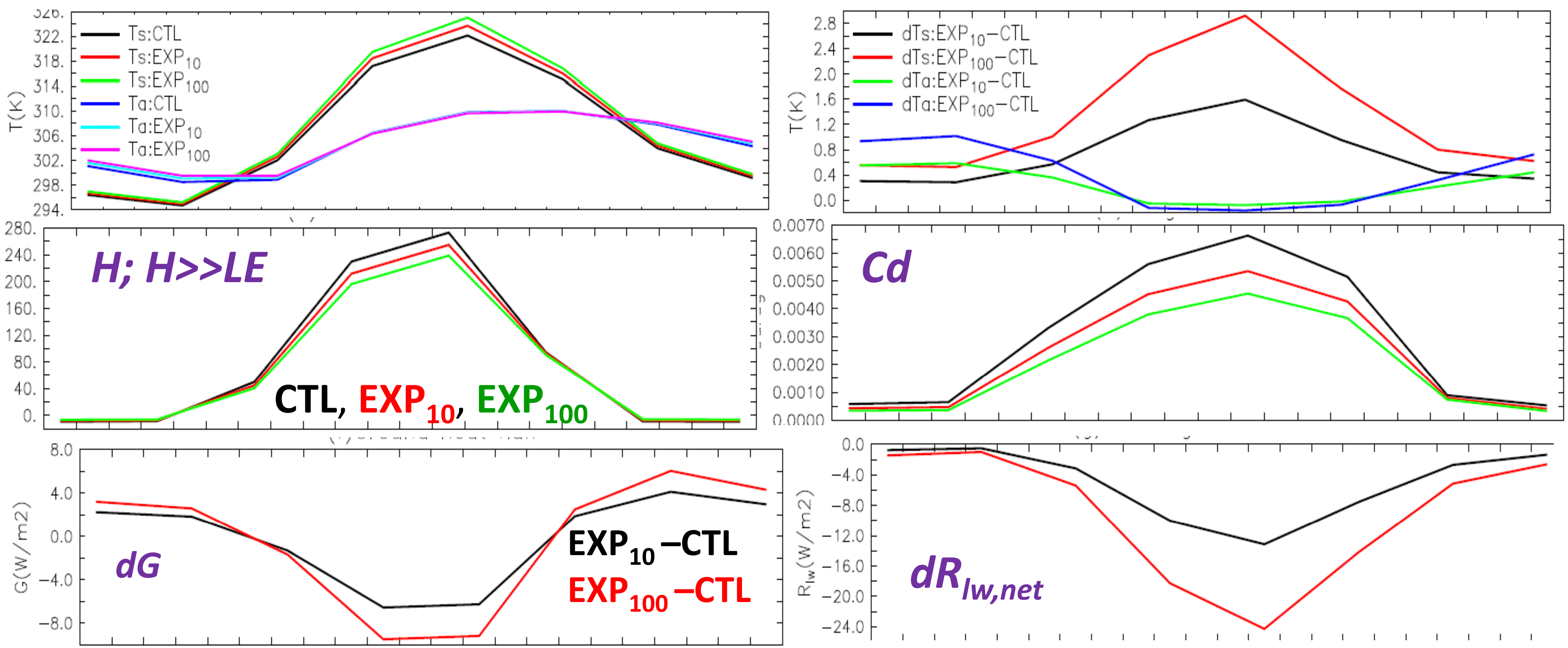


T_N ↑. T_N varies more than T_X; DTR (Diurnal range of Tair = T_X - T_N) ↓

Diurnal Cycles (Arid Environment)

Sahara desert [10W-10E, 20N-25N], July

DTsR ↑; DTR ↓



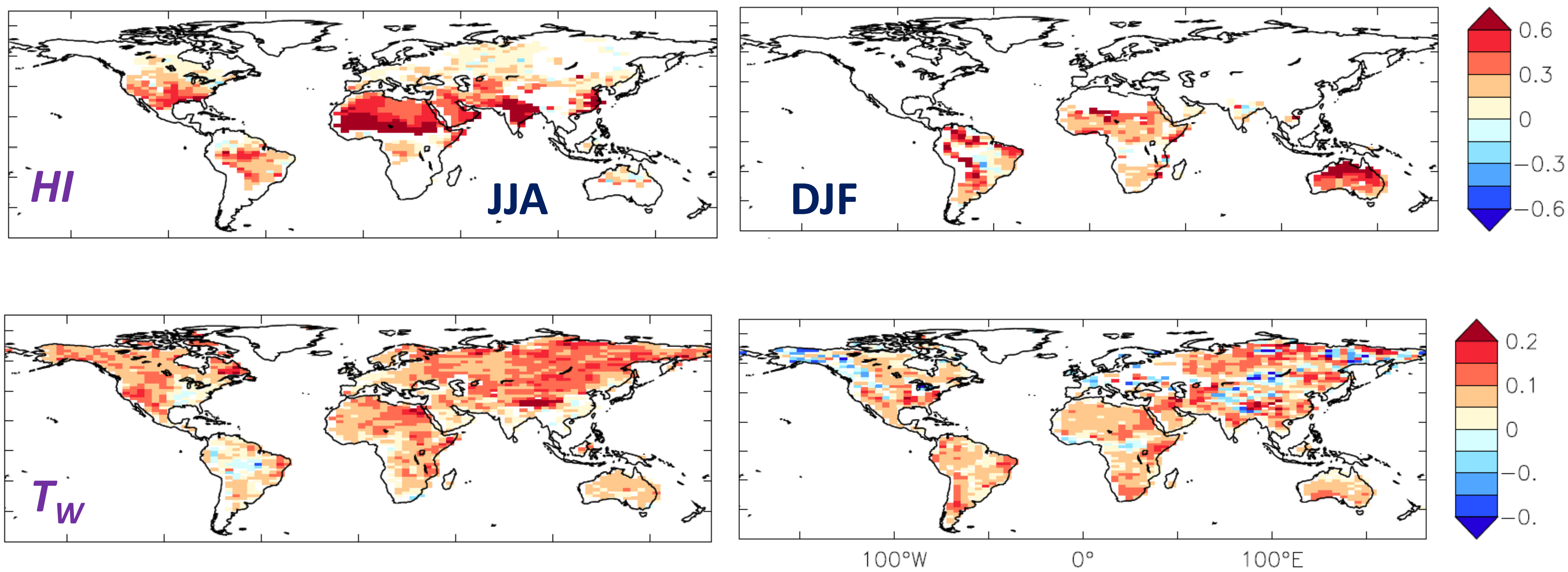
Daytime: ***H*** **large,** ***Cd*** **↓ → *H*↓ (weaker turbulent transfer) → *Ts* ↑ → heat absorbed by soil ↑; *H* ↓ compensated by $R_{lw,up}$ ↑ (little difference of diabatic heating of the lowest layer ,*Ta* less affected).**

Nighttime: ***H*** **~0,** ***Cd*** **changes small; heat released by soil ↑, $R_{lw,up}$ ↑ → *Ts, Ta* ↑**

Impacts on Heat Index & Wet-bulb T.

EXP$_{10}$ ($z_{0h} = z_{0m}$ / 10) **- CTL** ($z_{0m} = z_{0h}$)

Unit: K



HI ↑: **human-body feels hotter (*HI* measures the human-perceived equivalent temperature);**

T_W ↑: less net conductive & evaporative cooling of human body can occur to remove the metabolic heat.

Conclusions

- It is generally accepted that $z_{0h} \neq z_{0m}$, but $z_{0h}=z_{0m}$ in LMDZ-ORCHIDEE. Varies z_{0h} formulas were tested (1) $z_{0h}=z_{0m}/10$; (2) $z_{0h}=z_{0m}/100$; (3) CZ09 ($z_{0h}<z_{0m}$). Main findings are:

  I. A smaller z_{0h} (smaller drag coefficient) corresponds to a higher *Ts* & *Ta*, lower *LE*, *H*, & *Rn* (more significant change over arid region).

  II. For *Ts*, the increase of *Tsx* is larger than *Tsn*, DTsR increases (weaker turbulent during day); for *Ta*, DTR decreases (*Tn* increases greater than *Tx*) (larger ground heat flux and upward Rlw during night).

  III. The heat index and wet-bulb temperature increase as well, which implies hotter temperature of human body feels.

- Further directions

  I. Evaluation with observations (site to global).

  II. Another scheme is being tested [*Su et al.*, 2001; *Su*, 2002].

$$z_{0m} = \mathrm{h}(1 - \frac{d}{h})e^{-k\frac{u(h)}{u^*}} \qquad \ln\left(\frac{z_{0m}}{z_{0h}}\right) = \frac{kC_d}{4C_t\frac{u^*}{u(h)}(1-e^{-\frac{n}{2}})}f_c^2 + \frac{\kappa\frac{u^*}{u(h)}\frac{z_{0m}}{h}}{C_t^*}f_c f_s + \kappa B_S^{-1} f_s^2$$

Thank You for Your Attention !

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Formulas for S01

$$\frac{z_{0m}}{h} = (1 - \frac{d}{h})e^{-k\frac{u(h)}{u^*}}$$

$$kB^{-1} = \frac{kC_d}{4C_t \frac{u^*}{u(h)}(1 - e^{-\frac{n}{2}})} f_c^2 + \frac{k\frac{u^*}{u(h)}\frac{z_{0m}}{h}}{C_t^*} f_c f_s + kB_S^{-1} f_s^2$$

$$kB^{-1} = \ln(\frac{z_{0m}}{z_{0h}})$$

$$\zeta(z) = \int_0^z [\frac{C_d(z')\alpha(z')}{P_m(z')}]\,dz' \approx C_d \times LAI$$

$$\frac{u^*}{u(h)} = c_1 - c_2 e^{-c_3\zeta(h)}$$

$$n = \frac{\zeta(h)}{2\left[\frac{u^*}{u(h)}\right]^2}$$

$$\nu = 1.327 \times 10^{-5} \frac{p_0}{p}\left(\frac{T}{T_0}\right)^{1.81}$$

$$\kappa B_S^{-1} = 2.46(Re_*)^{1/4} - \ln(7.4)$$

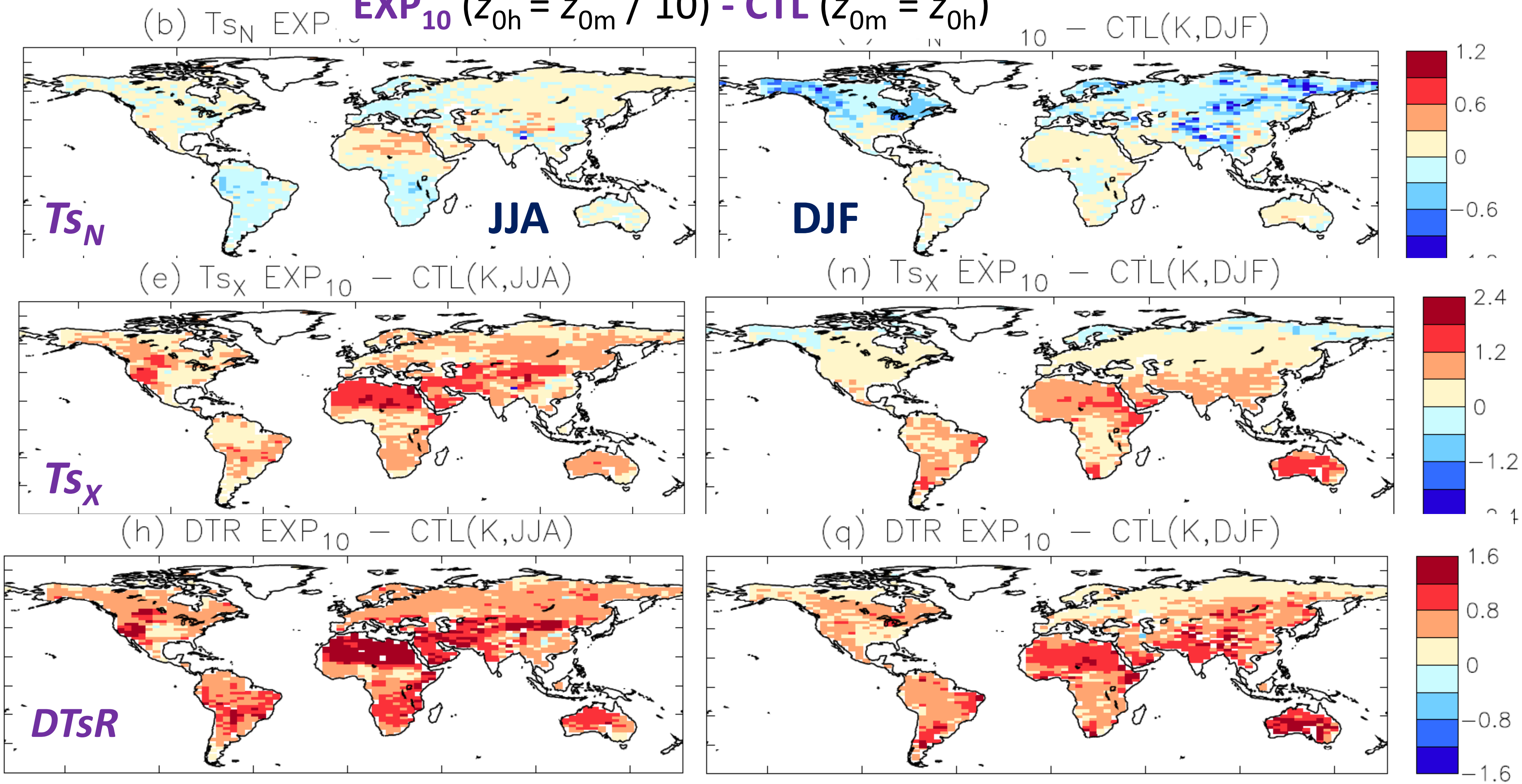
$$C_t^* = Pr^{-2/3} Re_*^{-1/2}$$

$$Re_* = \frac{z_{0m}u^*}{\nu}$$

B^{-1}: inverse Stanton number; f_c: fractional canopy coverage and f_s is its compliment; u: wind speed (m/s); u^* $(=\tau_0/\rho)^{1/2}$:friction velocity, τ_0: surface shear stress (kg/m/s^2), ρ:density of air (kg/m^3); p and T: ambient pressure and temperature, P_0=101.3kPa, T_0 = 273.14K; ν: fluid kinematical viscosity (m^2/s); c_1 (=0.320), c_2 (=0.264), c_3 (=15.1): model constants related to the bulk surface drag coefficient and to the substrate or soil drag coefficient c_s as discussed by Massman [1997]; $\zeta(h)$: cumulative leaf drag area per unit planform area, $\zeta(h) \approx C_d \times$ LAI ; C_d: drag coefficient of the foliage elements assumed to take the value of 0.2 [Su, 2002]; α: vertical leaf area density function; P_m: momentum shelter factor; C_t: heat transfer coefficient of the leaf. For most canopies and environmental conditions, C_t is bounded as 0.005N $\leq C_t \leq 0.075N$ (N : number of sides of a leaf to participate in heat exchange); C_t = 0.01 currently (why ?). For bare soil, kB_s^{-1} by [Brutsaert ,1982].

Impacts of z_{0h} on Max. Min. DTsR. of *Ts*

EXP$_{10}$ ($z_{0h} = z_{0m}$ / 10) **- CTL** ($z_{0m} = z_{0h}$)



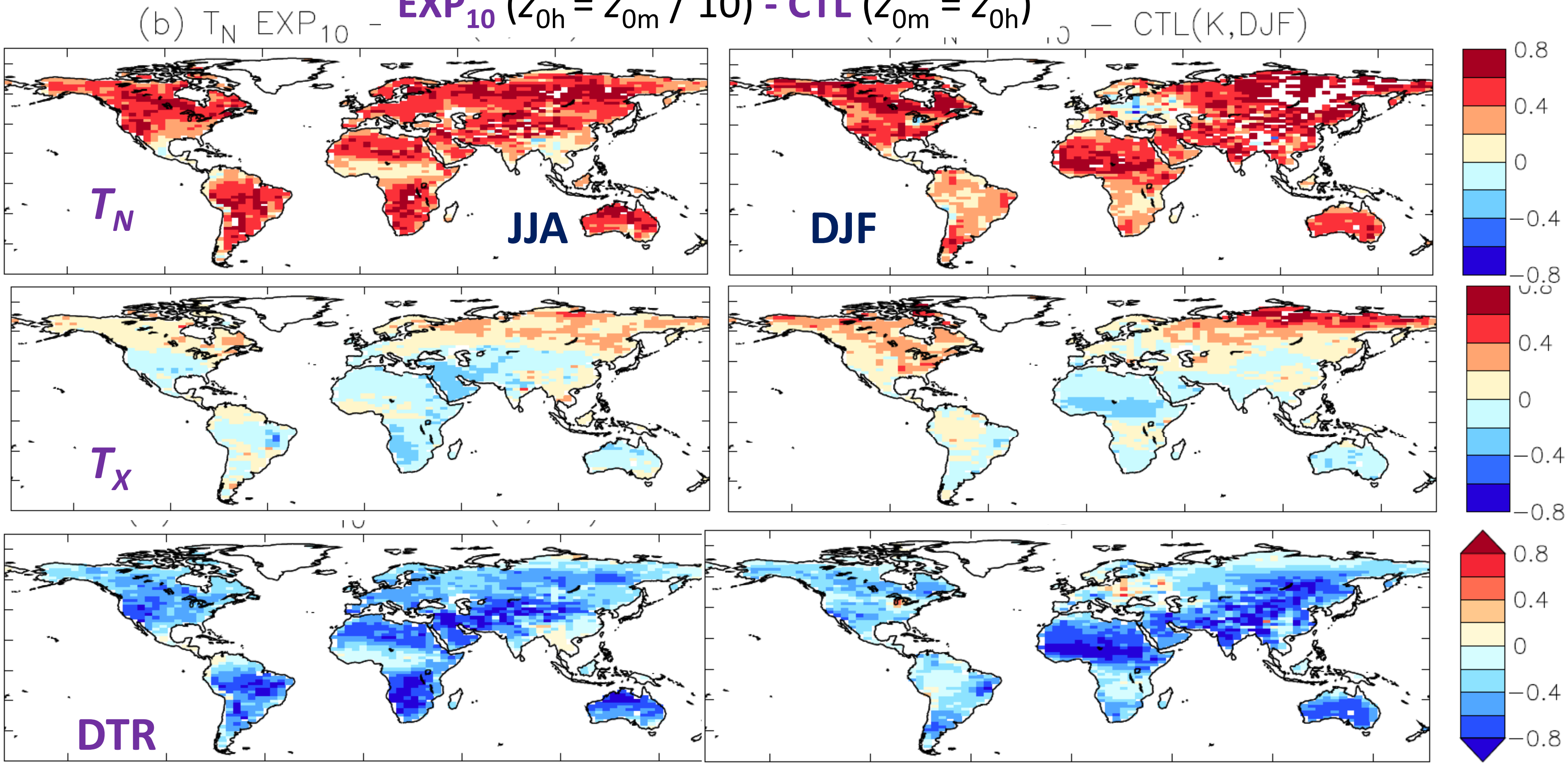
Ts$_X$ ↑ **(during the day, turbulent heat flux ↓).**

Ts$_N$ **small change (weak turbulent heat transfer during night).**

DTsR (=*Ts$_X$* - *Ts$_N$*) ↑ (most significant over desert); DTsR varies more for EXP$_{100}$.

Impacts of z_{0h} on Max. Min. DTR. of *Tair*

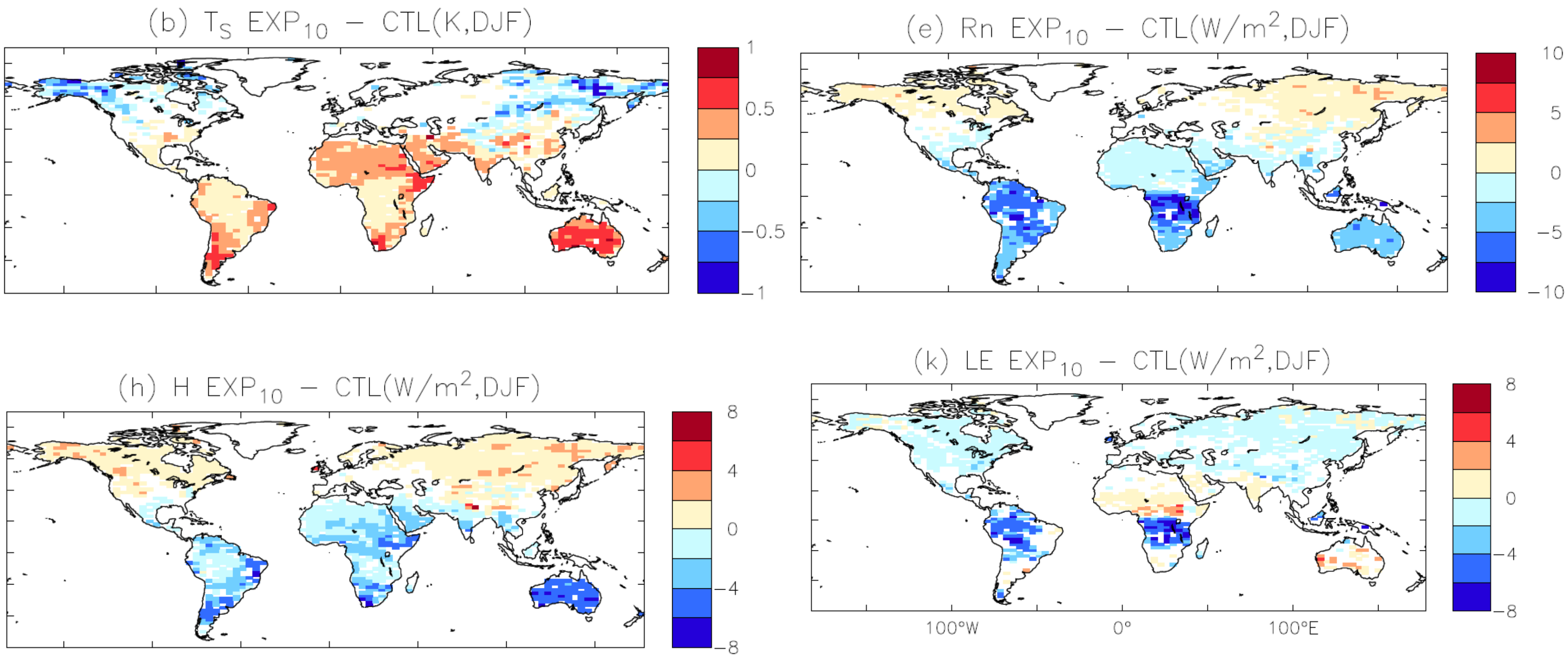
EXP$_{10}$ ($z_{0h} = z_{0m}$ / 10) - CTL ($z_{0m} = z_{0h}$)



T_N ↑. T_N increases more than T_X; DTR (=T_X - T_N) ↓

Impacts of z_{0h} on Ts, Rn, H, LE (DJF)

EXP$_{10}$-CTL

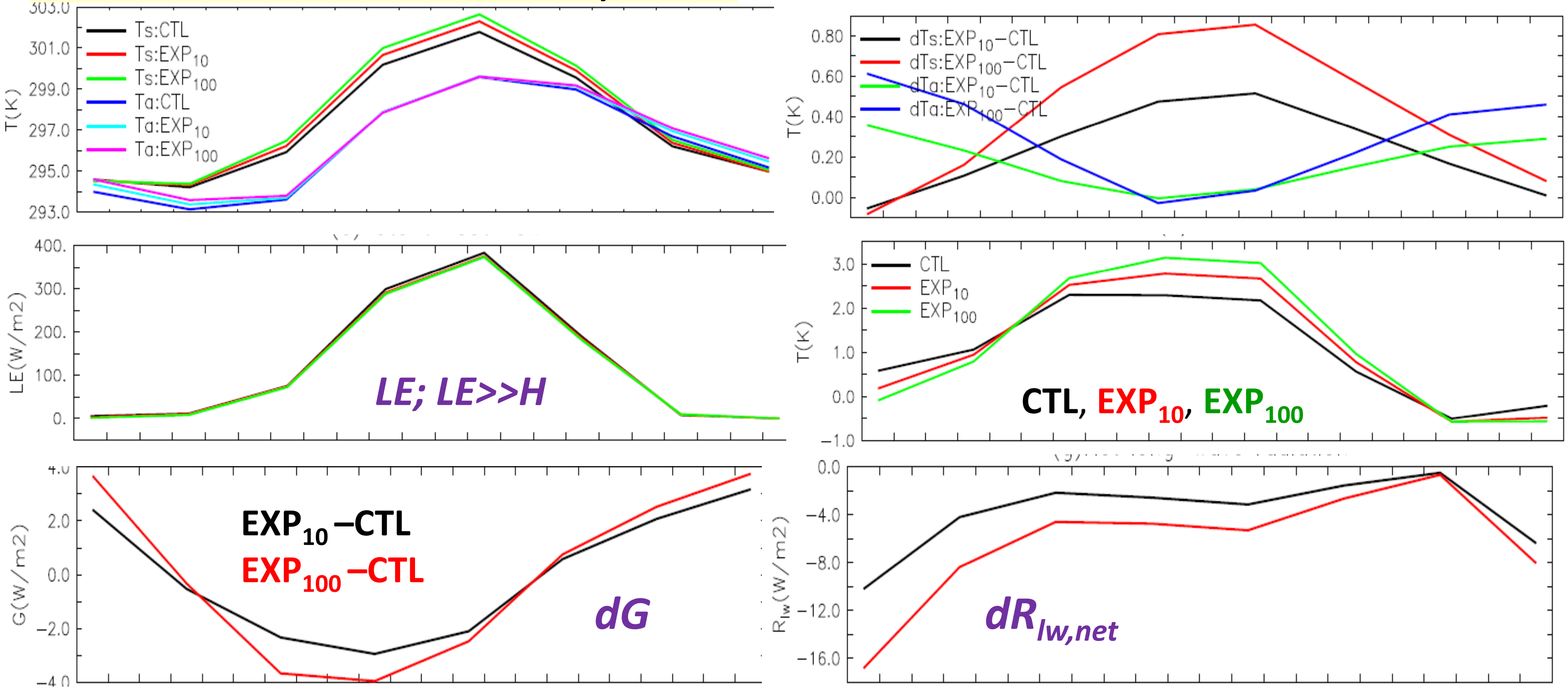


The Ts change is the most significant over bare soil for both JJA and DJF (lower soil heat capacity over the desert).

Diurnal Cycles (Humid Environment)

Sahel: [10W-10E, 10N-15N], July

DTsR ↑; DTR ↓

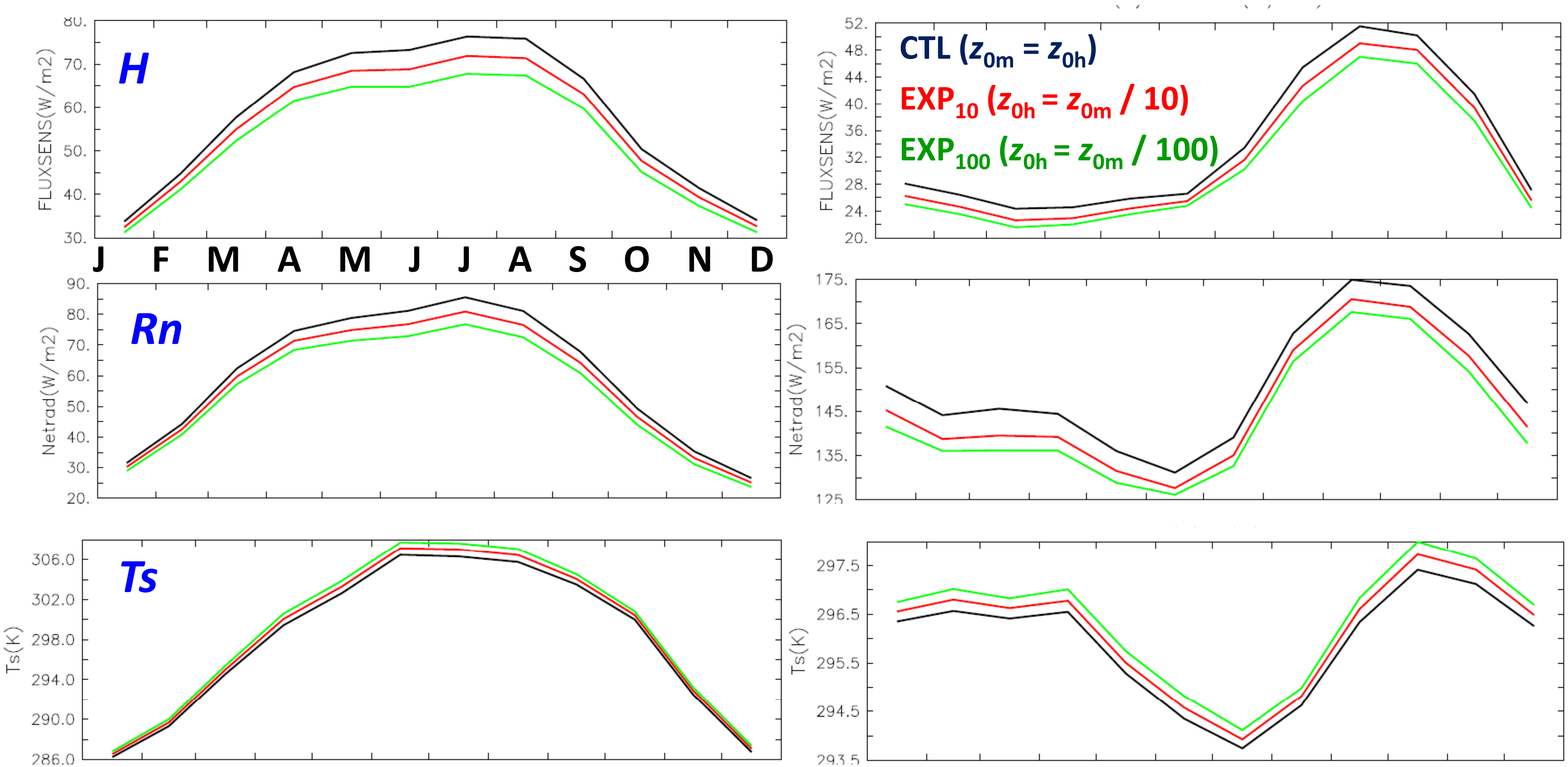


Daytime: *LE* large, *Cd* ↓ → *LE and H* ↓ → *Ts* ↑ → heat absorbed by soil ↑; *LE,* H↓ compensated by $R_{lw,up}$ ↑ (*Ta* less affected).

Nighttime: heat released by soil ↑, $R_{lw,up}$ ↑ → *Ts, Ta* ↑

Seasonal Cycles (Arid vs. Humid Region)

Sahara desert [10W-10E, 20N-25N] **Amazon** [80W-45W, 18S-5N]



Larger change of *H, Rn, Ts* over dry region (lower heat capacity) than wet region.

Arid : More significant in warm season (stronger turbulent) than cold season.

Humid: Similar change in warm and cold seasons.