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*On the opposing roles of
air temperature and wind speed variability
in flux estimation
over partially vegetated landscapes*

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Research problem

✓ Incomplete knowledge of how heterogeneous surface properties (canopy cover, surface temperature, soil moisture) excite heterogeneity in the properties of the lower atmosphere (T_a , q , U).

Motivation

✓ Detailed ($L \sim 10$ m) remote sensed data (surface temp. T_s , canopy fraction F_c , NDVI, LAI...), but coarser atmospheric information is available ($L \sim 10$ km) .

✓ Soil Vegetation Atmosphere Transfer (SVAT) models typically run with uniform atmospheric inputs often taken from not representative weather stations.

✓ Improve the estimation of surface atmospheric forcing variables for remote-sensed based SVAT models.

Study Outline

The problem :

- How heterogeneous surface properties affect heterogeneity in the states of the lower atmosphere?

Modeling approach :

- Fully dynamic ABL land-surface coupling.
- Large Eddy Simulation (LES) model coupled with a Land Surface Model (TSM).

Applications :

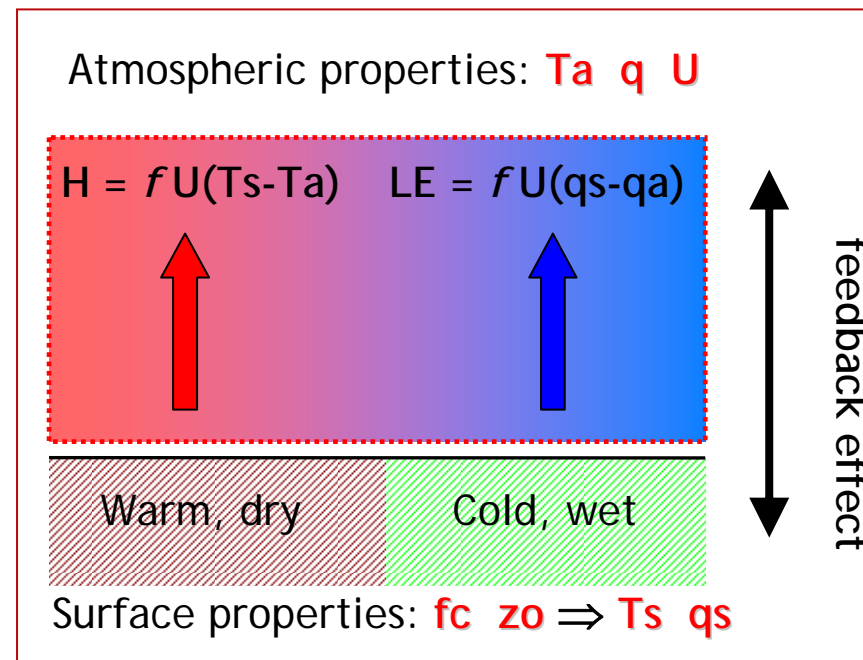
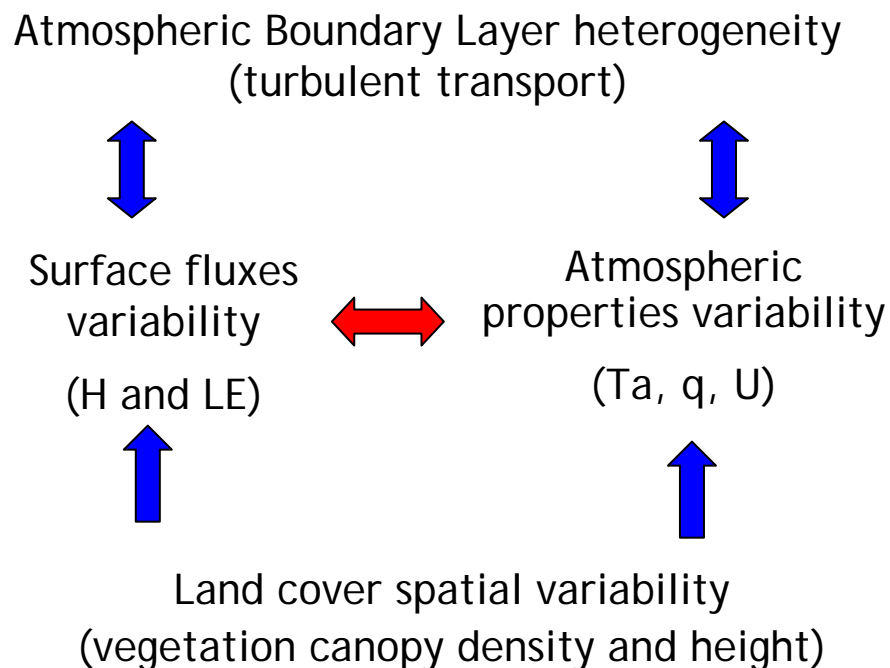
- Agricultural locations with strong contrast in canopy cover, surface temperature, soil moisture.

Results :

- Effects of land cover variability on T_a and U variability.
- Effects of T_a and U variability on surface fluxes.

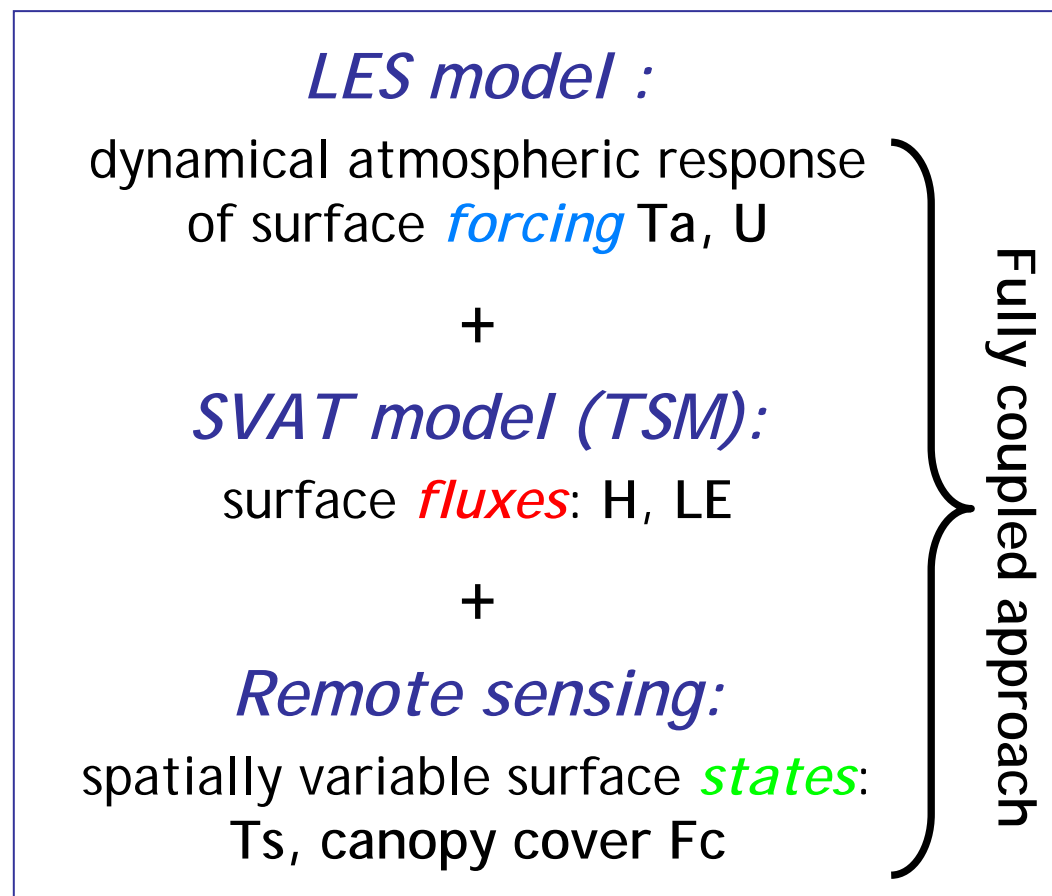
Practical implications:

- Identify the locations where ignoring the atmospheric properties spatial variability can lead to a significant error in fluxes estimation.



1. What is the improvement in surface fluxes estimation to have spatially variable (coupled) T_a and U ?
2. Is the surface property/atmospheric state feedback exacerbating or mitigating the contrast in surface fluxes?
3. It is only a local effect or it does also affect the surface fluxes regional average ?

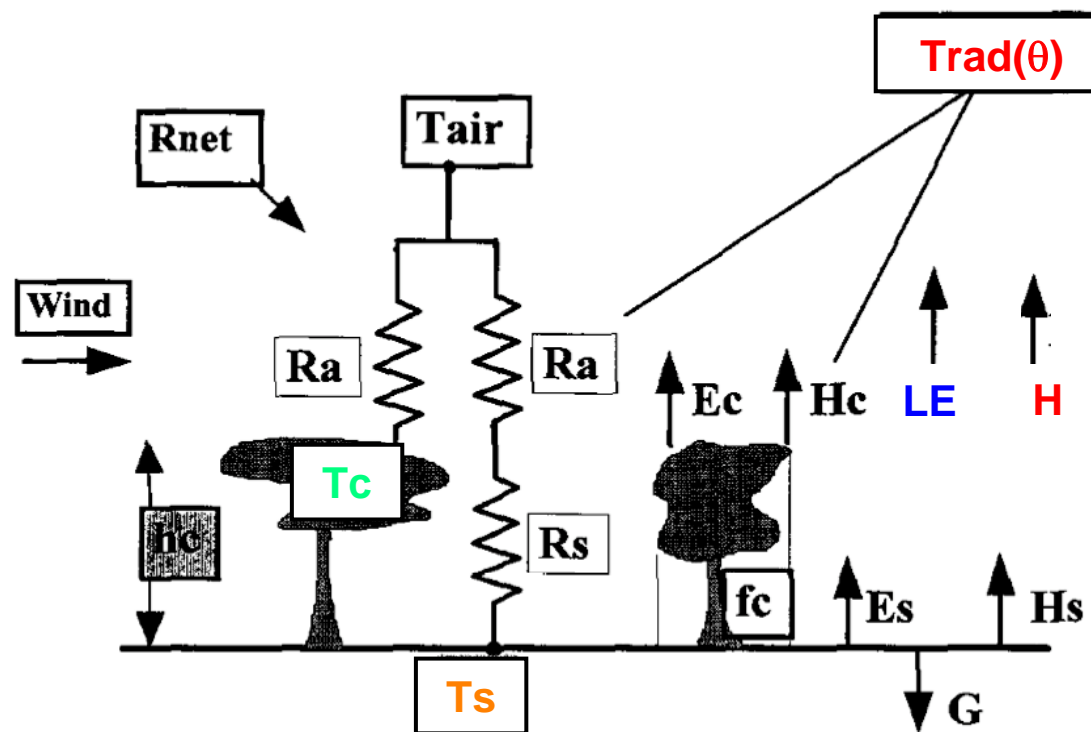
(Albertson et. al, 2001; Bertoldi et al., 2007)



⇒ **Full dynamic surface atmosphere coupling.**

(Norman and Kustas, 1995)

- **Input information from remote sensing (RS).**
 - Radiometric surface temperature **Trad**.
 - Surface properties: **NDVI**, **fc**, **hc**, **zo**, ...
 - Separates **soil** and **vegetation** components: $Trad^4 = fc Tc^4 + (1-fc) Ts^4$



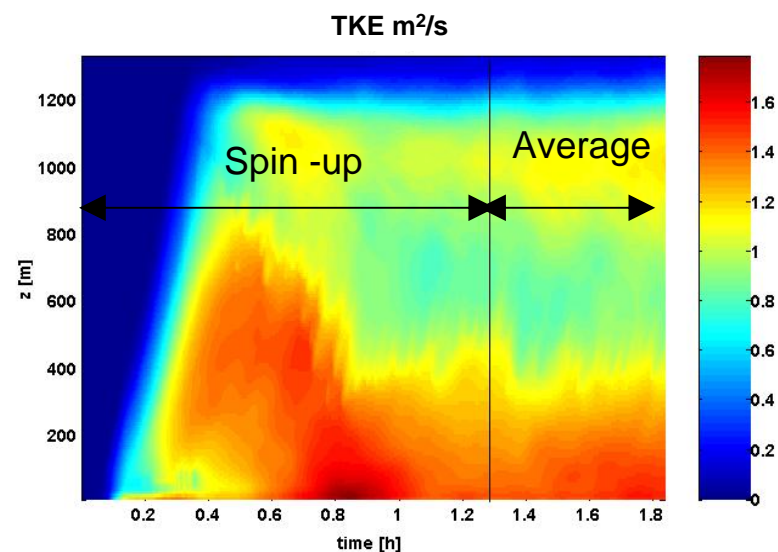
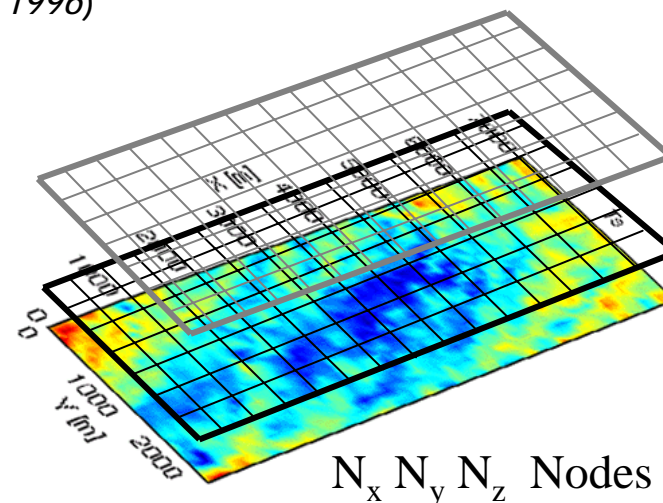
(Albertson, 1996)

Large Eddy Simulation (LES)

- Filtered 3D Navier-Stokes equations.
- Sub Grid Scale parameterized (Smagorinsky, 1963).

Model settings:

- Domain 128 x 128 x 171 grid cells.
- Resolution 48 x 48 x 5 m.
- Periodic boundary conditions.
- Initialized with observed vertical ρ , θ profiles.
- Spin-up until turbulence is fully developed.
- Scalars T_a , q , U and fluxes H , LE from LES over 1h averaging time.

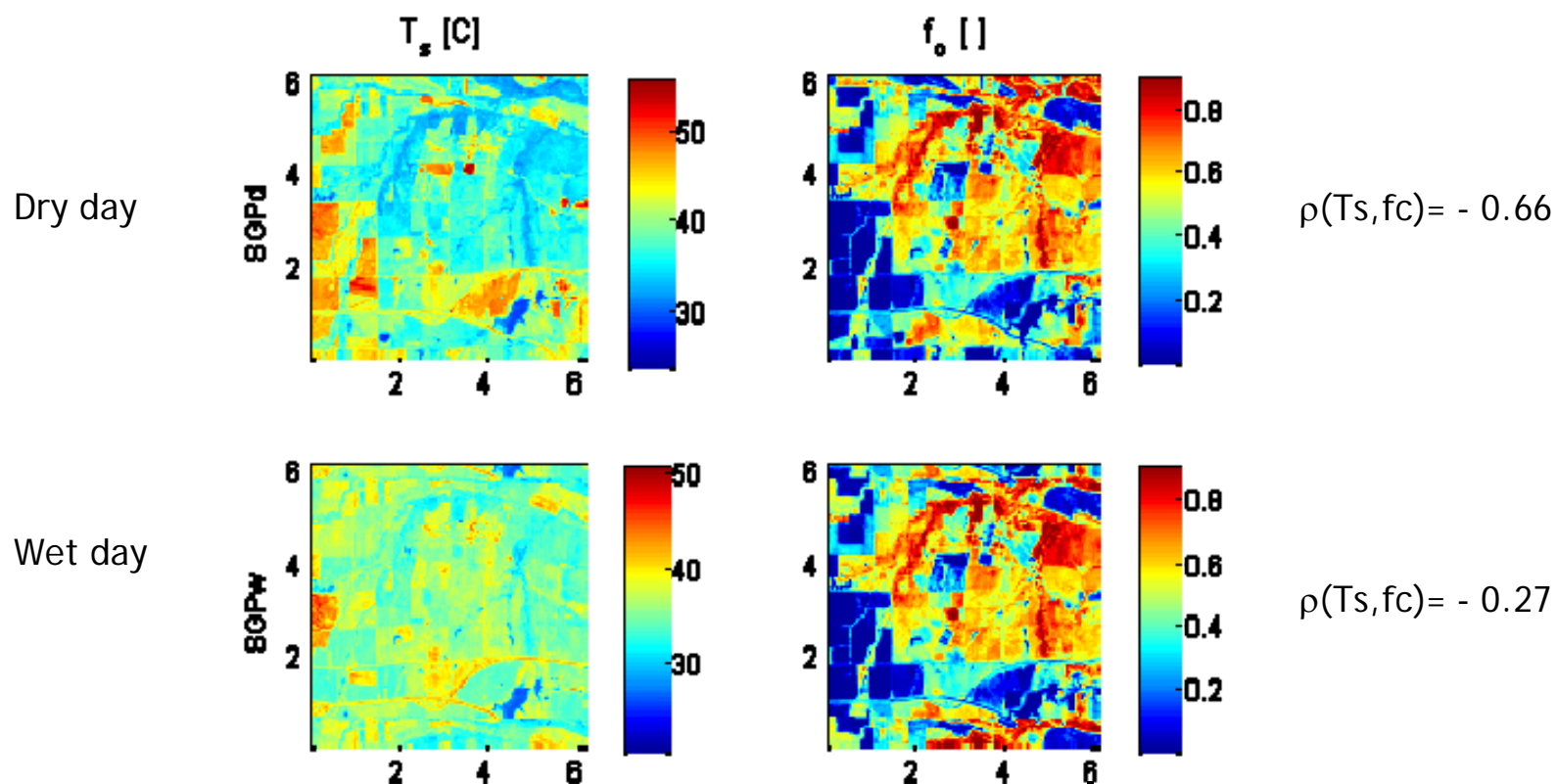


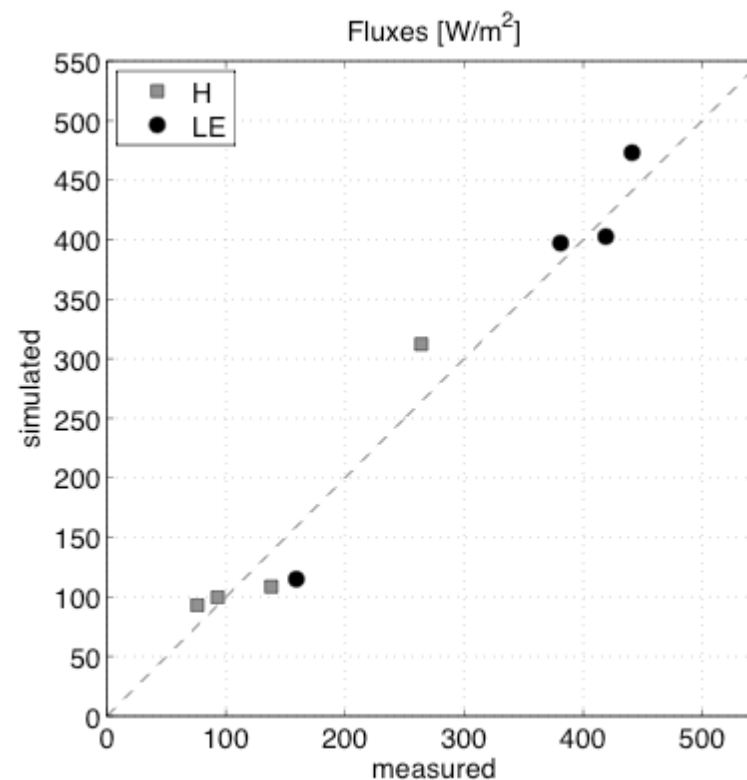
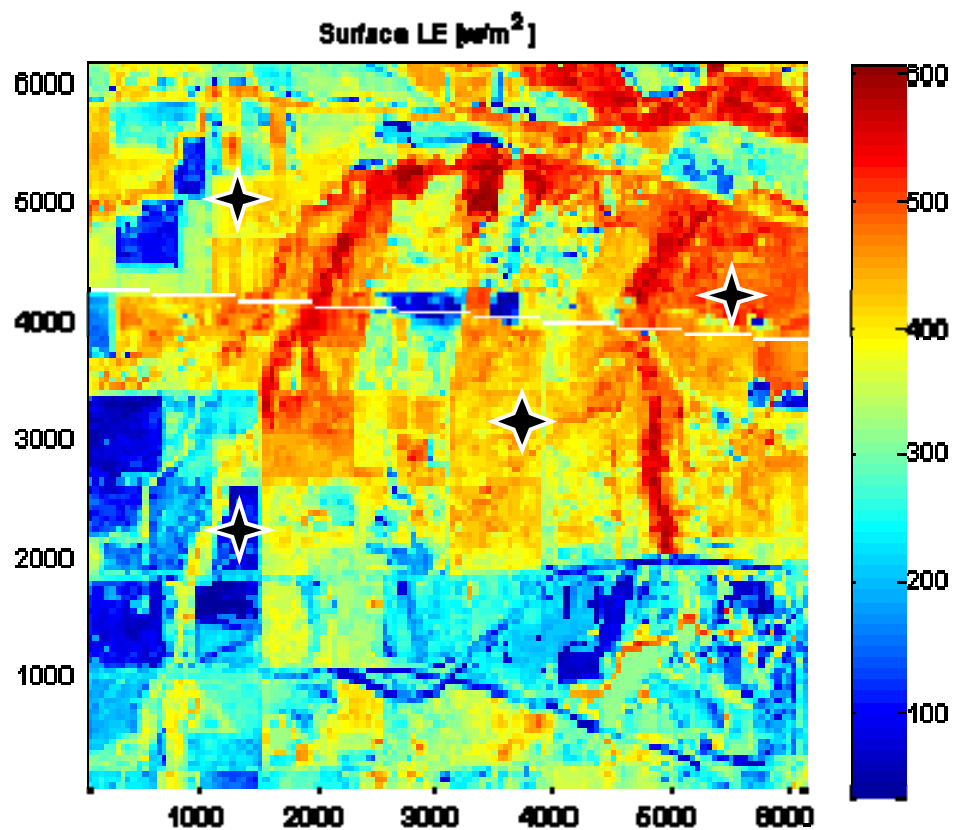
Agricultural regions with strong contrasts in canopy cover and surface temperature.

Domain scale: ~ 7 x 7 km; Patches scales: ~ 0.5 x 0.5 km;

SGP: Southern Great Plain region (OK, USA):

- Airborne IR Ts images 10.30 AM June 30 and 2 July 2, 1997.
- Different moisture conditions (beginning and end of a dry down period)





SGP dry case (2 July): 4 flux towers available for comparison

Realistic representation of the land - surface interactions

Simulation scenarios

1. Fully coupled simulation

- Coupled LES + TSM model: both Ta and U spatially variable.
- "True" "real world" scenario.

2. Uncoupled simulation :

- Only TSM model: Ta and U spatially uniform.
- Typical operational scenario (only one station or grid point available).

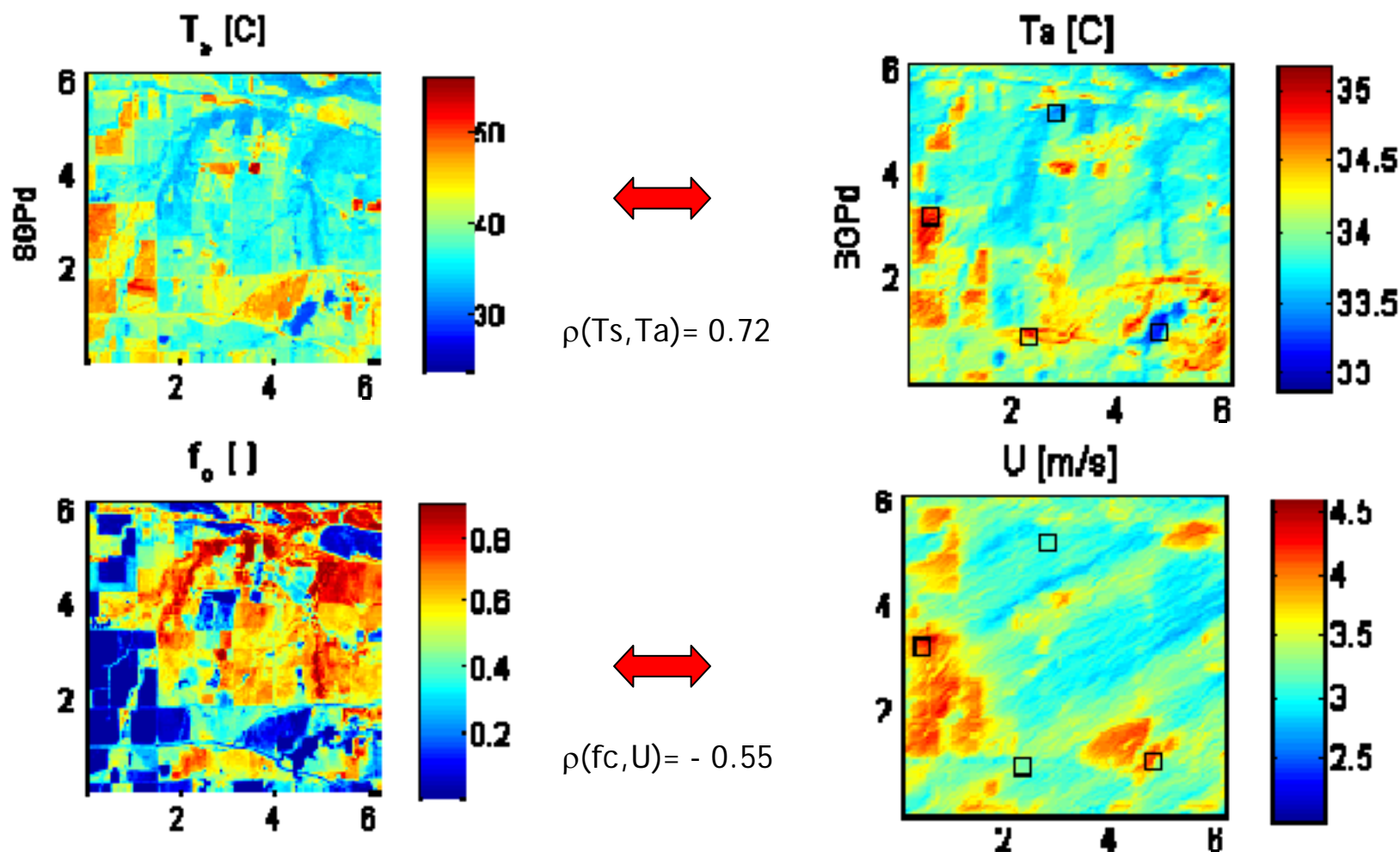
3. Partially coupled simulations

- To consider separately the effects of Ta and U spatial variability.
 1. Only Ta spatially variable.
 2. Only U spatially variable.

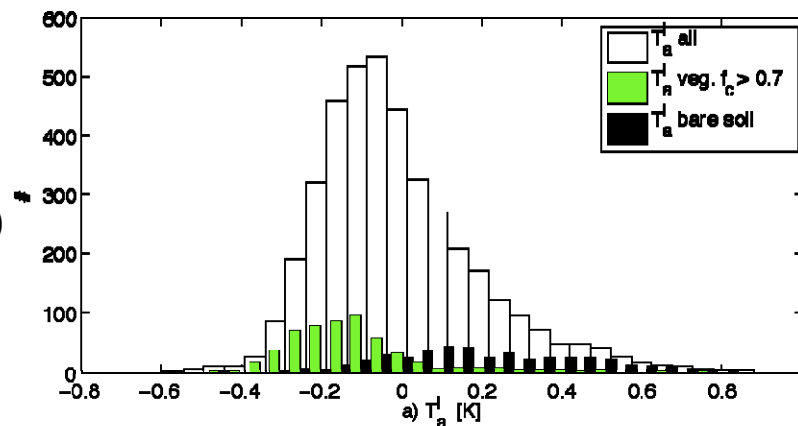
Fully coupled LES-TSM simulations results

Surface properties variability

Atmospheric properties variability

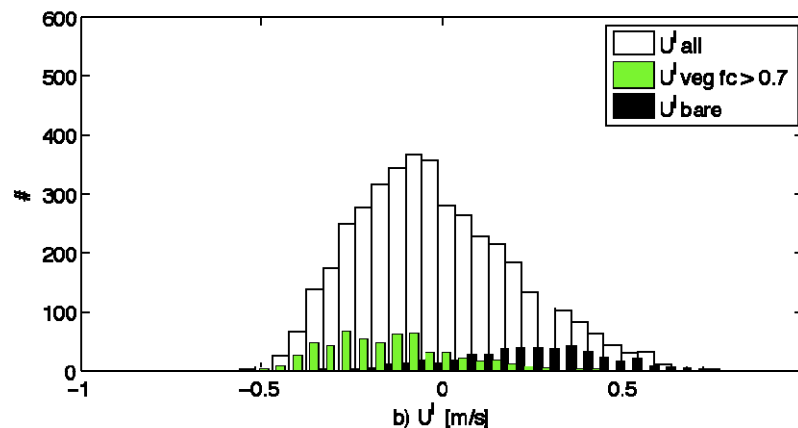


$T_a^l = T_a - \langle T_a \rangle$
(5 m above the surface)



T_a decreases over
vegetation;
 T_a increases over
bare soil.

$U^l = U - \langle U \rangle$
(5 m above the surface)



U decreases over
vegetation;
 U increases over
bare soil.

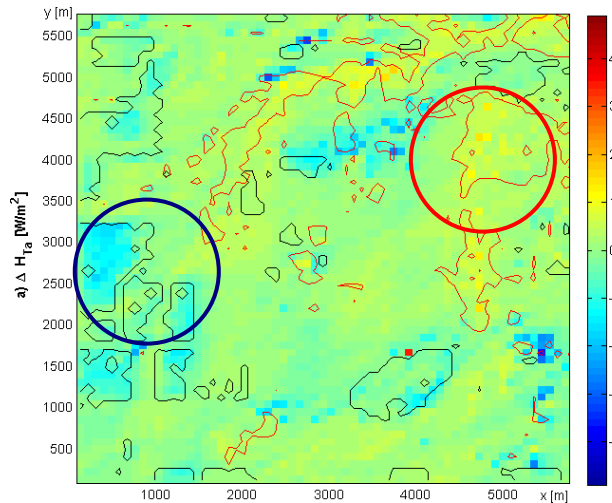
Strong control of vegetation on both T_a and U

At 5 m: $|T_a^l| \sim 1$ K; $|U^l| \sim 1$ m/s; ecological implications ...

... but what are the implications for surface fluxes estimation ?

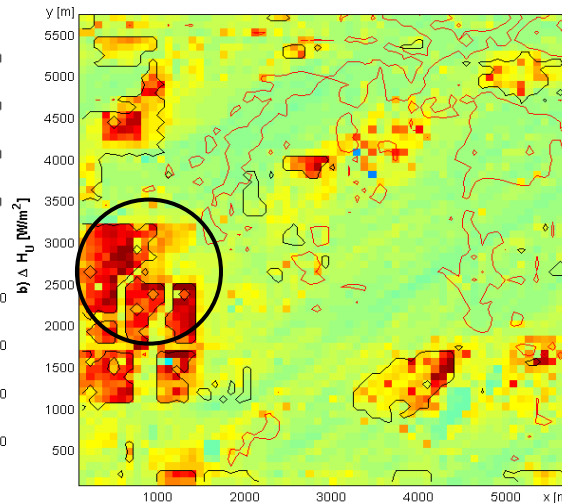
H: differences with respect the uniform case (T_a , U spatially constant)

1. Spatially variable T_a



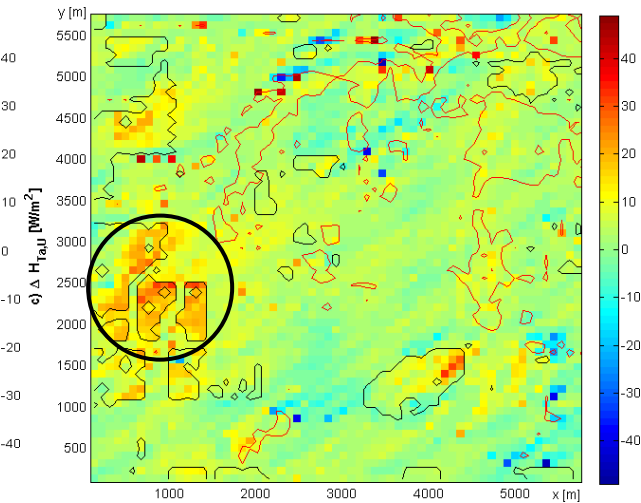
Min $\Delta H_{T_a} = -40 \text{ W/m}^2$
 $\langle \Delta H_{T_a} \rangle = -1 \text{ W/m}^2$

2. Spatially variable U



Max $\Delta H_{T_a} = +50 \text{ W/m}^2$
 $\langle \Delta H_{T_a} \rangle = +7 \text{ W/m}^2$

3. Spatially variable T_a and U



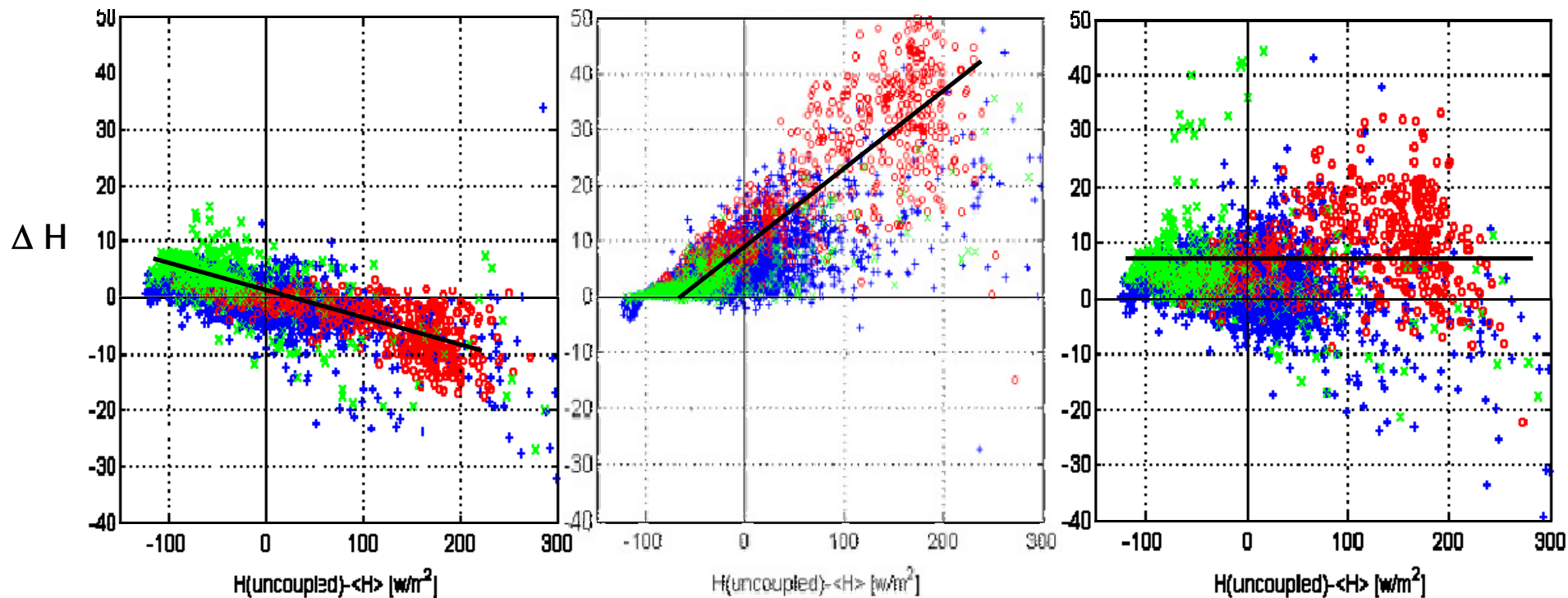
Max $\Delta H_{T_a} = +30 \text{ W/m}^2$
 $\langle \Delta H_{T_a} \rangle = +3 \text{ W/m}^2$

- ✓ Temperature spatial variability: H decreases over bare soil, increases over vegetation.
- ✓ Wind speed spatial variability: H increases over bare soil, slight decrease over vegetation.
- ✓ Full spatial variability is a combination of the two effects, partially canceling the two effects.
- ✓ Little effect on spatial averages, possible strong local effect (bare soil locations max sensitivity).

1. Spatially variable T_a

2. Spatially variable U

3. Spatially variable T_a and U



H^l_u

Decrease of variability

H^l_u

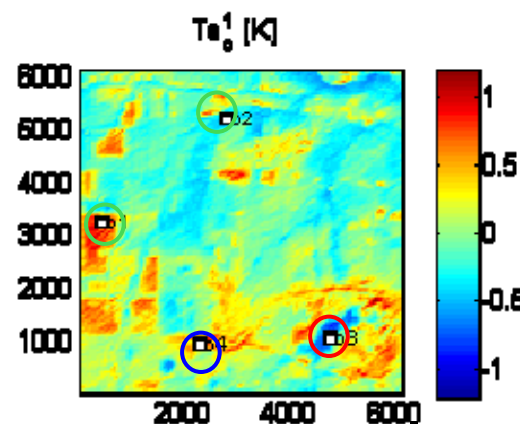
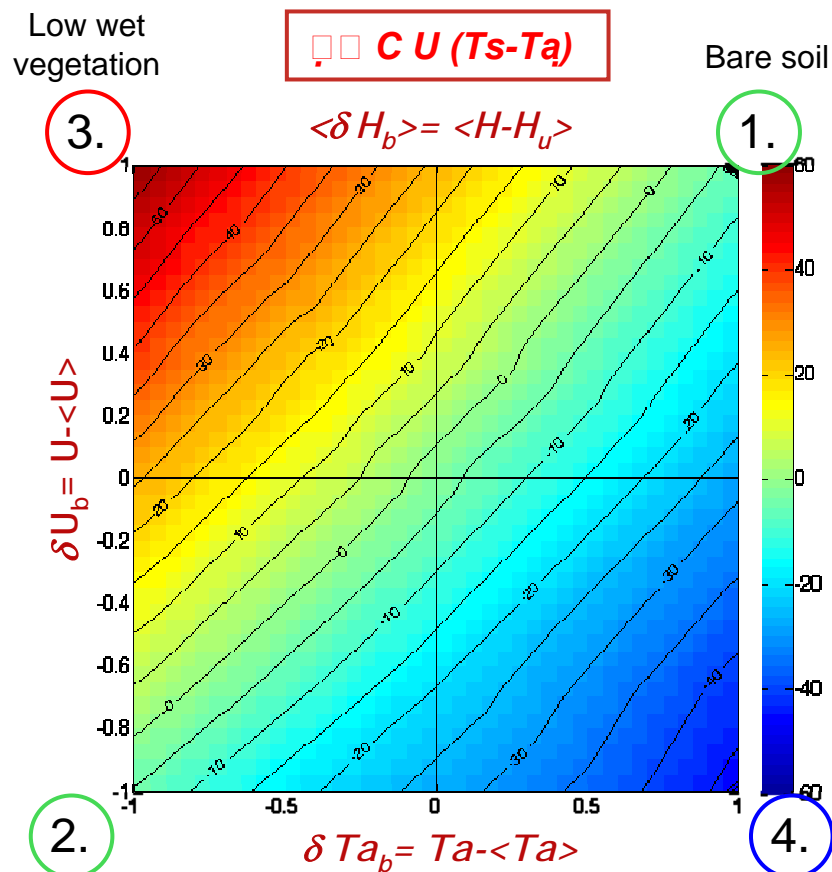
Increase of variability

H^l_u

Mixed effect

Little impact on regional averages

For which kind of land cover the effects of the T_a and U variability are additive ?



location	land cover	moisture	Zo	T _s	$\langle \delta T_{ab} \rangle$	$\langle \delta U_b \rangle$	$\langle \delta H_b \rangle$
1. warm, windy	dry bare soil	dry	low	high	+	+	⊕
2. cool, calm	irrigated tall cro forest	wet	high	low	-	-	⊖
3. cool, windy	irrigated meadow	wet	low	low	-	+	⊕
4. warm, calm	stressed crop, urban	dry	high	high	+	-	⊖

Tall vegetation

Stressed tall vegetation, urban

⇒ in locations (3) (4) additive effect of T_a and U variability:

Strong errors in regional surface fluxes estimation possible

Criteria to identify observation stations in not representative locations.

Conclusions

Effects of land cover variability on T_a and U variability :

- Vegetation has a systematic effect both on T_a and U .
- Local variations (at 5 m) of the order $|T_a| \sim 1$ K; $|U| \sim 1$ m/s.
- Little practical relevance: in the order of magnitude of instrumental errors.
- Ecological relevance: vegetation changes the local climate.

Effects of T_a and U variability on surface fluxes :

- T_a and U spatial variability has **opposite** effects on fluxes estimation over partially vegetated landscapes.
- Little impact on spatial averages, strong local effects (bare soil locations).
- Max errors for urban - stressed vegetation land cover types.

Application :

- Develop simple method to reduce the error in estimating surface fluxes using surface observations collected in not representative locations. (*Bertoldi, Kustas, Albertson, JAMC, in press*).

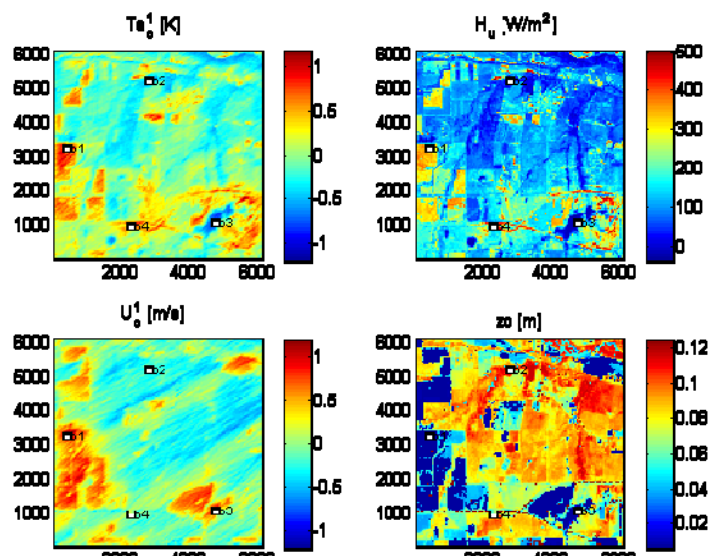
Acknowledgements

NASA-USDA project:

“Accounting for Effects of Subpixel Surface Variability on Regional Flux Estimation Using Large Eddy Simulation with Terra and Aqua Sensors”

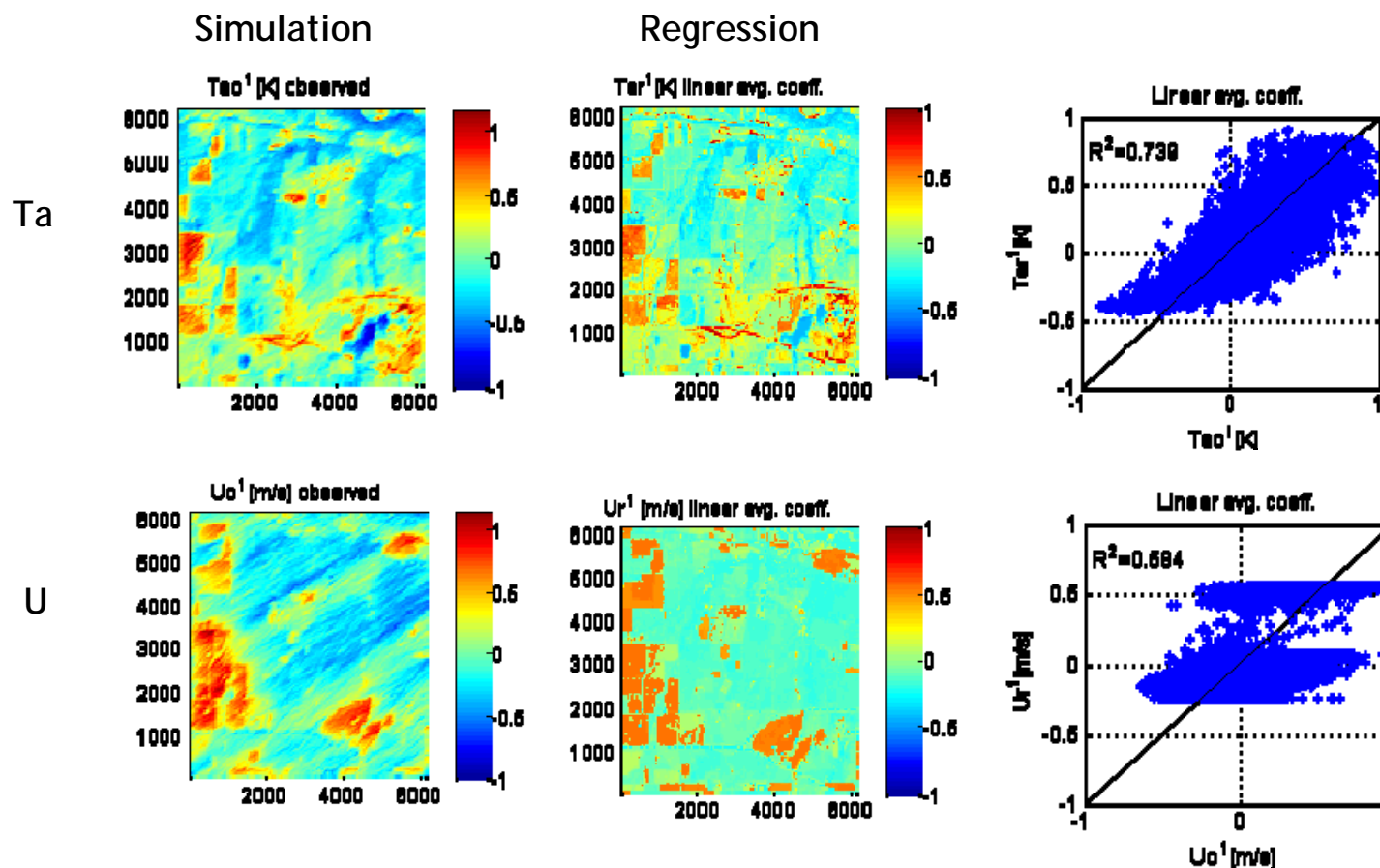
- Simple correction method to use operationally with **remote sensing data**..
- When observations only in not representative locations are available.
- Without employing Large Eddy Simulation.

1. Run the model with uniform surface properties to calculate approximate surface fluxes H_u , LE_u
2. Calculate an approximate spatial distribution of T_a , q , U using lagged-linear regression based on H_u , LE_u , z_{o_i} ; regression coefficients from LES.
3. Recalculate the fluxes distribution using the spatially distributed atmospheric variables T_a , q , U .

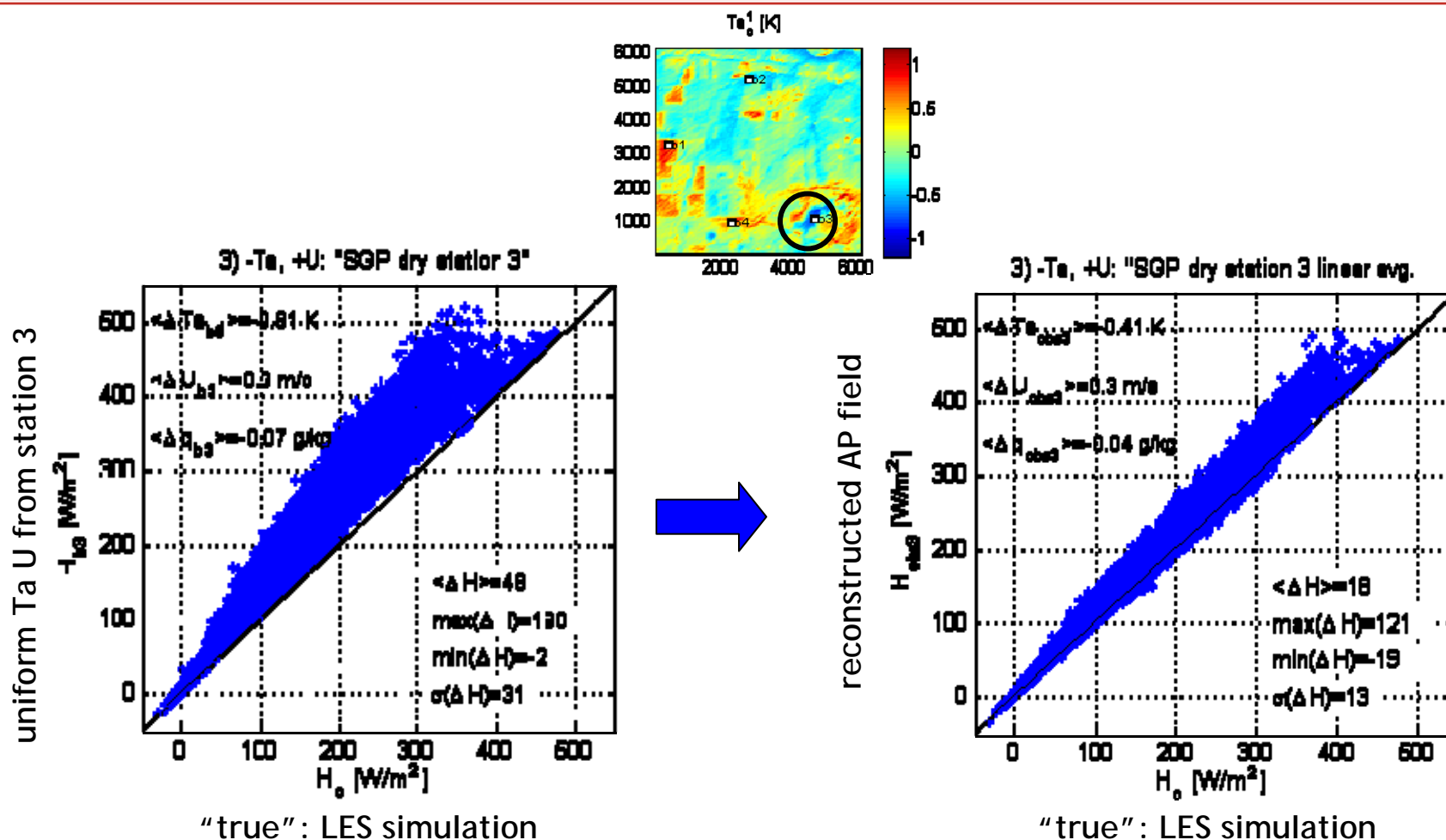


$$Ta' \propto H_u' \quad (R^2=0.86)$$

$$U' \propto z_o' \quad (R^2=0.77)$$



Little variation of the regression coefficients among the different locations.

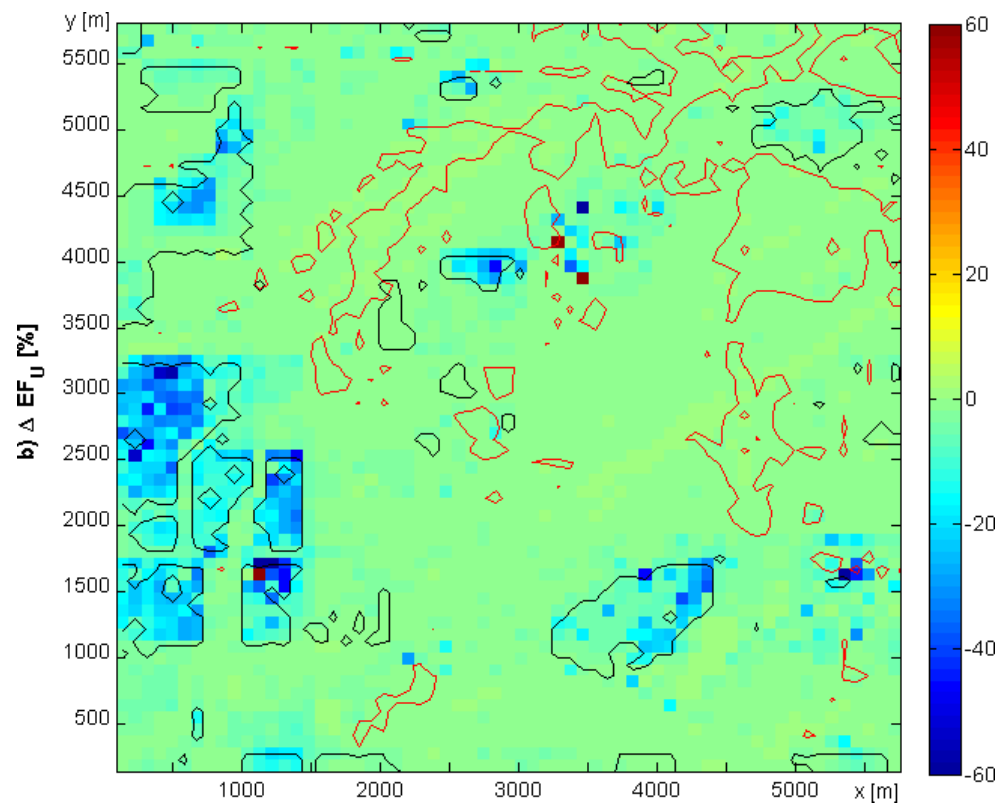


Reduction of the bias and of the dispersion of the H distribution, compared with the case with spatially uniform air properties.



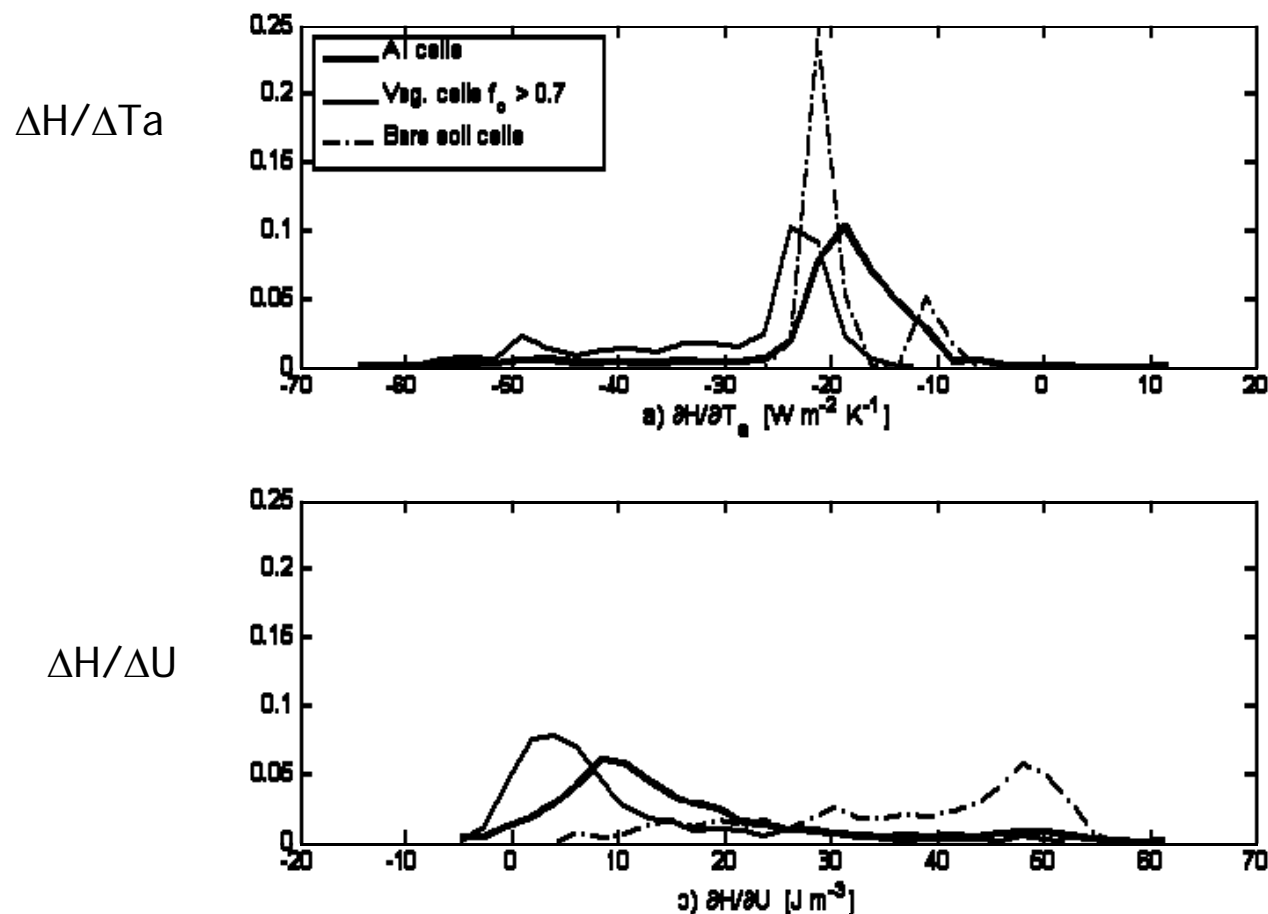
Thanks!

$$EF = \frac{LE}{LE + H}$$



Strong local effects for evaporative fraction in bare soil locations

What is the local error in H estimation ignoring the T_a , U spatial variability?



\Rightarrow Strongest sensitivity to wind speed errors in bare soil locations.

$\Delta H / \Delta U$ bare soil $\sim 50 W m^{-2} K^{-1}$