Evaluation of land-atmosphere coupling in the ARPEGE-SURFEX single-column model

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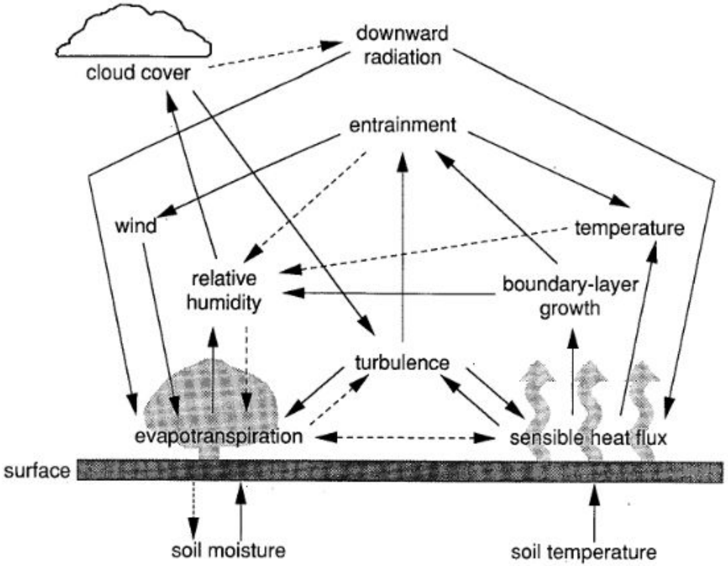
Introduction

Land-atmosphere coupling : interactions between the subsurface, land surface, and the atmosphere

➡ exchange of water, energy, tracers and momentum



Ek and Mahrt, 1994

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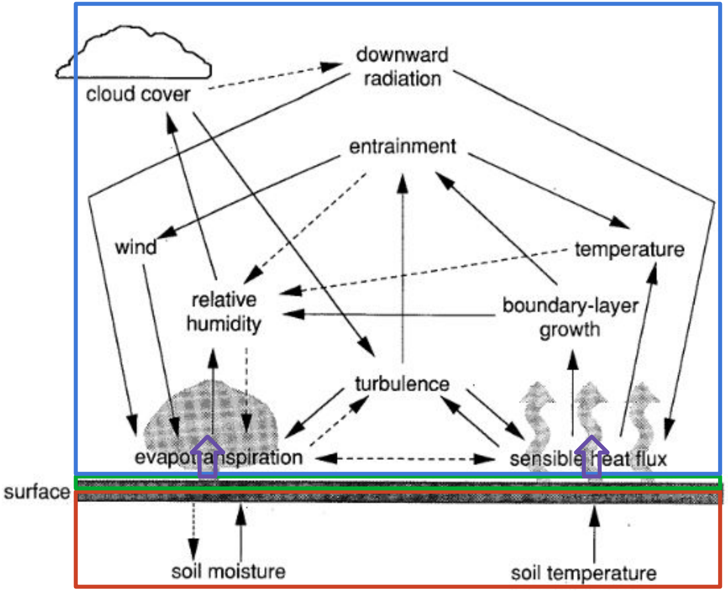

Ek and Mahrt, 1994

Surface fluxes

- **Subsurface** :
Moisture, temperature,...
- Land surface :
LAI, albedo, roughness length, ...
- Atmosphere :
ABL height, air temperature, cloud type and distribution, convection, precipitation,...

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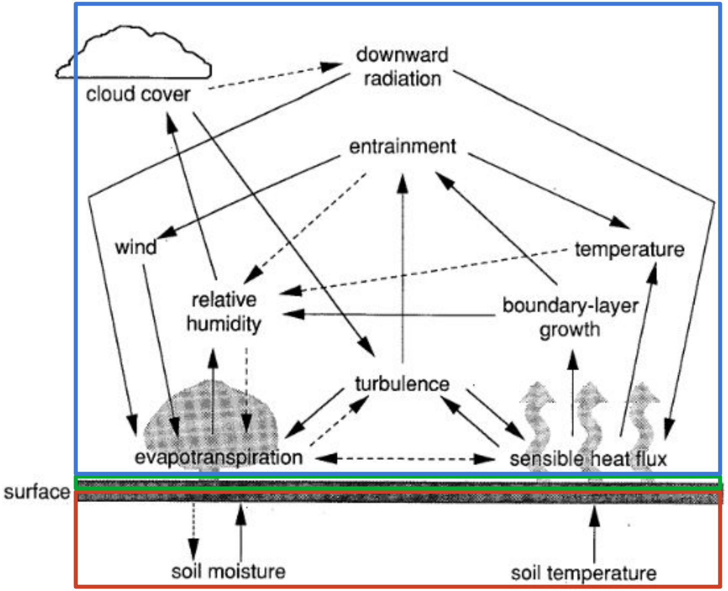

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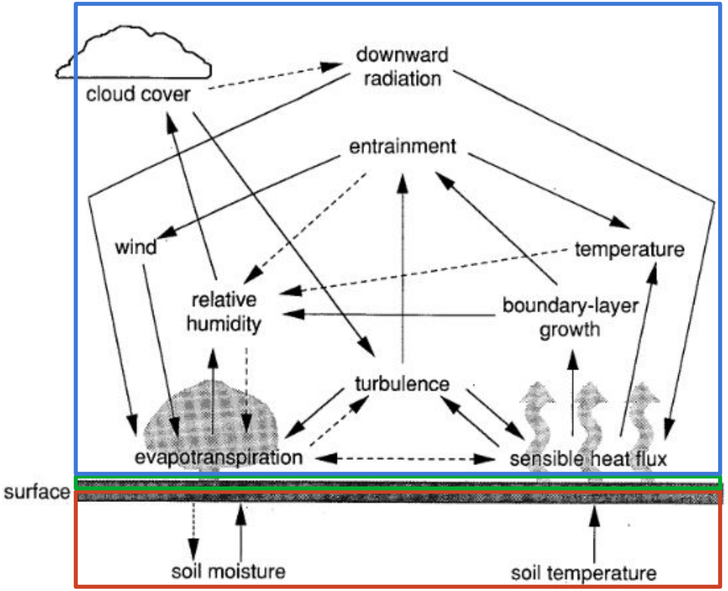

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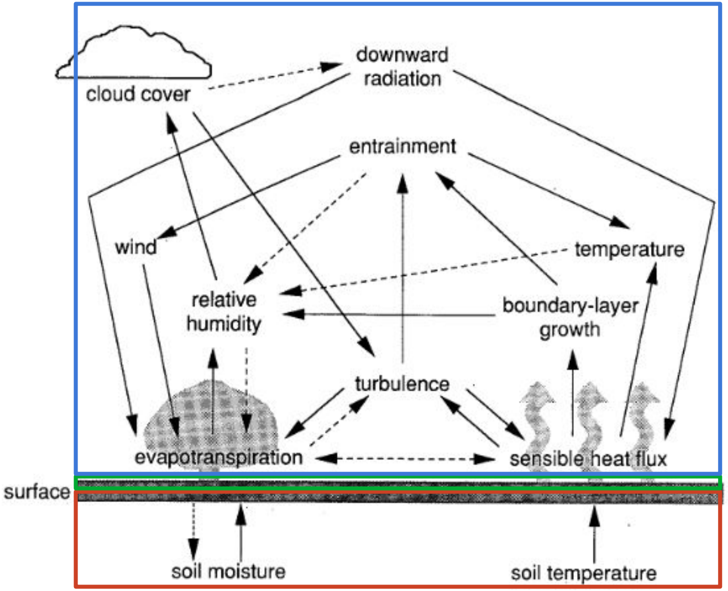

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LAI, albedo, roughness length, ...
- Atmosphere :
ABL height, air temperature, cloud type and distribution, convection, precipitation,...

➡ Important and complex interactions linked to human activities ... + extreme events


agriculture


urbanization


drought


heatwaves

Introduction

Land-atmosphere feedbacks are one of the key sources of uncertainty in climate or NWP models (WGNE, 2019)

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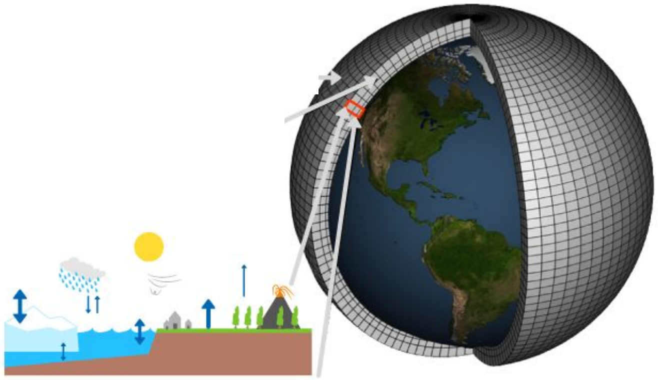
- How is land-atmosphere coupling represented in climate models?

Climate models



Land surface models

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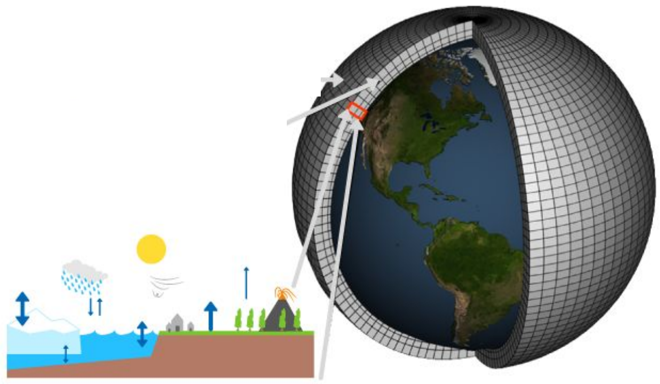


Land surface models

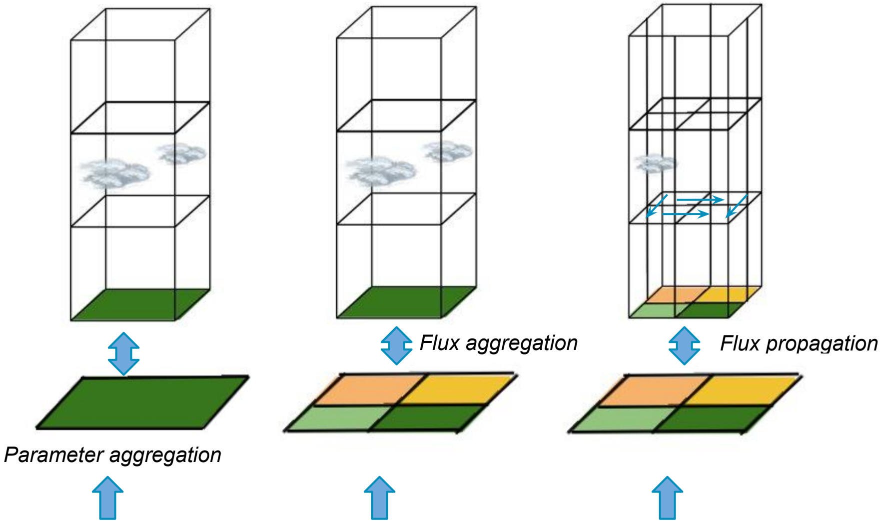
Atmospheric model

Surface model

Surface heterogeneities

Coupling methods

Parameter aggregation	Mosaïc	Extended Mosaïc
(Avissar and Pielke, 1989)	(Koster and Suarez, 1992)	(Molod et al., 2003)



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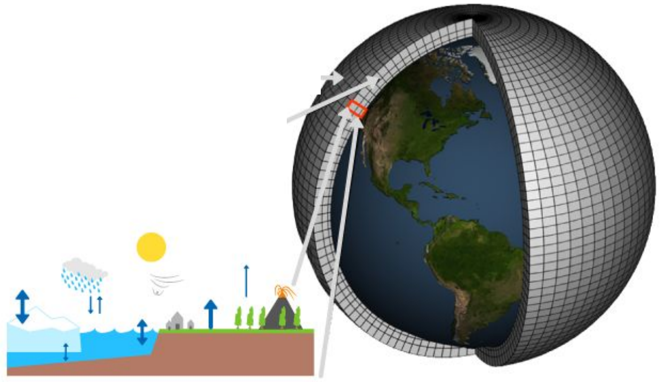


Land surface models

Surface fluxes are parameterized according to Monin-Obukhov similarity theory

➡ Hypothesis:
Homogeneity and stationarity of the boundary layer turbulent properties
Constant flux in the first model layer

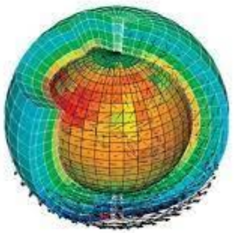
Introduction

- How is land-atmosphere coupling represented in CNRM-CM6-1?

CNRM-CM6-1

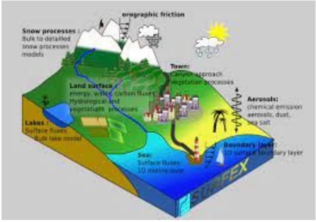
ARPEGE-SURFEX

ARPEGE-Climat 6.3
(Roehrig et al., 2020)



Climate model

SURFEX 8.1
(Masson et al., 2013)



Land surface model

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CNRM-CM6-1

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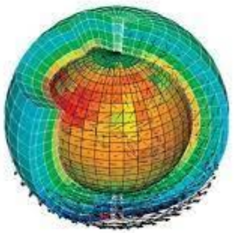

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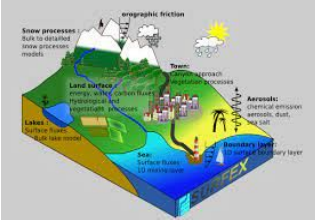
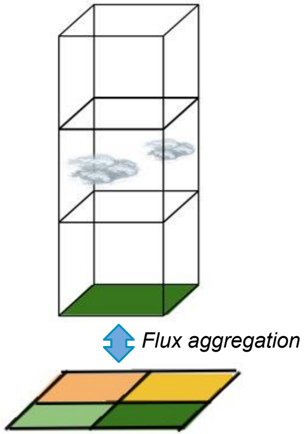


Land surface model

Mosaïc
(Koster and Suarez, 1992)



➡ Need for study cases to evaluate and better understand land-atmosphere coupling

Introduction

- How is land-atmosphere coupling represented in CNRM-CM6-1?

CNRM-CM6-1

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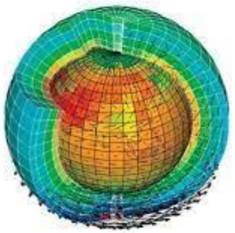

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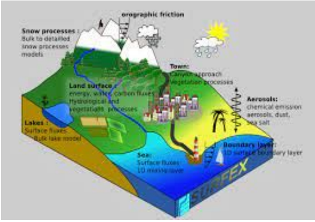


Land surface model

Outline

I. Study cases setup
II. Evaluation of the land-atmosphere coupling in ARPEGE-SURFEX
III. Sensitivity study of land-atmosphere coupling to surface parameterization

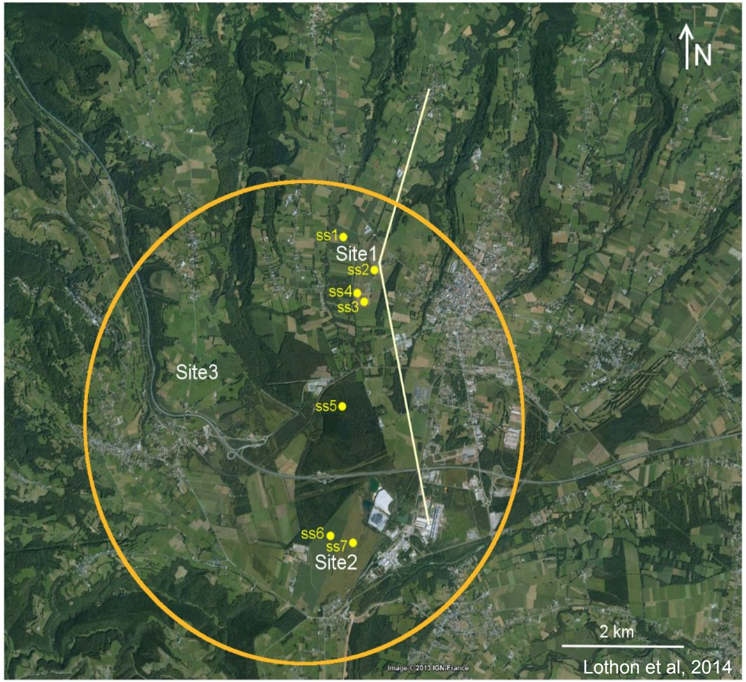
Preliminary results : Land-atmosphere coupling in heterogeneous conditions

➡ Need for study cases to evaluate and better understand land-atmosphere coupling

I. Study cases setup

The BLLAST (Boundary Layer Late Afternoon and Sunset Turbulence) campaign

14 June to 8 July 2011



Study site location

- **Study site**

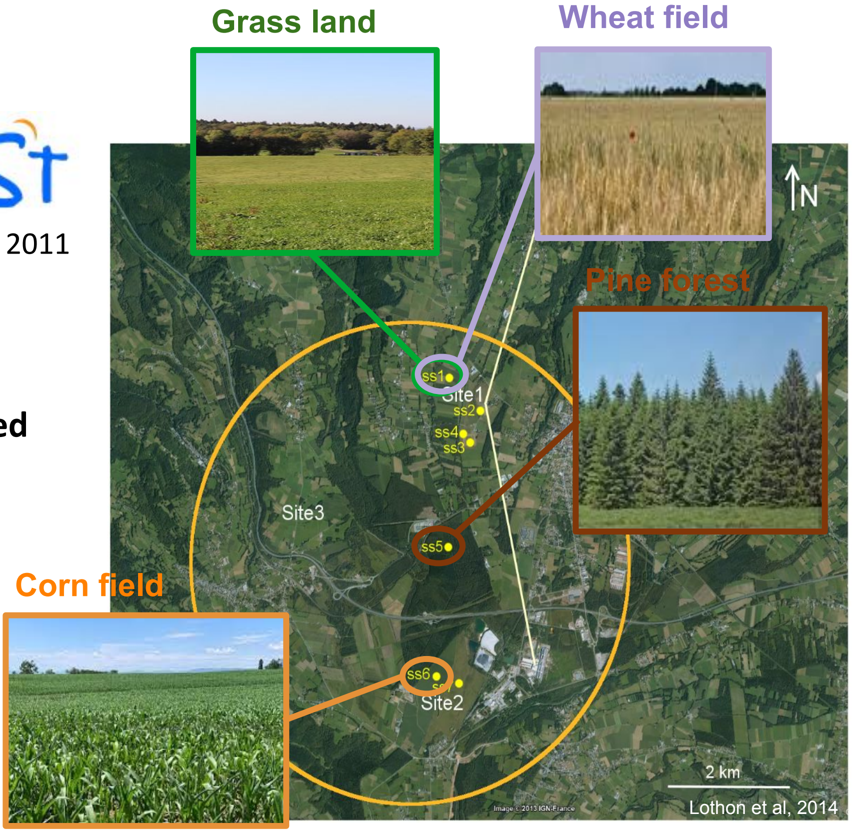
Lannemezan (France) : 43.13°N, 0.37°E
Alt : 600 m asl

I. Study cases setup

BLLAST

14 June to 8 July 2011

➡ **4 selected covers**



Study site location

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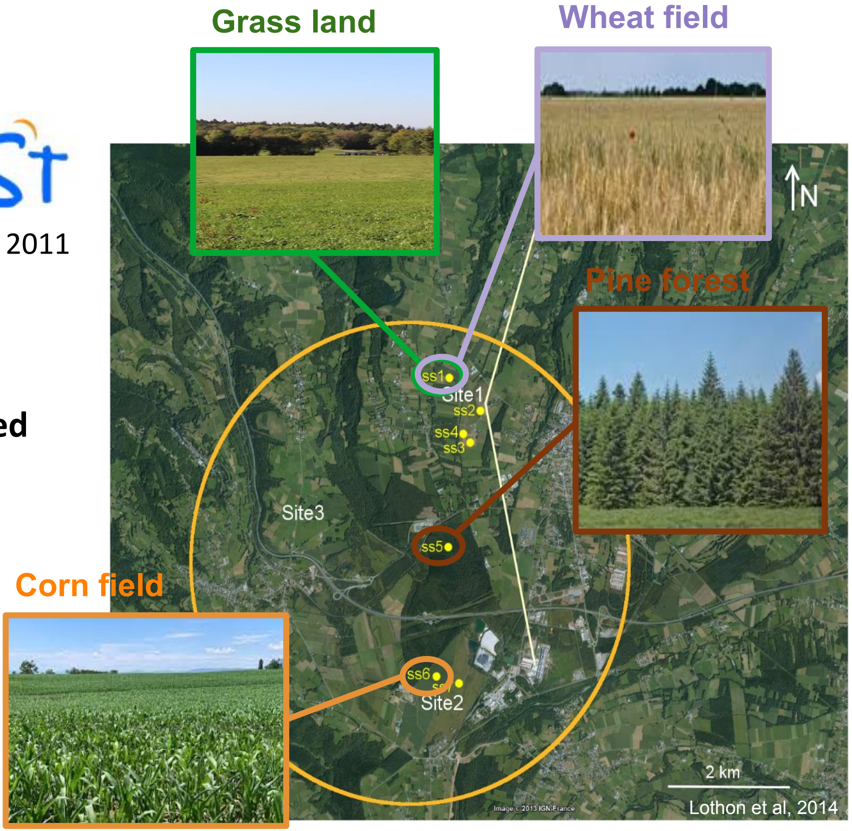

Study site location

→ Golden day : 20 June 2011
(Darbieu et al., 2015)

Clear sky
Weak wind
Convective day

I. Study cases setup

14 June to 8 July 2011

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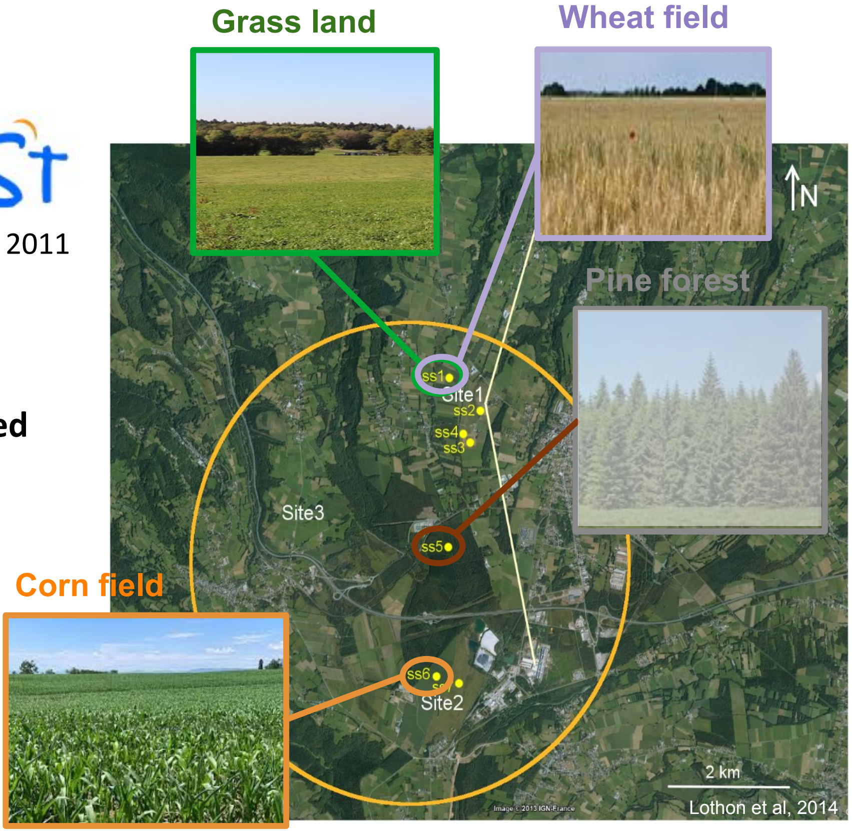

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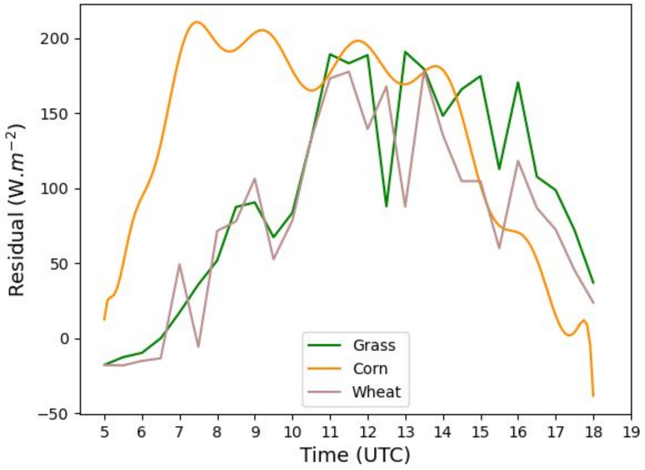
Surface energy balance non-closure



$$residual = Rn - (H + LE + G)$$

I. Study cases setup

BLLAST

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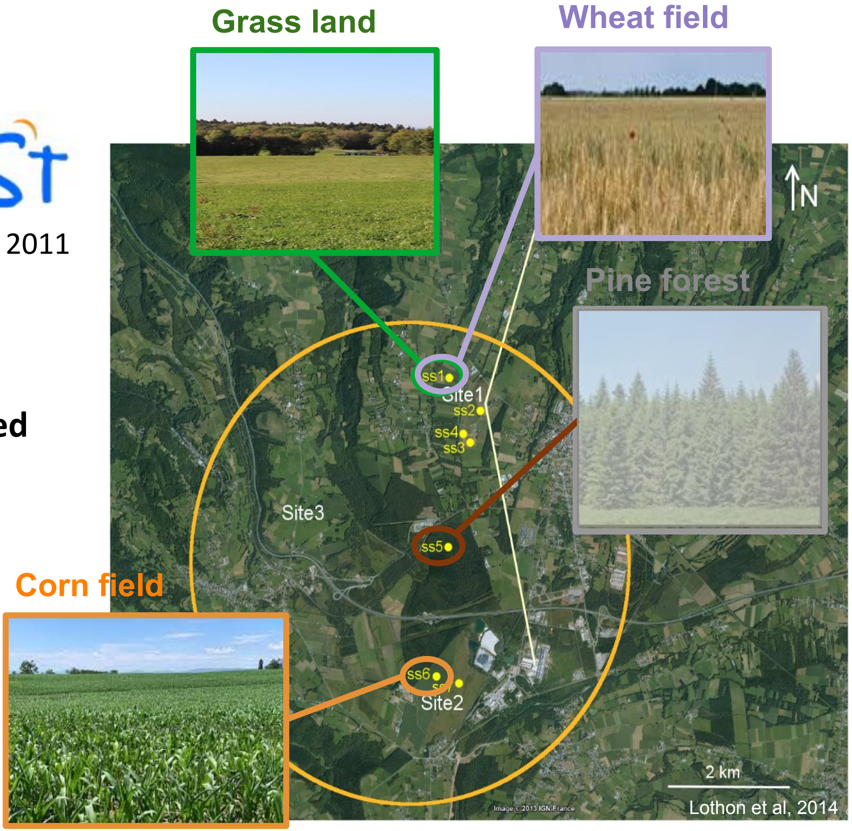

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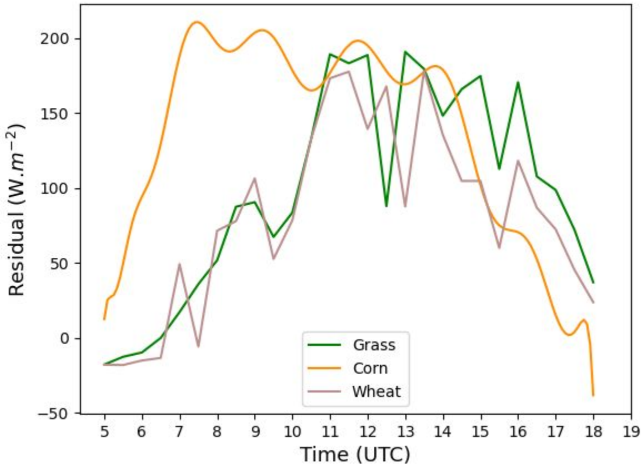

- <u>Bowen ratio preserving method</u>

  (Pastorello et al., 2020)

Rapport de Bowen : $\beta = \frac{H}{LE}$

$$LE\ corr = LE + residual * \frac{LE}{H + LE}$$

$$H\ corr = H + residual * \frac{H}{H + LE}$$

I. Study cases setup

BLLAST

14 June to 8 July 2011

Grass land

Wheat field

Corn field

Pine forest

ARPEGE-SURFEX 1D

Setup :
- Surface : ECOCLIMAP-II
- Idealized initial profile from the BLLAST radiosounding at 5 UTC
- Initialization of ground variables based on obs. and the AROME operational analysis

- Creation of 4 cases of homogeneous single-column for the study of land-atmosphere coupling

II. Evaluation of the land-atmosphere coupling

Observations

Grass land

ARPEGE-SURFEX 1D

Setup :
- Surface : ECOCLIMAP-II
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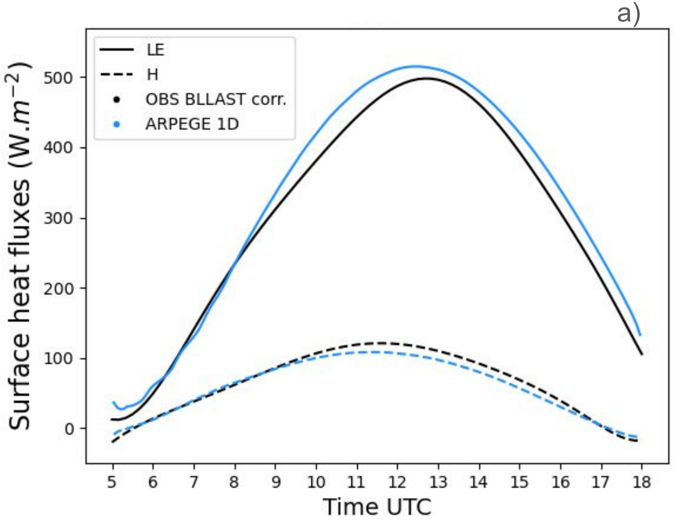
Grass land
20 June 2011



a) ARPEGE-SURFEX captures well observed fluxes

II. Evaluation of the land-atmosphere coupling

Large Eddy Scale simulations

Grass land

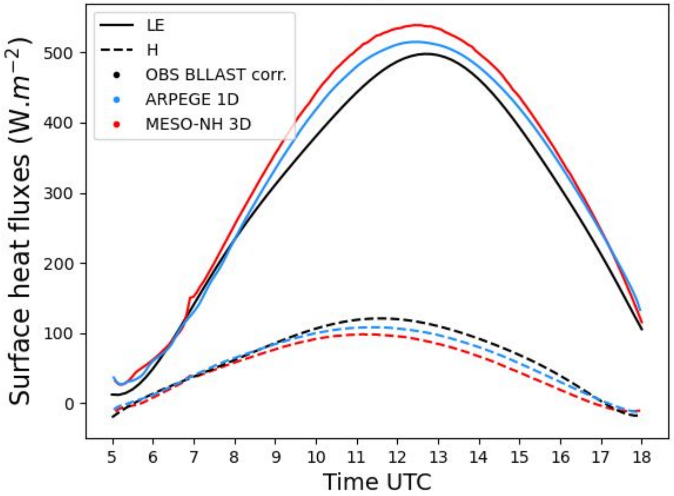
ARPEGE-SURFEX 1D

Méso-NH-SURFEX LES

Setup :
- Surface : ECOCLIMAP-II
- Idealized initial profile from the BLLAST radiosounding at 5 UTC
- Initialization of ground variables based on obs. and the AROME operational analysis

Grass land
20 June 2011

a)



a) ARPEGE-SURFEX captures well observed fluxes

Same for MESO-NH-SURFEX

II. Evaluation of the land-atmosphere coupling

Large Eddy Scale simulations

Grass land

ARPEGE-SURFEX 1D

Méso-NH-SURFEX LES

Setup :
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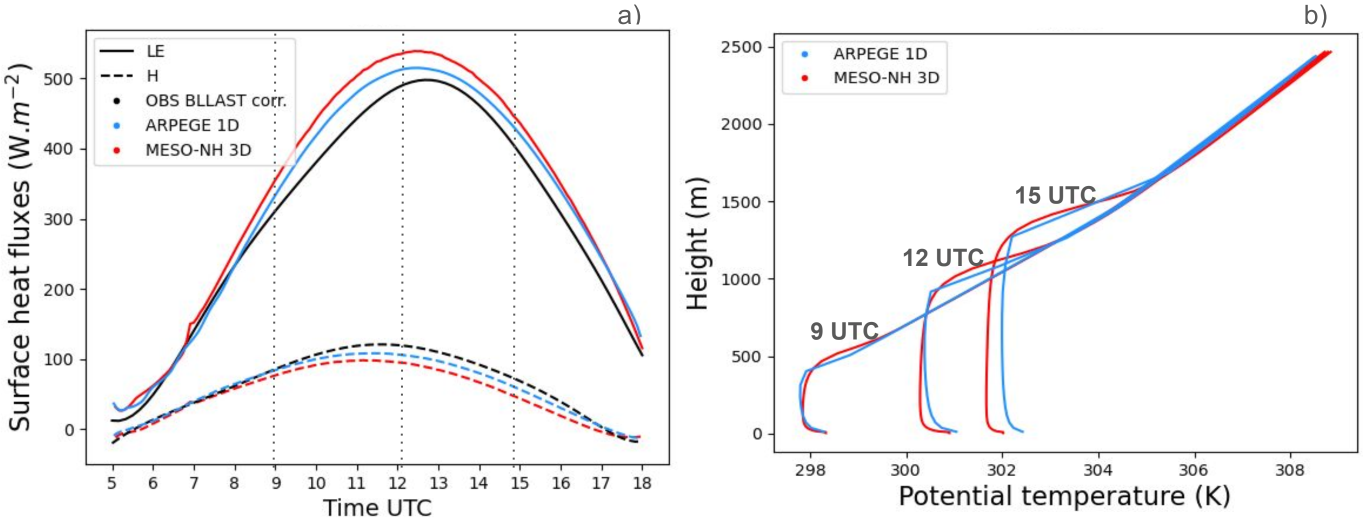
Grass land
20 June 2011



b) The coupled 1D model reproduces well the atmospheric boundary layer

Though the boundary layer remains slightly unstable related to a convection scheme not sufficiently active
Higher sensible heat flux consistent with higher temperature in the mixing layer for ARPEGE-SURFEX

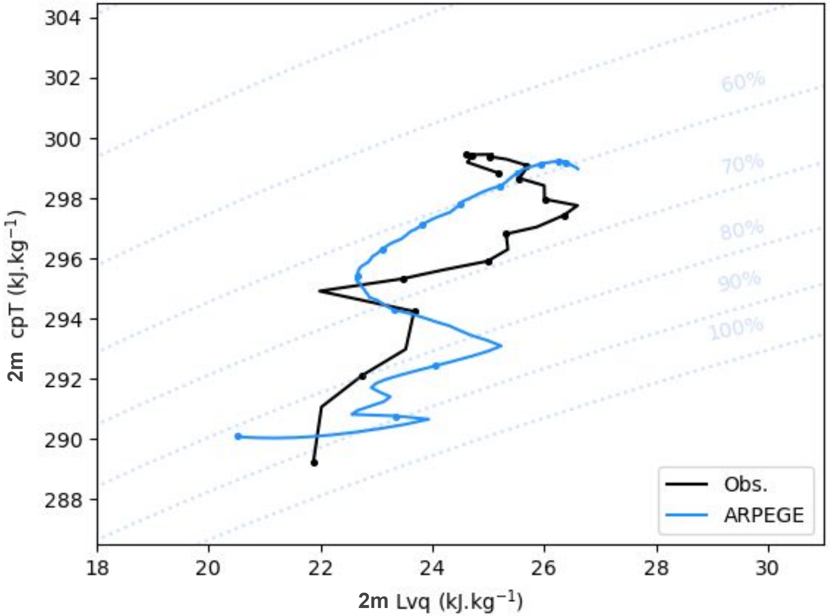
II. Evaluation of the land-atmosphere coupling

Grassland

Mixing diagram

Co-evolution of diurnal temperature and humidity in the mixed layer (Santanello et al., 2009)

20 june 2011

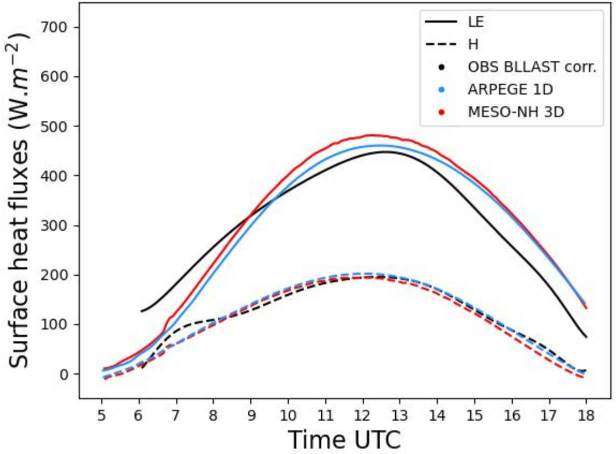


- Good temporal evolution of the temperature and humidity conditions of the mixed layer by ARPEGE-SURFEX
- Increase in temperature and specific humidity

II. Evaluation of the land-atmosphere coupling

Simulated fluxes over the other study cases

Corn field



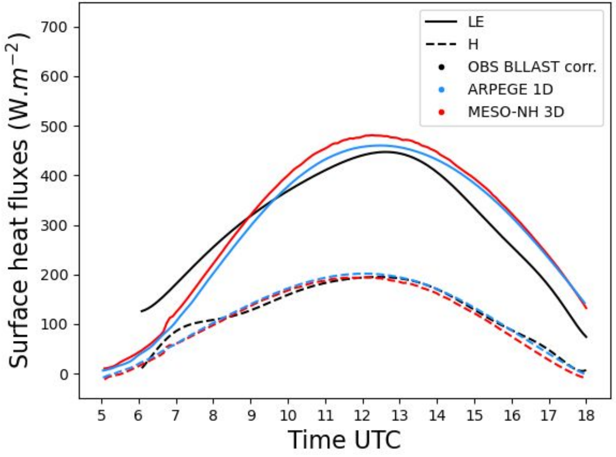
- Method for creating homogeneous cases in good agreement with observations

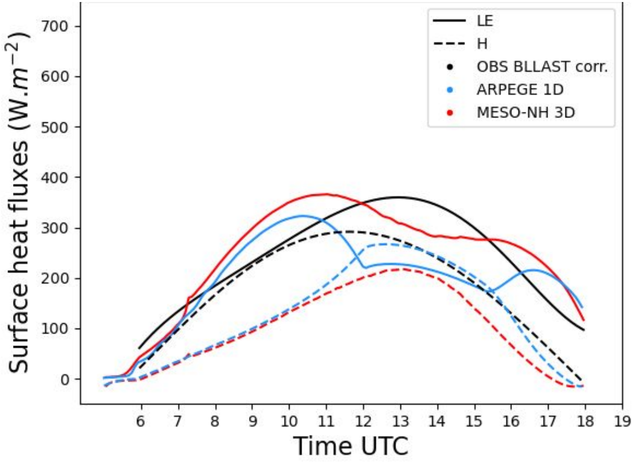
II. Evaluation of the land-atmosphere coupling

Simulated fluxes over the other study cases

Corn field

Wheat field

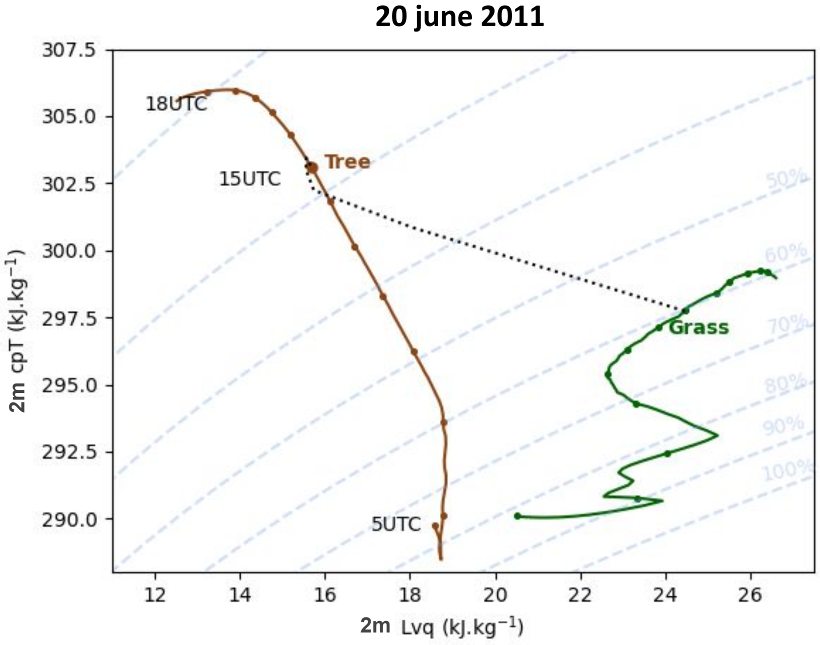




- Method for creating homogeneous cases in good agreement with observations
- Highlight parametrization weakness ⇨ Coupled 1D studies

III. Sensitivity study of surface parameterization on L-A coupling

Steps from grass land to pine forest



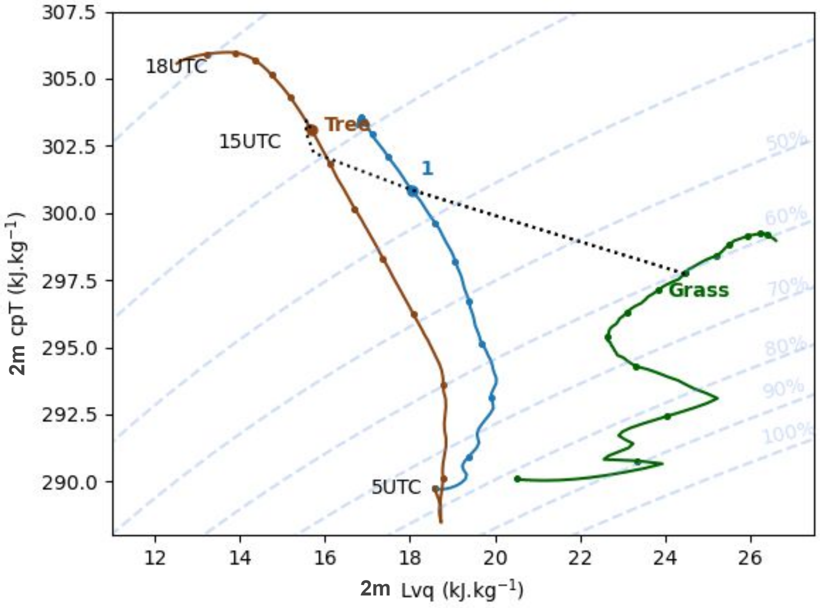
Grass land → **Pine forest**

	0	5
Hydric stress parameterization	○	✓
Leaf Area Index	○	✓
Radiative properties	○	✓
Roughness length	○	✓
Soil initialisation	○	✓
	Grass land	Pine Forest

III. Sensitivity study of surface parameterization on L-A coupling

Steps from grass land to pine forest

20 june 2011



Grass land

Pine forest

	0	1	5
Hydric stress parameterization	○	✓	✓
Leaf Area Index	○	○	✓
Radiative properties	○	○	✓
Roughness length	○	○	✓
Soil initialisation	○	○	✓
	Grass land		Pine Forest

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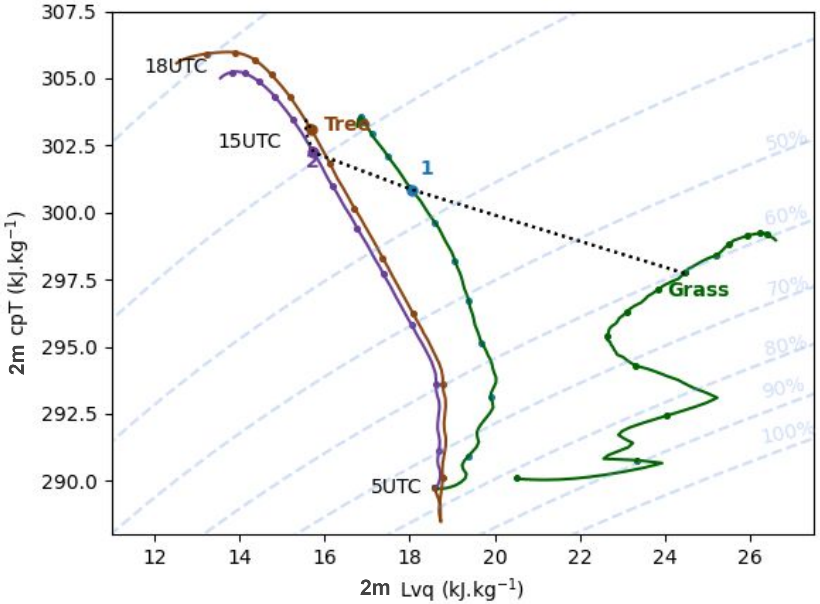

Grass land

Pine forest

LAI 3.65 → 4.82

	0	1	2	5
Hydric stress parameterization	○	✓	✓	✓
Leaf Area Index	○	○	✓	✓
Radiative properties	○	○	○	✓
Roughness length	○	○	○	✓
Soil initialisation	○	○	○	✓
	Grass land			Pine Forest

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Steps from grass land to pine forest

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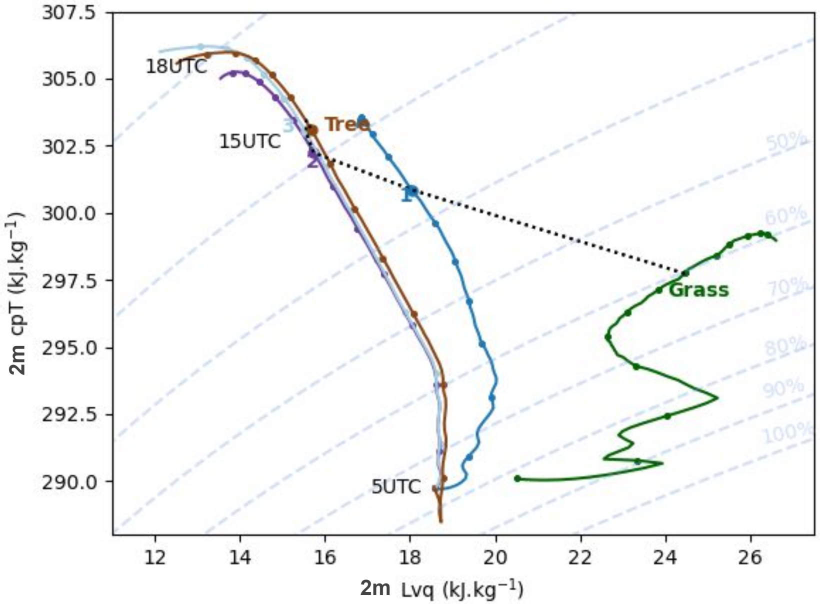


Grass land

Pine forest

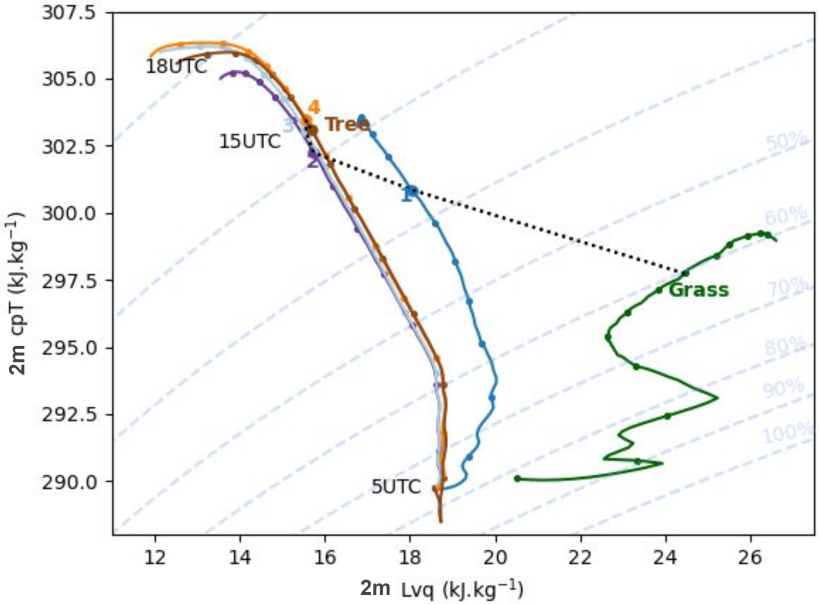
albedo broadband 0.19 → 0.09

	0	1	2	3	5
Hydric stress parameterization	○	✓	✓	✓	✓
Leaf Area Index	○	○	✓	✓	✓
Radiative properties	○	○	○	✓	✓
Roughness length	○	○	○	○	✓
Soil initialisation	○	○	○	○	✓
	Grass land				Pine Forest

III. Sensitivity study of surface parameterization on L-A coupling

Steps from grass land to pine forest

20 june 2011



Grass land

Pine forest

Z0 0.079 m → 1.43 m

	0	1	2	3	4	5
Hydric stress parameterization	○	✓	✓	✓	✓	
Leaf Area Index	○	○	✓	✓	✓	
Radiative properties	○	○	○	✓	✓	
Roughness length	○	○	○	○	✓	
Soil initialisation	○	○	○	○	○	
	Grass land					Pine Forest

III. Sensitivity study of surface parameterization on L-A coupling

Steps from grass land to pine forest

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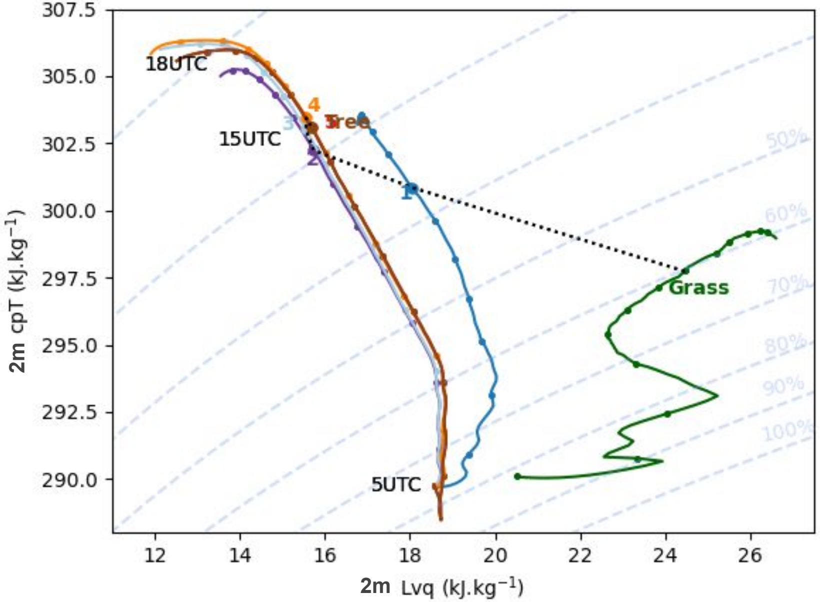

Grass land

Pine forest

	Grass land		Pine forest
Soil depth	1.5 m	→	3 m
Tsol	290 K	→	284 K

	0	1	2	3	4	5
Hydric stress parameterization	○	✓	✓	✓	✓	✓
Leaf Area Index	○	○	✓	✓	✓	✓
Radiative properties	○	○	○	✓	✓	✓
Roughness length	○	○	○	○	✓	✓
Soil initialisation	○	○	○	○	○	✓
	Grass land					Pine Forest

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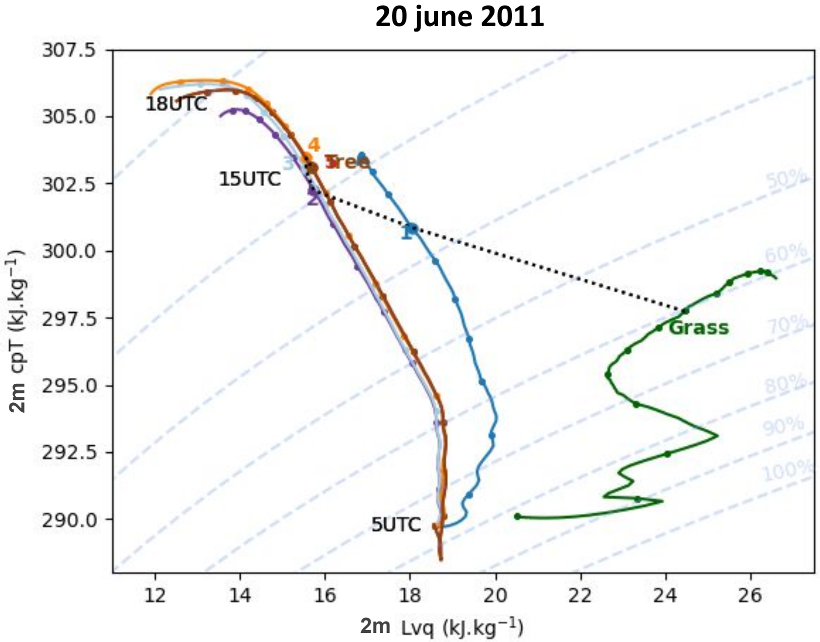
Steps from grass land to pine forest



- Weak impact of the order of modification of surface properties
- Amplitude of variation depends on land cover and time of day

Grass land

Pine forest

	0	1	2	3	4	5
Hydric stress parameterization	○	✓	✓	✓	✓	✓
Leaf Area Index	○	○	✓	✓	✓	✓
Radiative properties	○	○	○	✓	✓	✓
Roughness length	○	○	○	○	✓	✓
Soil initialisation	○	○	○	○	○	✓
	Grass land					Pine Forest

- Strong influence of vegetation type selection
- Importance to impose a reliable LAI

Conclusion

- Methodology for creating homogeneous study cases setup from observations

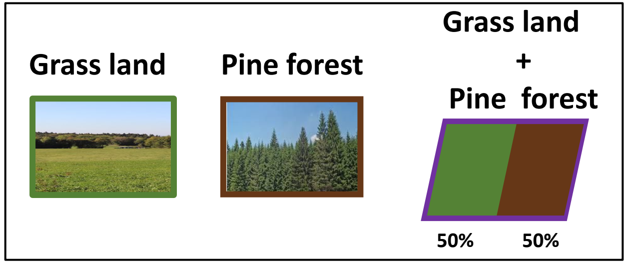
- Study cases ready and available for use by the community

ARPEGE model in CMIP6 configuration satisfactorily reproduces land-atmosphere coupling under homogeneous conditions for the grass land and the corn field cases.

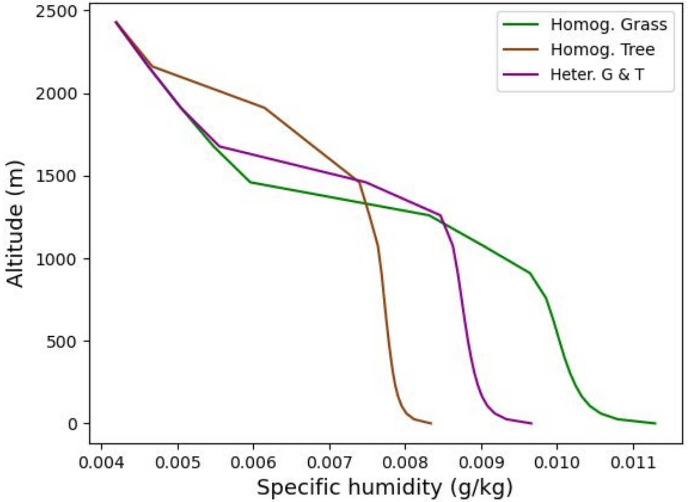
- In ARPEGE-SURFEX setup, the vegetation type and the LAI imposed are important drivers of humidity and temperature in the mixing layer

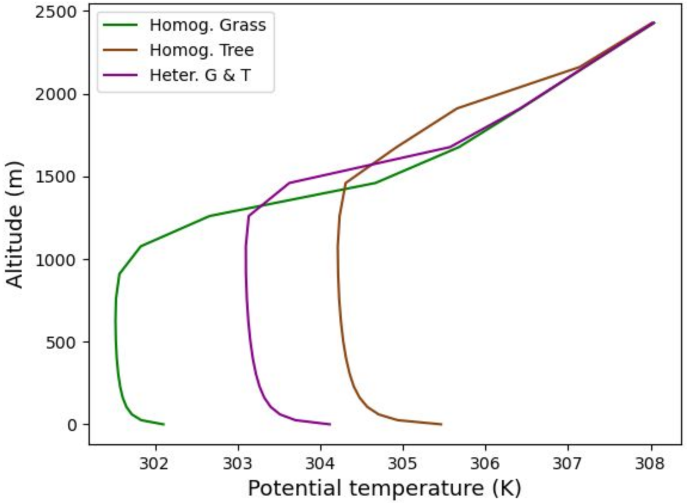
Preliminary results : Heterogeneous cover representation

ARPEGE-SURFEX 1D



20 june 2011 14 UTC

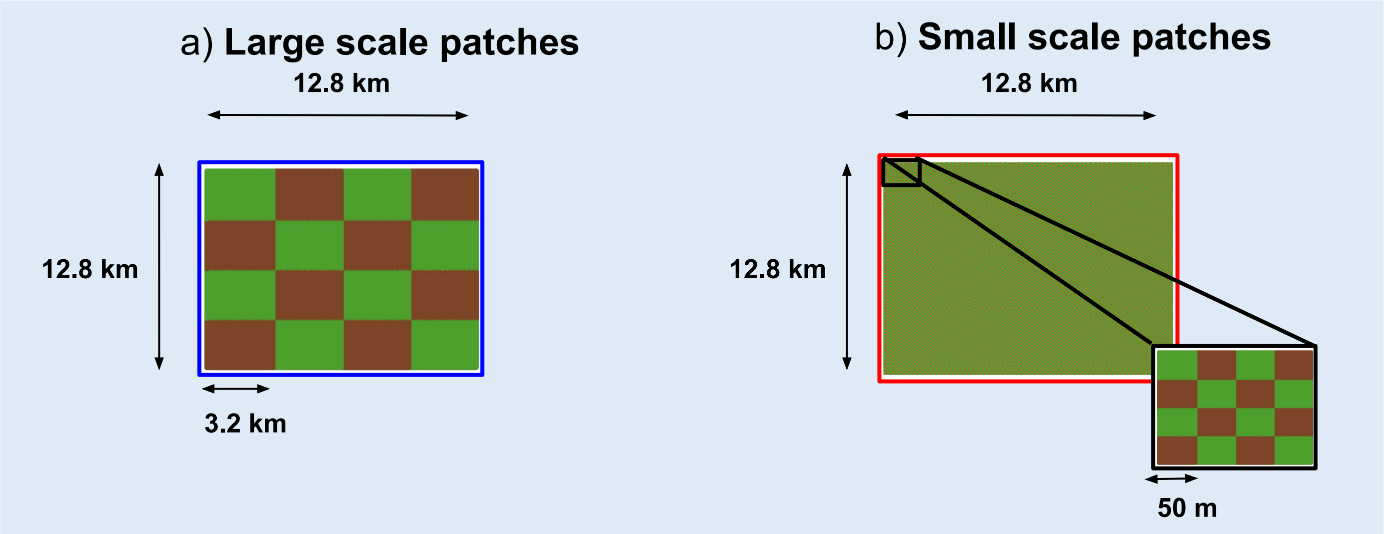




Preliminary results : Heterogeneous cover representation

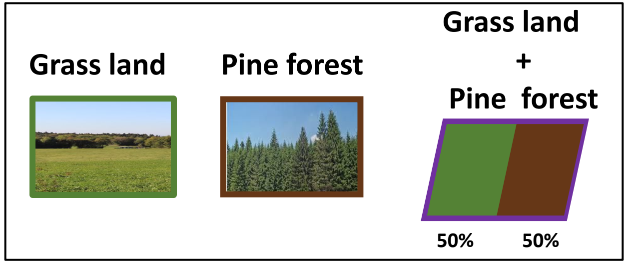
MESO-NH-SURFEX 3D

Heterogeneous setup : Grass land + Pine forest

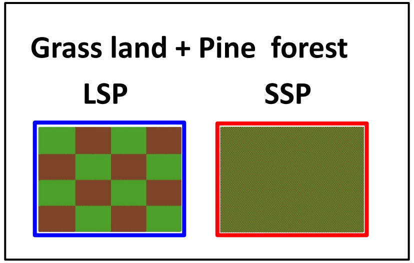


Preliminary results : Heterogeneous cover representation

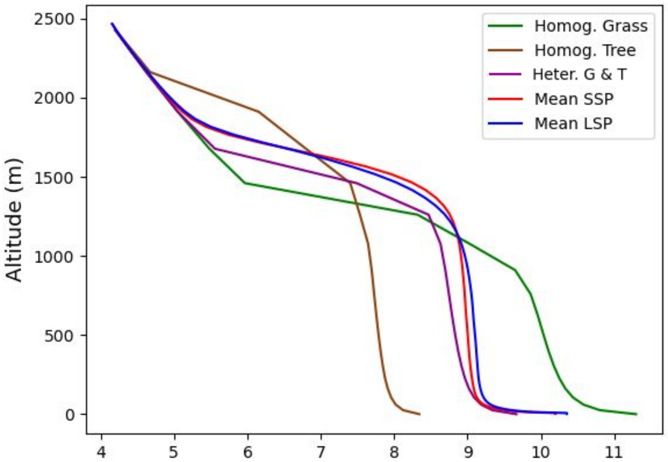
ARPEGE-SURFEX 1D

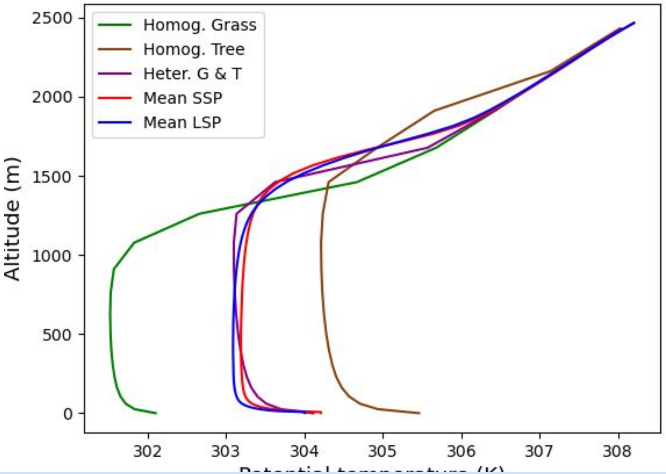


MESO-NH-SURFEX 3D



20 june 2011 14 UTC



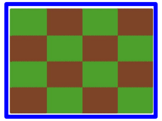


Preliminary results : Heterogeneous cover representation

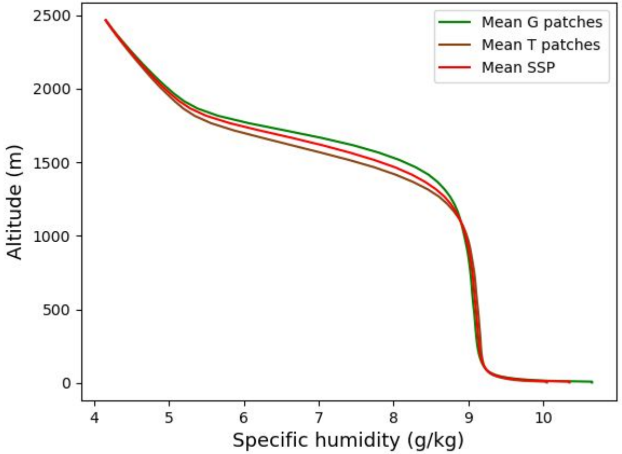
MESO-NH-SURFEX 3D

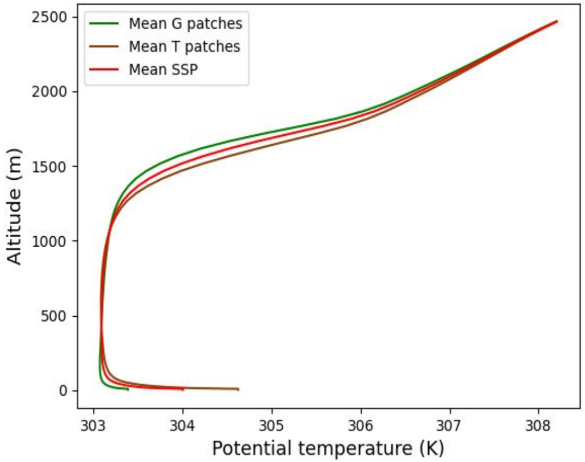
Grass land + Pine forest

LSP



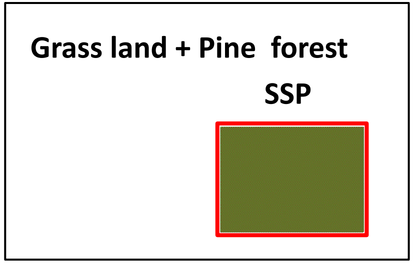
20 june 2011 14 UTC



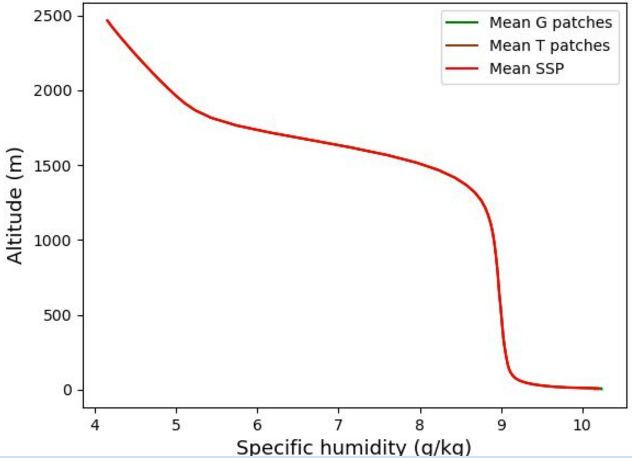


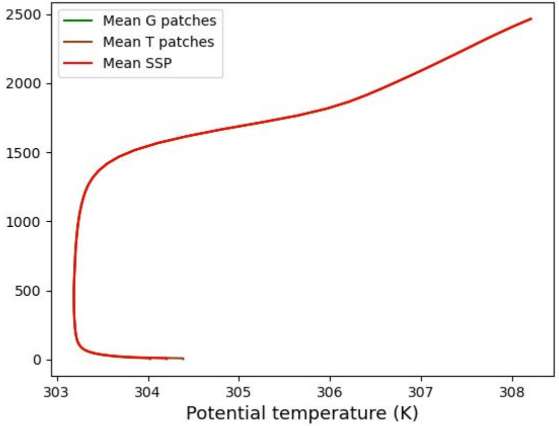
Preliminary results : Heterogeneous cover representation

MESO-NH-SURFEX 3D



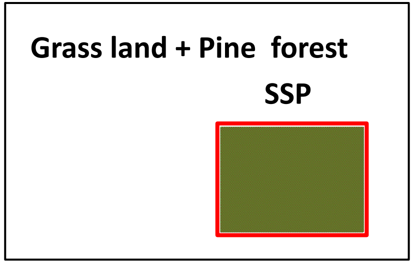
20 june 2011 14 UTC





Preliminary results : Heterogeneous cover representation

MESO-NH-SURFEX 3D



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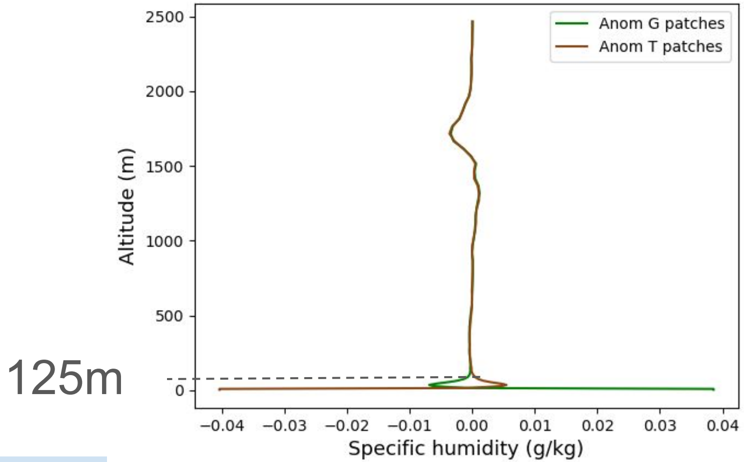
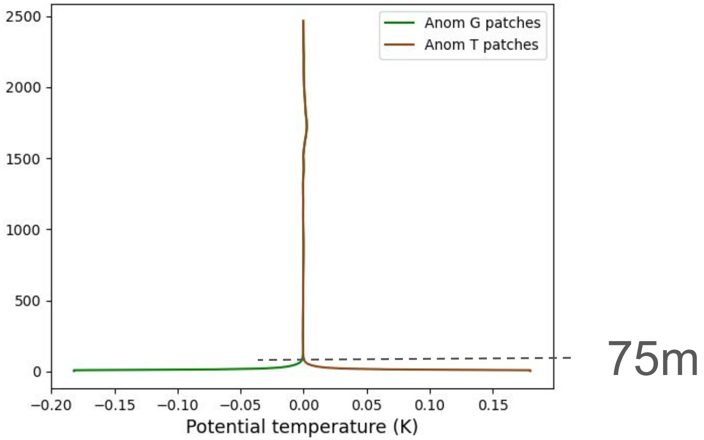
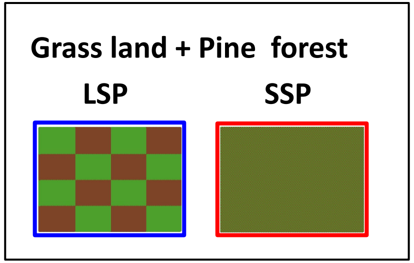
Blending height : Height scale for turbulent flow above an inhomogeneous surface, at which the influences of individual surface patches on vertical profiles or fluxes become horizontally blended.





Preliminary results : Heterogeneous cover representation

MESO-NH-SURFEX 3D



- Blending height is highly impacted by patch size

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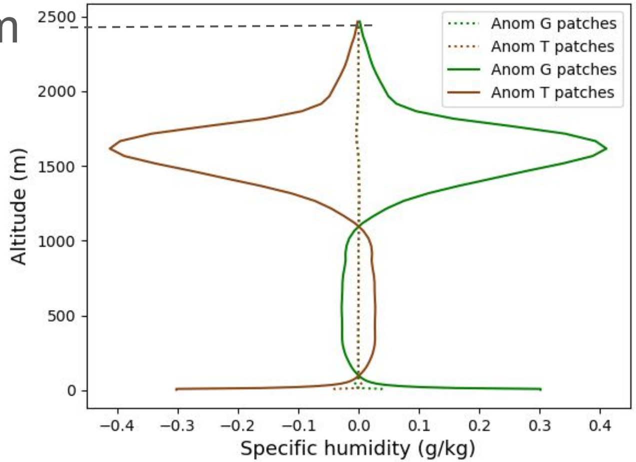
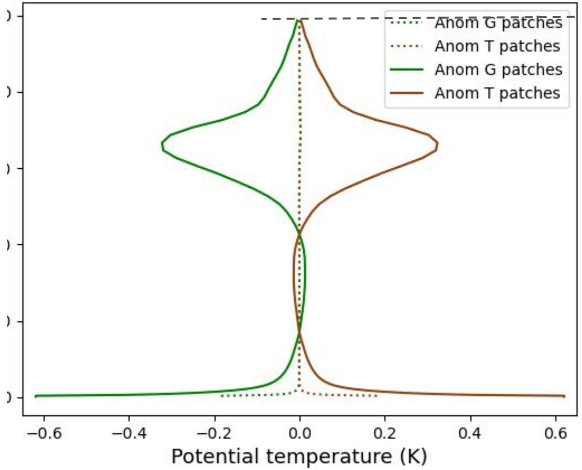
~ 2500m





~ 2500m

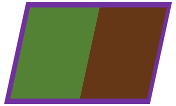
Preliminary results : Heterogeneous cover representation

ARPEGE-SURFEX 1D

Grass land

Pine forest

Grass land + Pine forest

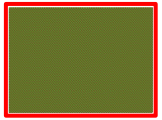


50% 50%

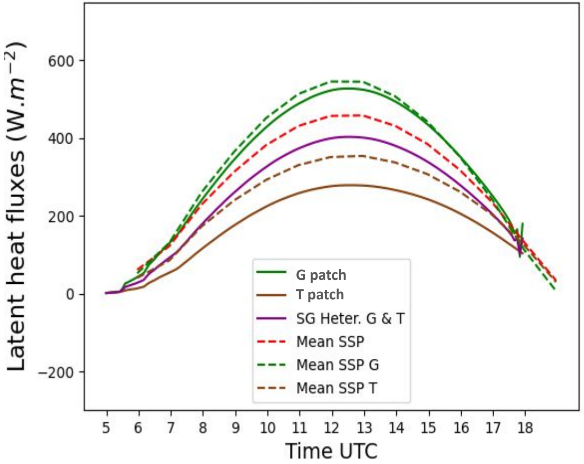
MESO-NH-SURFEX 3D

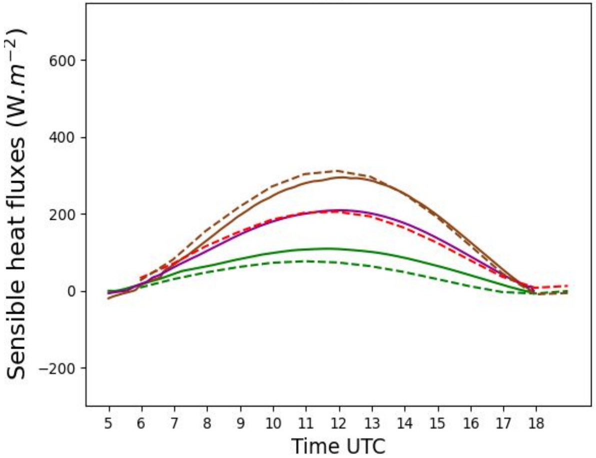
Grass land + Pine forest

SSP



- Increase of fluxes in LES setup





Preliminary results : Heterogeneous cover representation

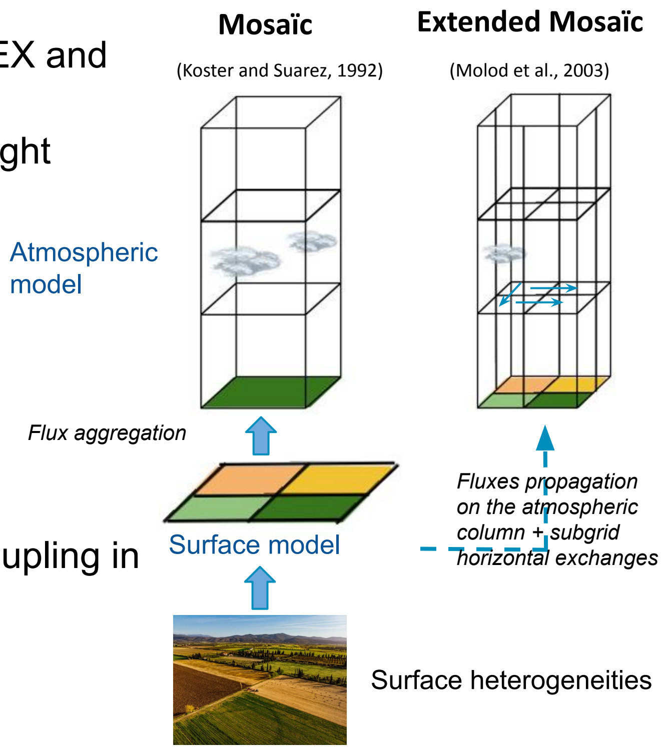
Conclusion

- Few differences in mean profiles between ARPEGE-SURFEX and MESO-NH
- Size of the patches have a large impact on the blending height
- Important change in surface fluxes between LES and 1D heterogeneous setups

Future work

- Implement and evaluate a new subgrid land-atmosphere coupling in ARPEGE-SURFEX based on the extended mosaïc method

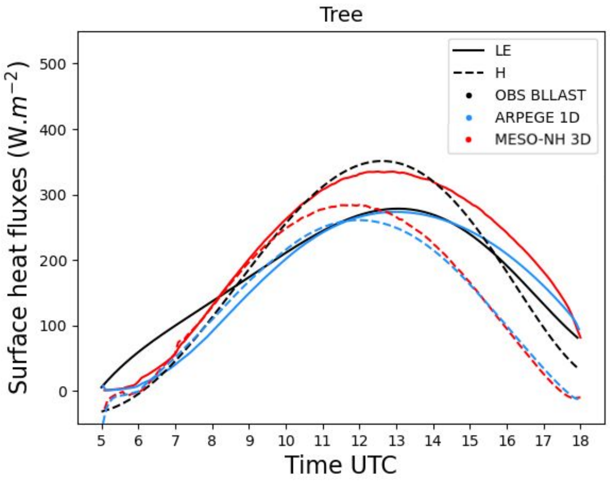
Coupling methods



II. Evaluation of the land-atmosphere coupling

Simulated fluxes over the other study cases

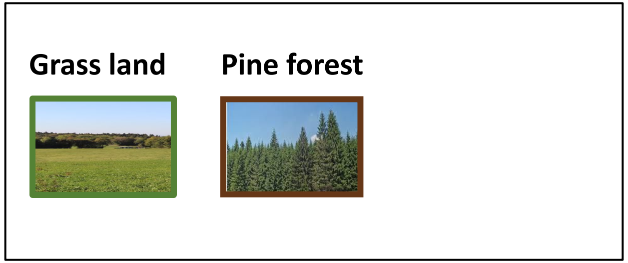
Pine forest



- Impossible to correct surface fluxes (missing G)
- Creation of the case following previously described method

Preliminary results : Heterogeneous cover representation

ARPEGE-SURFEX 1D



20 june 2011 14 UTC