OCCUPATION DES TERRES ET CLIMAT RÉGIONAL

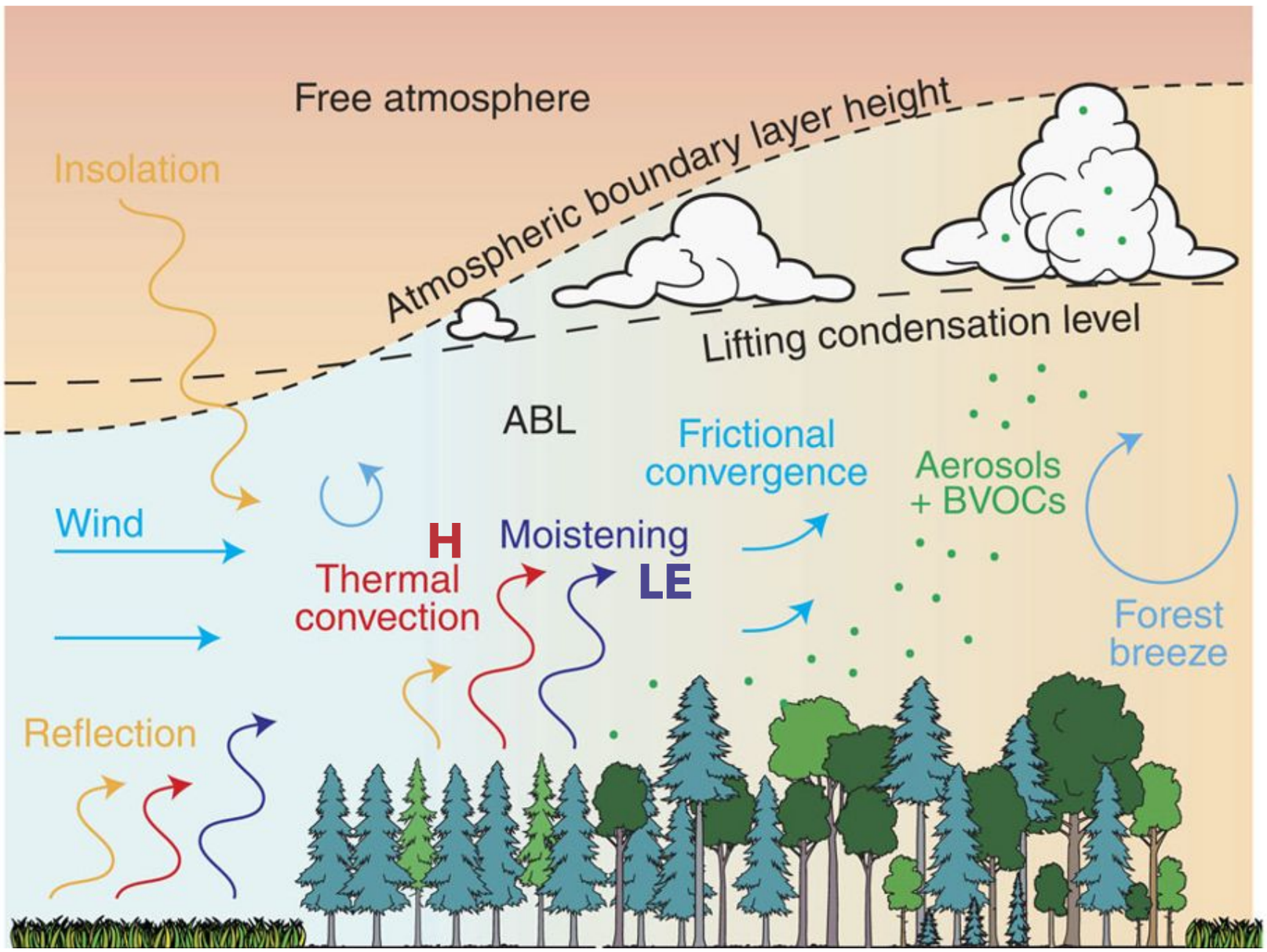
IMPACT DES SURFACES FORESTIÈRES SUR L'ENNUAGEMENT DANS LE SUD-OUEST DE LA FRANCE

Gaëtan Noual

Supervision de la thèse : Yves Brunet (INRAE, ISPA, Bordeaux)
Christine Lac (CNRM, Météo-France, Toulouse)
Patrick Le Moigne (CNRM, Météo-France, Toulouse)

- L'interaction de la forêt avec l'atmosphère la plus étudiée : sa contribution au cycle du carbone

➡ Mais la forêt influence l'atmosphère de nombreuses autres manières !

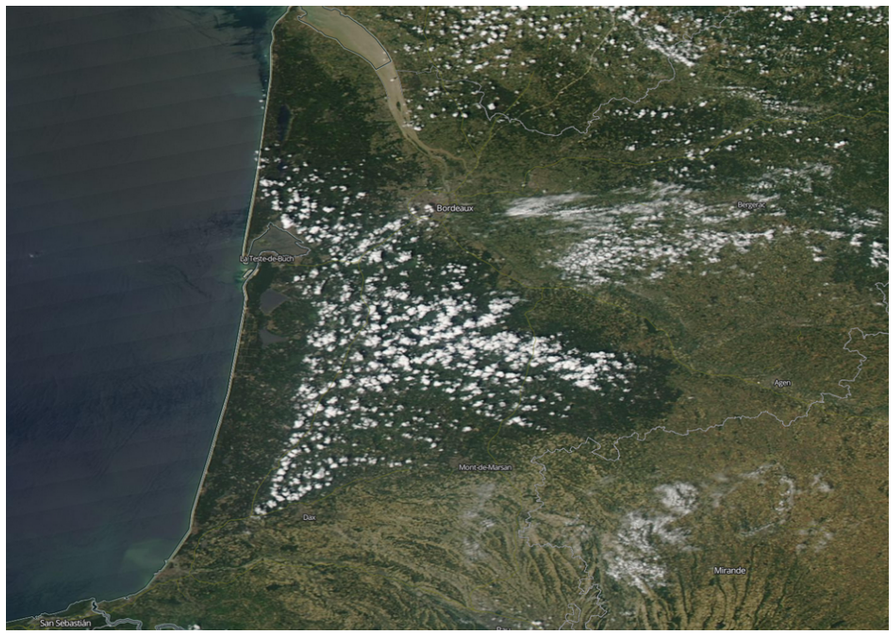


Teuling et al. (2017)

Atmosphère libre

Couche limite atmosphérique ≈ Portion de l'atmosphère directement influencée par la surface

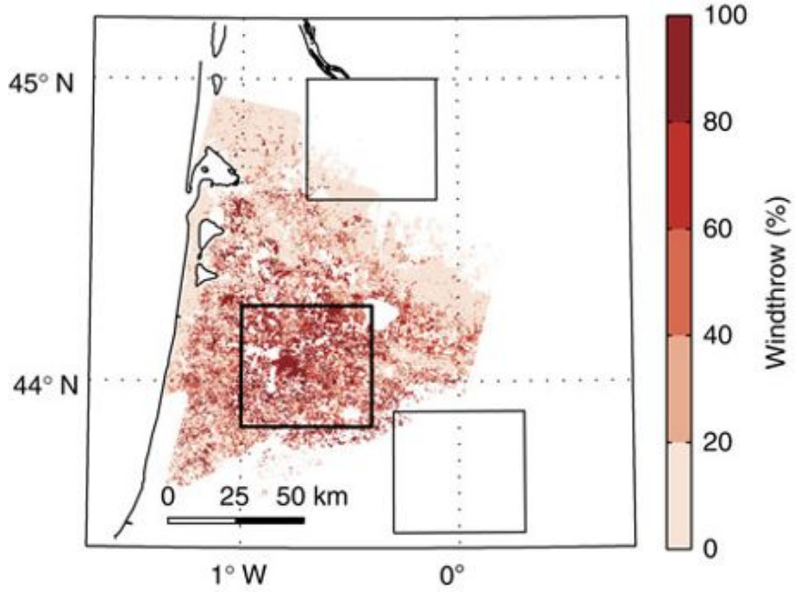
- Impact de la forêt des Landes sur l'ennuagement

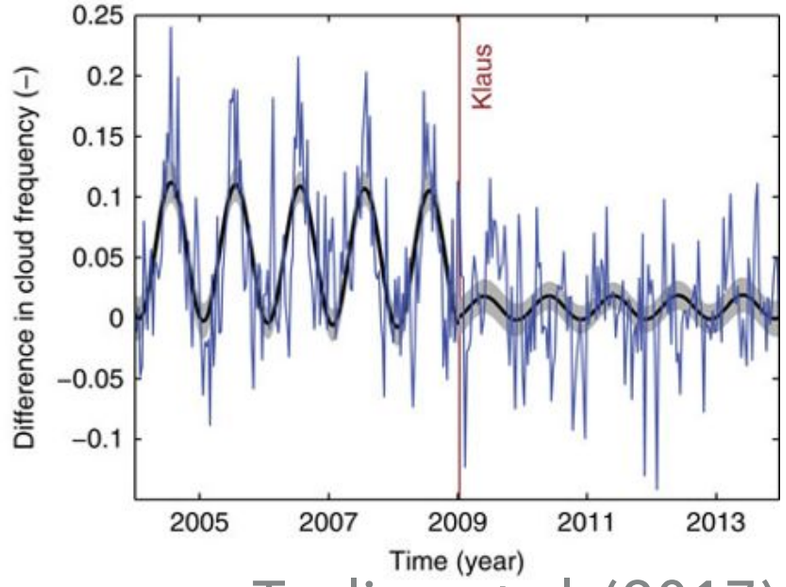


➡ Une situation typique de nuages de couche limite (CL) au-dessus de la forêt des Landes

➡ *9 juillet 2013*

- Impact de la tempête Klaus (2009) sur l'ennuagement





Teuling et al. (2017)

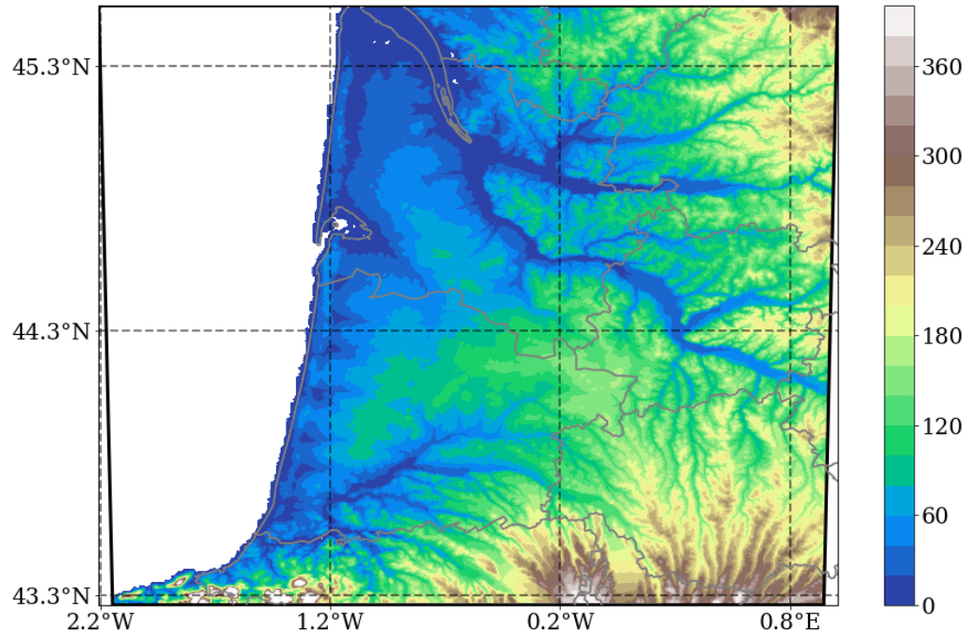
- Modèle atmosphérique de recherche du CNRM/LAero: Méso-NH (Lac et al. , 2018) ; couplé avec le modèle de surface SURFEX (Masson et al. , 2013)

- ISBA (Decharme et al, 2013) : modèle d'échange sol-végétation

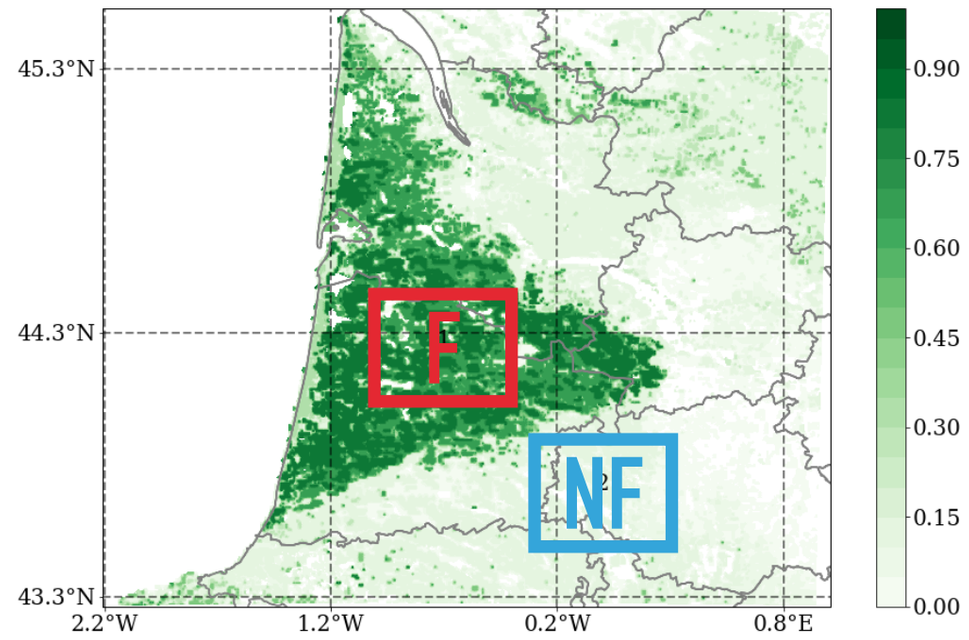
- Résolution horizontale de 500 m

- 90 niveau verticaux ; 32 niveaux dans la couche limite atmosphérique (CL)

- Base de données d'occupation des sols à 1 km de résolution : ECOCLIMAP (Faroux et al., 2013)



Orographie du domaine (m)

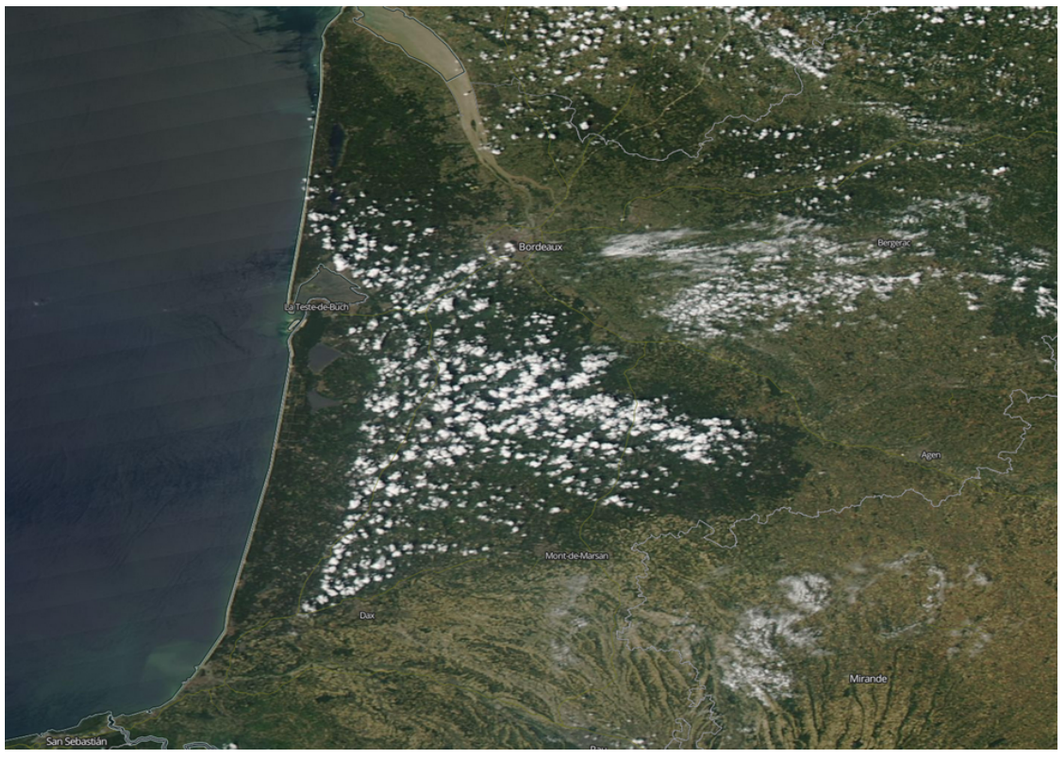


Ratio de couvert forestier (conifère tempéré)

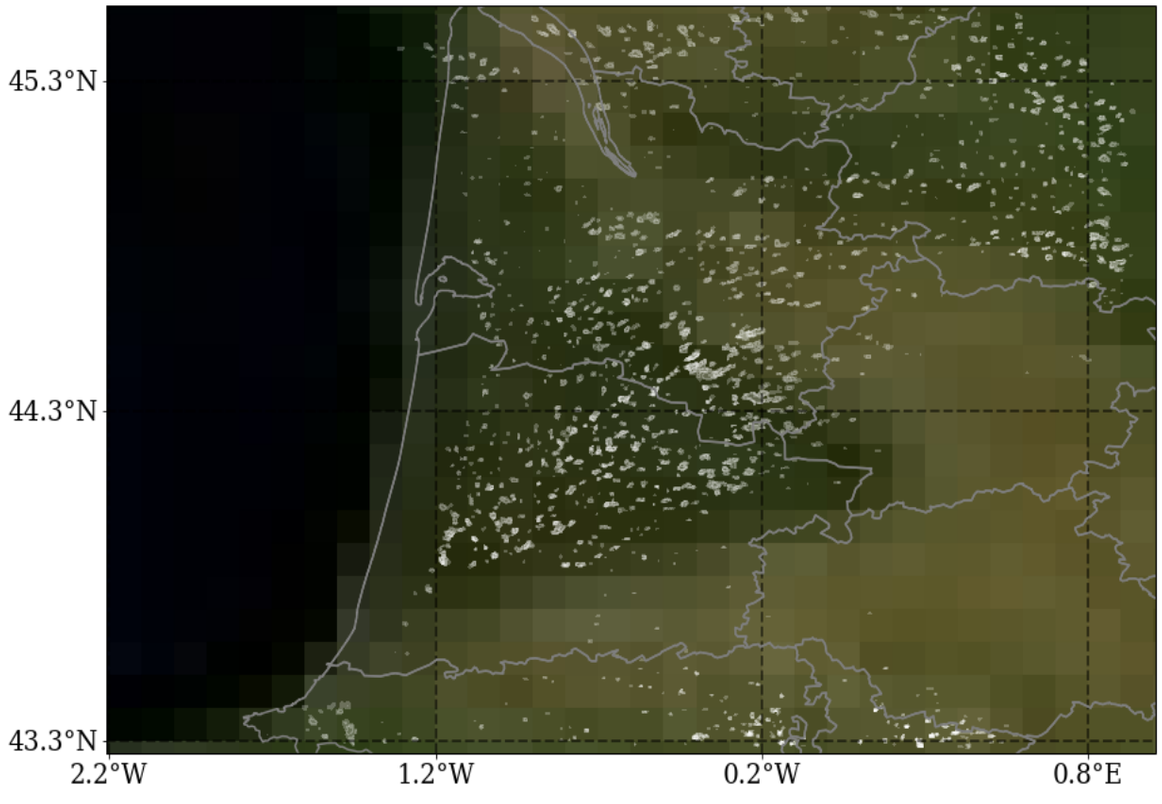
- Après de nombreux tests sur la configuration du modèle de surface et du modèle atmosphérique …

9 juillet 2013 13 UTC

Observation



Simulation

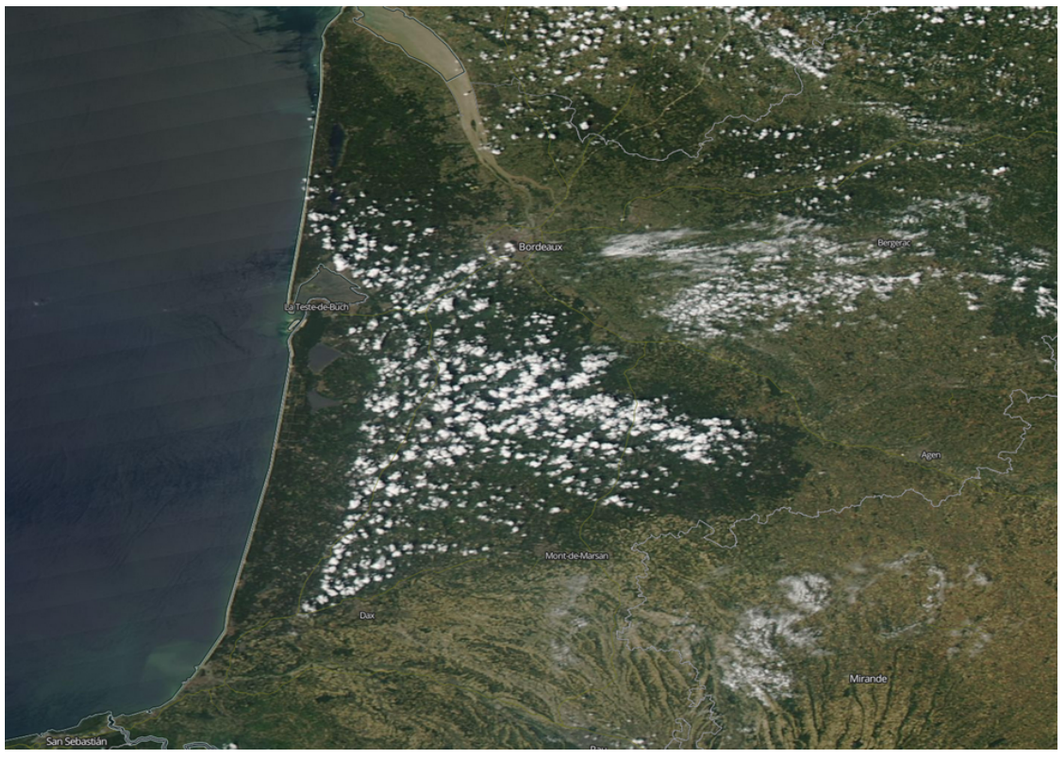


- On représente bien les nuages de couche limite dans le modèle au-dessus de la forêt

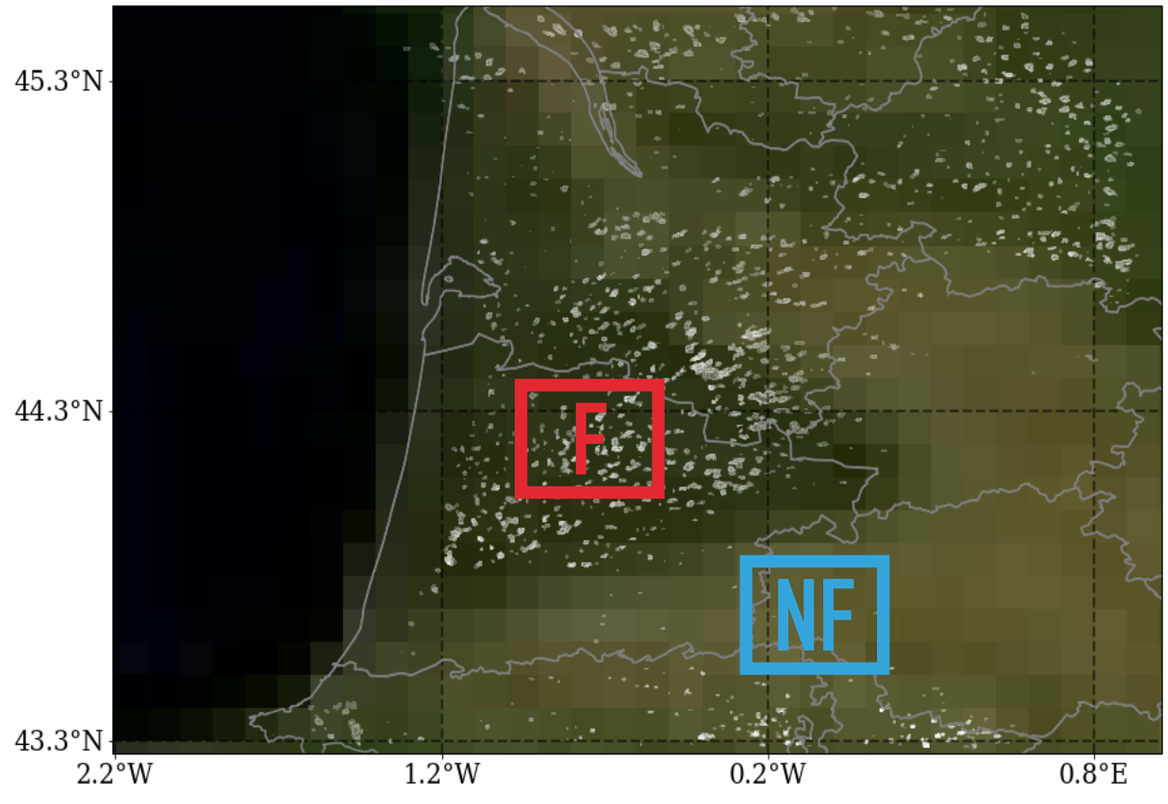
- Après de nombreux tests sur la configuration du modèle de surface et du modèle atmosphérique …

9 juillet 2013 13 UTC

Observation



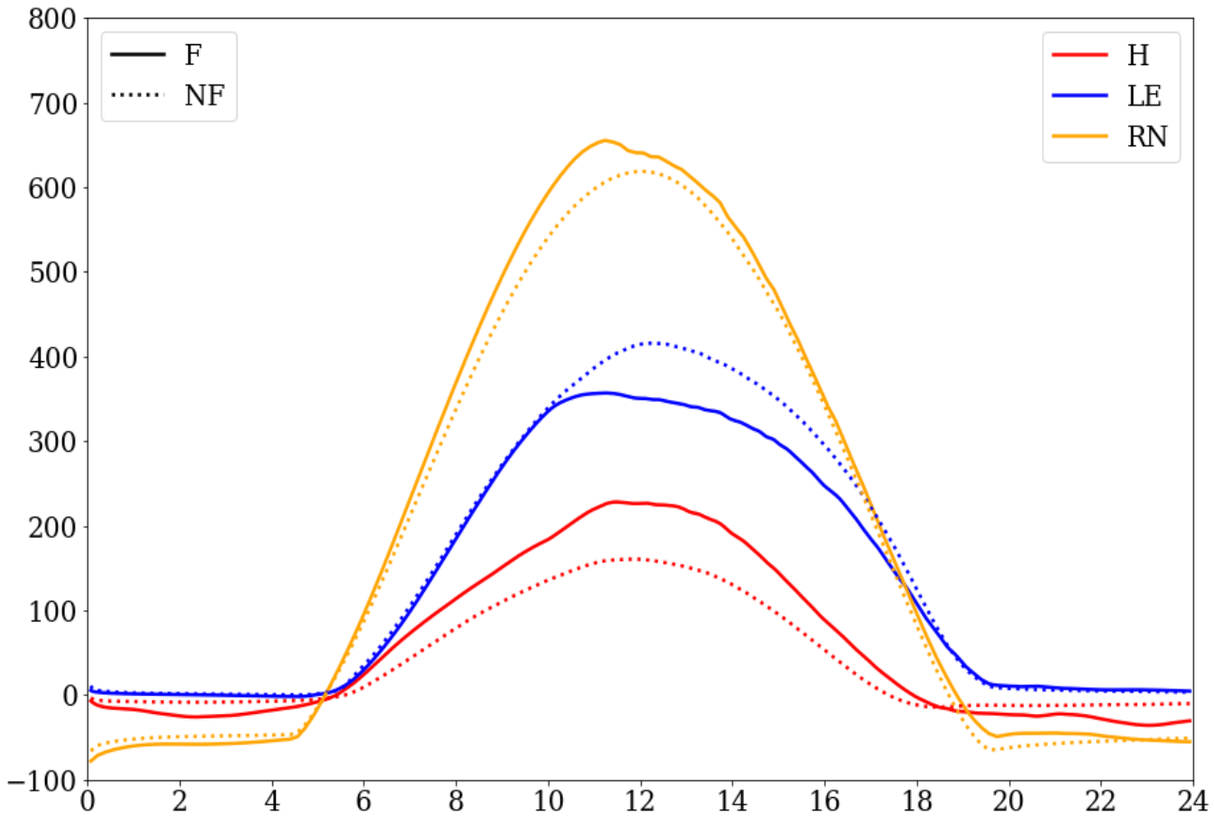
Simulation



- On représente bien les nuages de couche limite dans le modèle au-dessus de la forêt
  - Quels sont donc les processus physiques présents dans le modèle qui expliquent les différences entre forêt (F) et non-forêt (NF) ?

9 juillet 2013

Bilan d'énergie de surface

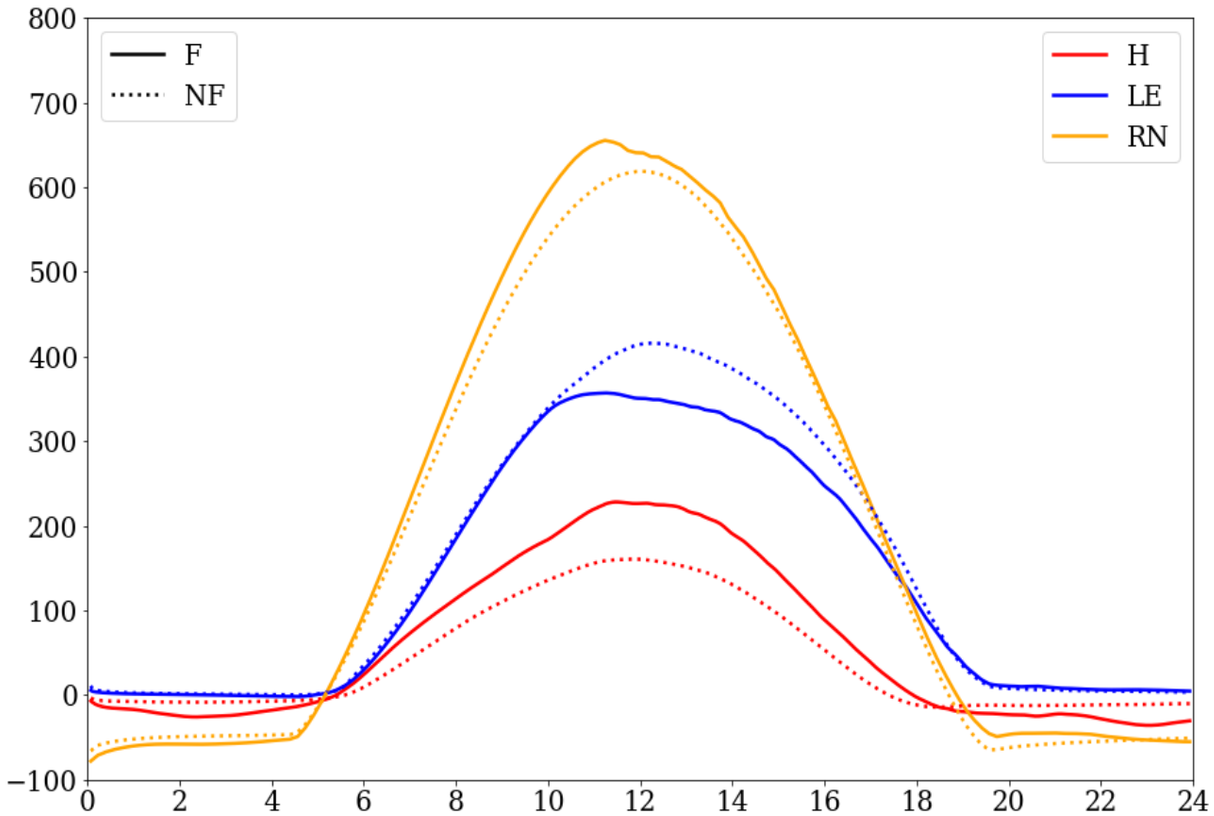


- Impact de la forêt
  - Rayonnement net (RN) D'abord légèrement plus haut au-dessus de la forêt (effet de l'albédo inférieur)
  - Flux de chaleur sensible (H) supérieur et flux de chaleur latente (LE) inférieur

9 juillet 2013

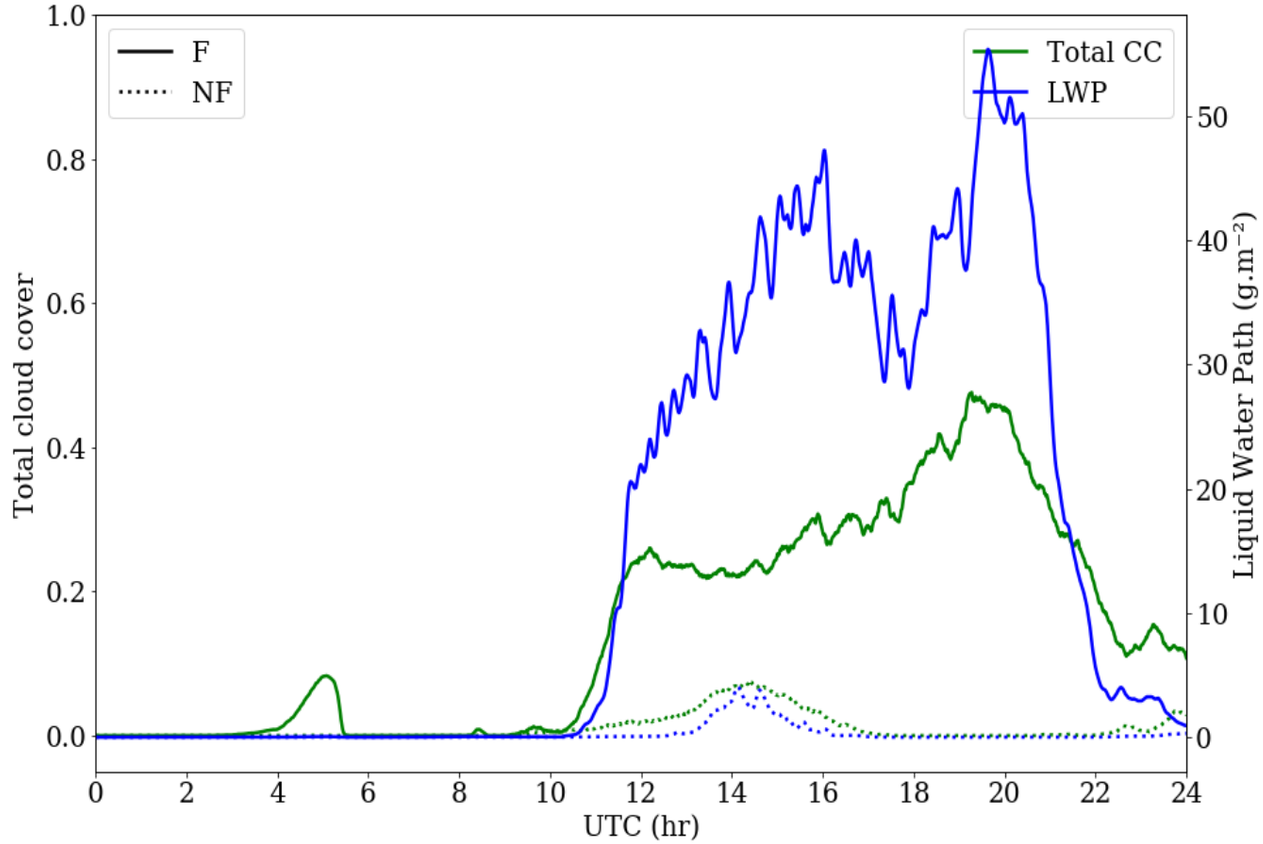
Bilan d'énergie de surface

W.m^{-2}



Couverture nuageuse et liquid water path (LWP)

g.m^{-2}



- Impact de la forêt
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  - Flux de chaleur sensible (H) supérieur et flux de chaleur latente (LE) inférieur

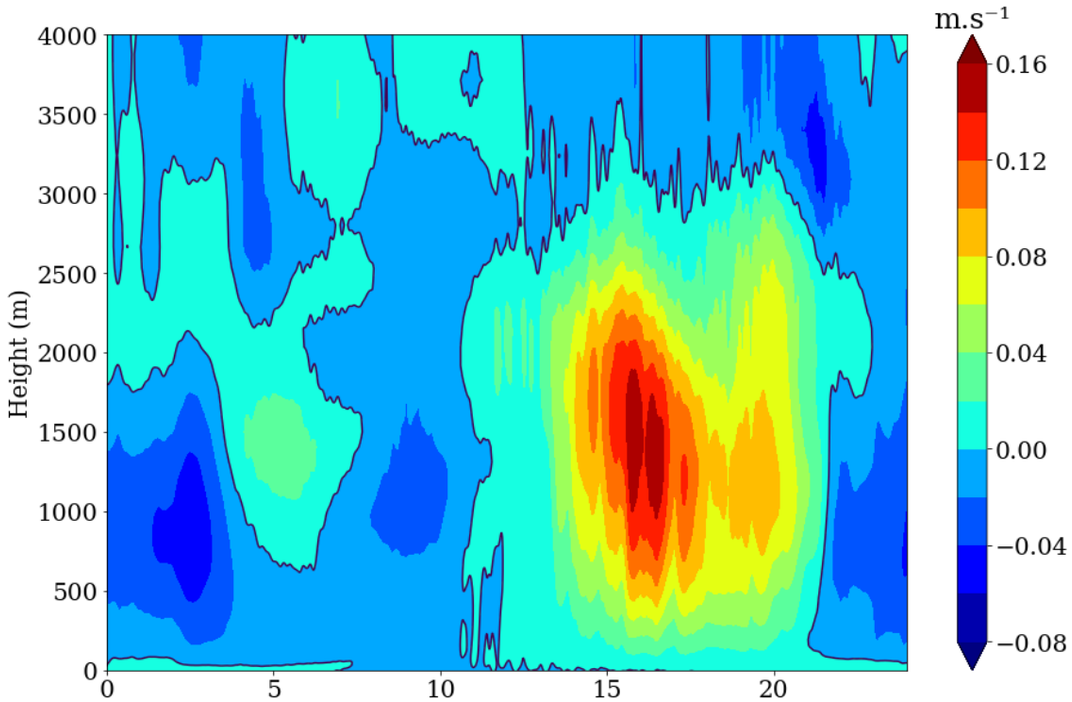
➡ Couverture nuageuse (Total CC) nettement plus forte

- Effet sur la dynamique atmosphérique *9 juillet 2013*

Différence : « Forêt (F) - Non-forêt (NF) »

Vitesse du vent vertical

+

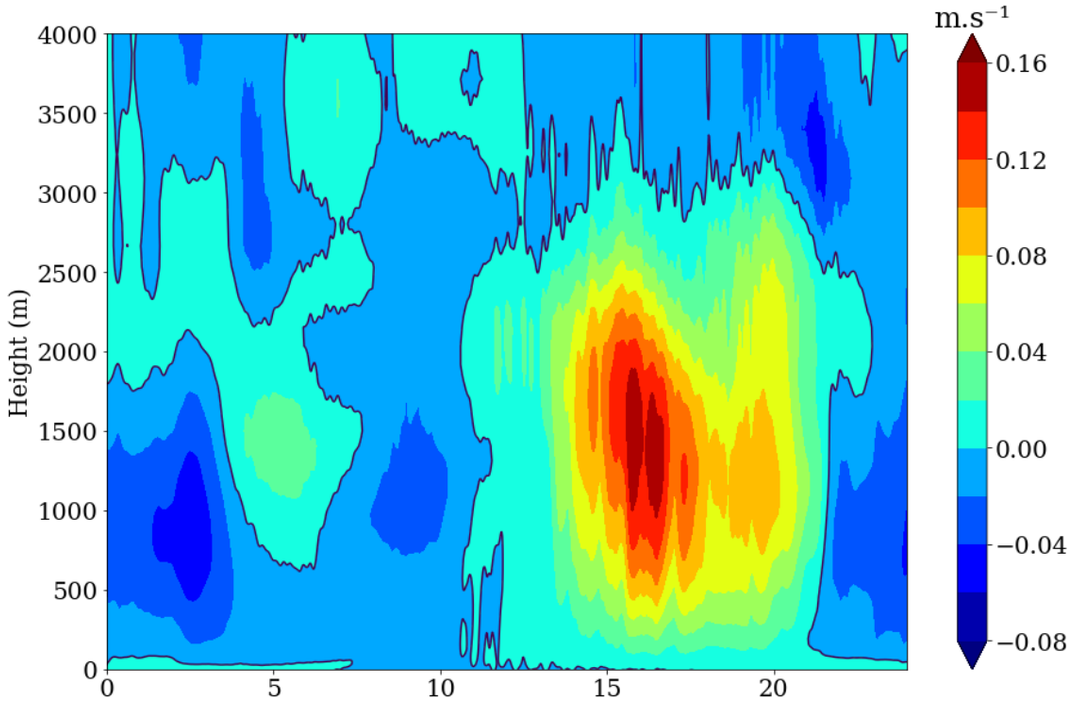


- Les **courants ascendants au-dessus de la forêt** sont générées par le **flux de chaleur sensible élevé**

- Effet sur la dynamique atmosphérique *9 juillet 2013*

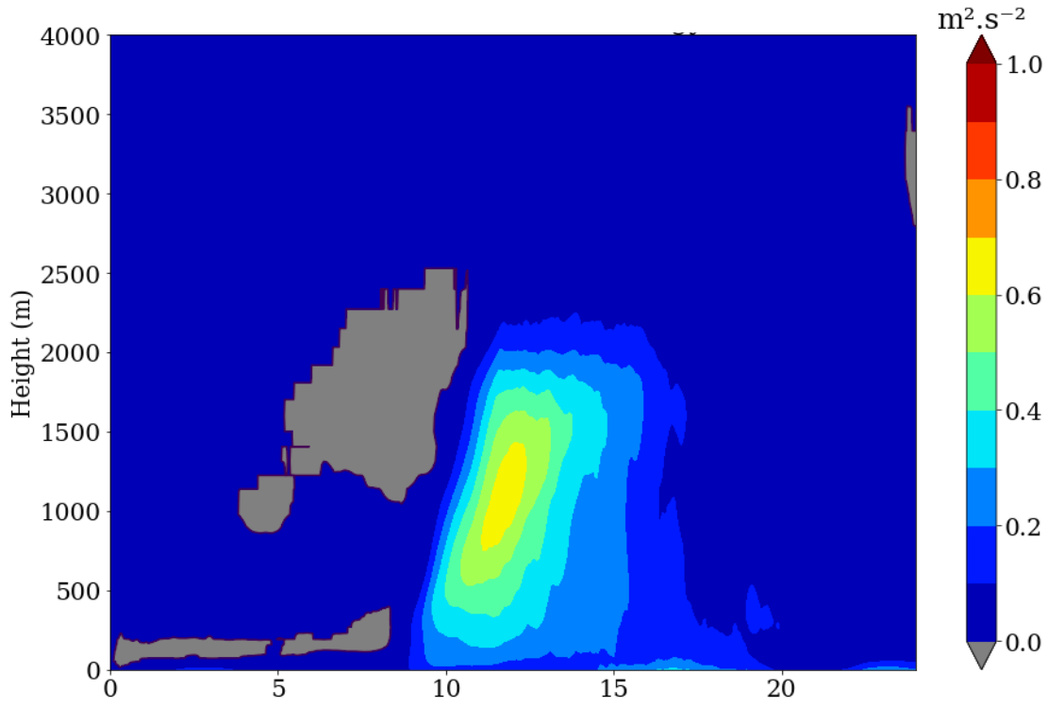
Différence : « Forêt (F) - Non-forêt (NF) »

Vitesse du vent vertical



- Les **courants ascendants au-dessus de la forêt** sont générées par le **flux de chaleur sensible élevé**

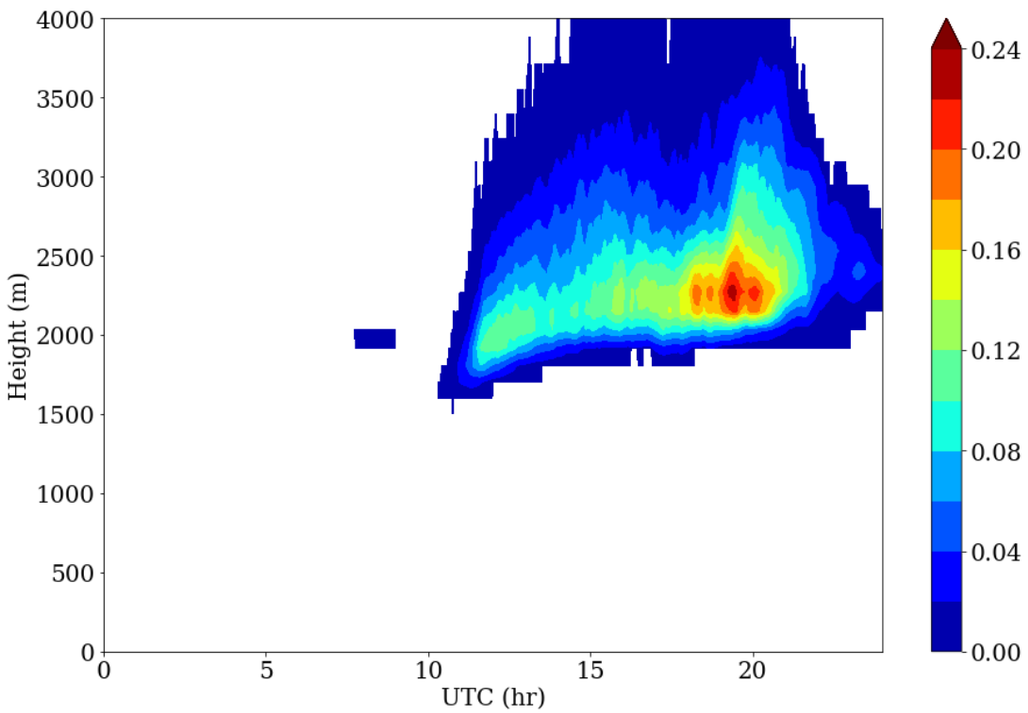
Energie turbulence cinétique



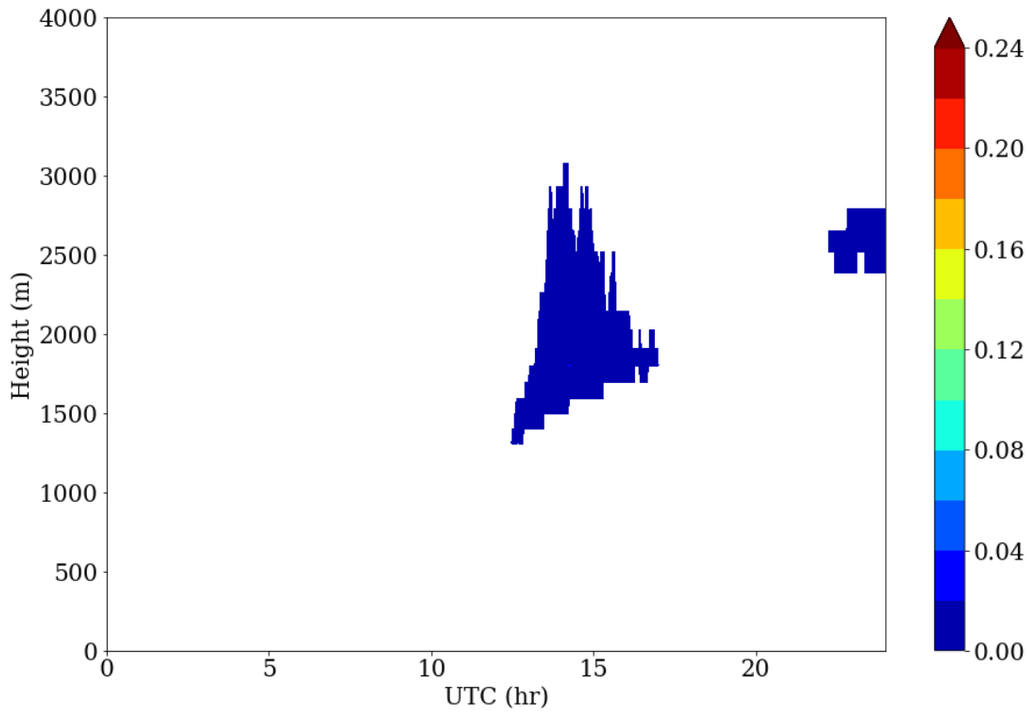
- **Forte turbulence au-dessus de la forêt** causée par :
  - Le flux de chaleur sensible (production thermique de turbulence)
  - La longueur de rugosité de la forêt (production dynamique de turbulence)

- Développement nuageux *9 juillet 2013*

Couverture nuageuse



Forêt



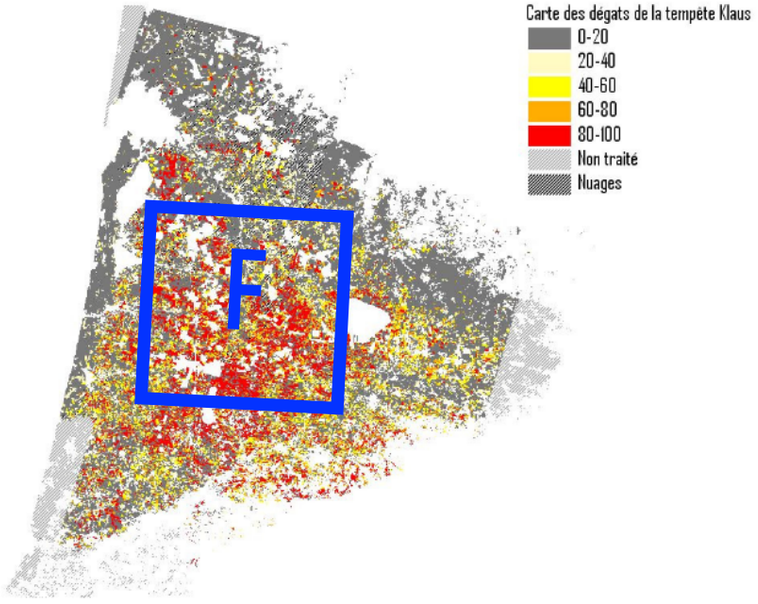
Non-forêt

- Forêt : plus de nuages avec une base et un sommet plus élevés

IV. A. IMPACT DE LA TEMPÊTE KLAUS SUR LA REPRÉSENTATION DE LA SURFACE

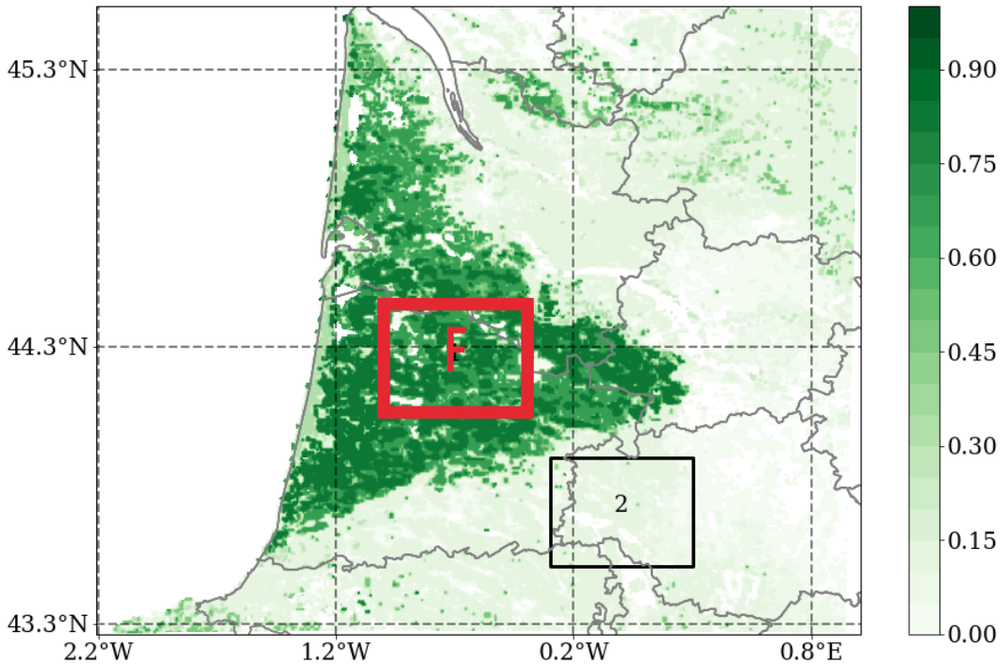
- Carte de déforestation de la tempête Klaus

  ➡ Produit par l'IGN (Institut national de l'information géographique et forestière)

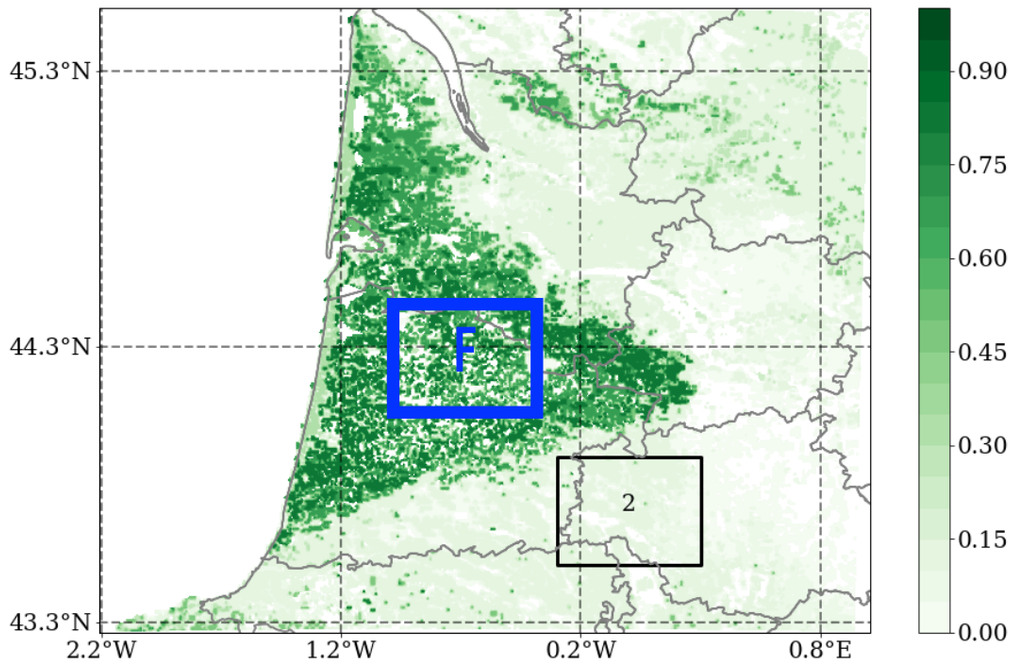


- Prise en compte dans le modèle :

PreKlaus 61% de forêt (F)

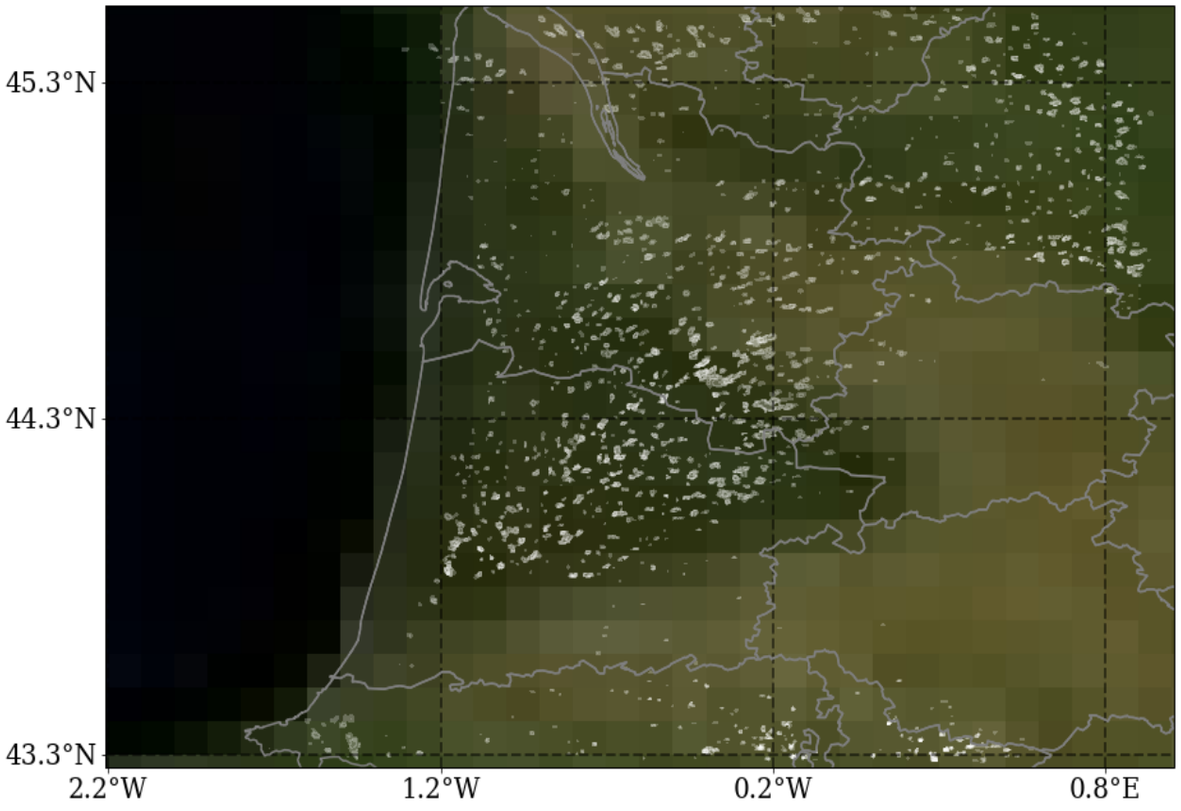


PostKlaus 38% de forêt (F)

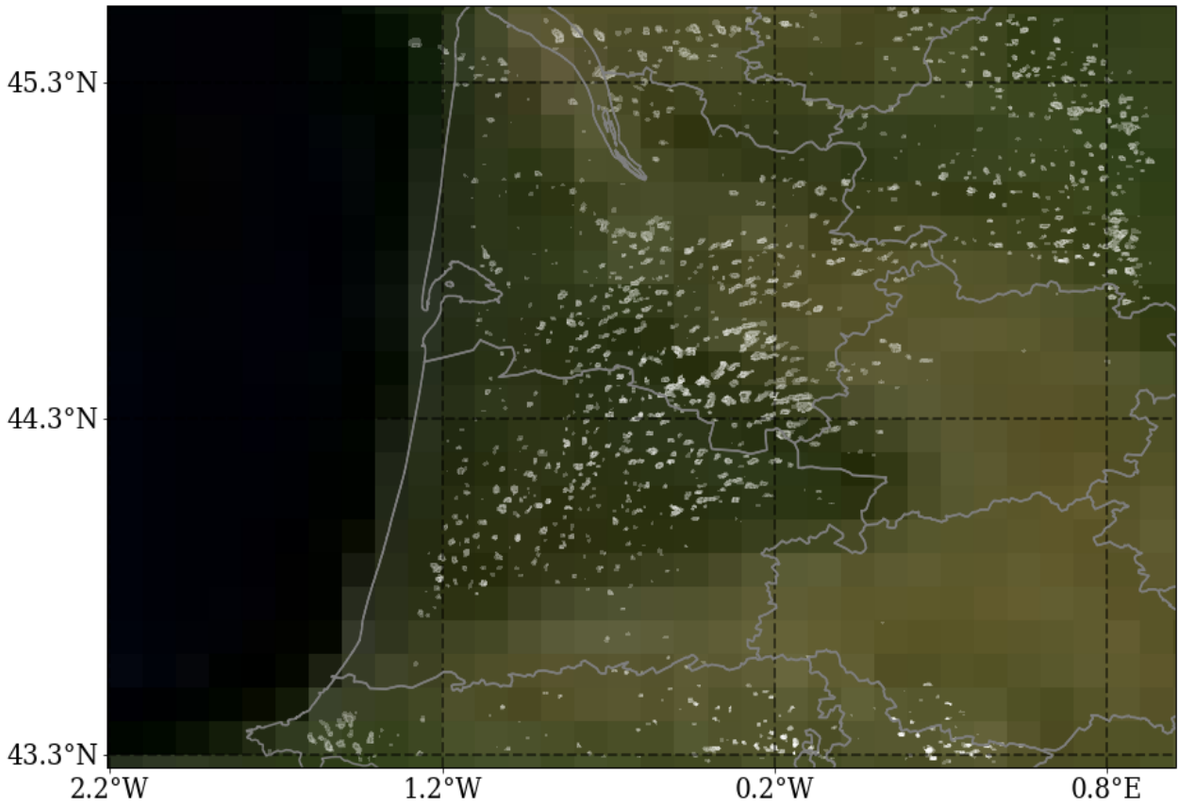


9 juillet 2013 13 UTC

PreKlaus

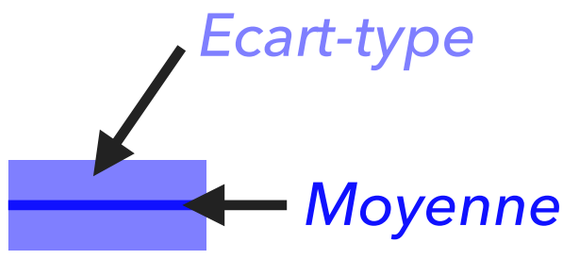


PostKlaus



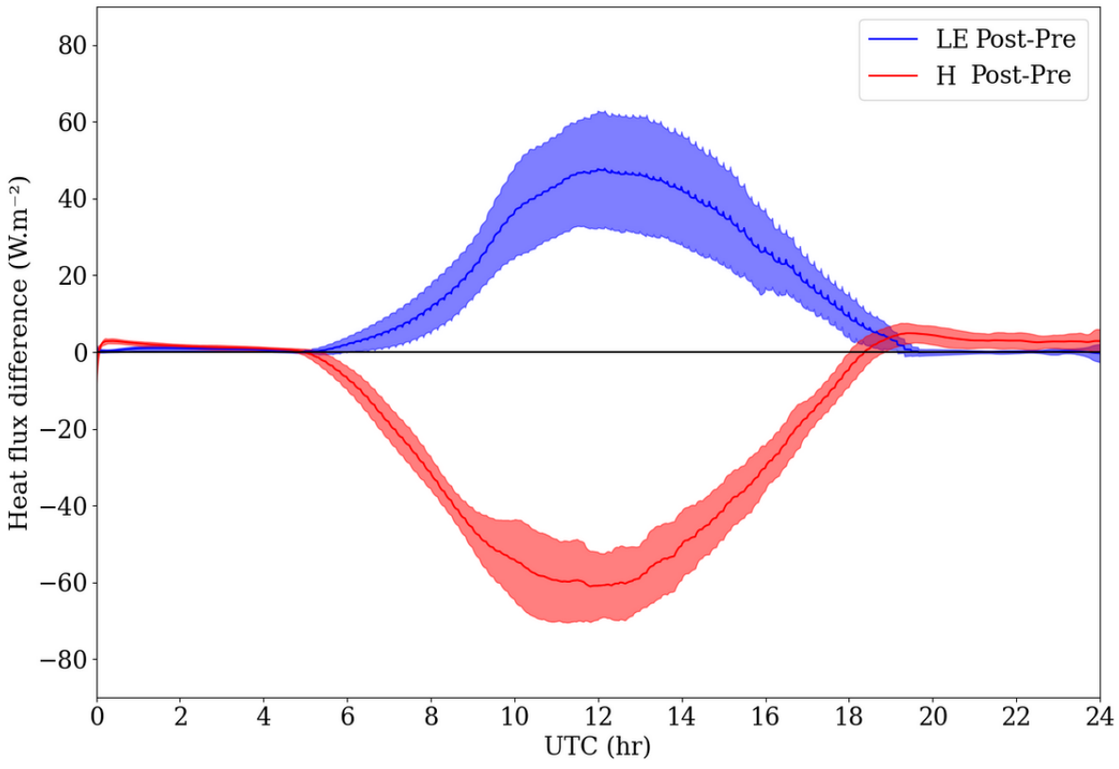
➡ La couverture nuageuse sur la forêt diminue lorsque la couverture forestière diminue

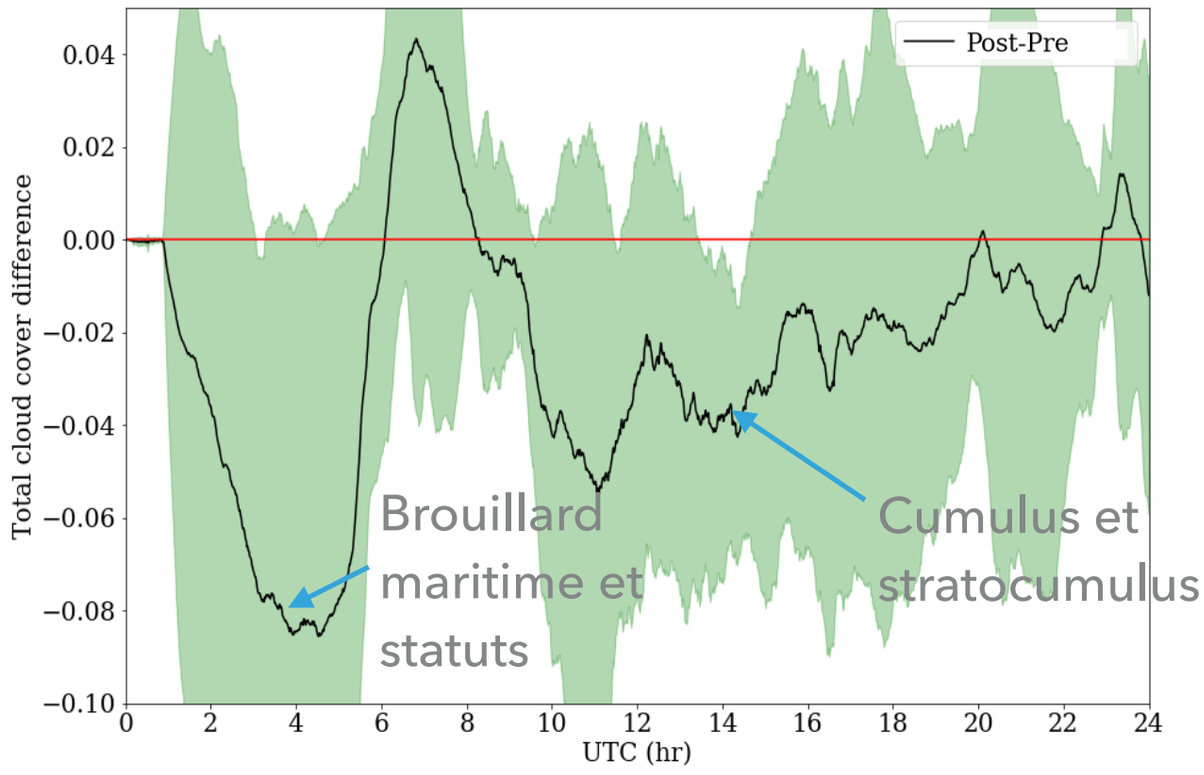
- Validation sur 14 cas de nuages de CL entre 2016 et 2022



Moyenne sur les 14 cas de la différence « PostKlaus - PréKlaus » pour le carré F

W.m^{-2}



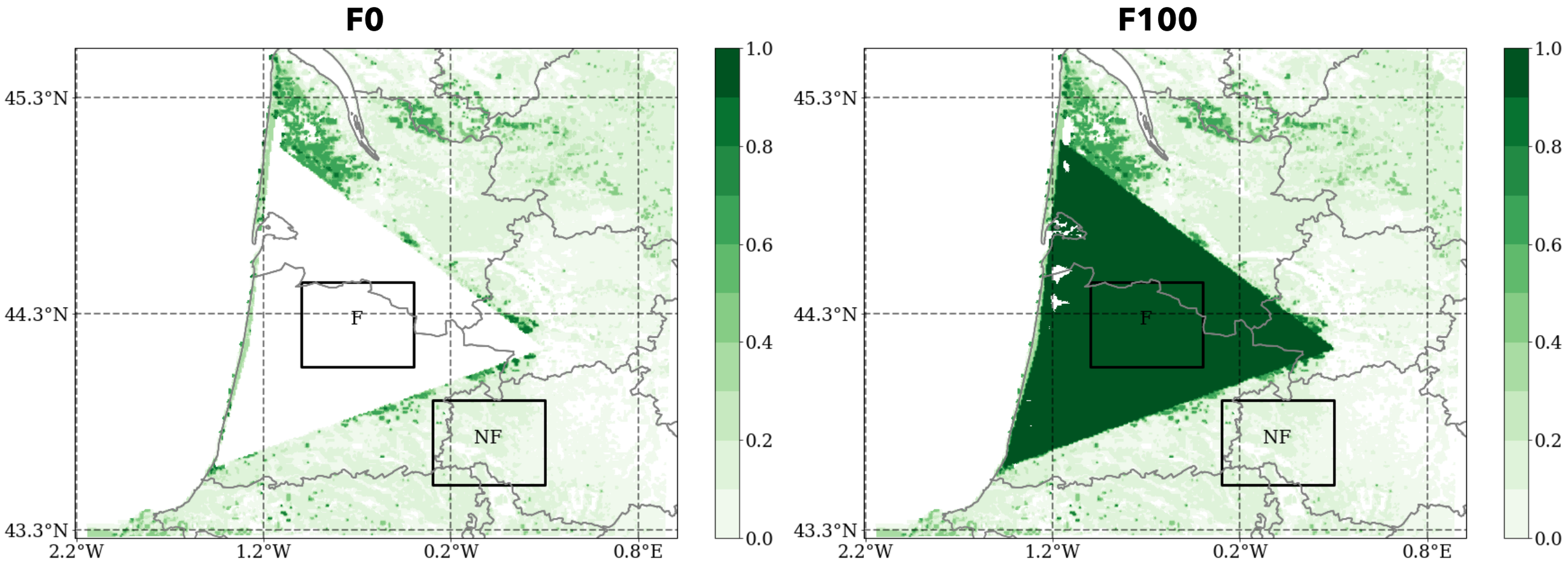


- Après la tempête Klaus :
  - LE : + 20%
  - H : - 20%

➡ Couverture nuageuse : - 25% (Teuling et al., 2017)

Robustesse des résultats sur 14 cas

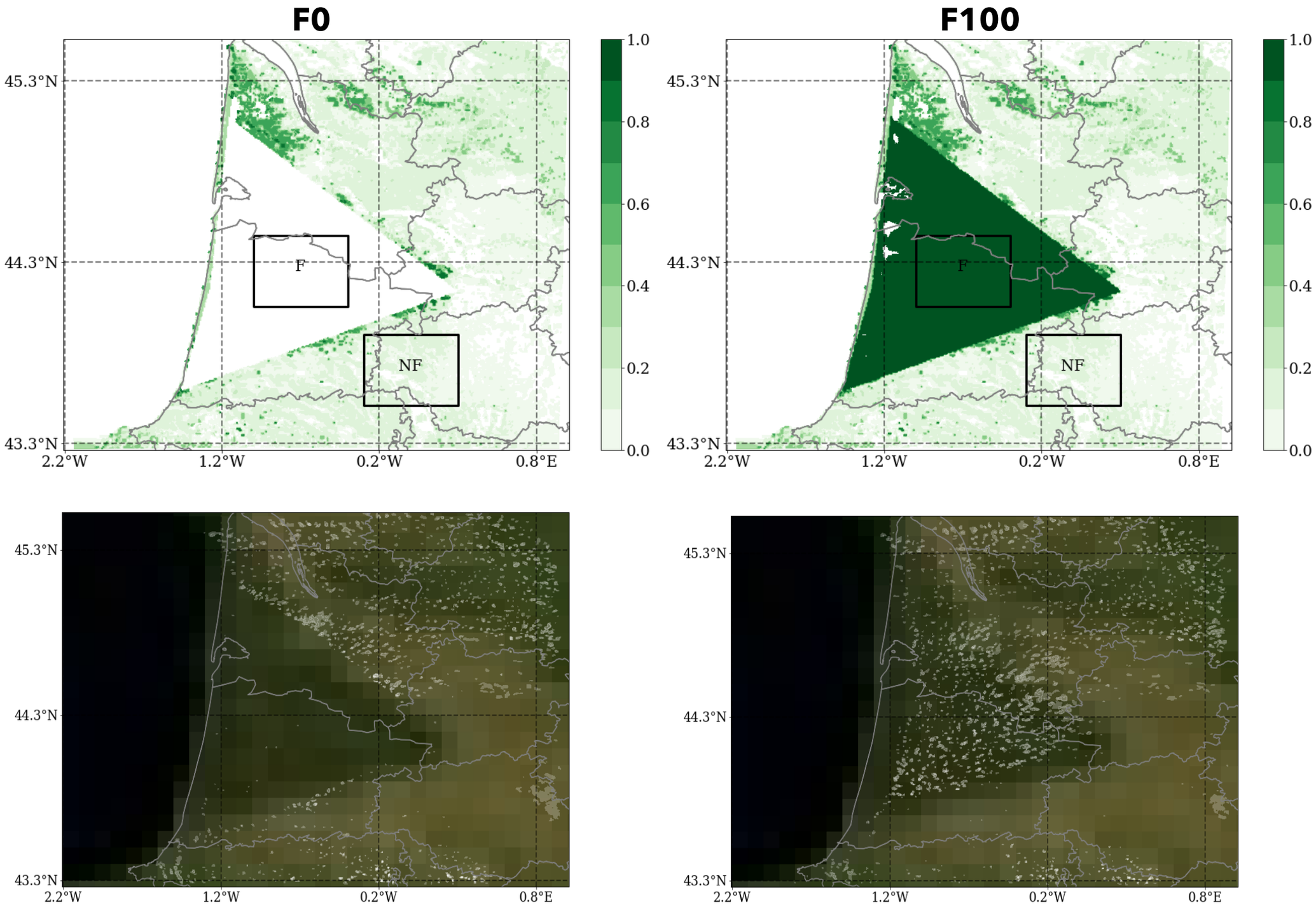
- Remplacement de la forêt des Landes par une couverture de surface idéalisée de prairie/conifère tempéré pour le cas 9 juillet 2013



- 0% de conifère tempéré (F0)
- 100% prairie
- 100% conifère temperé (F100)
- 0% prairie

- Scénarios considérés : F0, F20, F40, F60, F80 et F100 (PreKlaus: 61%, PostKlaus: 38%)

- Remplacement de la forêt des Landes par une couverture de surface idéalisée de prairie/conifère tempéré pour le cas 9 juillet 2013



V. CONCLUSIONS ET PERSPECTIVES

- **Simulation réaliste** de la couverture nuageuse forestière de CL par le modèle couplé surface-atmosphère

- **Processus physiques** responsables de la différence d'ennuagement de CL **identifiés** :

  - Albédo plus faible : RN plus fort

  - H plus fort et LE plus faible : H prévaut

  - H prévaut : mouvement convectif plus fort (vent vertical et production thermique de turbulence)

  - Augmentation de la longueur de rugosité générant de la production dynamique de turbulence

- La **diminution de la couverture nuageuse** après Klaus montré par Teuling et al. (2017) a bien été **simulée et quantifiée** sur 14 cas

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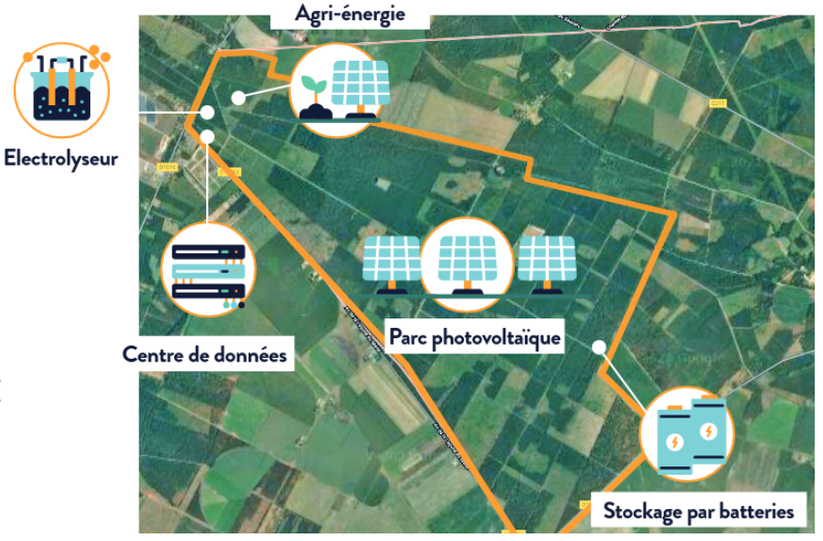
- La **diminution de la couverture nuageuse** après Klaus montré par Teuling et al. (2017) a bien été **simulée et quantifiée** sur 14 cas

- **Utilisation prospective** plus approfondie **du modèle** pour un **changement d'utilisation des terres**
  - Exemple de projet de développement foncier : ferme solaire Horizeo (1000 ha)



Projet Horizeo

Occupation des terres et climat régional : impact des surfaces forestières sur l'ennuagement dans le sud-ouest de la France

Gaëtan Noual

https://theses.hal.science/tel-04211022

JGR Atmospheres

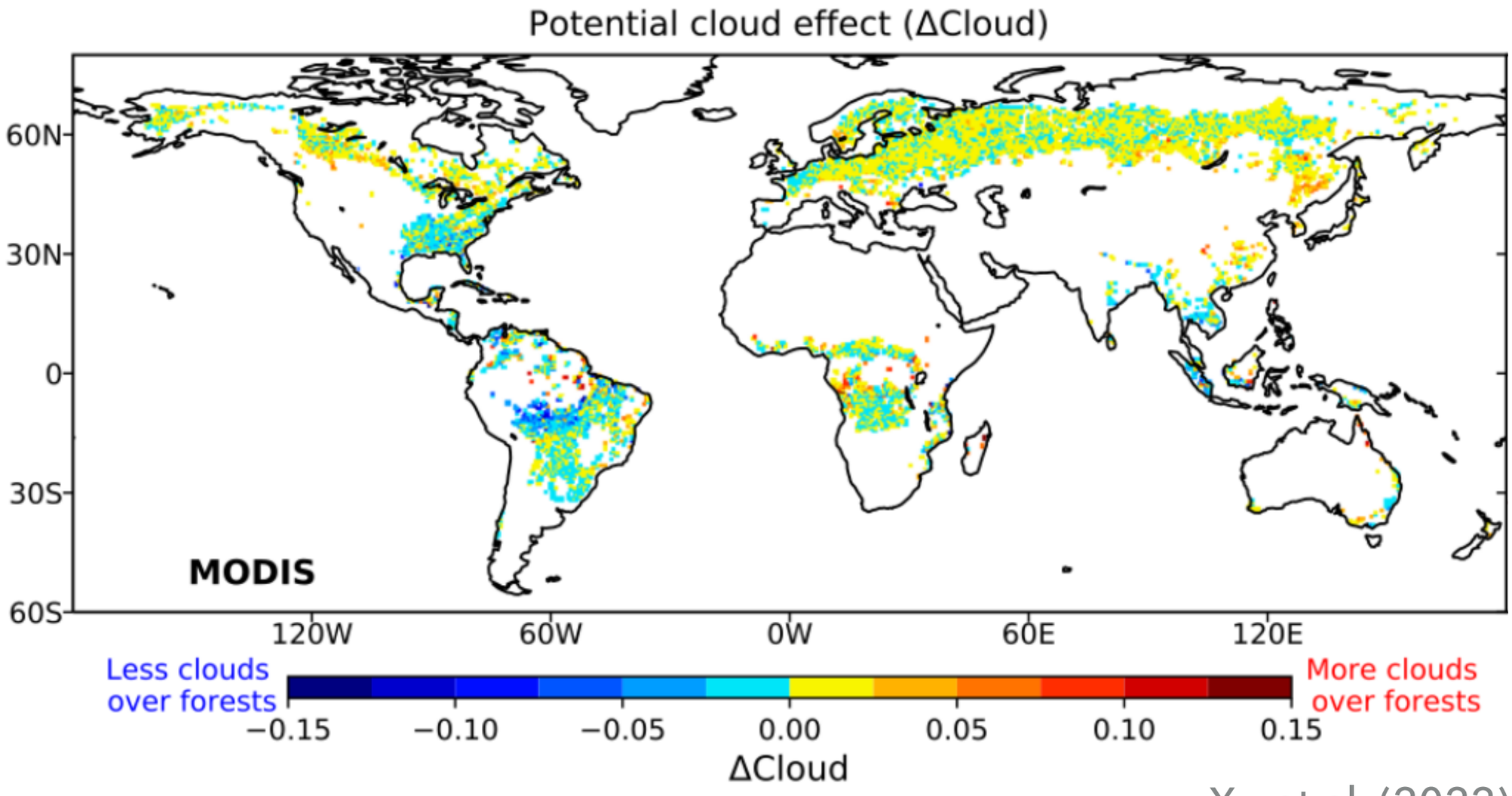
Simulating the Effects of Regional Forest Cover and Windthrow-Induced Cover Changes on Mid-Latitude Boundary-Layer Clouds

G. Noual[1,2], Y. Brunet[1], P. Le Moigne[2], and C. Lac[2]

[1]ISPA, INRAE, Villenave d'Ornon, France, [2]CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France

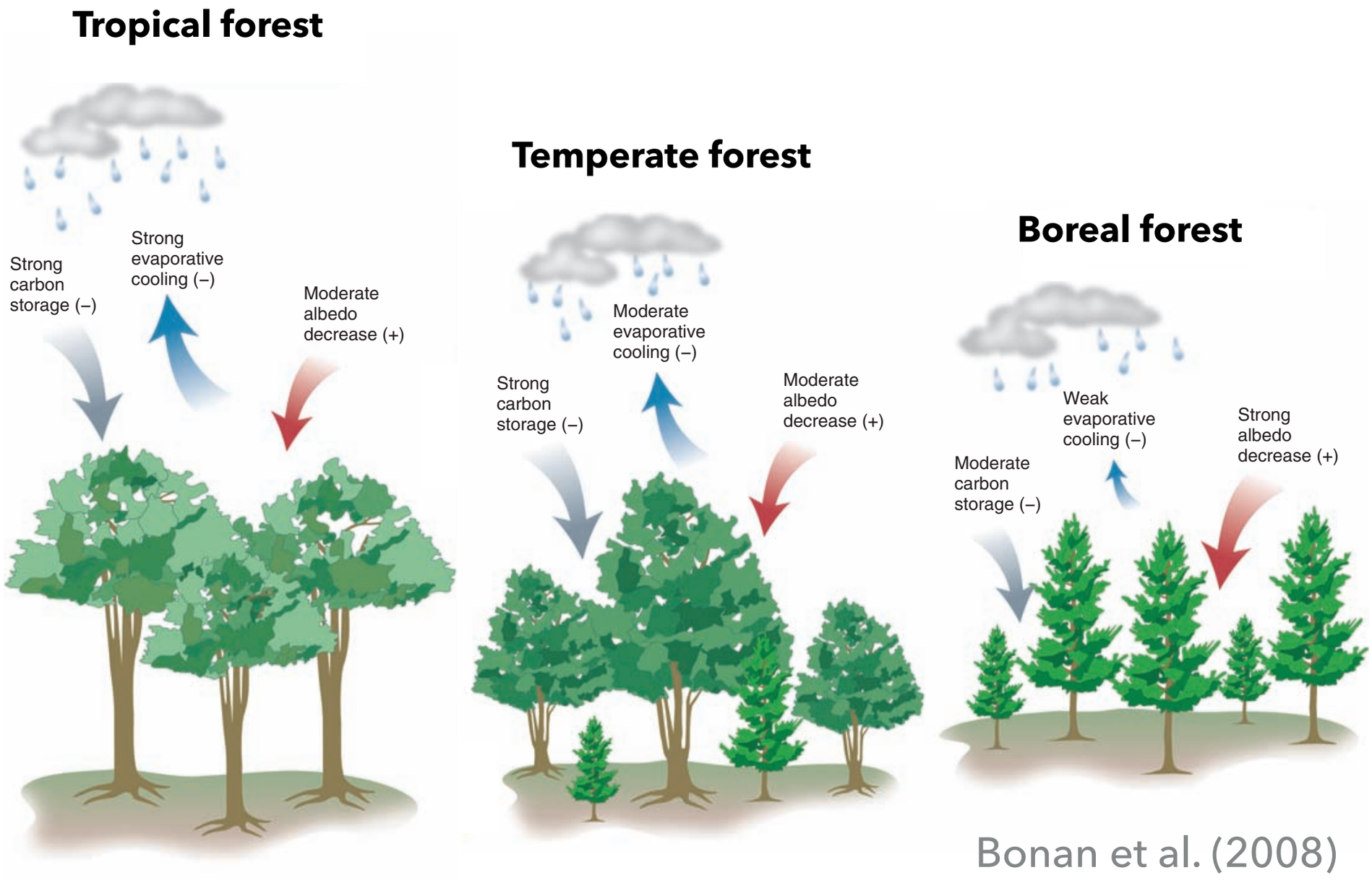
MERCI POUR VOTRE ATTENTION

- Effect of the forest on cloudiness is highly dependent on the region



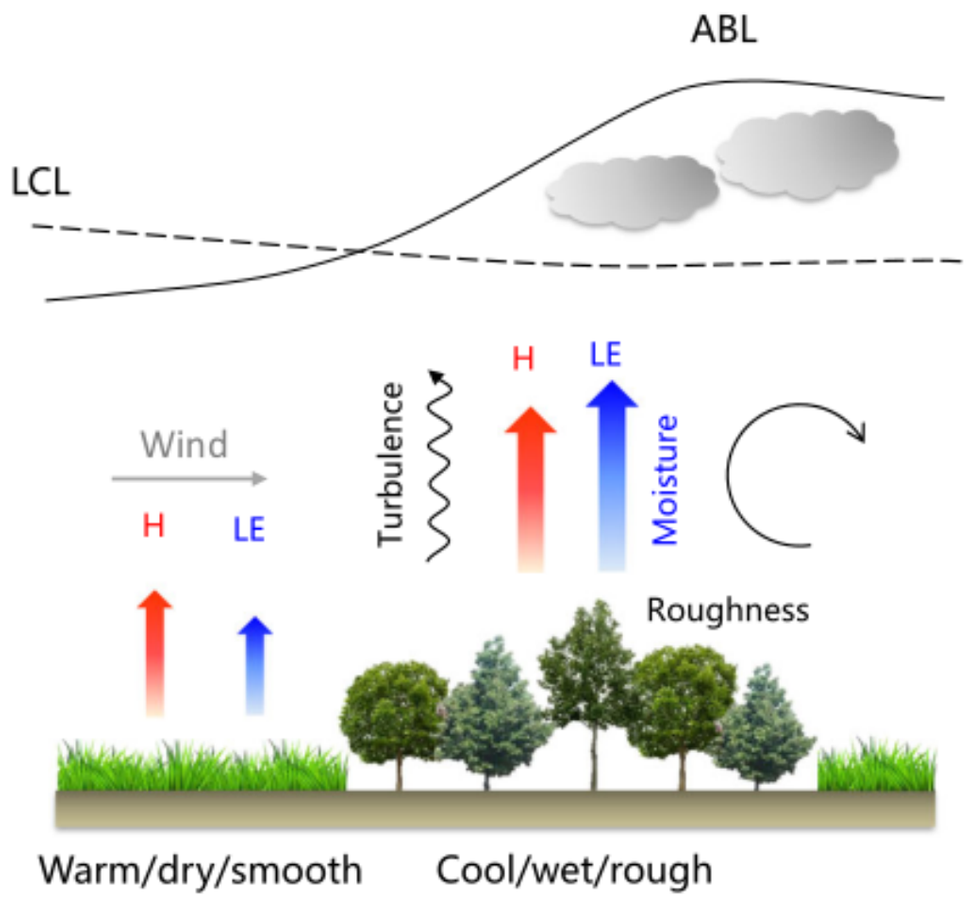
Xu et al. (2022)

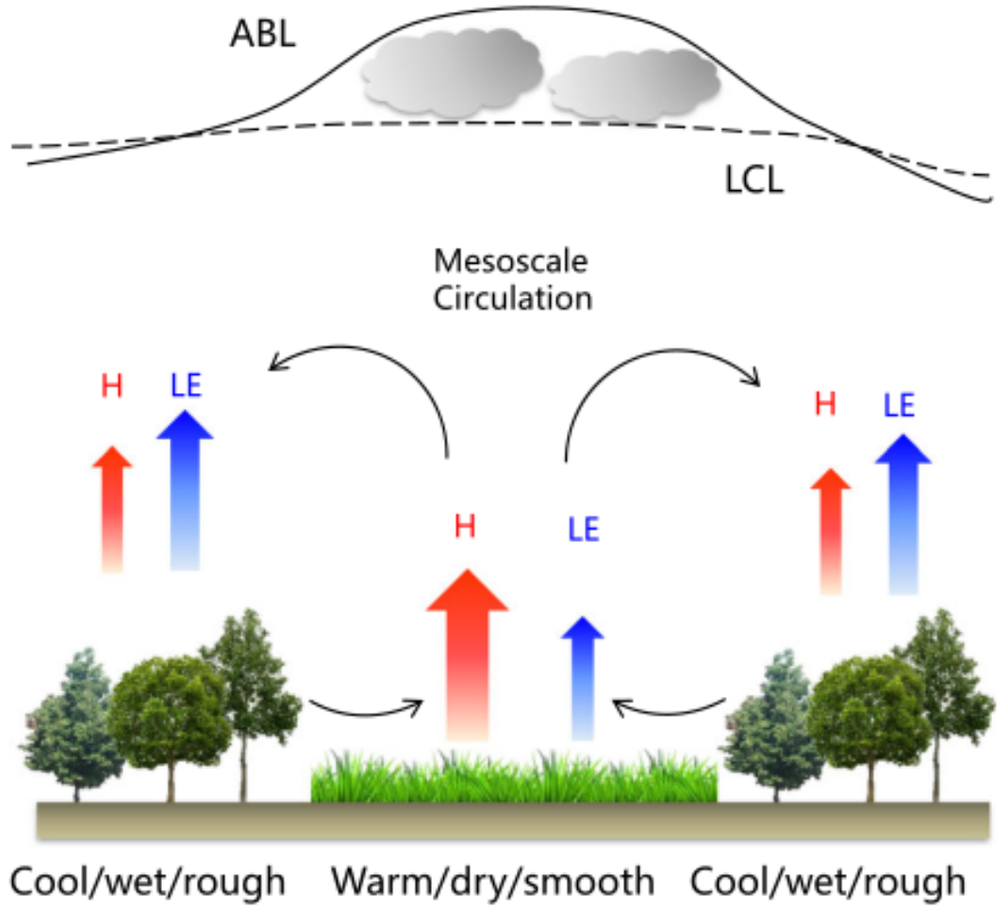
- Impact of the climate region



Bonan et al. (2008)

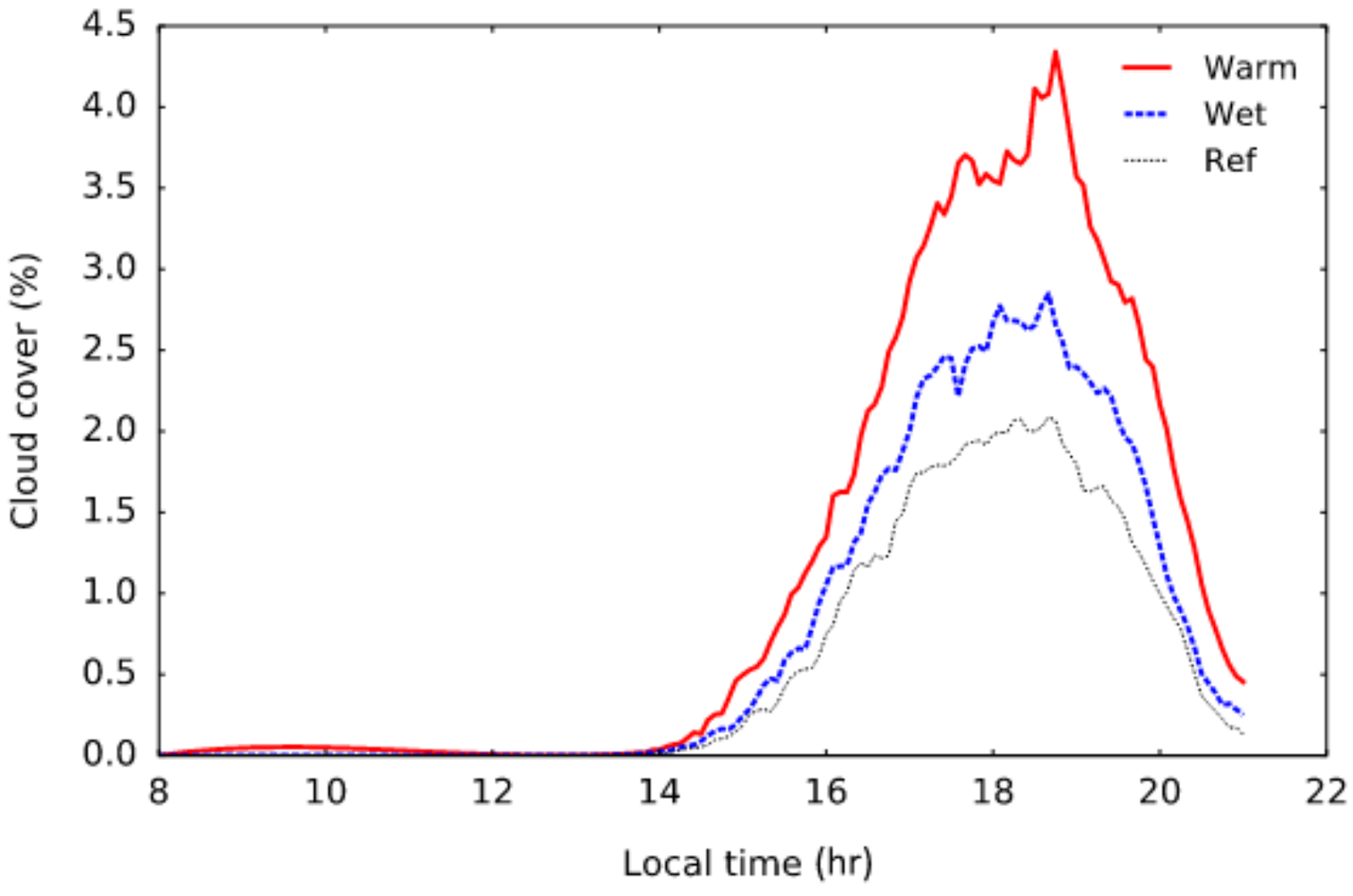
- Surface heterogeneities: contrasted results





Xu et al. (2022)

- Key role of the distribution between sensible (H) and latent (LE) heat surface fluxes



- Warm: Ref + 5% H
- Wet: Ref + 5% LE

Bosman et al. (2019)

- Is a coupled surface-atmosphere mesoscale model capable of reproducing a BL cloud cover contrast between forest and non-forest?

➡ **Evaluation of mesoscale modelling**

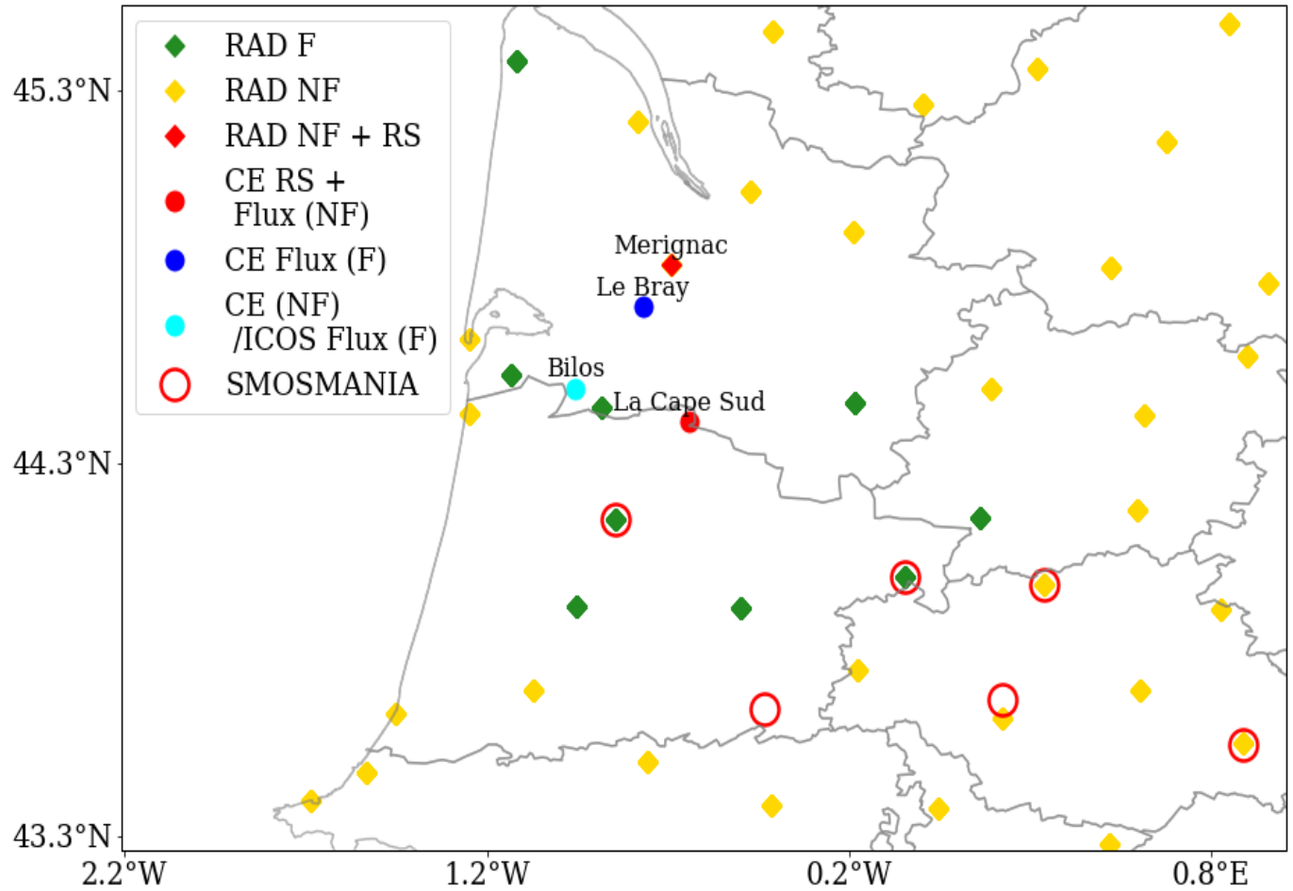
- What are the predominant BL processes that generate differences in cloudiness between forest and non-forest?

➡ **Improvement of the understanding the processes**

- What is the effect of changes in forest cover on cloud diurnal cycle?

➡ **Quantification of forest cover change impact**

- Satellite data: MSG or MODIS
- CarboEurope (CE) campaign measurement
- BL survey: radiosonde (RS)
- Flux measurement: Bilos ICOS station
- Operational ground network: RADOME (RAD F or NF)
- Soil measurement: SMOSMANIA

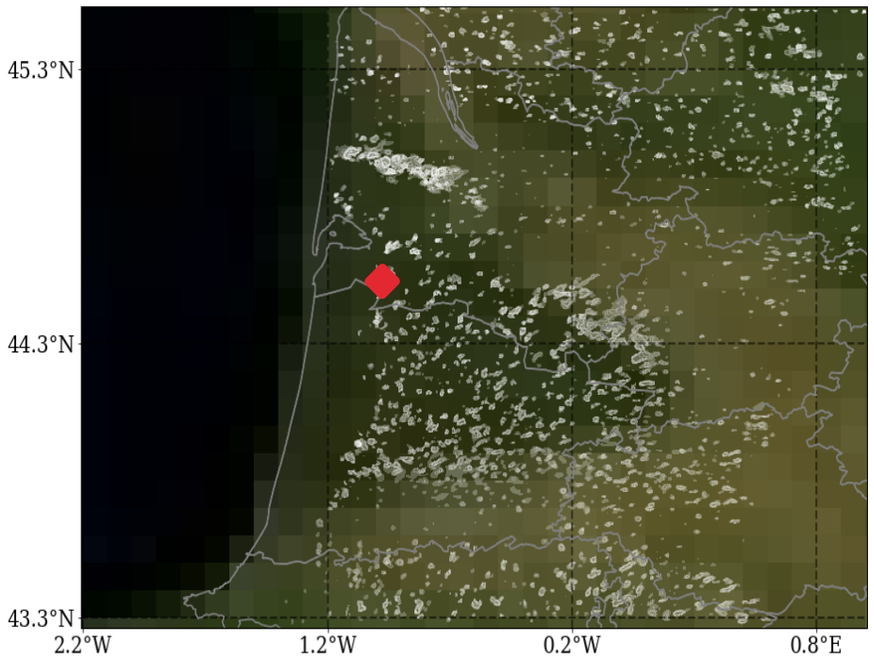


Location of observation data

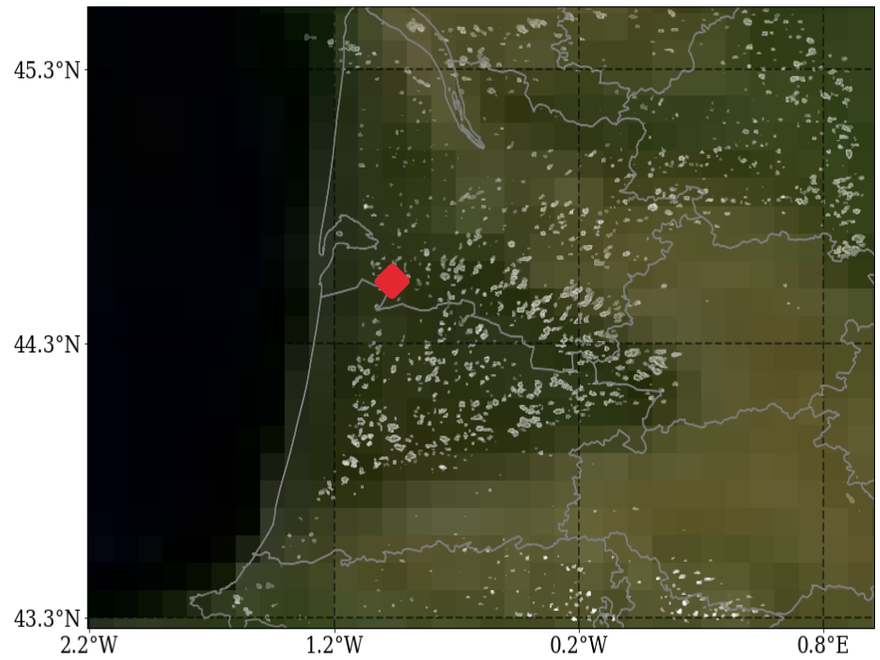
- Model initialization and boundary conditions *9 July 2013*

Average cloud fraction between 500 and 3000 m at 13 UTC

AQUA Satellite

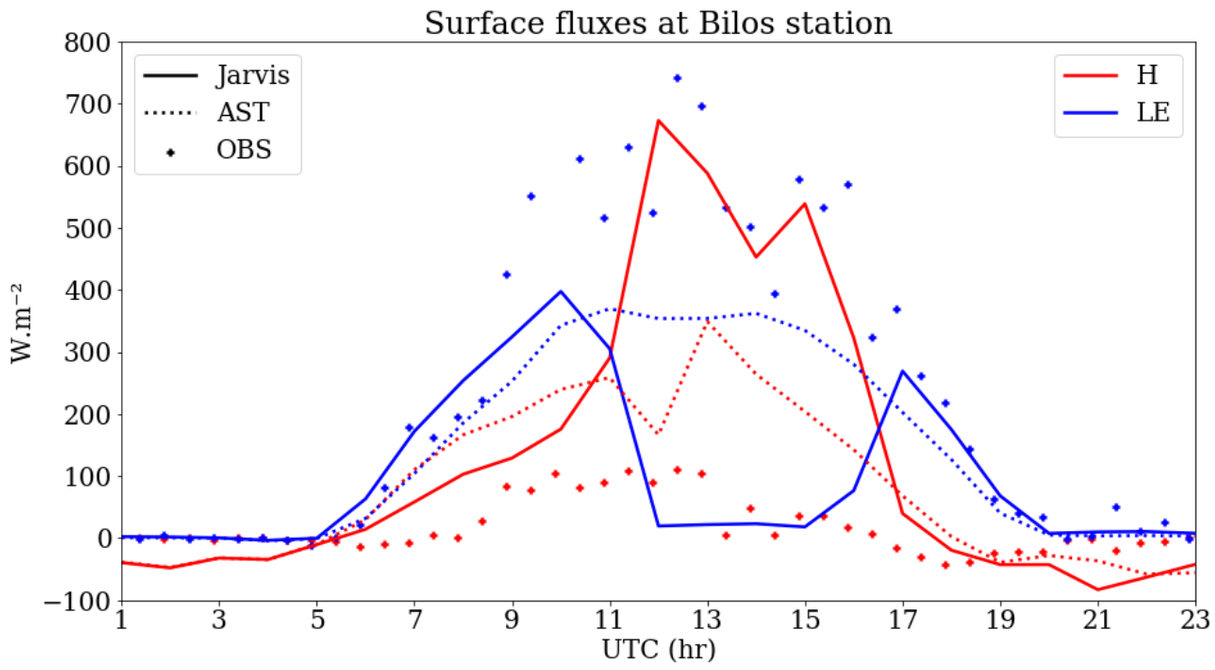


AROME Init



ECMWF Init

- Photosynthesis parameterization (Stomatal control)
  - Jarvis : semi-empirical approach
  - ISBA-A-gs (AST) : physical approach
    - ➡ High impact on surface fluxes

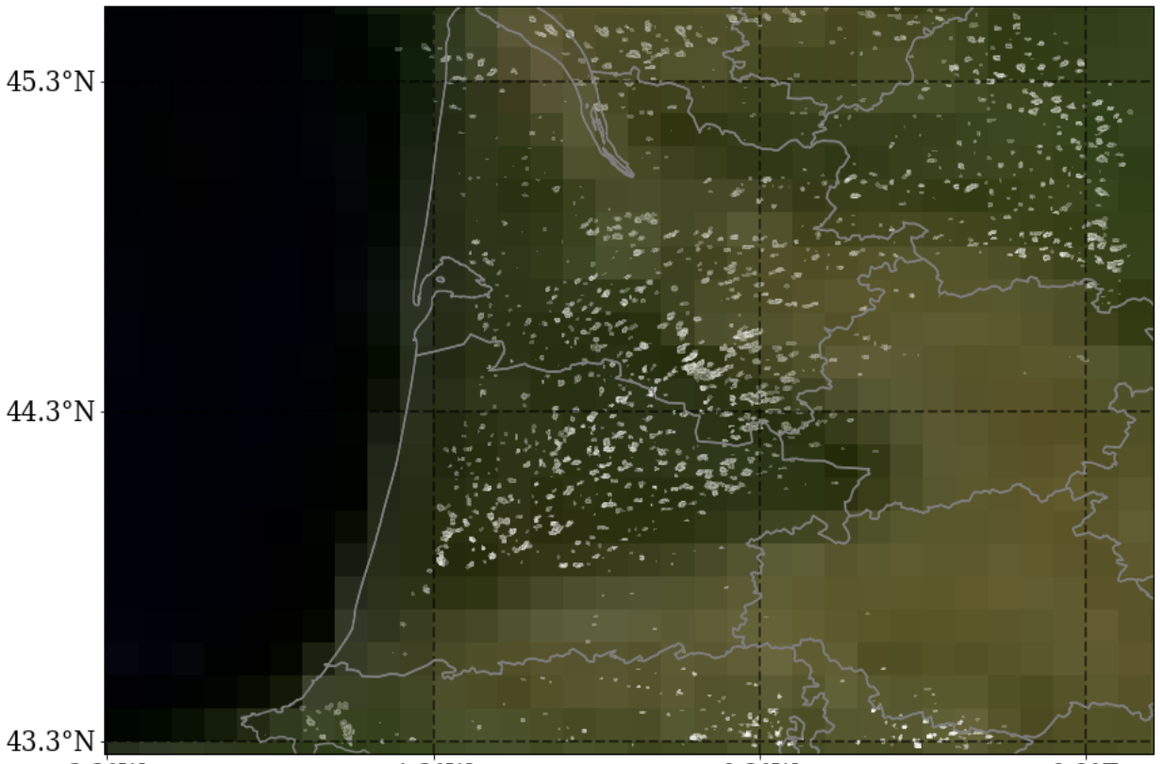


- **Initialization and atmospheric forcing**: AROME, **ECMWF**
- **Surface parameterization**: **ISBA** soil and vegetation model: 3L, DIF, **DIF/MEB**
- **Plant photosynthesis parameterization**: Jarvis, **AST**
- **Atmospheric parameterization**:
  - Shallow convection scheme: EDMF, EDMF-GZ, **OFF**
  - Turbulence scheme: **TURB1D** (cost)
  - Radiation scheme: **ECRAD**

9 July 2013 13 UTC

Observation

Simulation

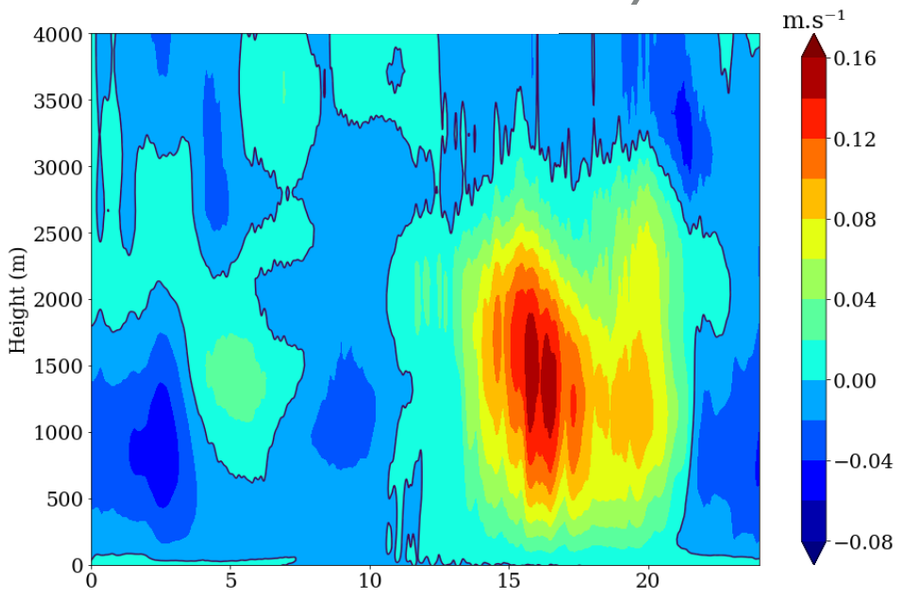


- Effects on dynamics

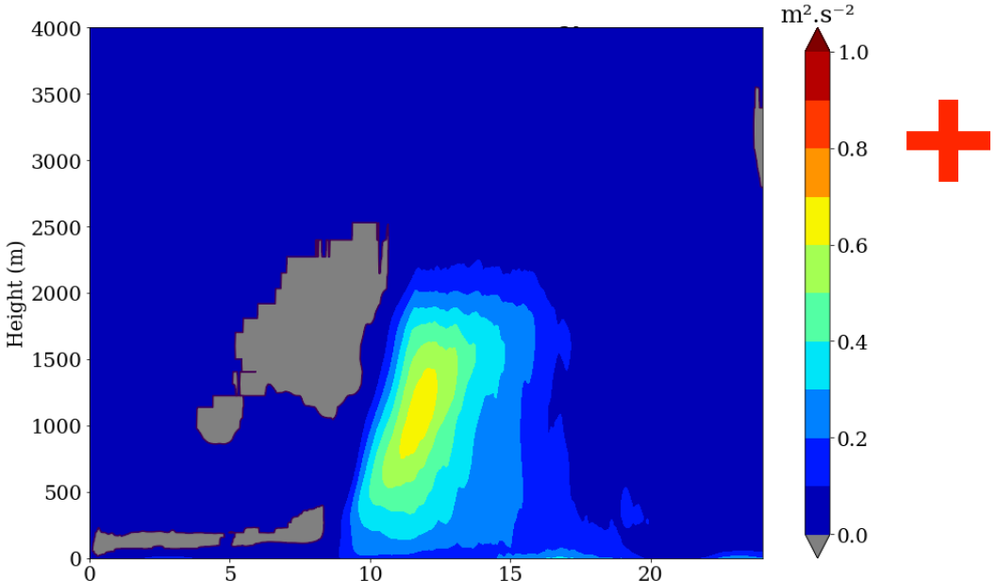
Forest-NonForest difference

9 July 2013

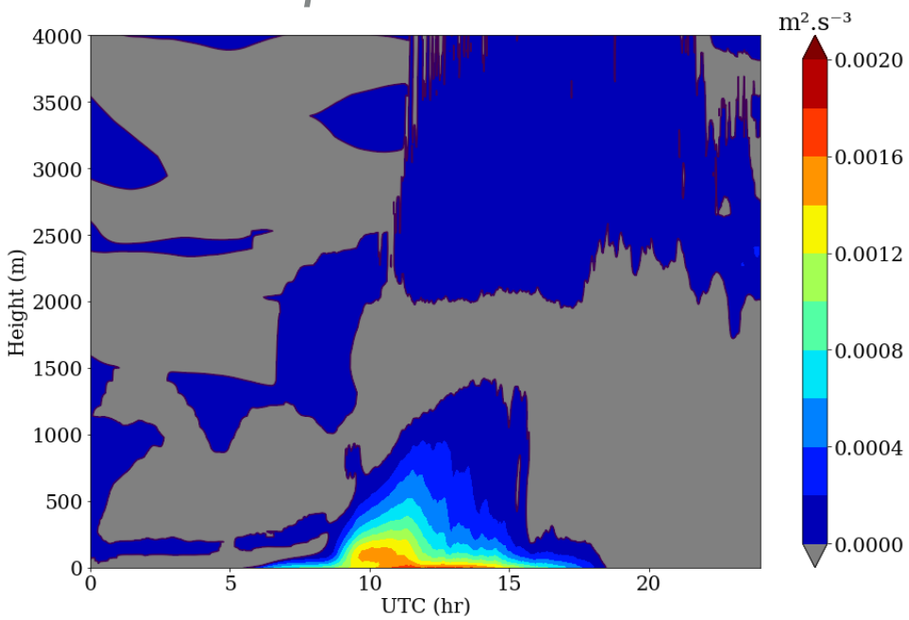
Vertical velocity



TKE

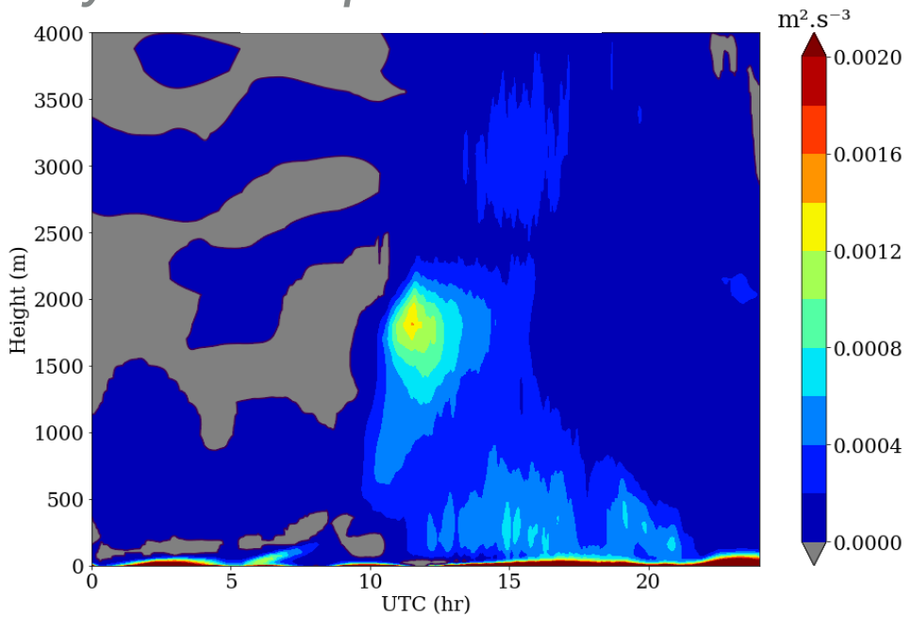


Thermal production of TKE



- Thermal production in the lower part of the BL

Dynamical production of TKE



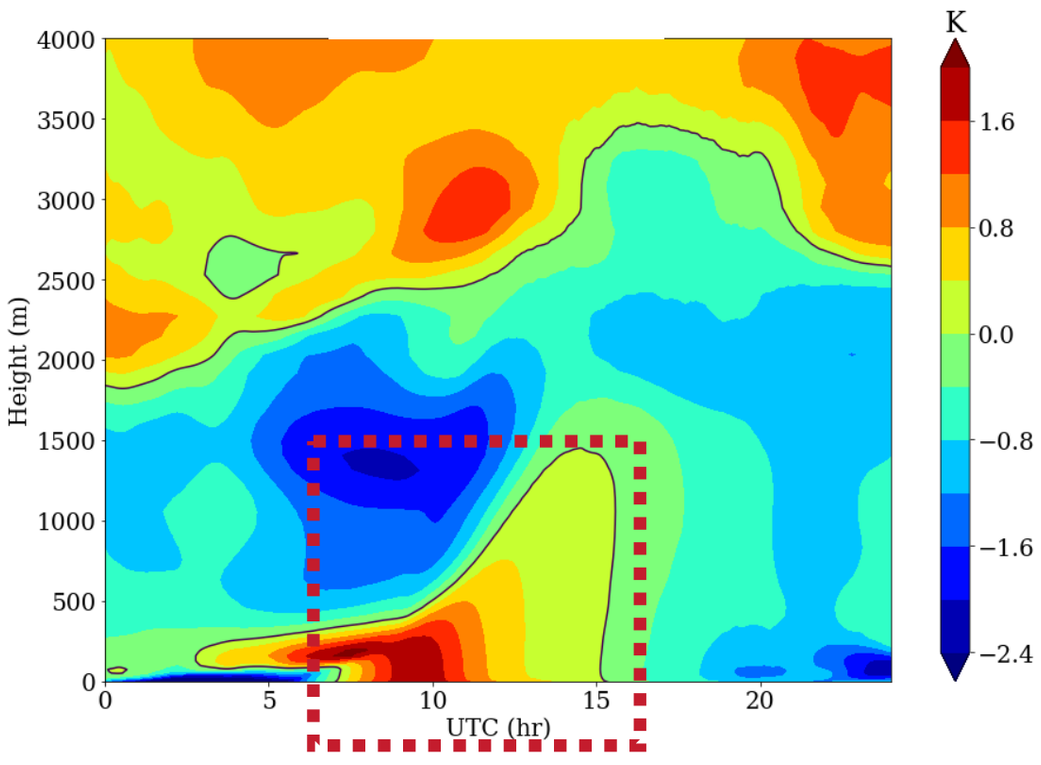
- Dynamical production in the upper part

- Effects on thermodynamics

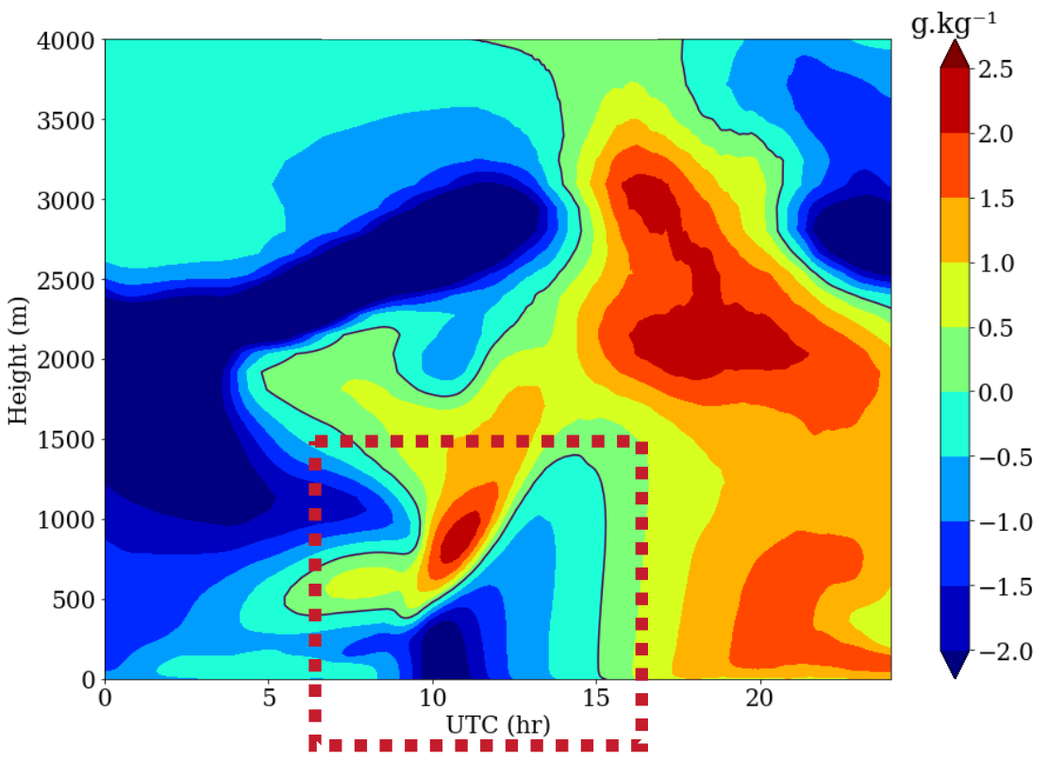
9 July 2013

Forest-NonForest difference

Potential temperature



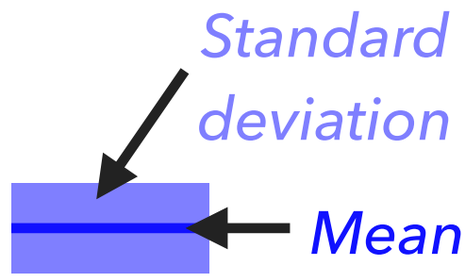
Vapour mixing ratio



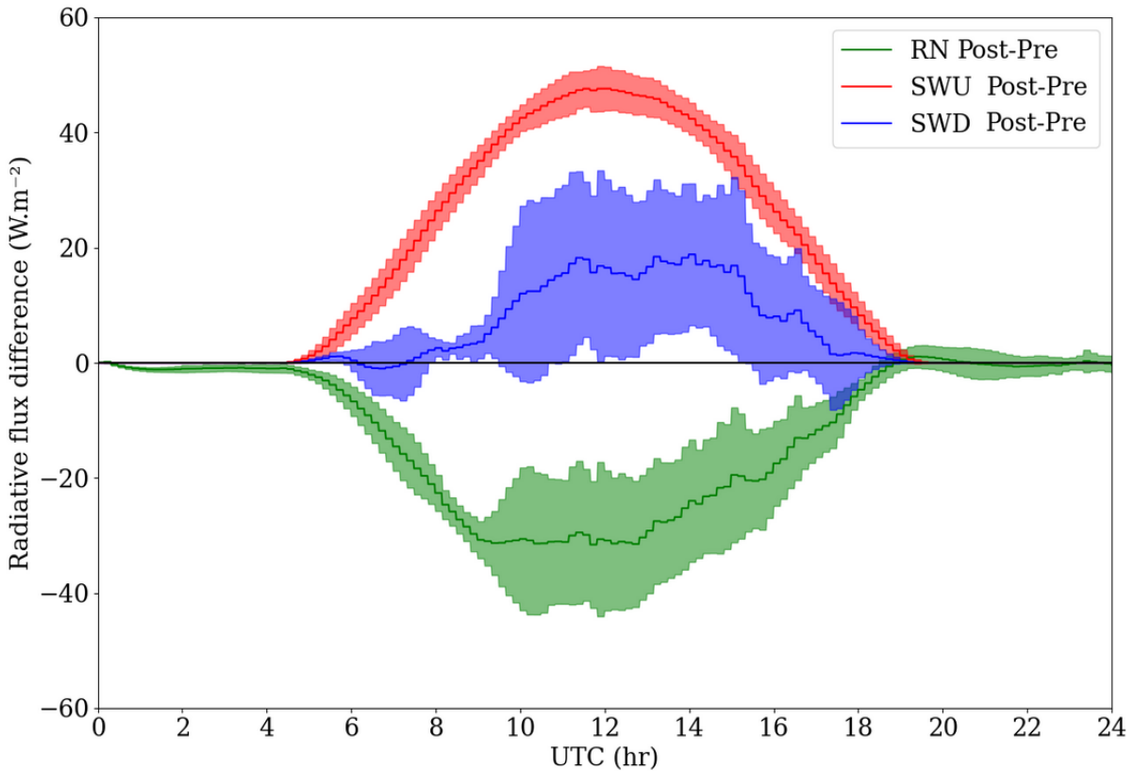
- Higher sensible heat flux on forest
  - ➡ Warmer BL

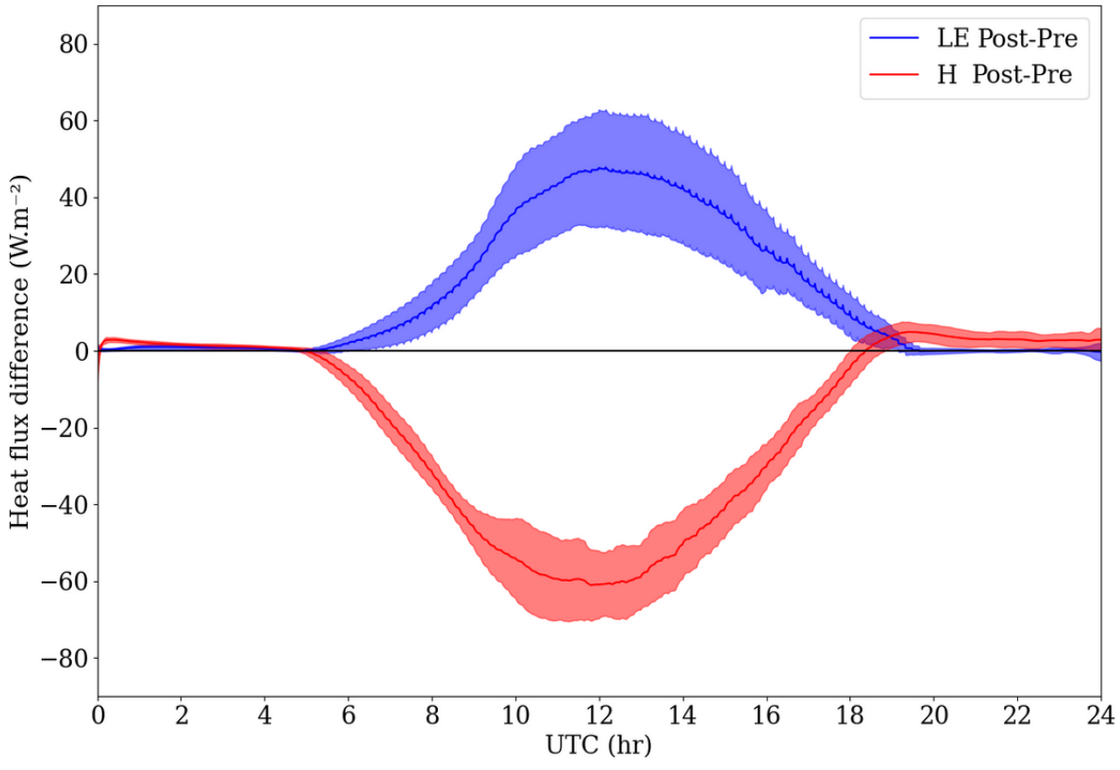
- Lower latent heat flux on forest
  - ➡ Drier BL

- Validation on 14 summer BL cloud cases between 2016 and 2022



Mean over F





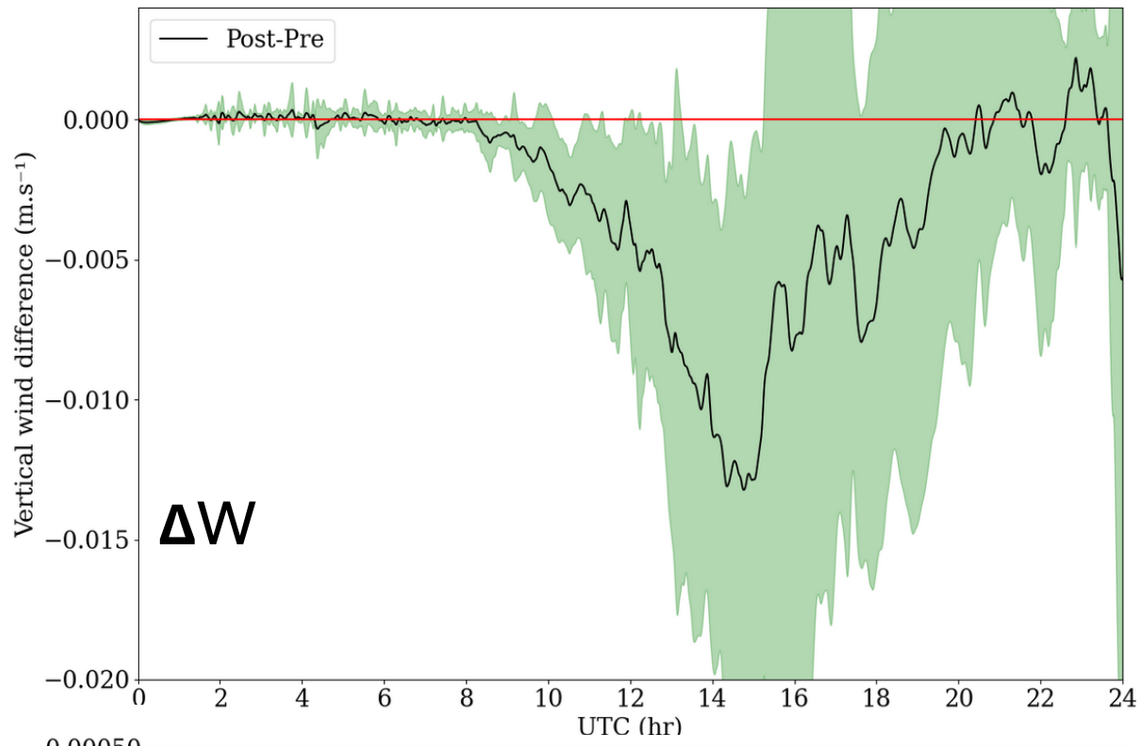
- Net radiation: - 5%
- Short wave down: + 3%
- Short wave up: + 40%

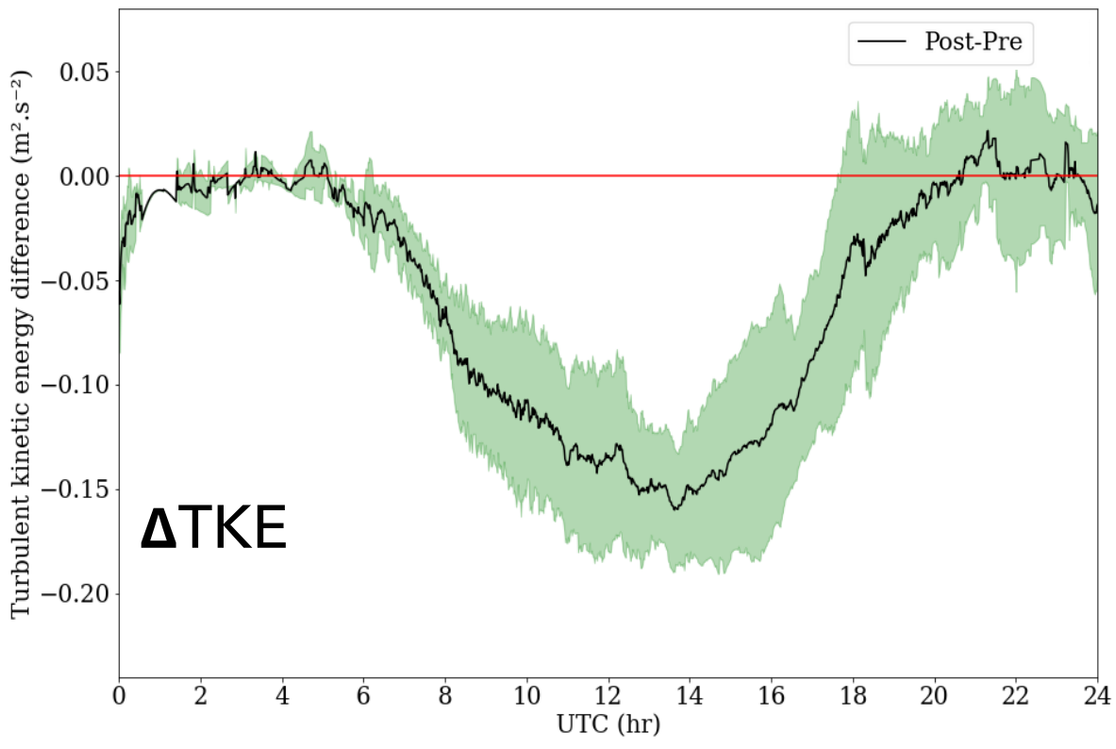
- Latent heat flux: + 20%
- Sensible heat flux: - 20%

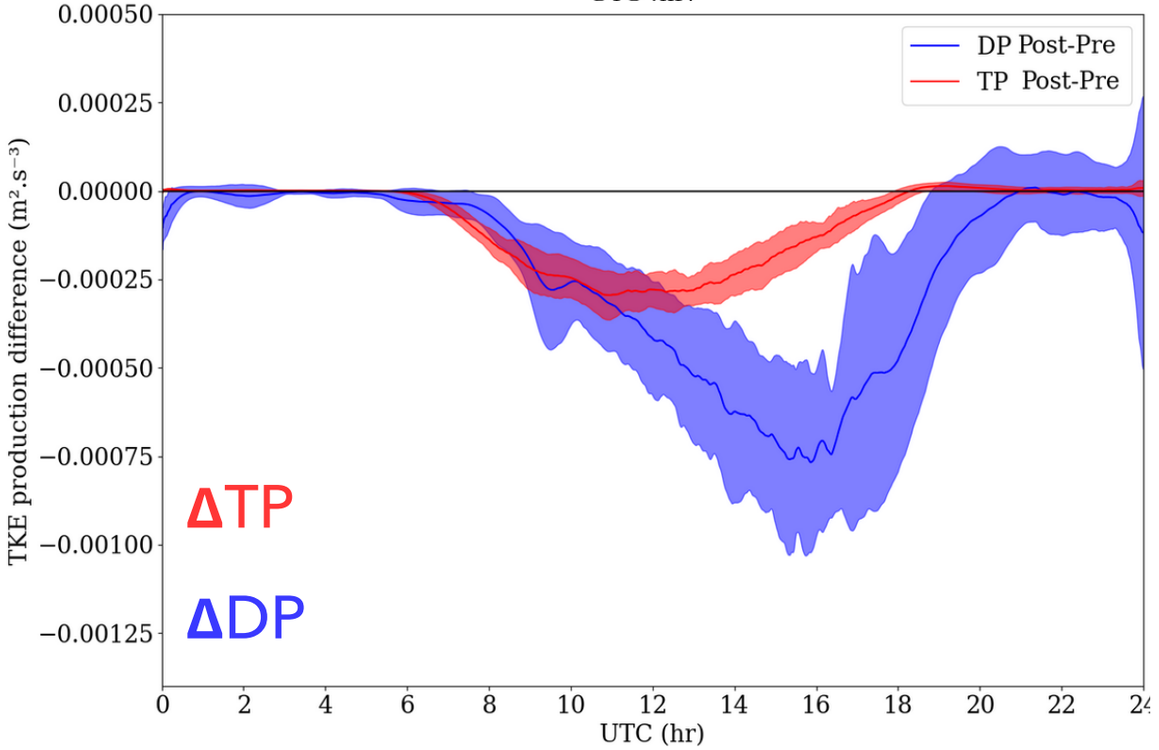
- Validation on 14 summer BL cloud cases between 2016 and 2022

Mean over F on the first 4000 m

- Turbulent kinetic energy: - 18%
  - ➡ Dynamical production: - 35%
  - ➡ Thermal production: - 30%

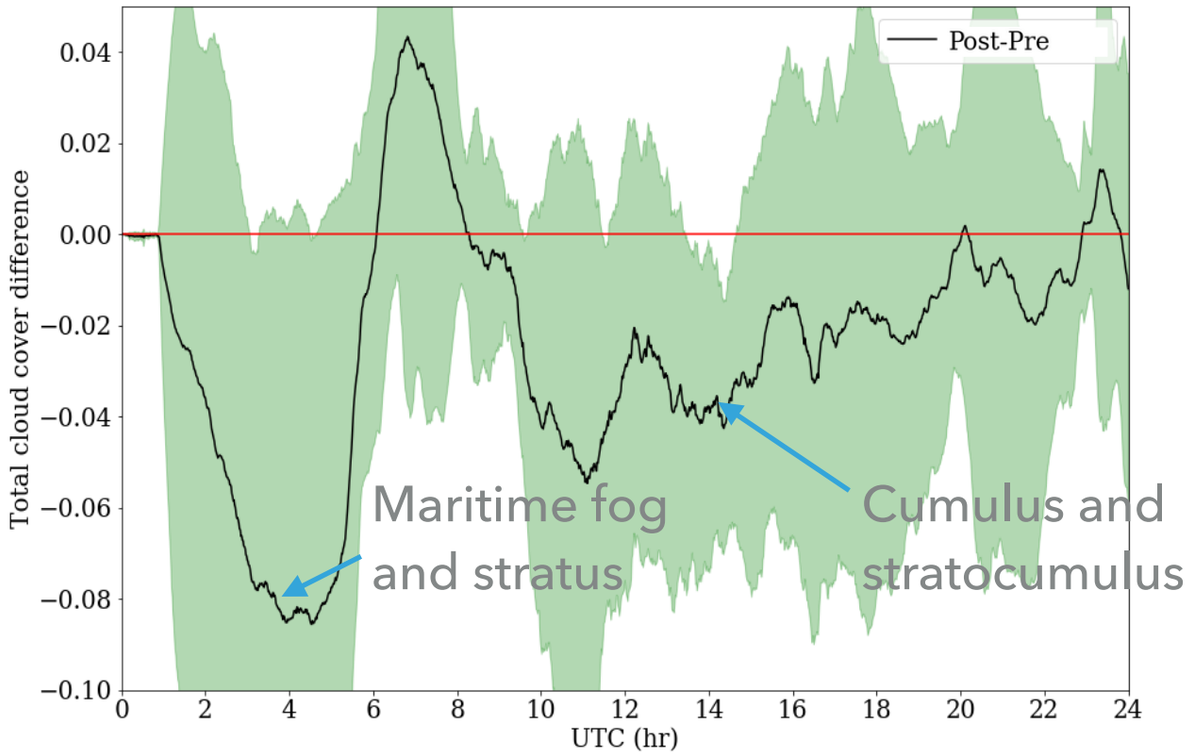


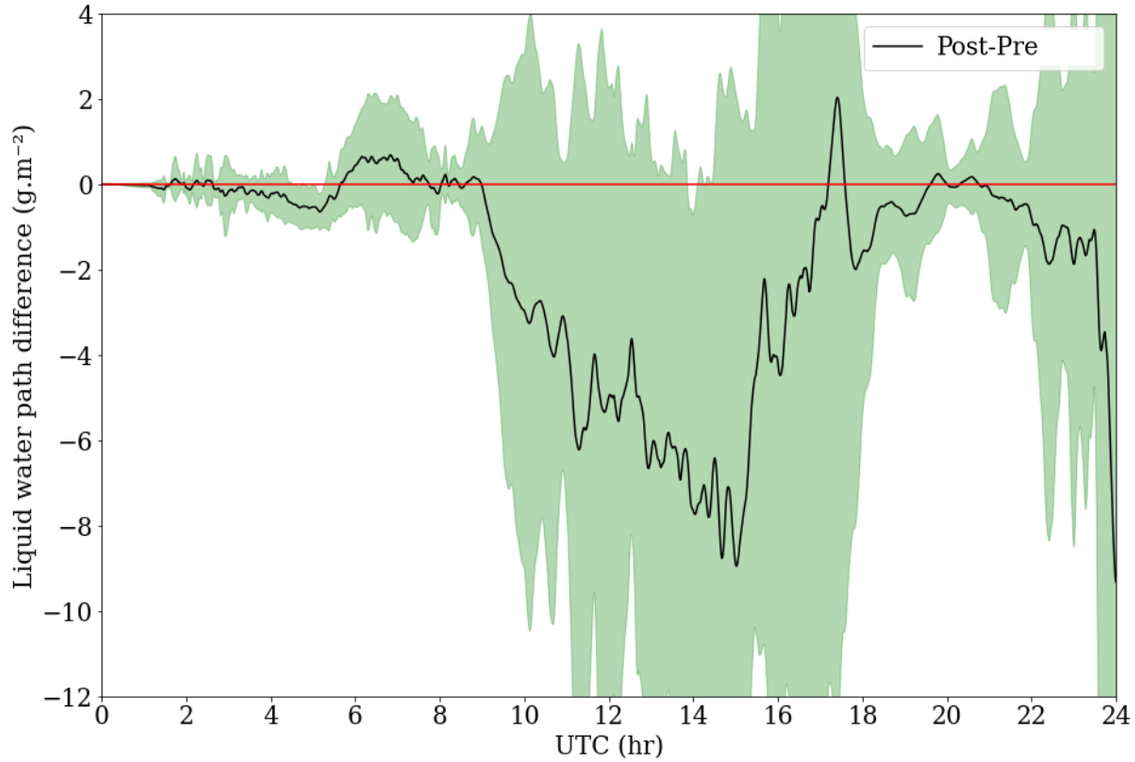




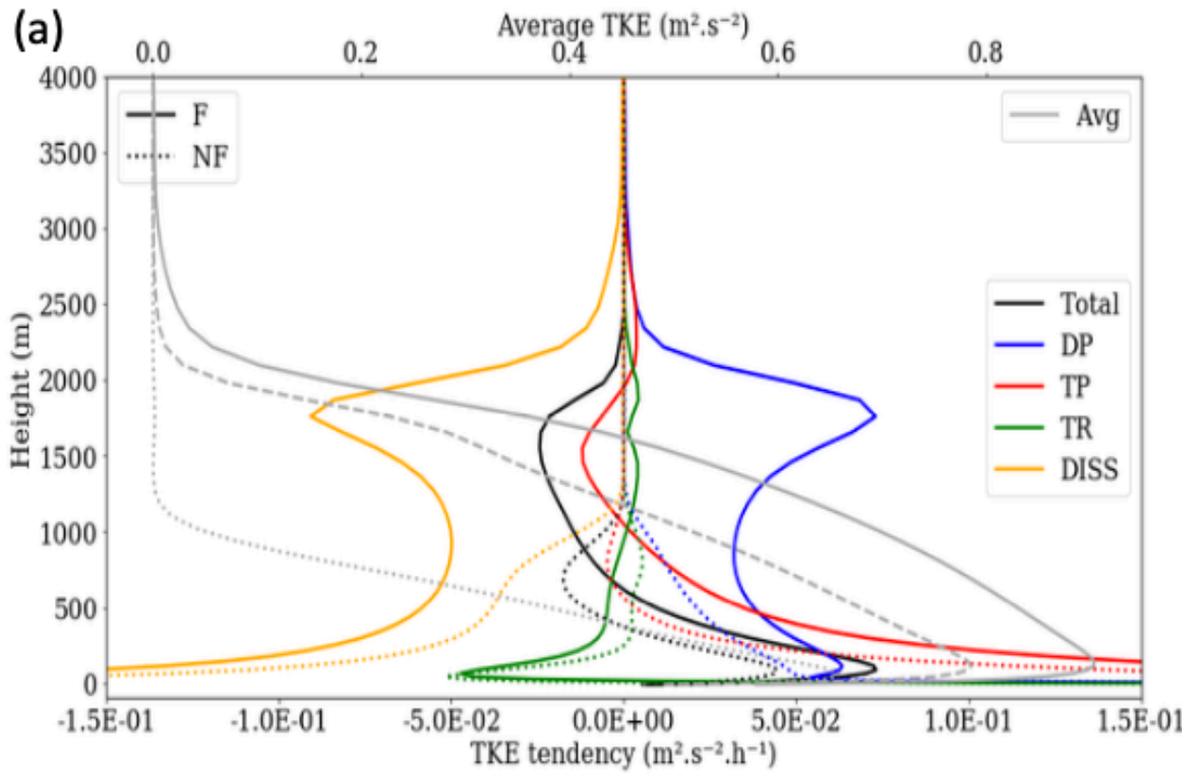
- Validation on 14 summer BL cloud cases between 2016 and 2022

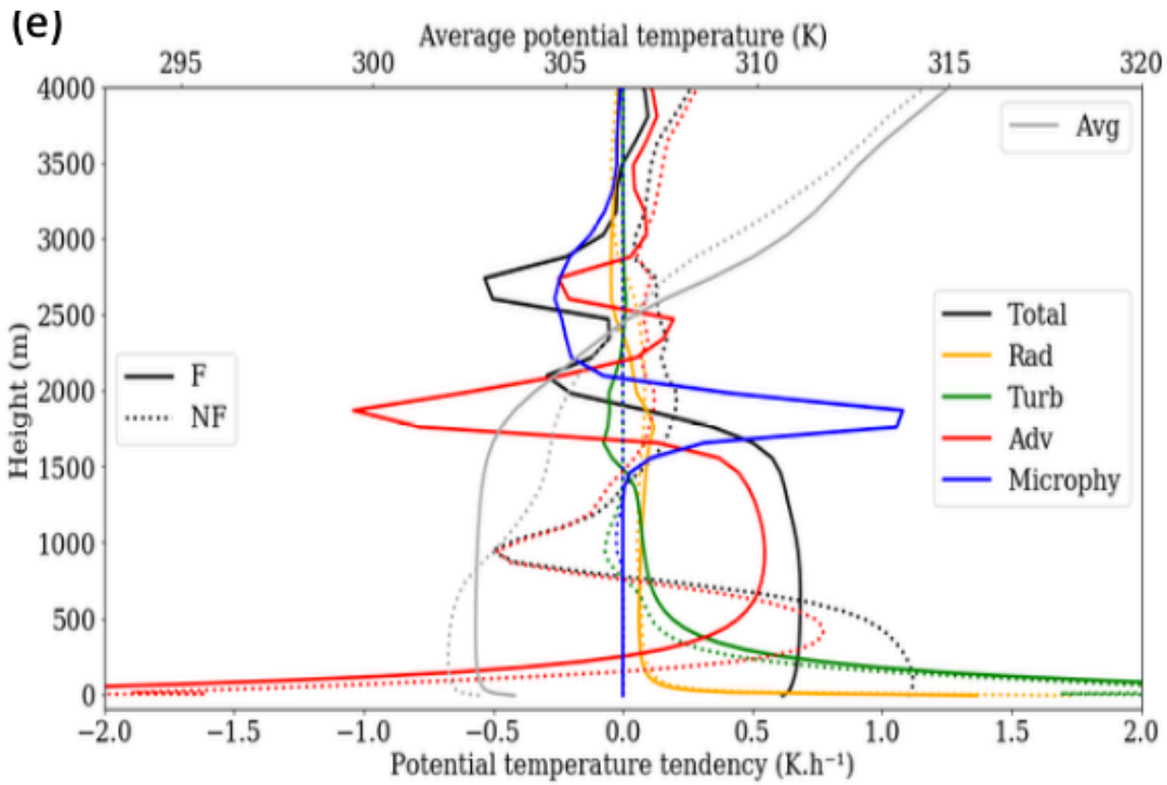
Mean over F on the first 4000 m

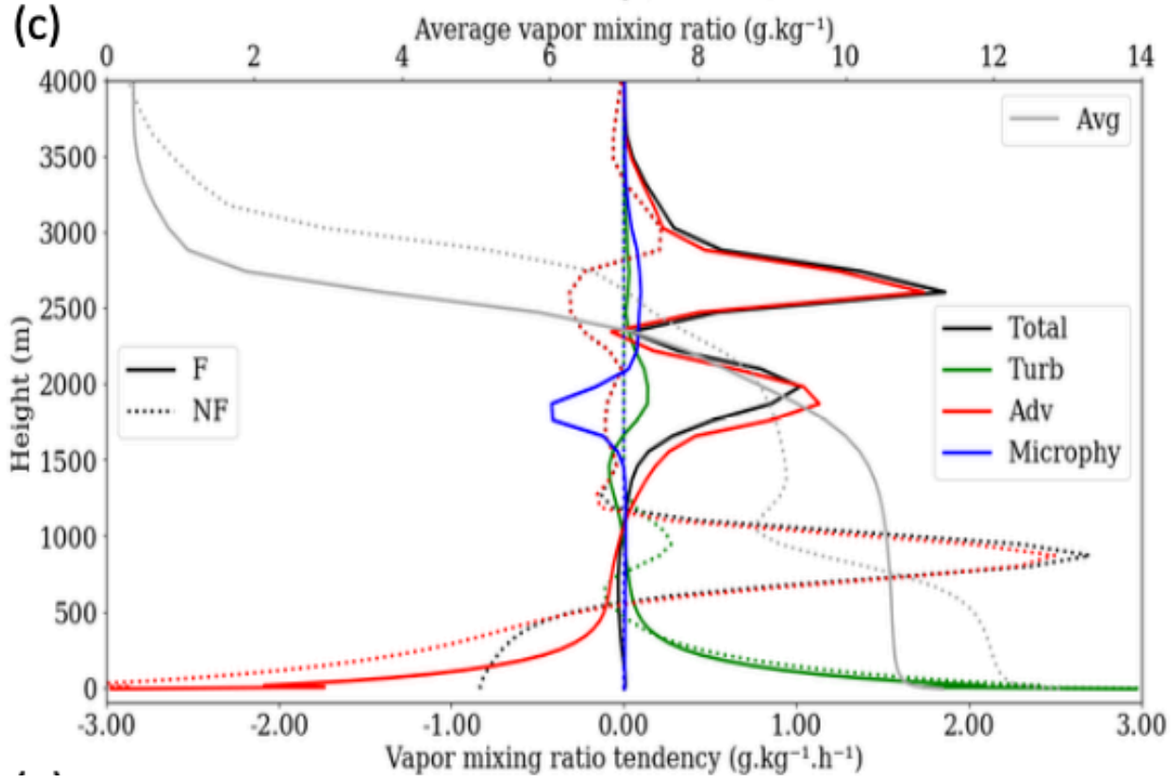


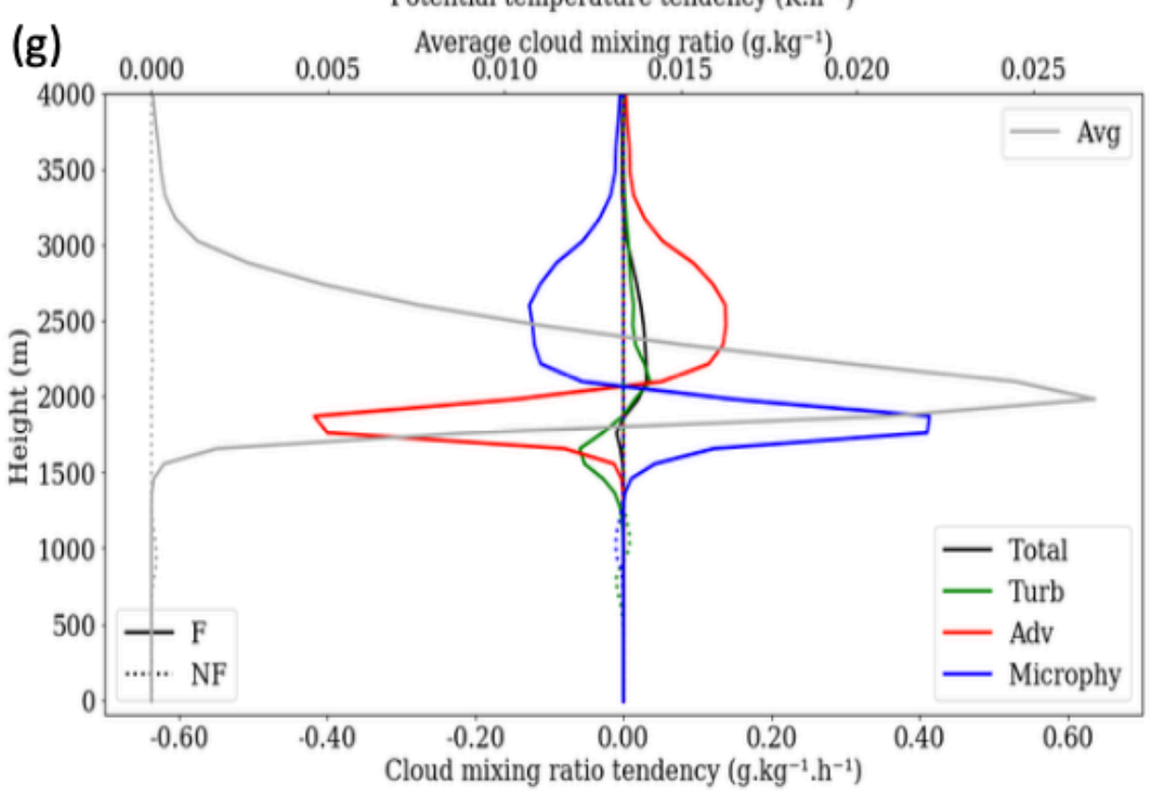


- During the convective phase:
  - ➡ Cloud cover: - 25% (Teuling et al., 2017)
  - ➡ Liquid water path: - 30%
- Less nocturnal low clouds (Pauli et al., 2022)
- Reliability of the results over 14 cases

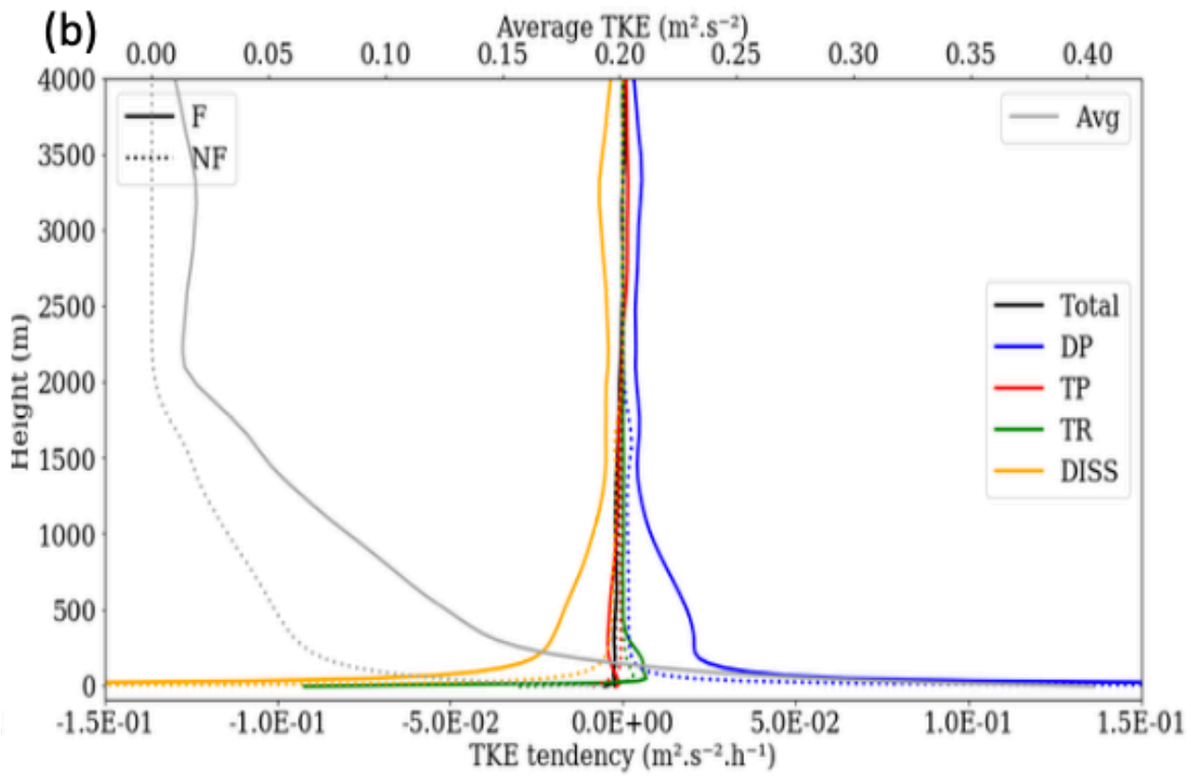

(a)
Average TKE (m².s⁻²)
0.0
0.2
0.4
0.6
0.8
Height (m)
4000
3500
3000
2500
2000
1500
1000
500
0
F
NF
Avg
Total
DP
TP
TR
DISS
-1.5E-01
-1.0E-01
-5.0E-02
0.0E+00
5.0E-02
1.0E-01
1.5E-01
TKE tendency (m².s⁻².h⁻¹)

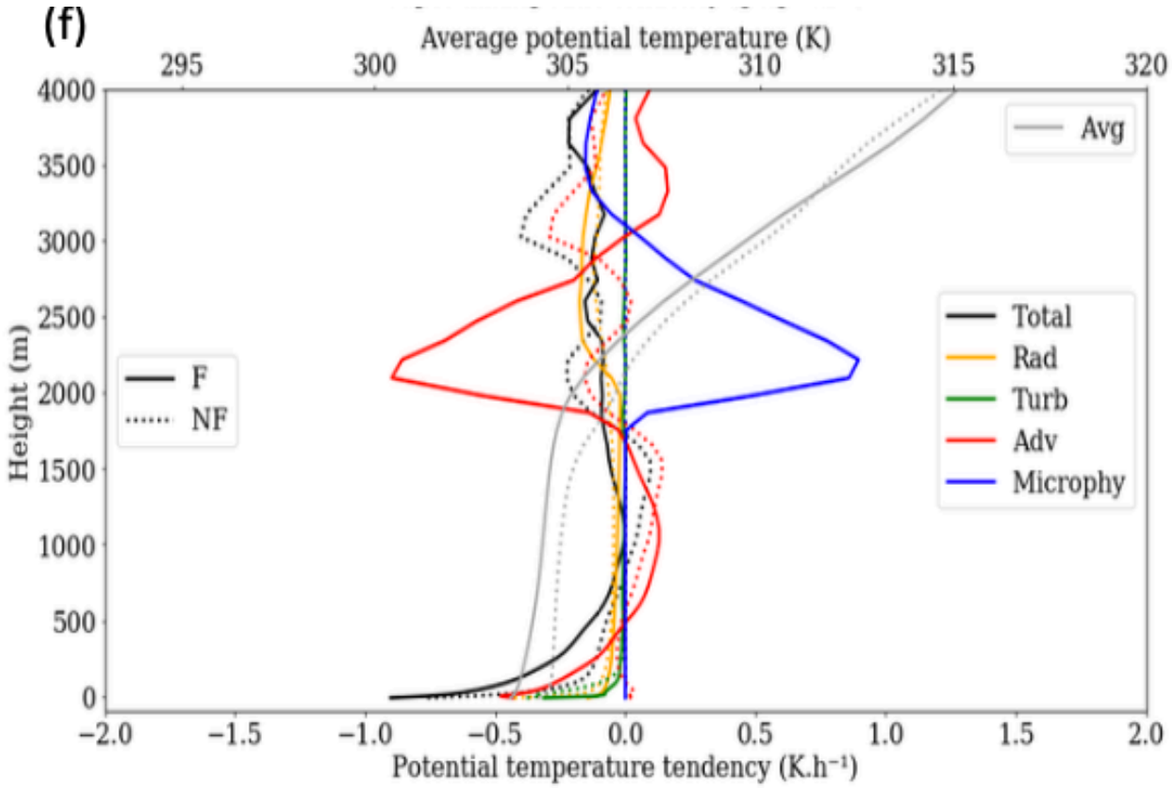

(e)
Average potential temperature (K)
295
300
305
310
315
320
Height (m)
4000
3500
3000
2500
2000
1500
1000
500
0
F
NF
Avg
Total
Rad
Turb
Adv
Microphy
−2.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
Potential temperature tendency (K.h⁻¹)

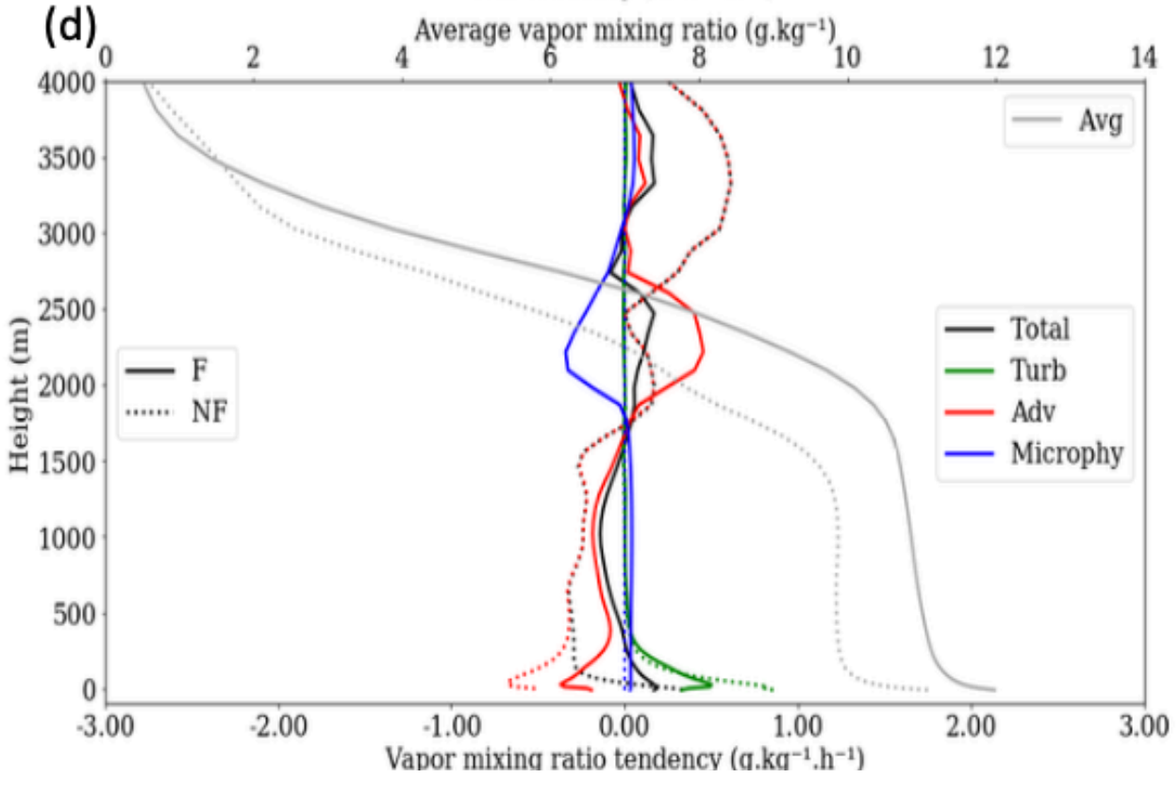

(c)
Average vapor mixing ratio (g.kg⁻¹)
0
2
4
6
8
10
12
14
Height (m)
4000
3500
3000
2500
2000
1500
1000
500
0
F
NF
Avg
Total
Turb
Adv
Microphy
-3.00
-2.00
-1.00
0.00
1.00
2.00
3.00
Vapor mixing ratio tendency (g.kg⁻¹.h⁻¹)

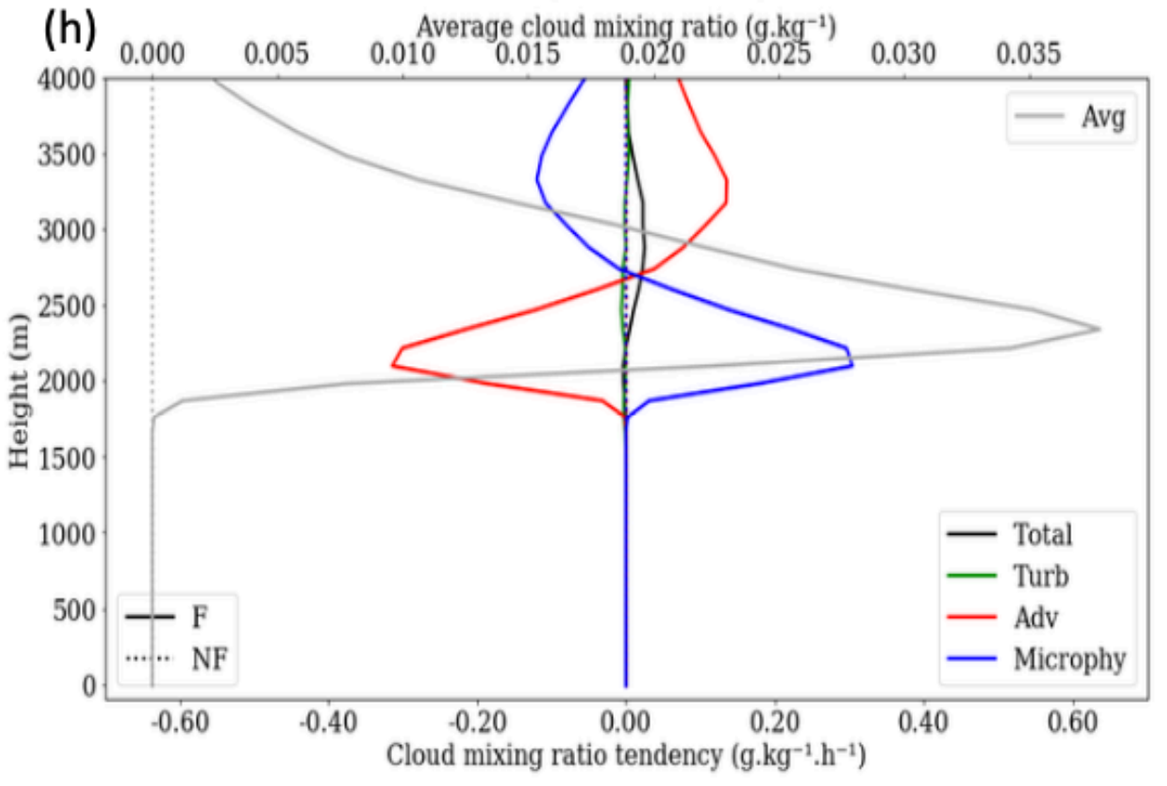

(g)
Average cloud mixing ratio (g.kg⁻¹)
0.000
0.005
0.010
0.015
0.020
0.025
Height (m)
4000
3500
3000
2500
2000
1500
1000
500
0
F
NF
Avg
Total
Turb
Adv
Microphy
-0.60
-0.40
-0.20
0.00
0.20
0.40
0.60
Cloud mixing ratio tendency (g.kg⁻¹.h⁻¹)

11h30 → 12h

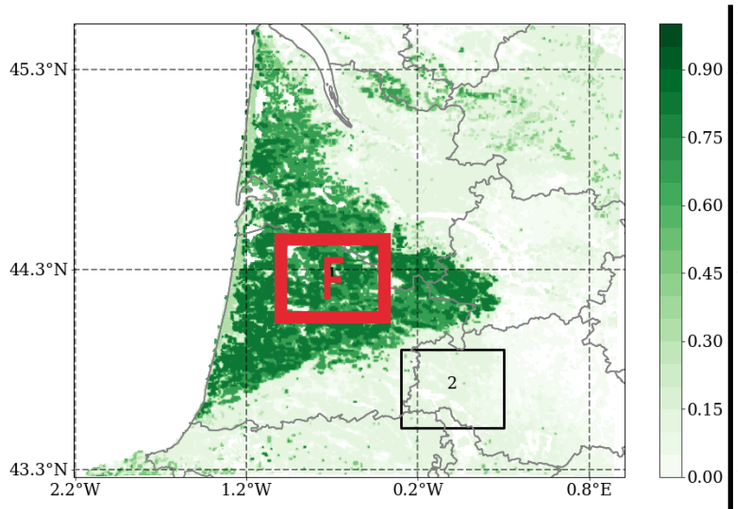
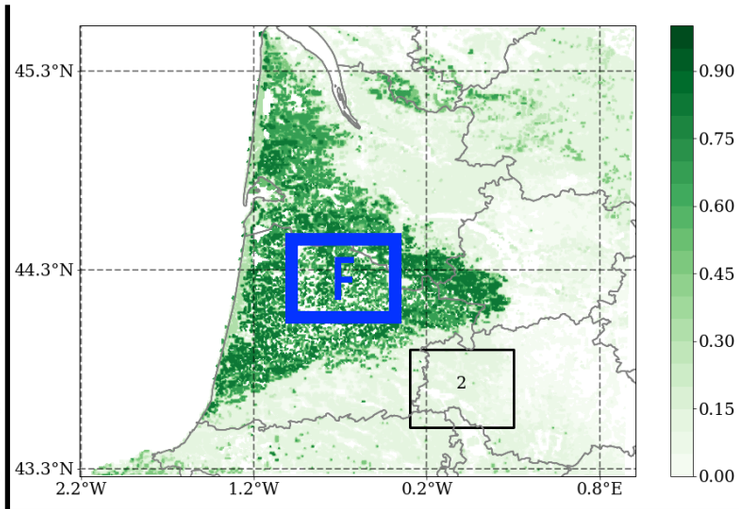
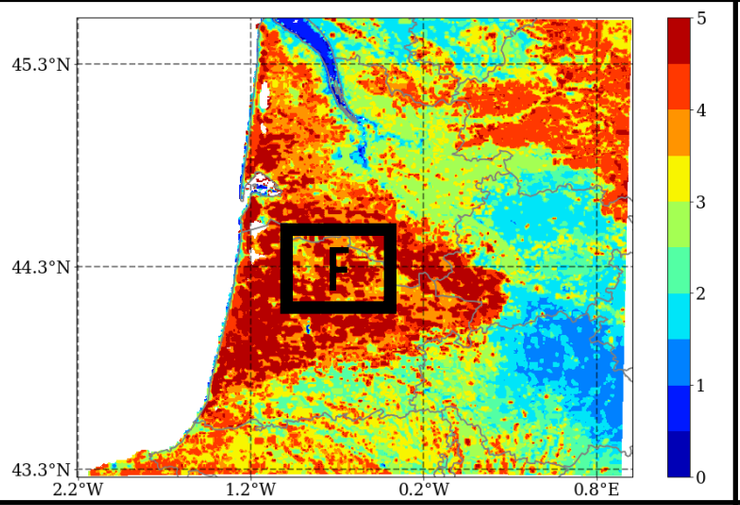
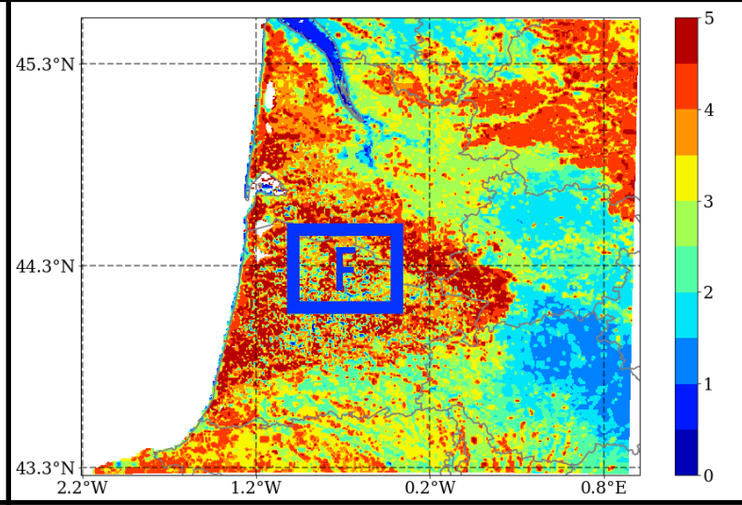
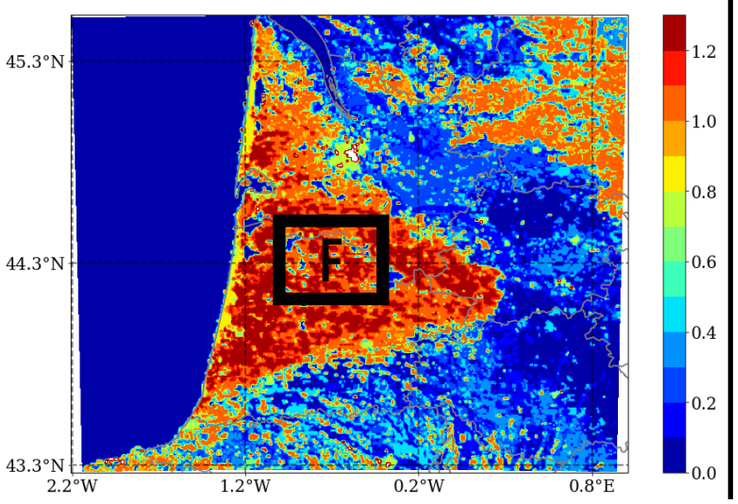
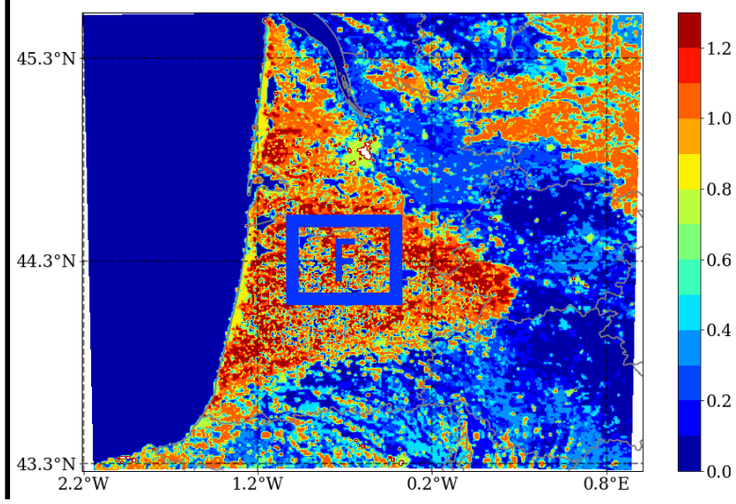

(b)
Average TKE (m².s⁻²)
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40
F
NF
Avg
Total
DP
TP
TR
DISS
Height (m)
4000 3500 3000 2500 2000 1500 1000 500 0
-1.5E-01 -1.0E-01 -5.0E-02 0.0E+00 5.0E-02 1.0E-01 1.5E-01
TKE tendency (m².s⁻².h⁻¹)


(f)
Average potential temperature (K)
295 300 305 310 315 320
F
NF
Avg
Total
Rad
Turb
Adv
Microphy
Height (m)
4000 3500 3000 2500 2000 1500 1000 500 0
−2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0 1.5 2.0
Potential temperature tendency (K.h⁻¹)


(d)
Average vapor mixing ratio (g.kg⁻¹)
0 2 4 6 8 10 12 14
F
NF
Avg
Total
Turb
Adv
Microphy
Height (m)
4000 3500 3000 2500 2000 1500 1000 500 0
-3.00 -2.00 -1.00 0.00 1.00 2.00 3.00
Vapor mixing ratio tendency (g.kg⁻¹.h⁻¹)

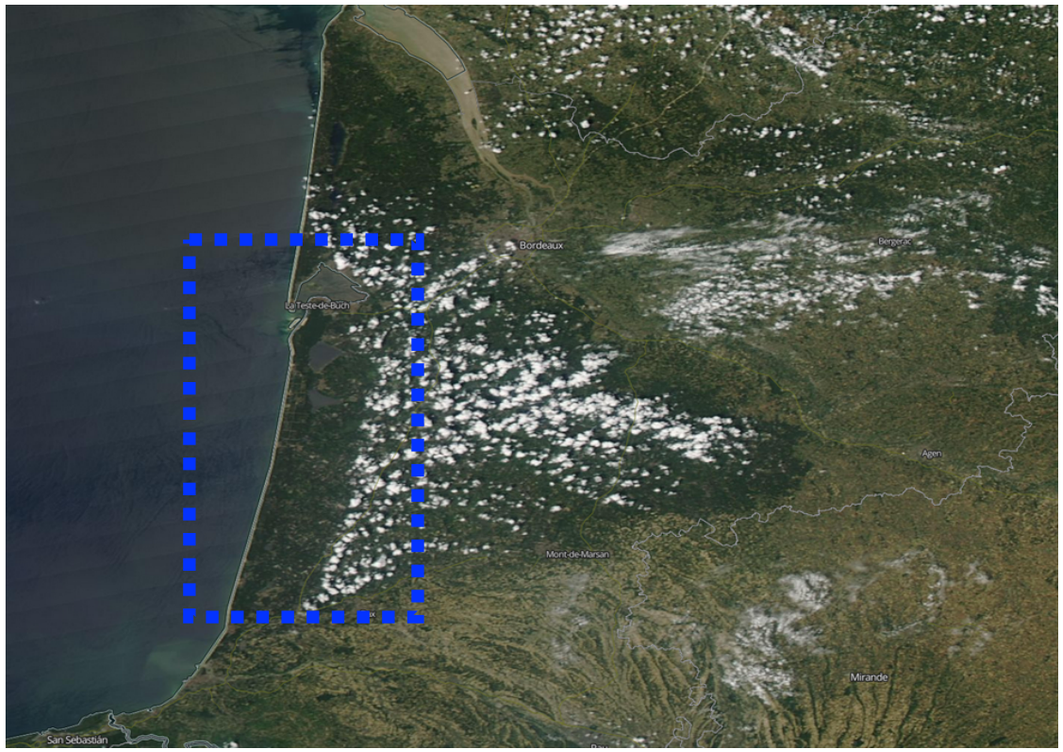

(h)
Average cloud mixing ratio (g.kg⁻¹)
0.000 0.005 0.010 0.015 0.020 0.025 0.030 0.035
F
NF
Avg
Total
Turb
Adv
Microphy
Height (m)
4000 3500 3000 2500 2000 1500 1000 500 0
-0.60 -0.40 -0.20 0.00 0.20 0.40 0.60
Cloud mixing ratio tendency (g.kg⁻¹.h⁻¹)

18h → 18h30

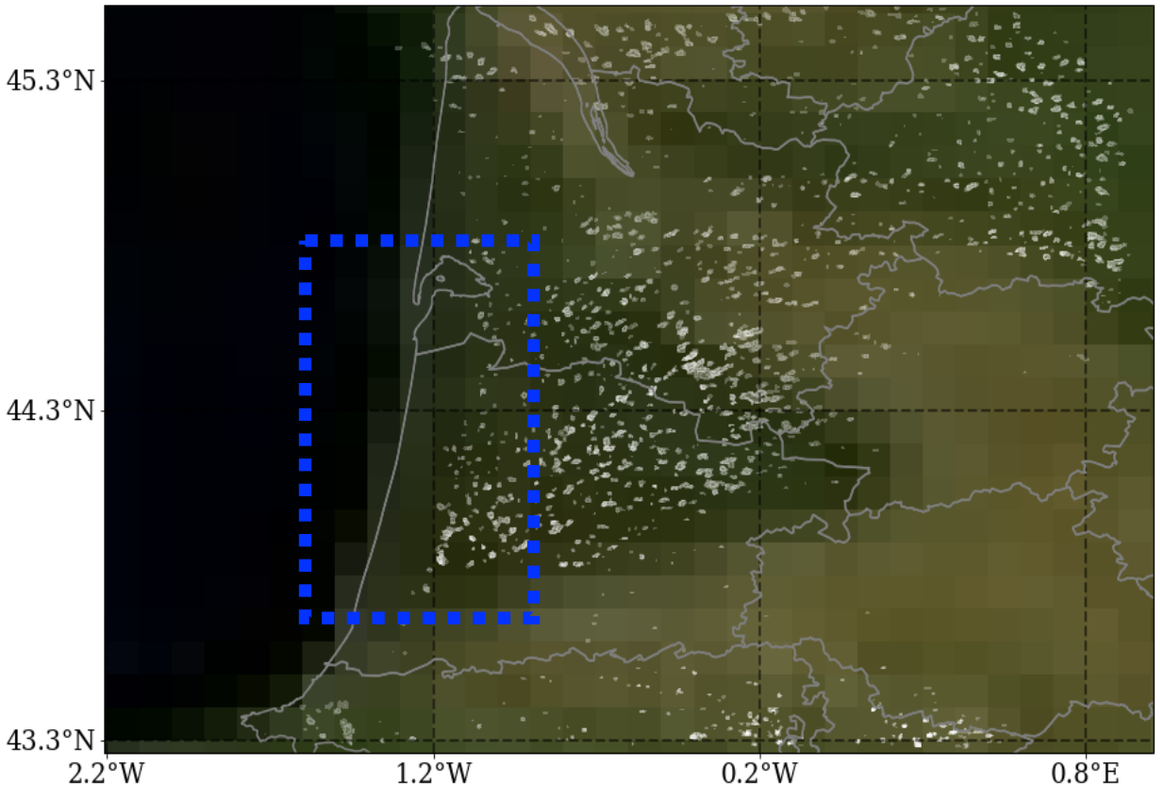
	PreKlaus	PostKlaus	PreKlaus Over F	PostKlaus Over F
Temperate conifer fraction			61%	38%
Leaf Area Index (LAI)			4,0	2,9 Shamambo et al. (2019)
Roughness length (m)			0,96	0,63

- Visualisation of the impact of sea breeze on cloud formation

9 July 2013 13 UTC

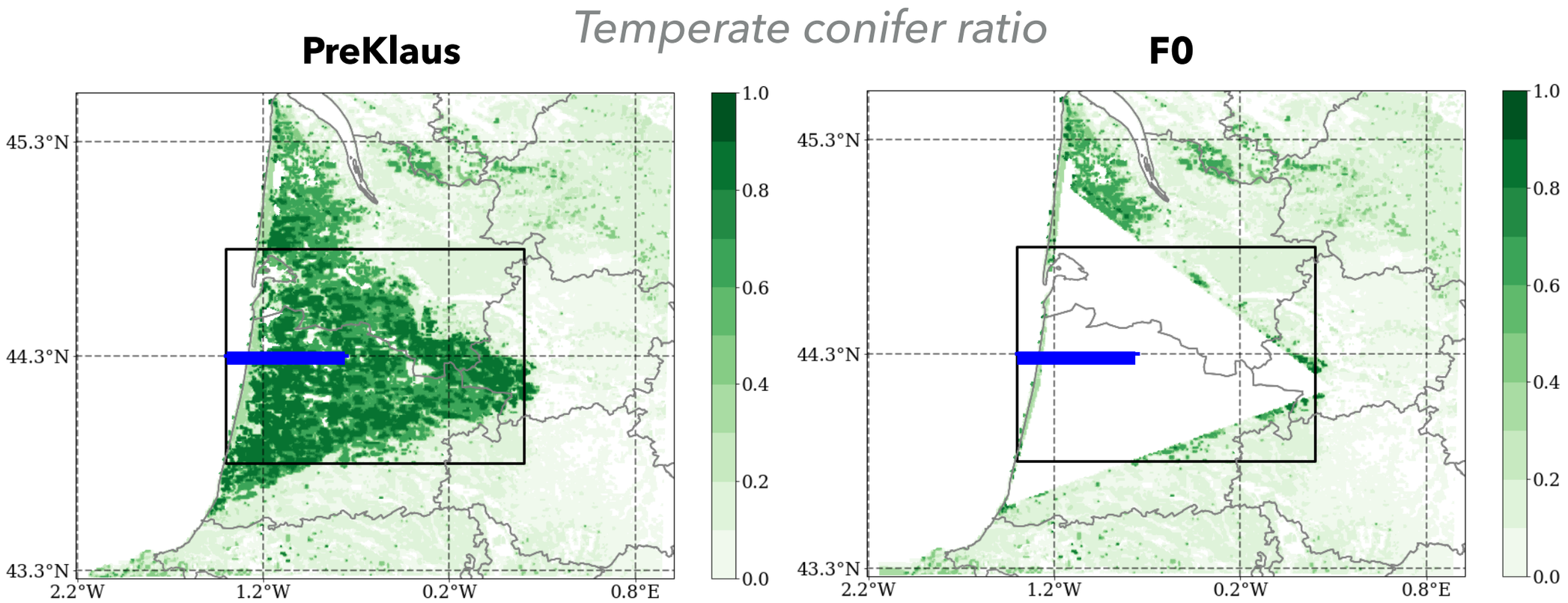


AQUA Satellite



Simulation

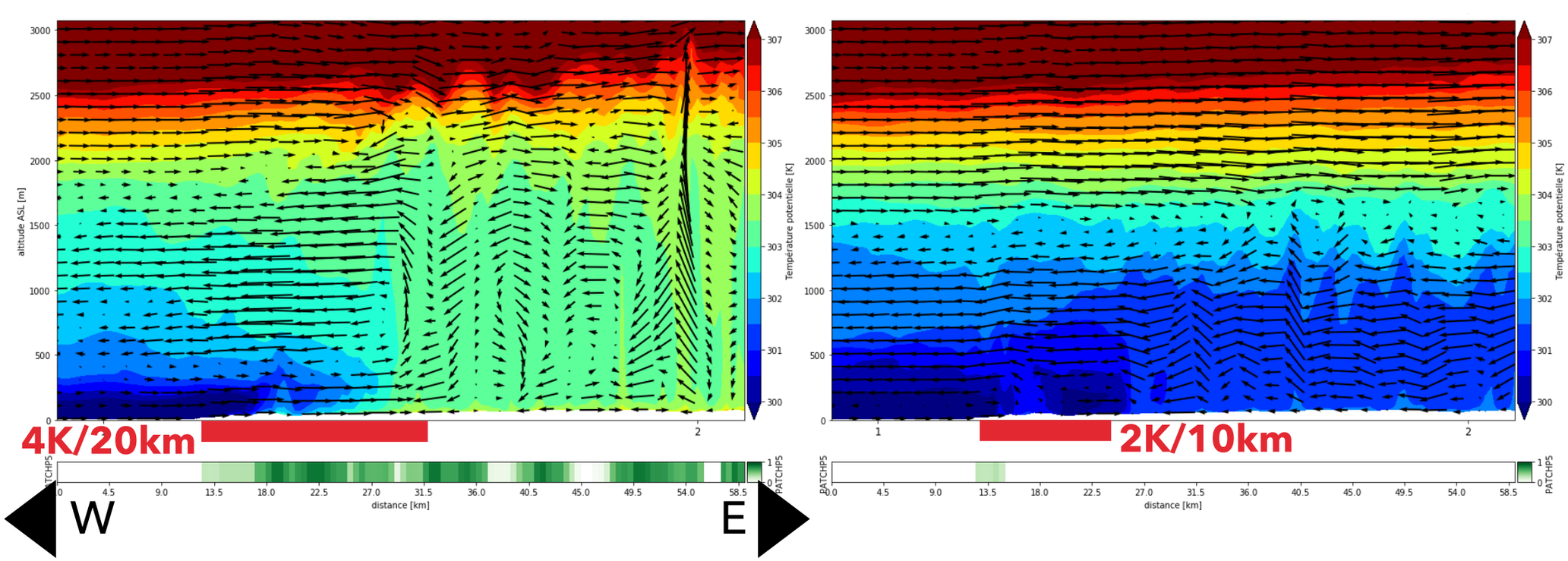
- Remove the forest to assess its impact on sea breeze



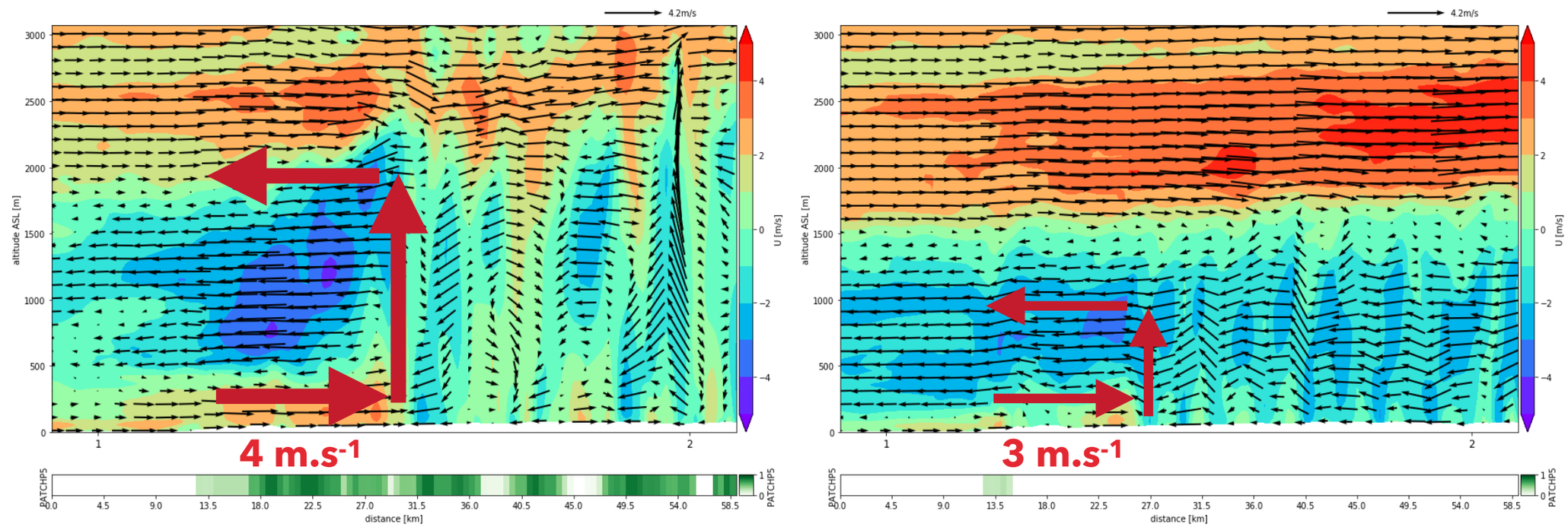
- Sea breeze

9 July 2013 13 UTC

Potential temperature



Zonal wind

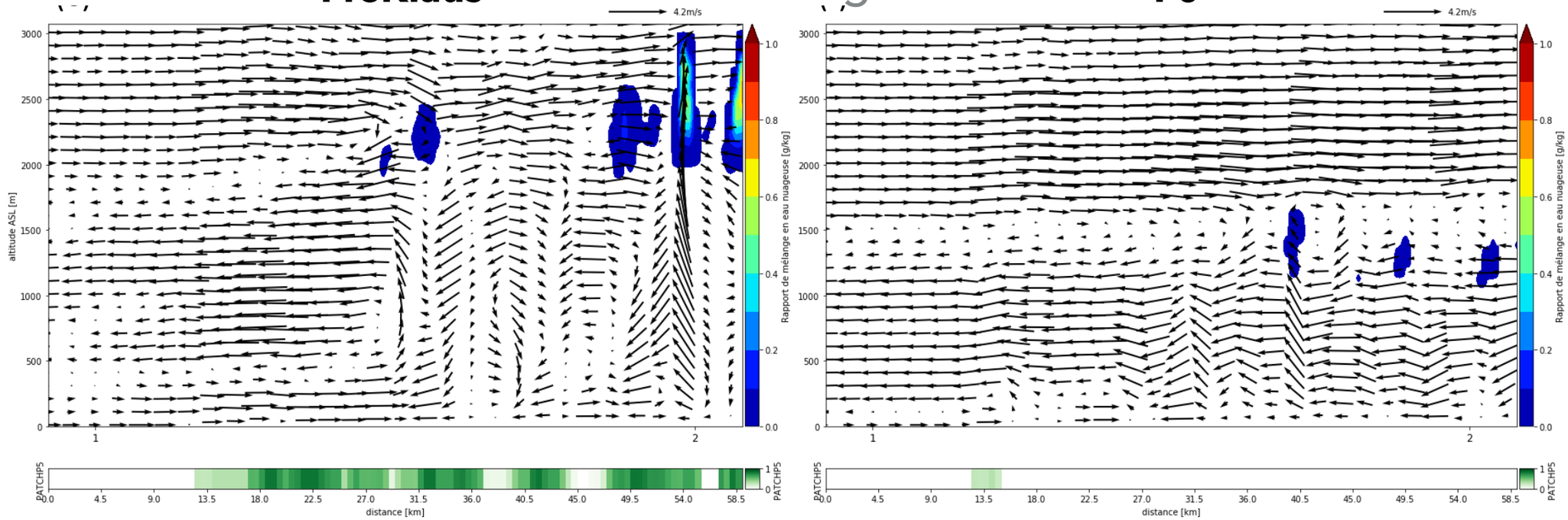


- Sea breeze

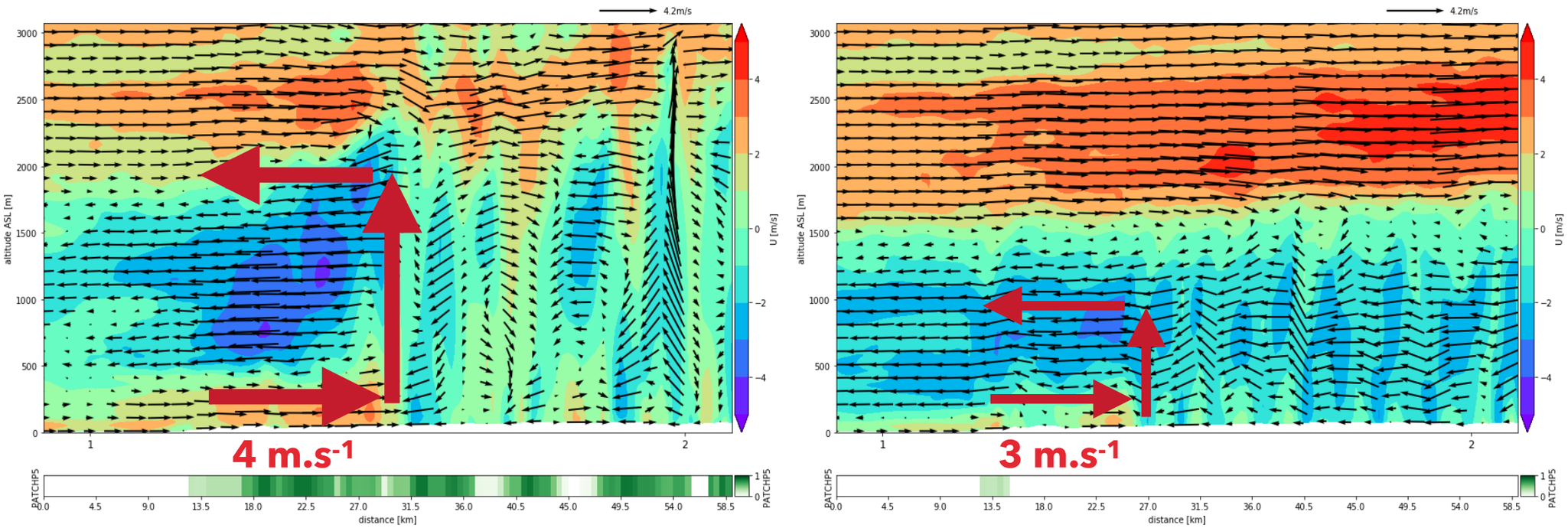
9 July 2013 13 UTC

PreKlaus **F0**

Cloud mixing ratio



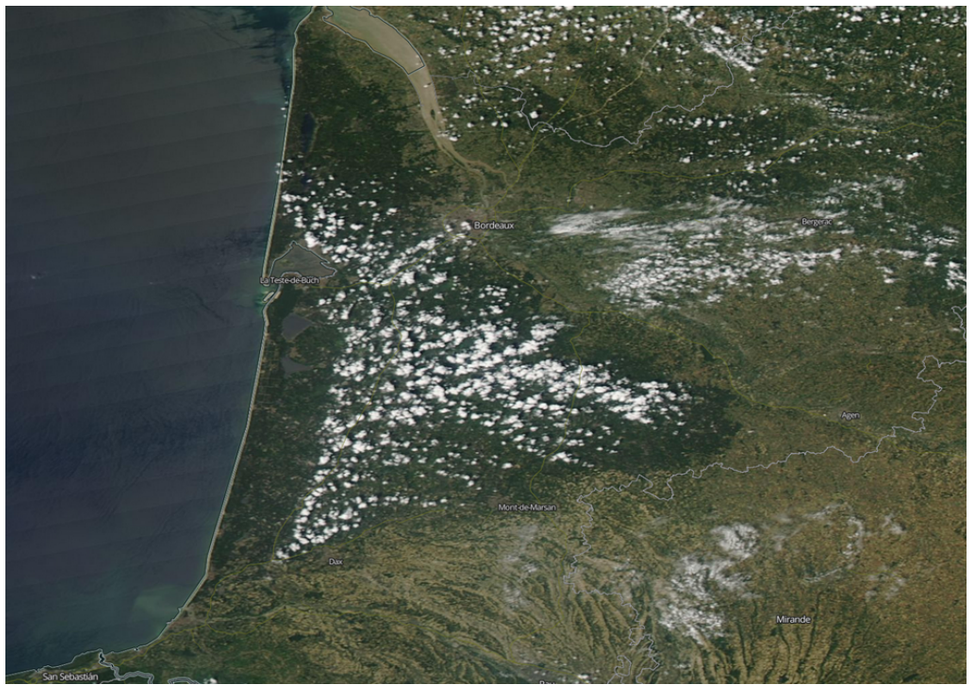
Zonal wind



- Cloud formation begins at the breeze front

- Visualisation of the impact of forest breeze on cloud formation

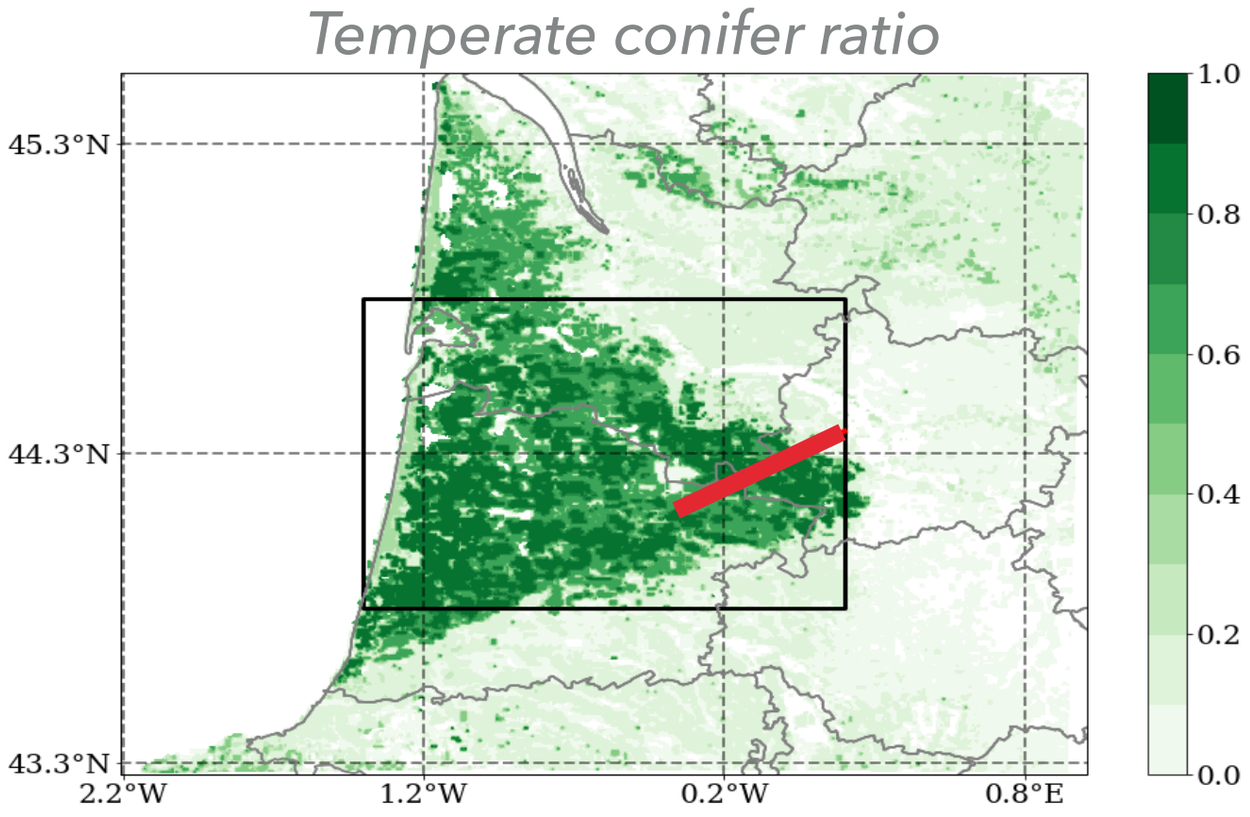
AQUA Satellite



9 July 2013

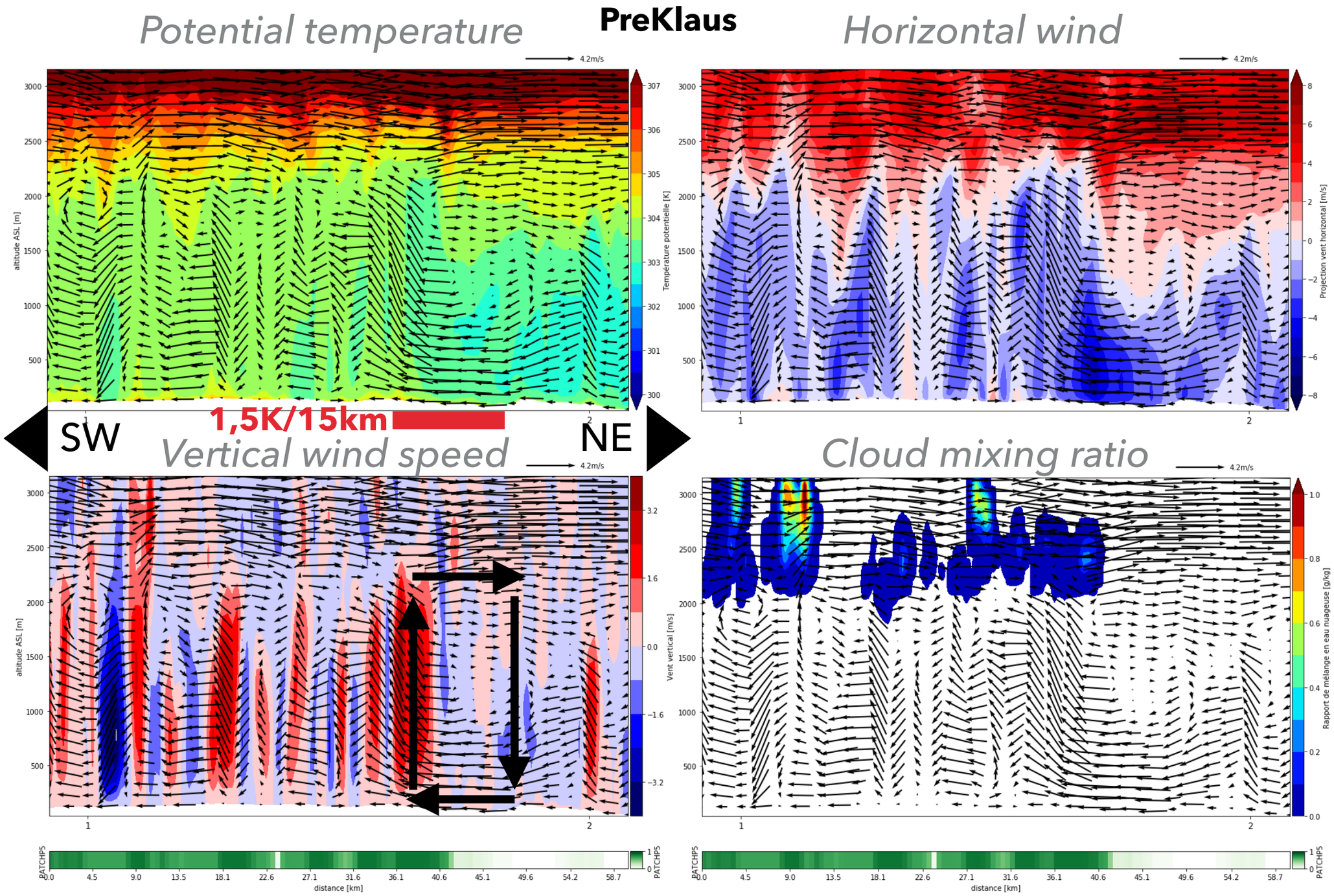
13 UTC

PreKlaus



- Forest breeze

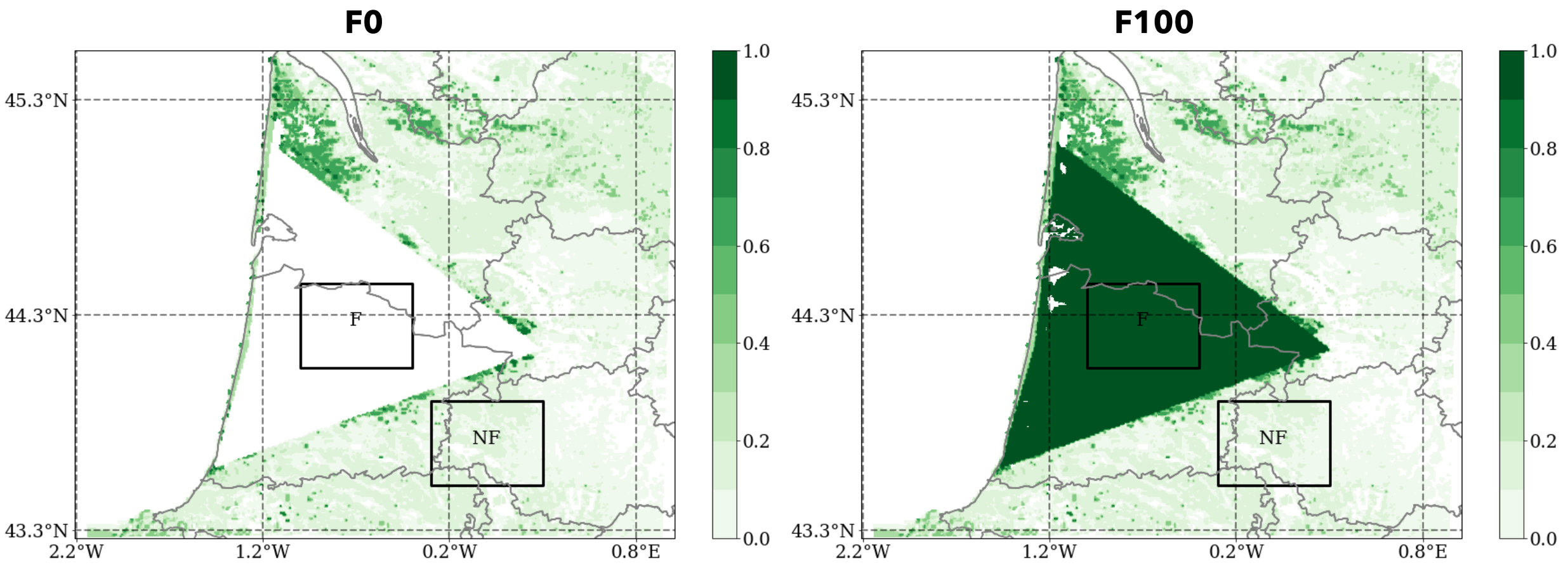
9 July 2013 13 UTC



- Local circulation at the forest edge
- Higher resolution would be necessary to get more details

- Replacement of the Landes forest by an idealised surface cover for 9 July 2013

  ➡ Mix of temperate conifer and grassland in place of the Landes forest

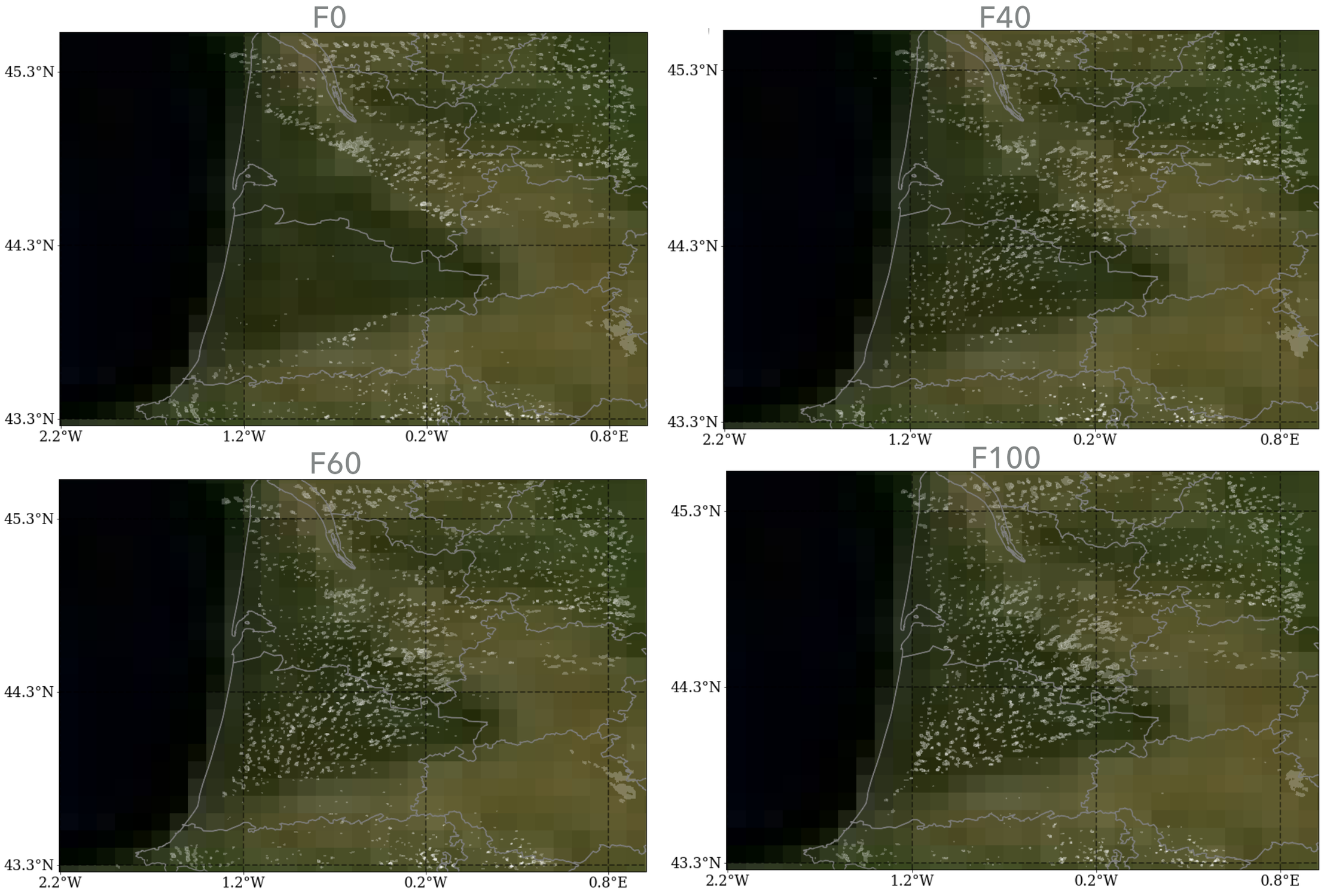


- 0% temperate conifer (F0)
- 100% grassland
- 100% temperate conifer (F100)
- 0% grassland

- Considered scenarii: F0, F20, F40, F60, F80 and F100
- Temperate conifer PreKlaus: 61%, PostKlaus: 38%

- Simulated cloud cover

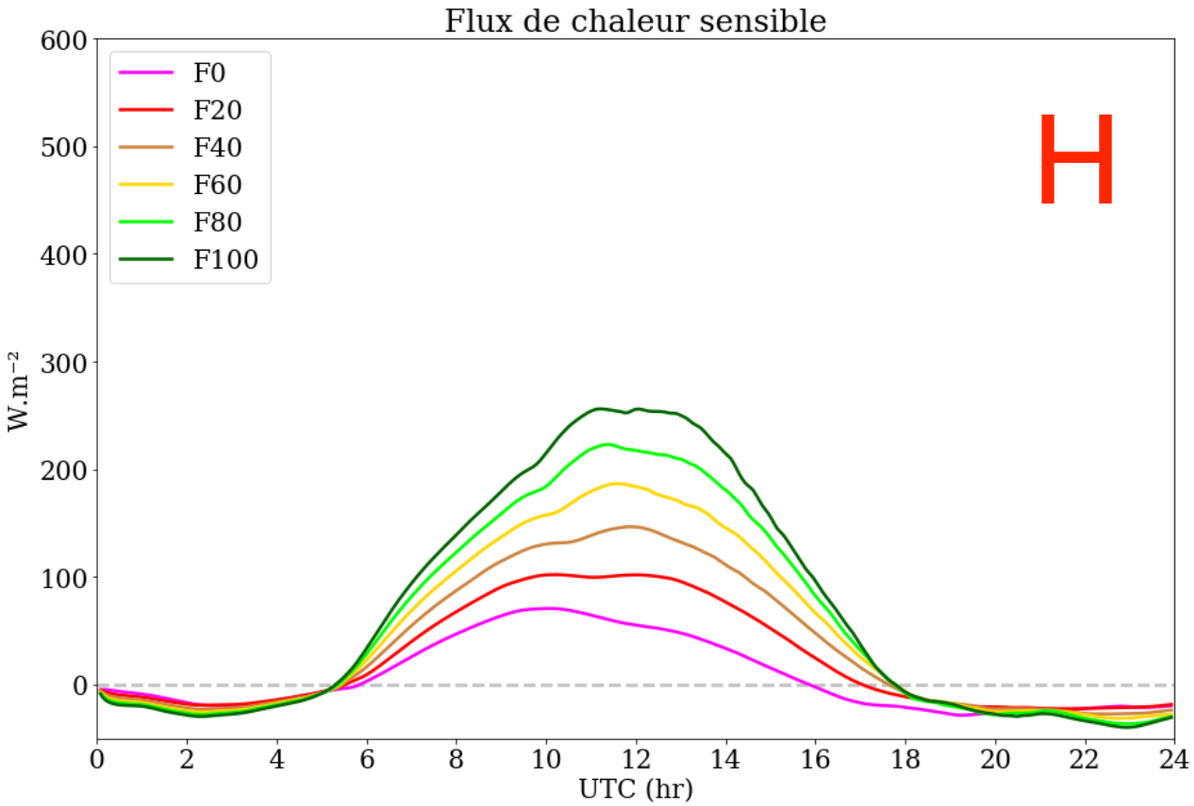
9 July 2013 13 UTC

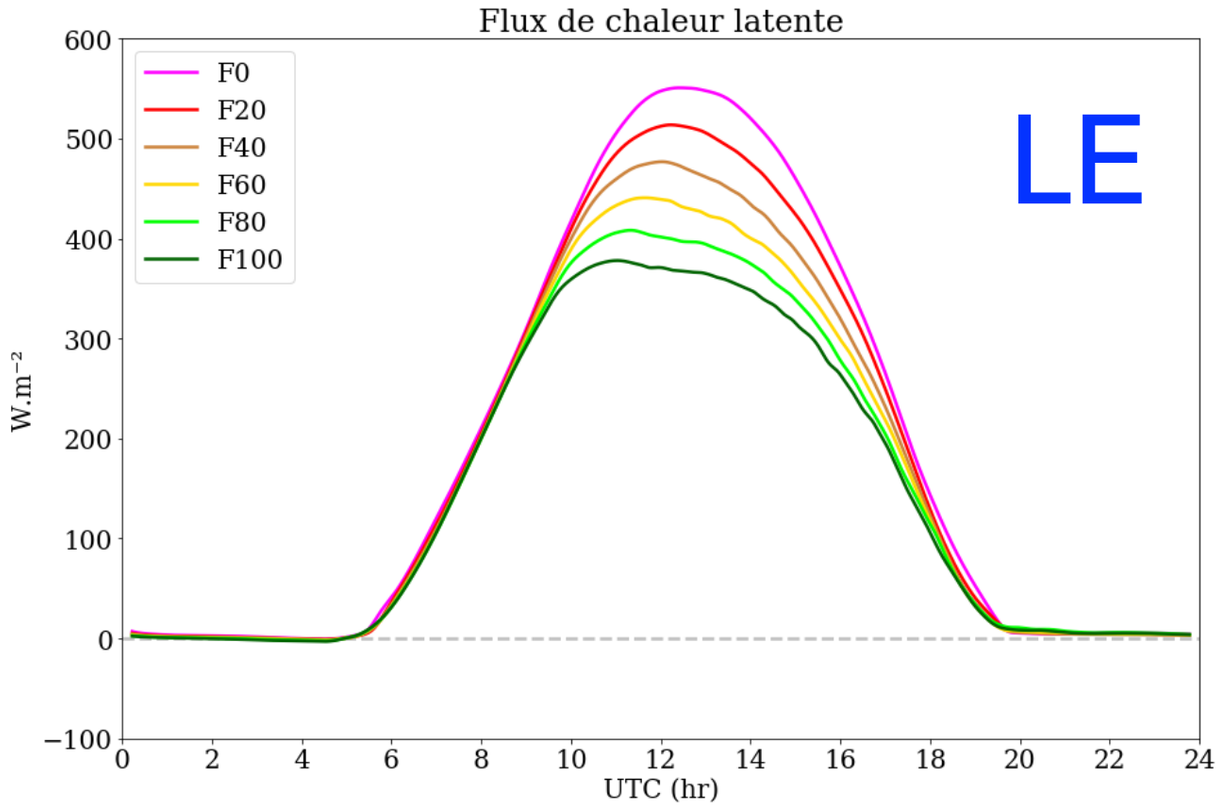


- Surface fluxes

9 July 2013

Mean over F



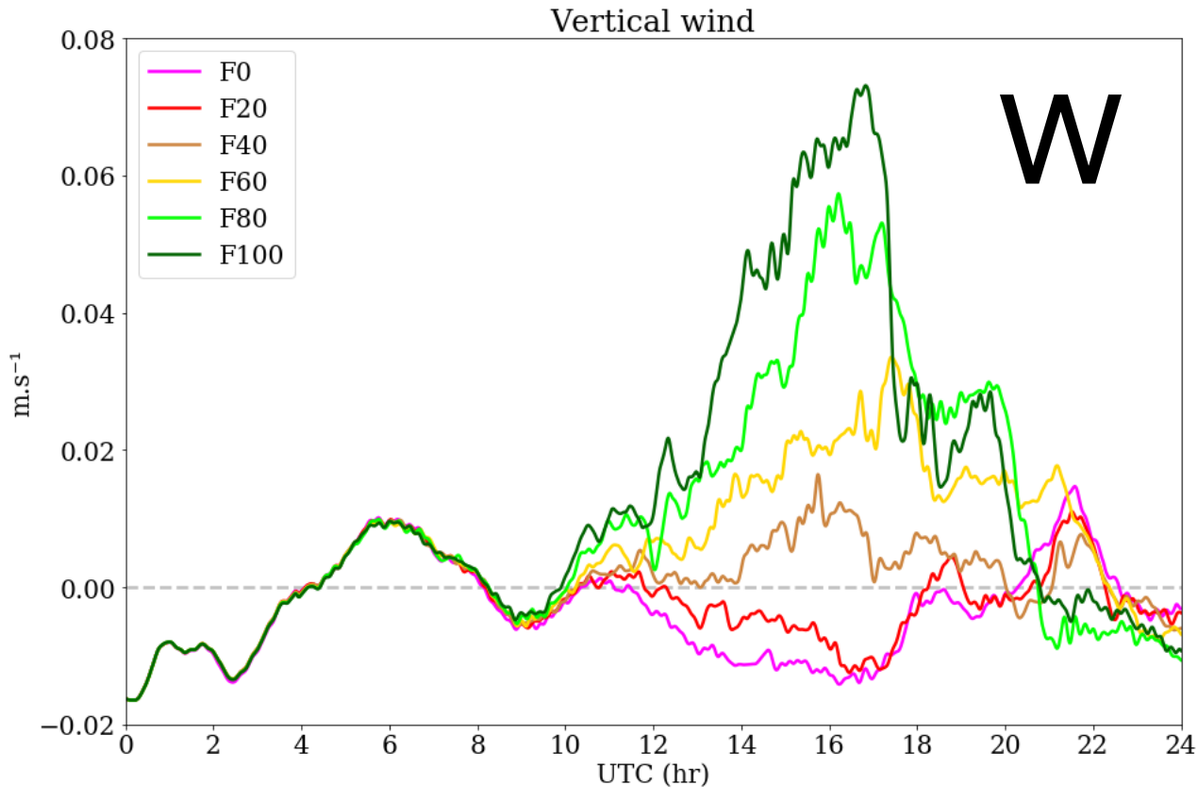


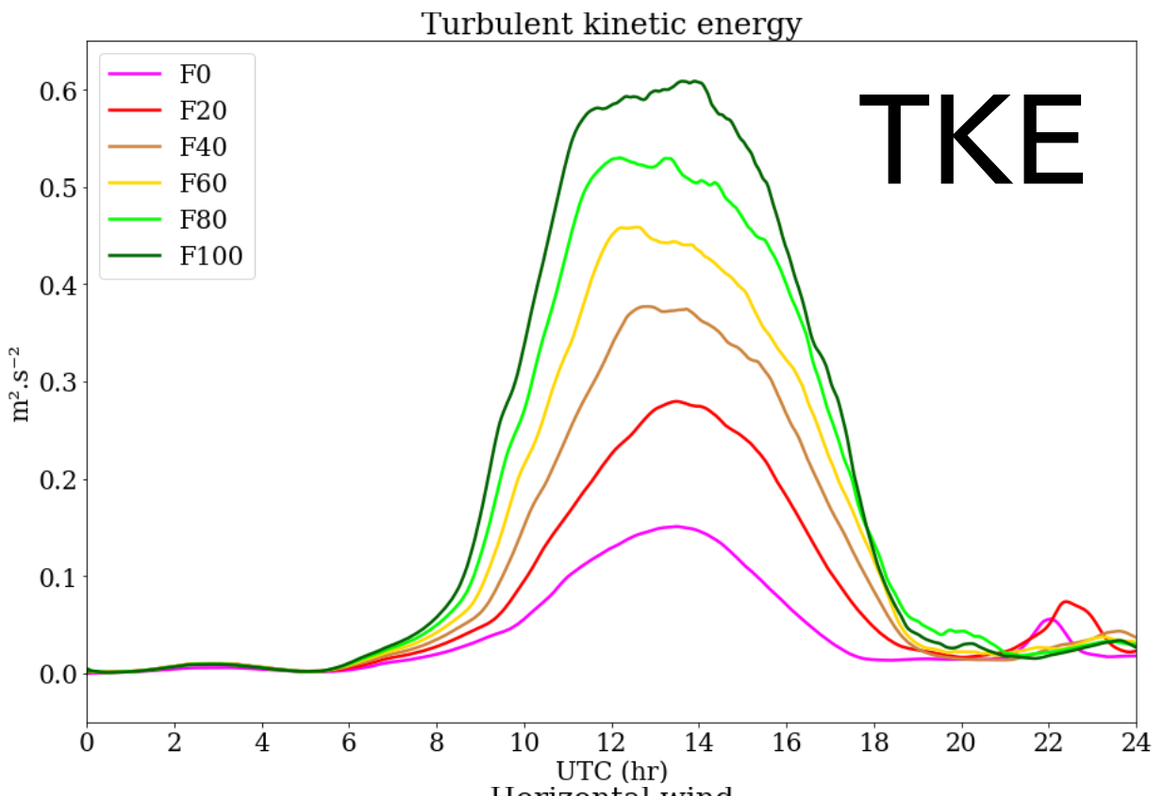
- Quasi-linear variation with forest density
- Reduction of the convective period

- Dynamics

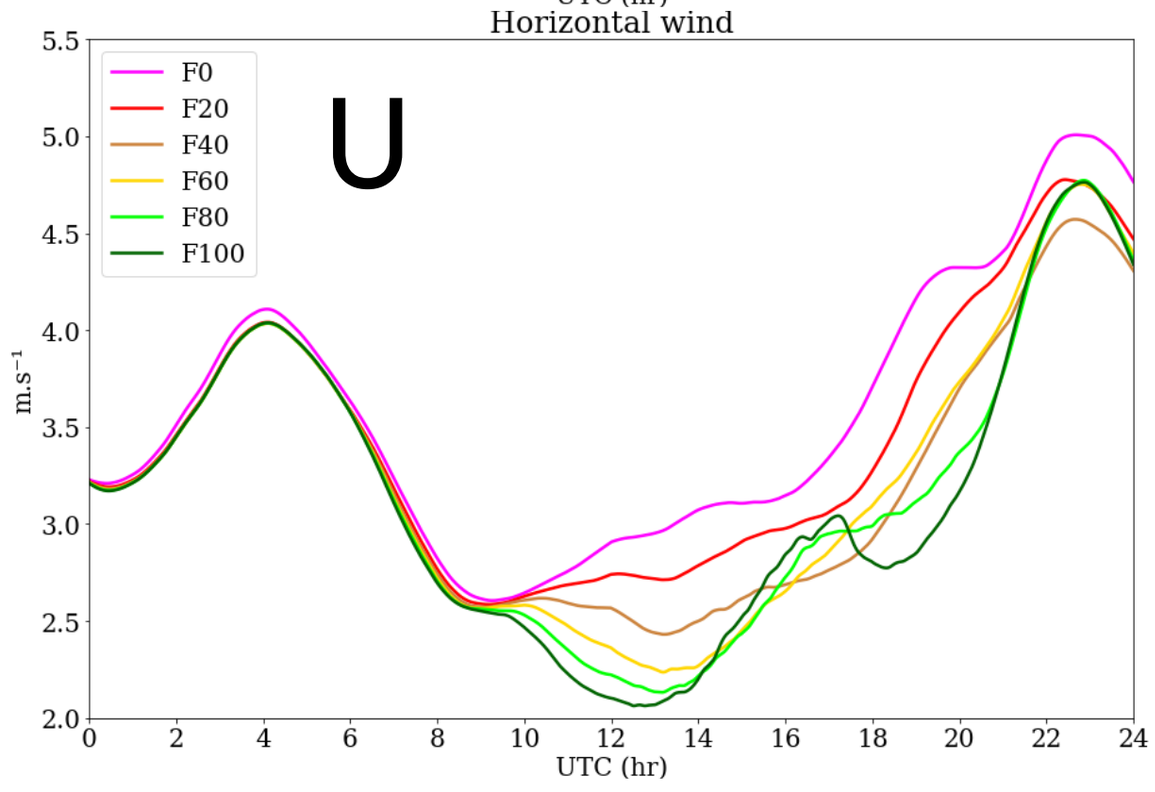
9 July 2013

Mean over F on the first 4000 m



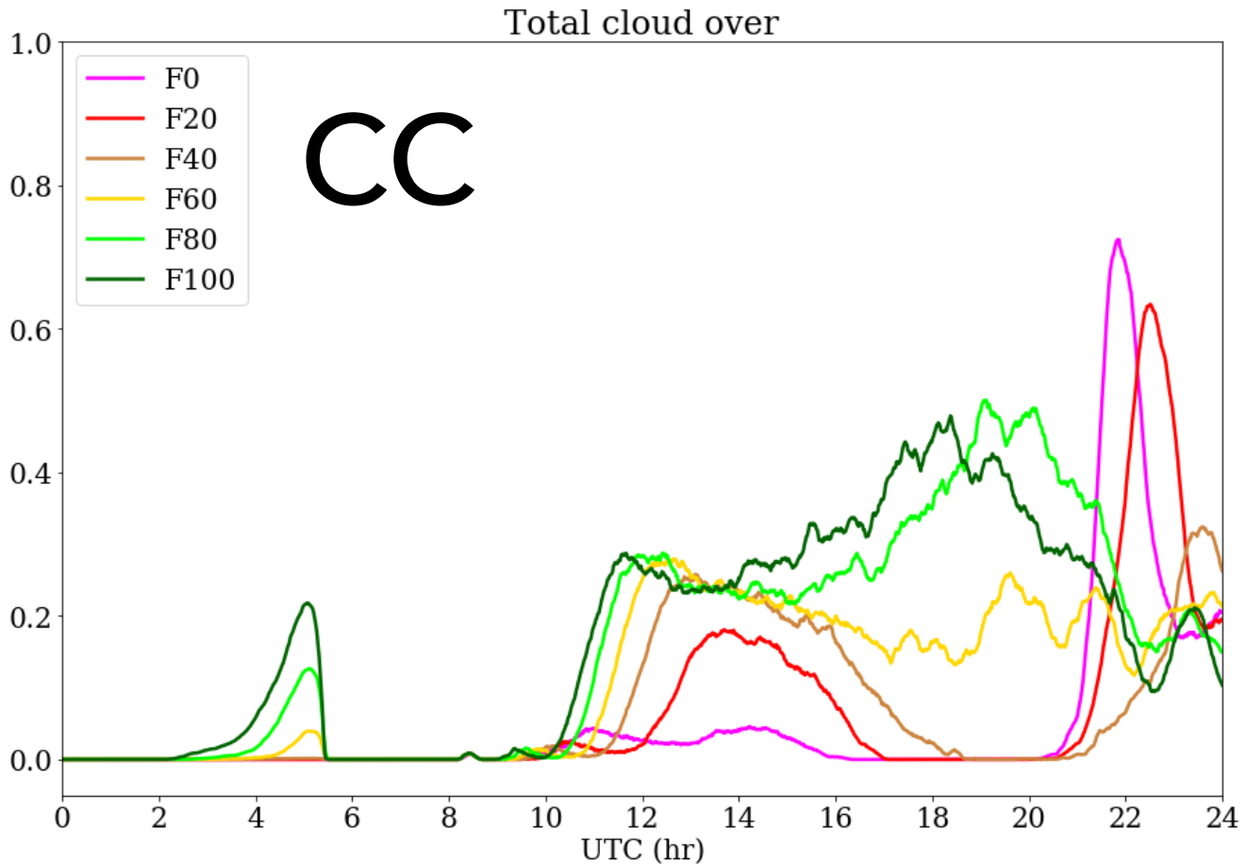


- Mean subsidence and low turbulence for F0 and F20
- Mean ascent and higher turbulence for the others increasing with forest density
- Mean horizontal wind higher from 10 UTC for F0 and F20 due to lower roughness length



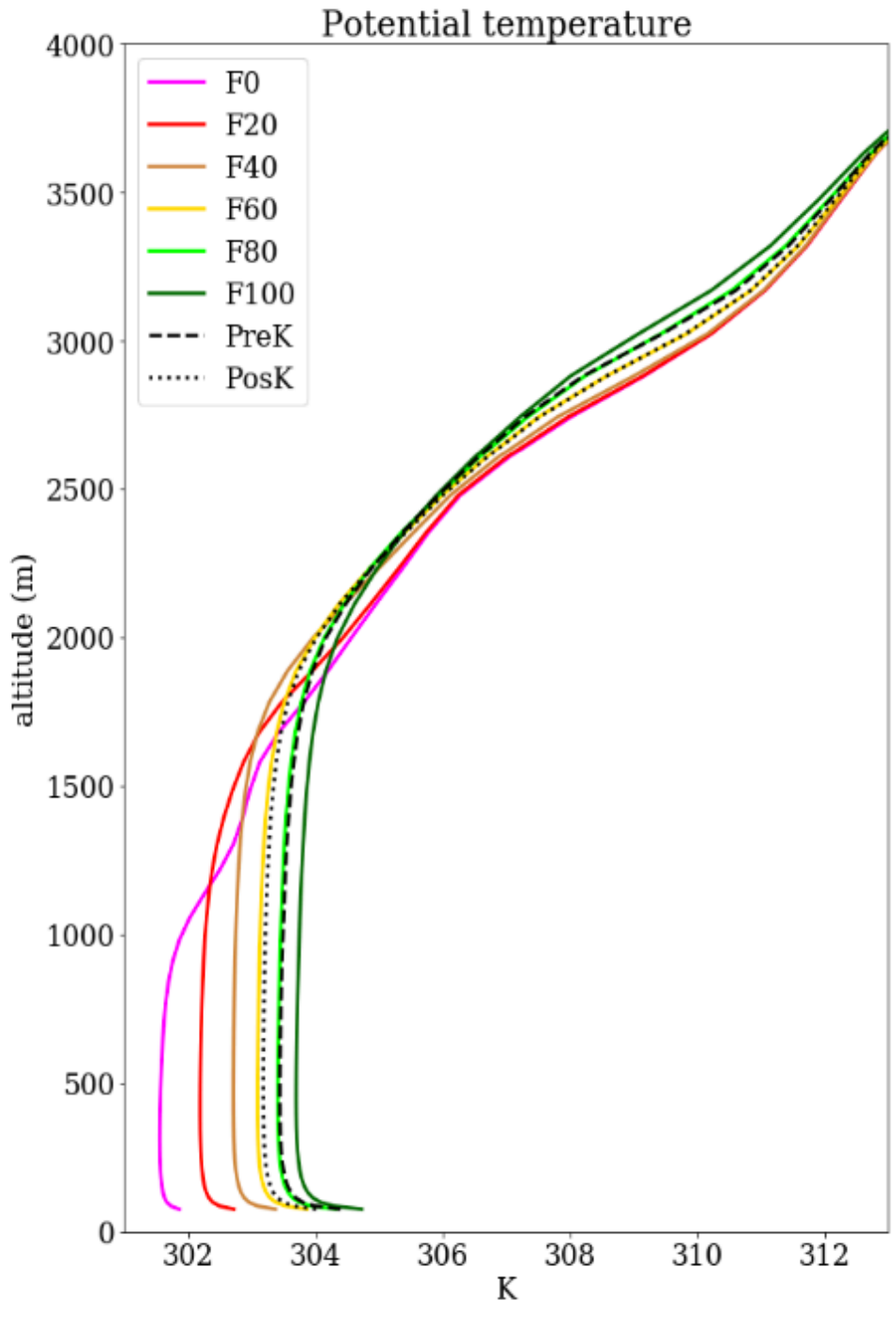
- Cloud cover

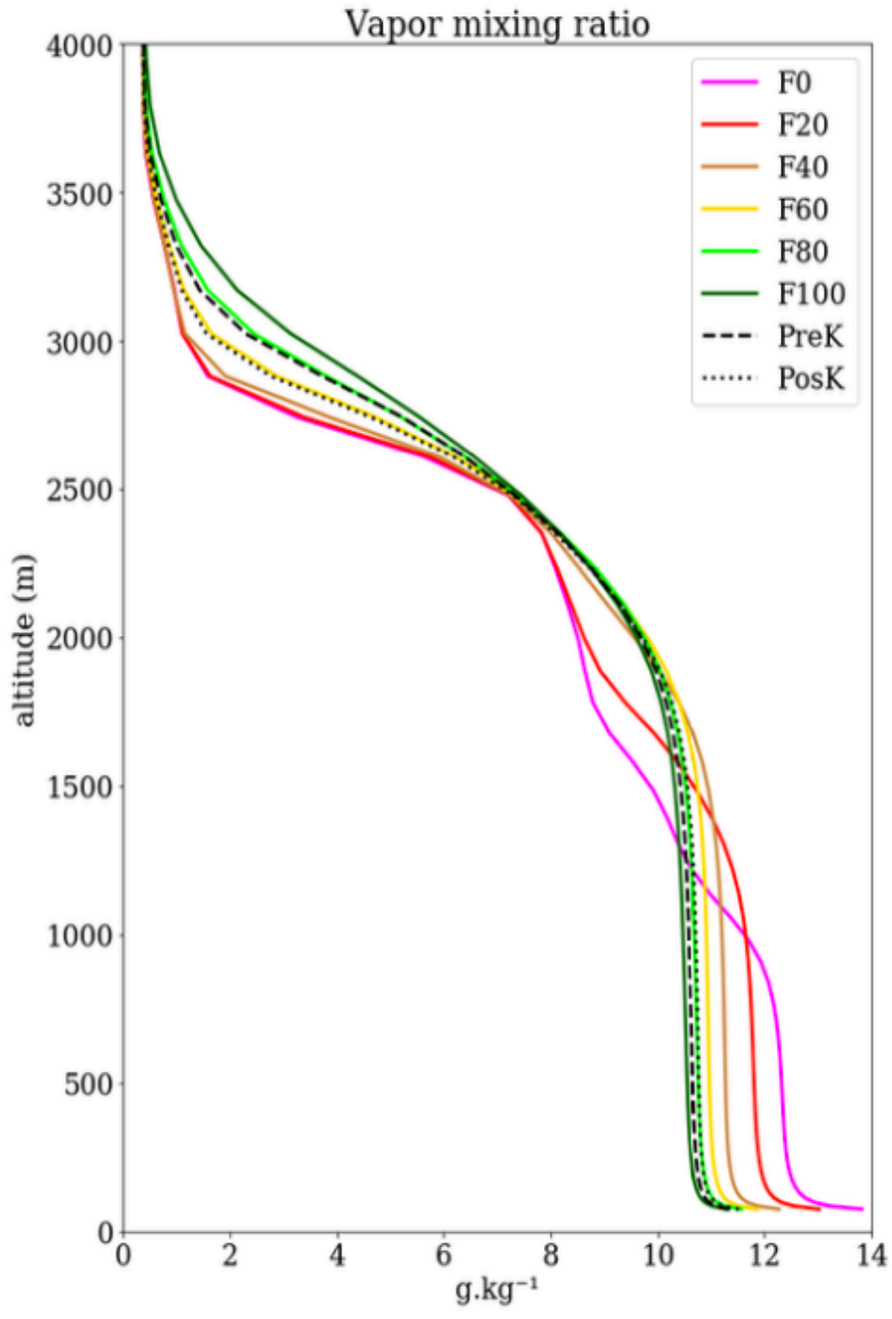
Mean over F on the first 4000 m *9 July 2013*



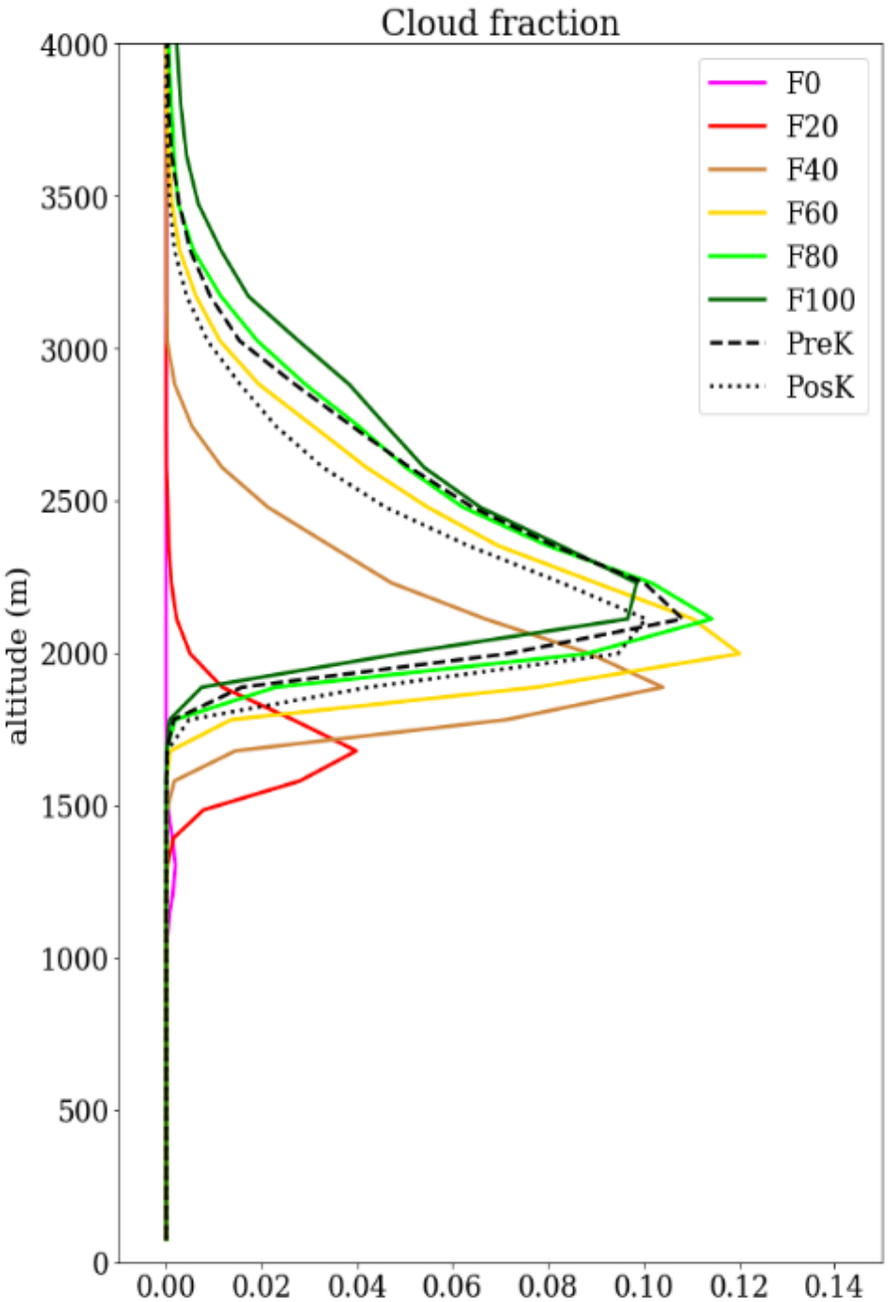
- Non-linear variation with forest density
- During convective phase: duration and amount of cloud cover correlated with forest density
- During the night (5 UTC): more stratus and fog with forest density
- During the evening (22 UTC): higher cloud for F0 and F20: marine stratocumulus advected by stronger horizontal wind with lower density

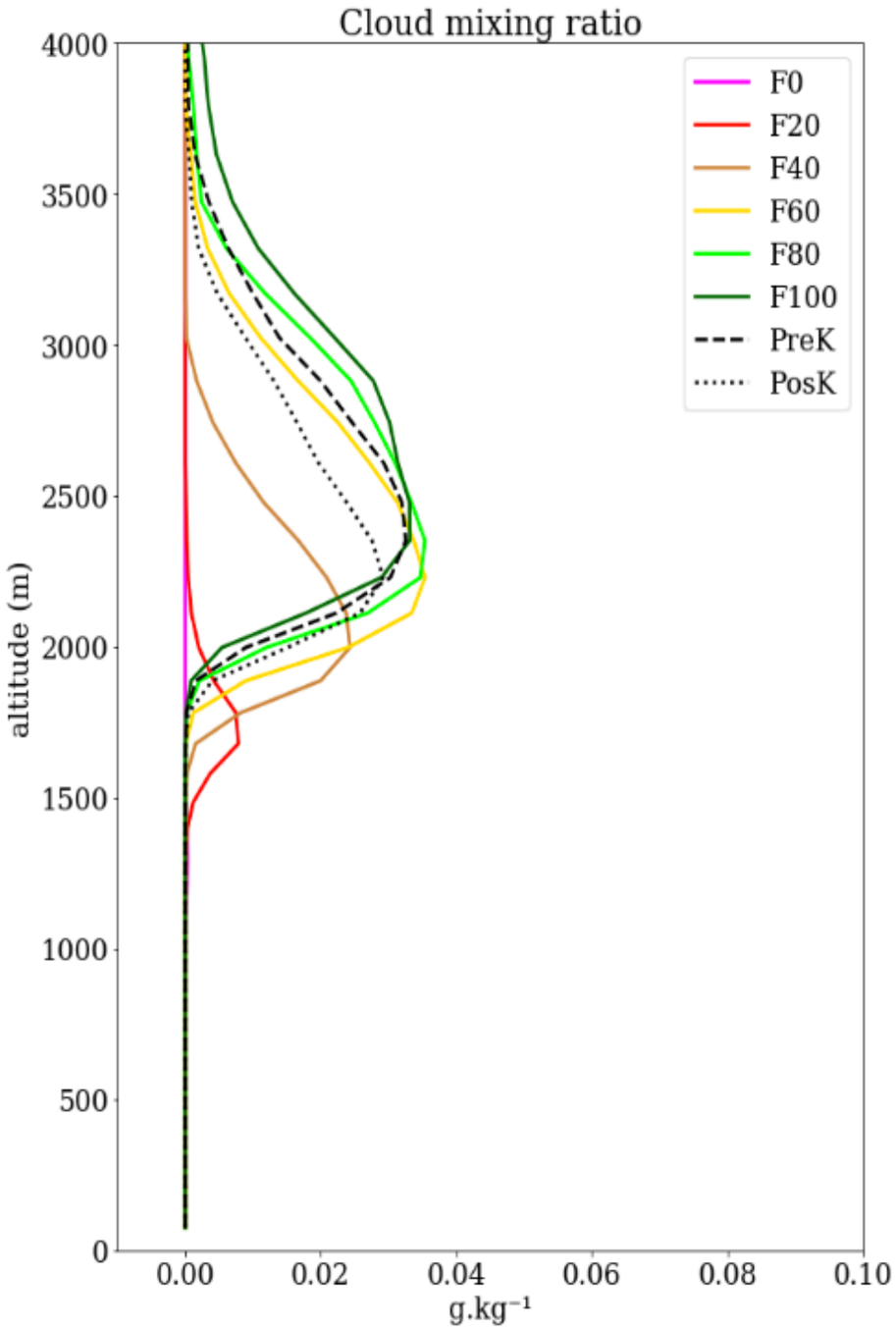
9 July 2013 13 UTC





9 July 2013 13 UTC

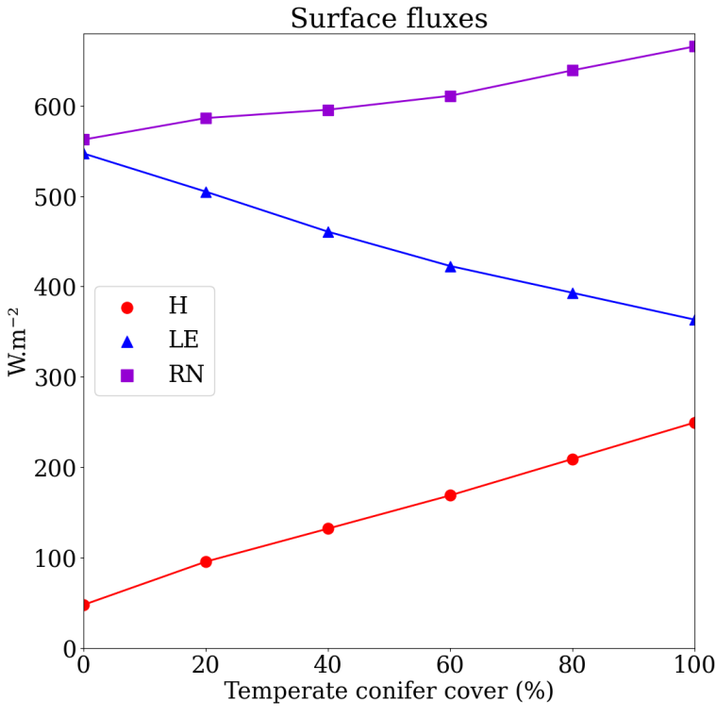


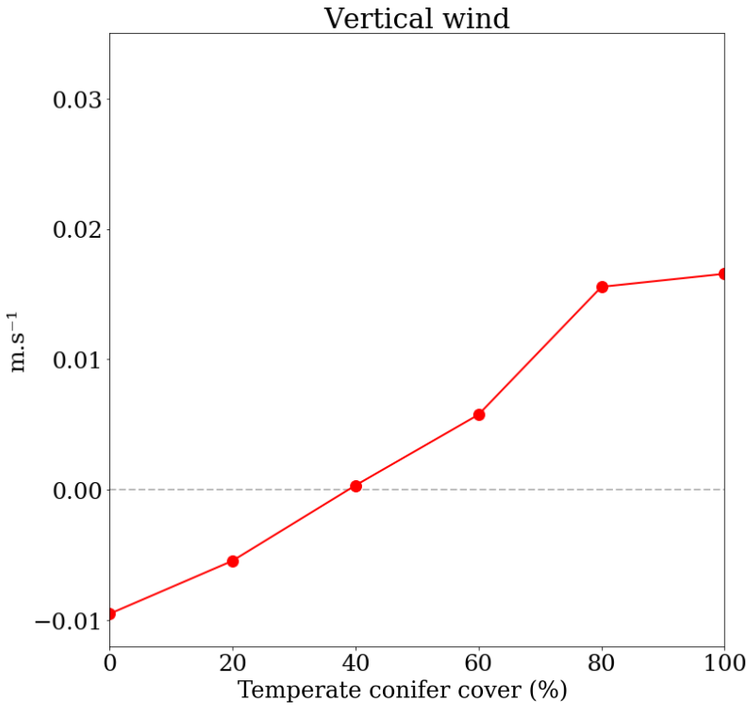


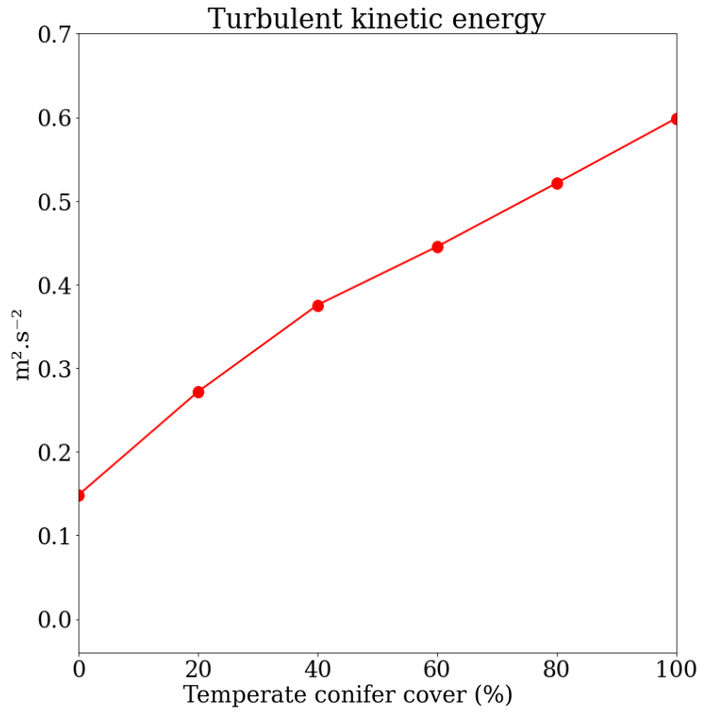
IV. B. IDEALISED CHANGE OF FOREST COVER

13 UTC

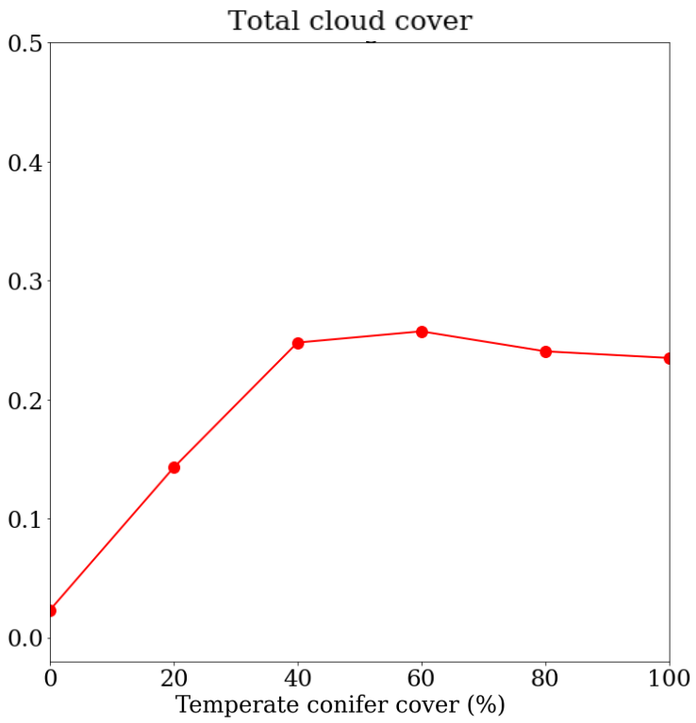
9 July 2013

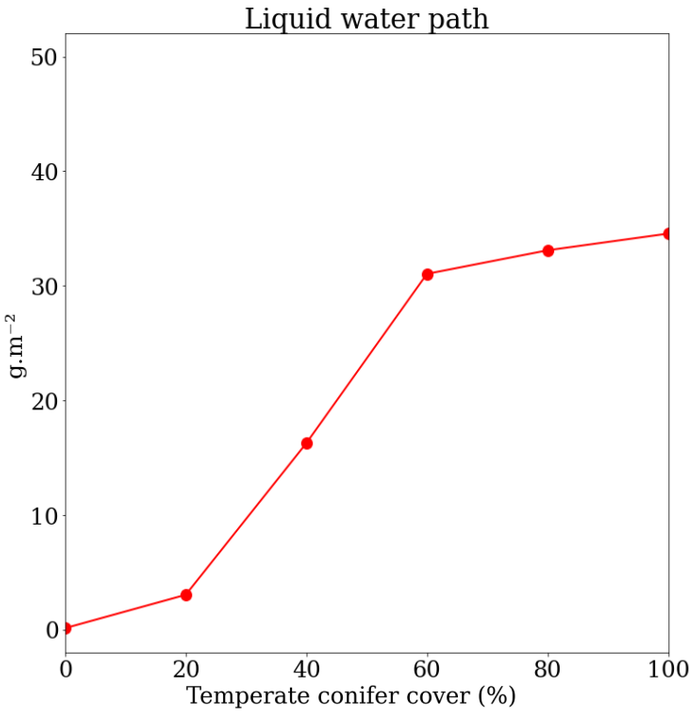






- Quasi-linear response of surfaces fluxes, W and TKE





- Non-linear response of clouds

➡ Highest sensitivity of cloud cover with intermediate forest fraction

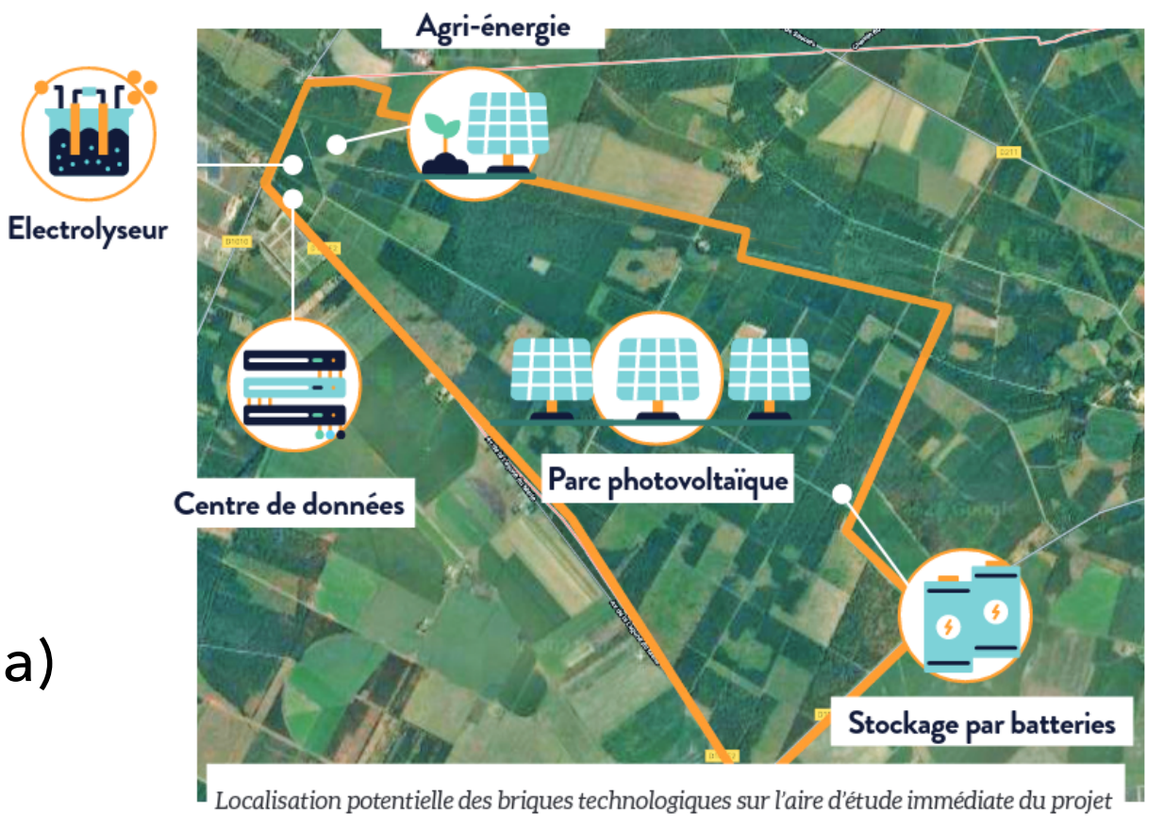
- Keep improving the realism of the **input data** of the model
  - Use of reanalyses for more realistic initial states: ARRA (1.3 km over France)
  - Up-to-date surface parameters and databases: EcoClimap-SG
- Improve representation of **physical processes**
  - Take into account the evolution of the vegetation response in a context of climate change: ISBA with interactive vegetation
  - Drag approach of forest dynamics
  - 2-moment microphysical scheme (LIMA)
- Better understand the processes involved in **cloud formation**
  - Biogenic aerosols and cloud condensation nuclei

- What is the **critical heterogeneity size** at which the impact on cloudiness becomes significant?

  ➡ Necessity of **LES**

- Further prospective use of the model for **land use changes**

  - Example of land development projects: Horizeo solar farm (1000 ha)



Localisation potentielle des briques technologiques sur l'aire d'étude immédiate du projet

Horizeo project

- Impact of **agricultural practices** on local circulation

  - Role of irrigation (Phd of Tanguy Lunel)