Large-Eddy Simulation of a radiation fog : impact of surface heterogeneities and droplet deposition

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Introduction

- Important progress in fog processes understanding with the campaigns : Cardington, Fog-82, Po Valley, ParisFog
- Progress with 1D simulations (Bergot et al., 2007...) : vertical resolution essential
- Large Eddy Simulations (**LES, meter resolution**) necessary to represent heterogeneities and to progress (Nakanishi, 2000 ; Bergot, 2013)
- Most LES consider surface homogeneity (except Bergot et al., 2015 with buildings) : 1st fog LES with vegetation heterogeneities
- Most NWP and LES models fail to reproduce realistic microphysical fields :

Observations

LWC ~ [0.05-0.3] $g.m^{-3}$

Nc ~ [10-200] cm^{-3}
Mazoyer et et al. 2016 : < 150 cm^{-3}
[800-1000] cm^{-3} (China)

Simulations

LWC ~ [0.2-0.6] $g.m^{-3}$

Nc fix : 100 ou 300 cm^{-3}
Nc pronostic : 250 cm^{-3} (Stolaki et al., 2015)
800 cm^{-3} (Zhang et al., 2014)

- Is there a missing term ?

PLAN

1. Study case and validation of the reference simulation : microphysics, visibility
2. Heterogeneities inside the fog layer
3. Sensitivity tests : barrier of tree, deposition
4. Conclusion/perspectives

1. Case study over the SIRTA site (Mazoyer et al., 2017, ACPD)

From the Paris-Fog campaign

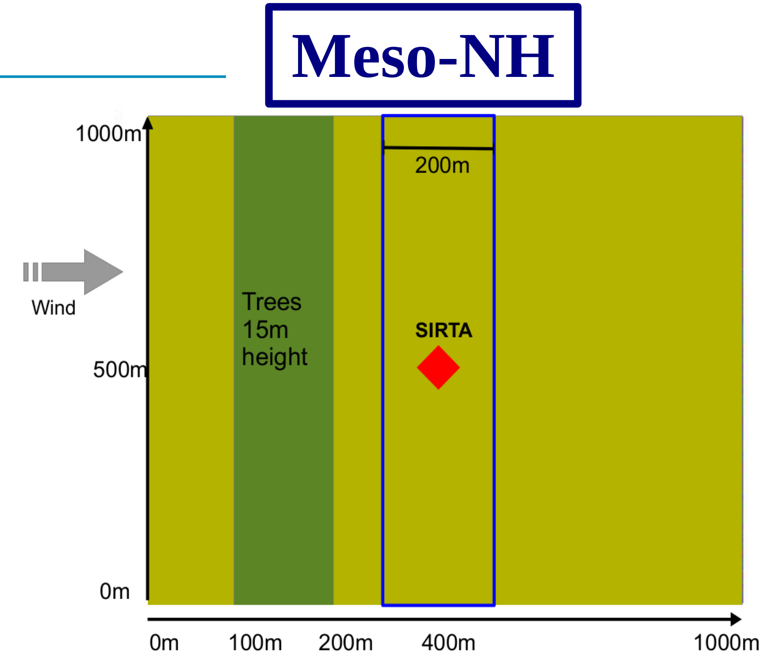
Site located near Paris on a semi-urban area

Instrumental zone near a forest area : Strong surface heterogeneity – Tree barrier (Zaïdi et al., 2013)

A characteristic of the site : **88 % of the radiative fogs are elevated at the onset**

Case November 15 2011 : cloud layer 150m agl and 30min later fog at the surface

1. Case study over the SIRTA site (Mazoyer et al., 2017, ACPD)



- $\Delta x=\Delta y=$**5m** ; $\Delta z=$**1m**, 156 levels up to1500m – Initialization with a radiosounding
- SURFEX : ISBA : grass + barrier of tree (15m height)
- 3D Turbulence scheme (Cuxart et al., 2000)

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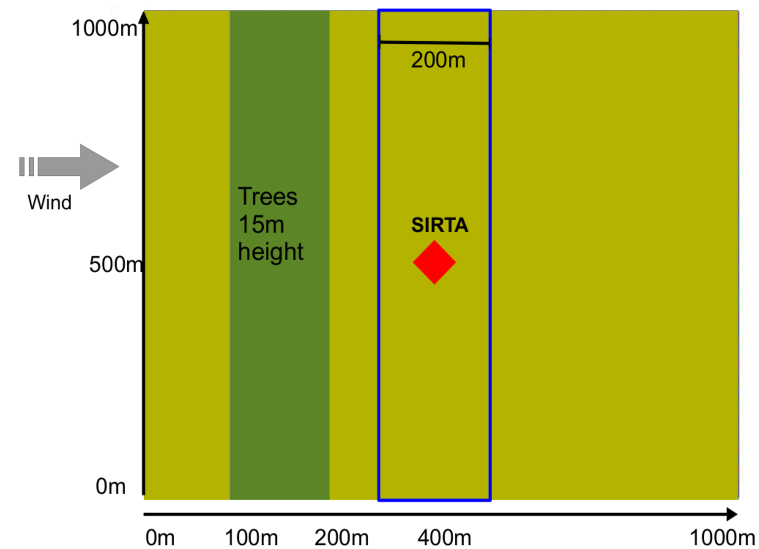
Meso-NH



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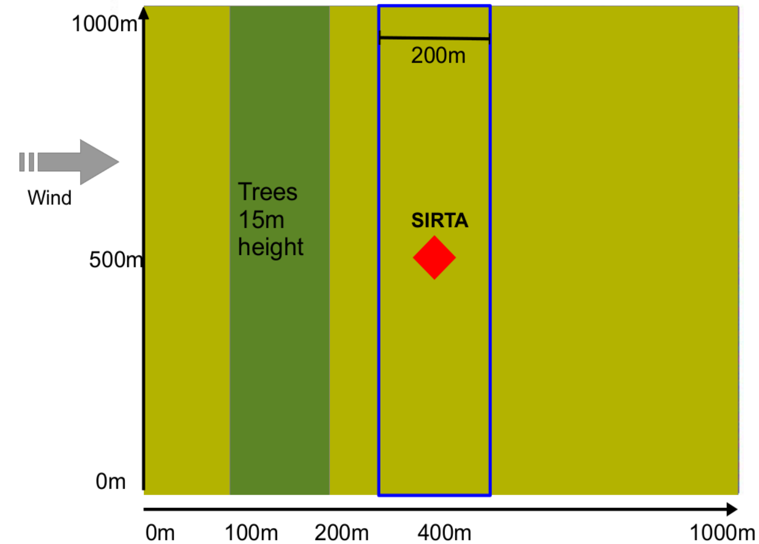

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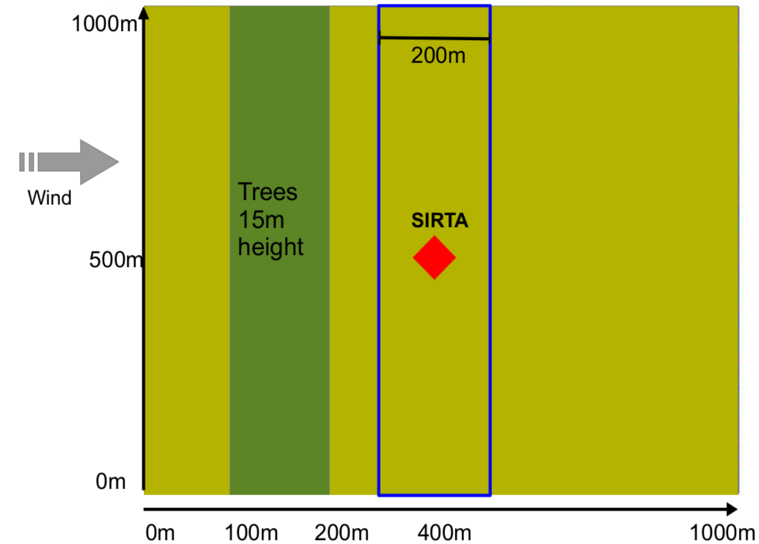

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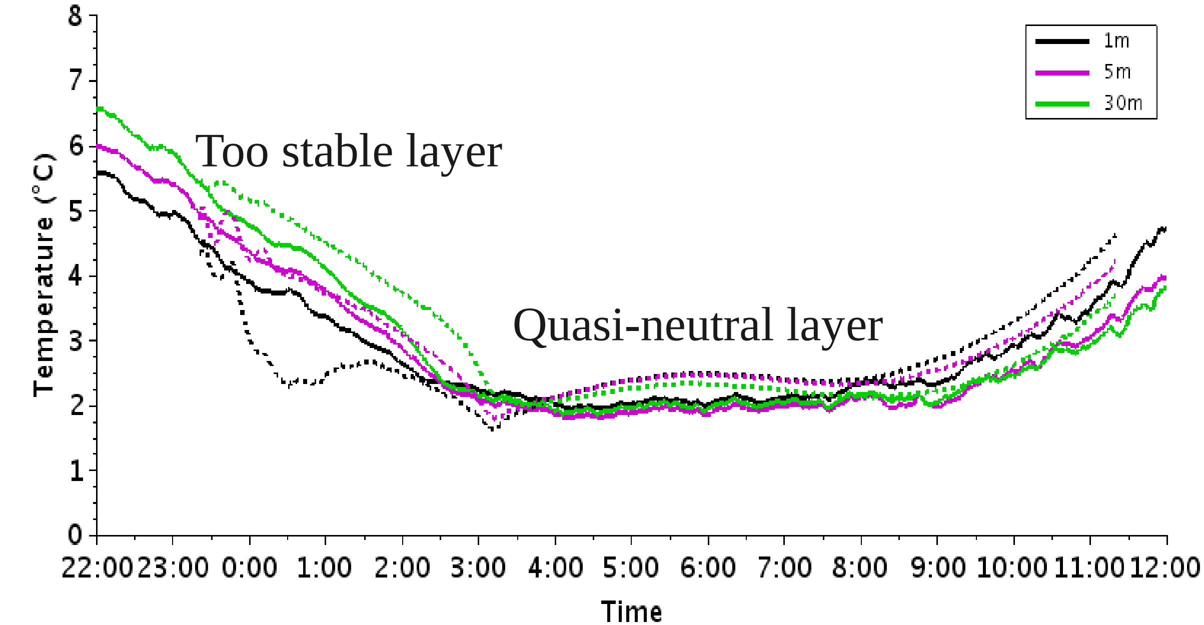
- Add a new process : **Deposition of droplets on the vegetation** **(direct droplet interception by the plant canopies)** : only at the first vertical level on grass and over 15m trees :

$$\rho_a . r_c . V_{DEP} \; avec \; V_{DEP} = 2 \; cm/s$$

Katata (2014) : 2 cm/s < V_{DEP} < 8 cm/s on low vegetation

1. Thermodynamical evolution

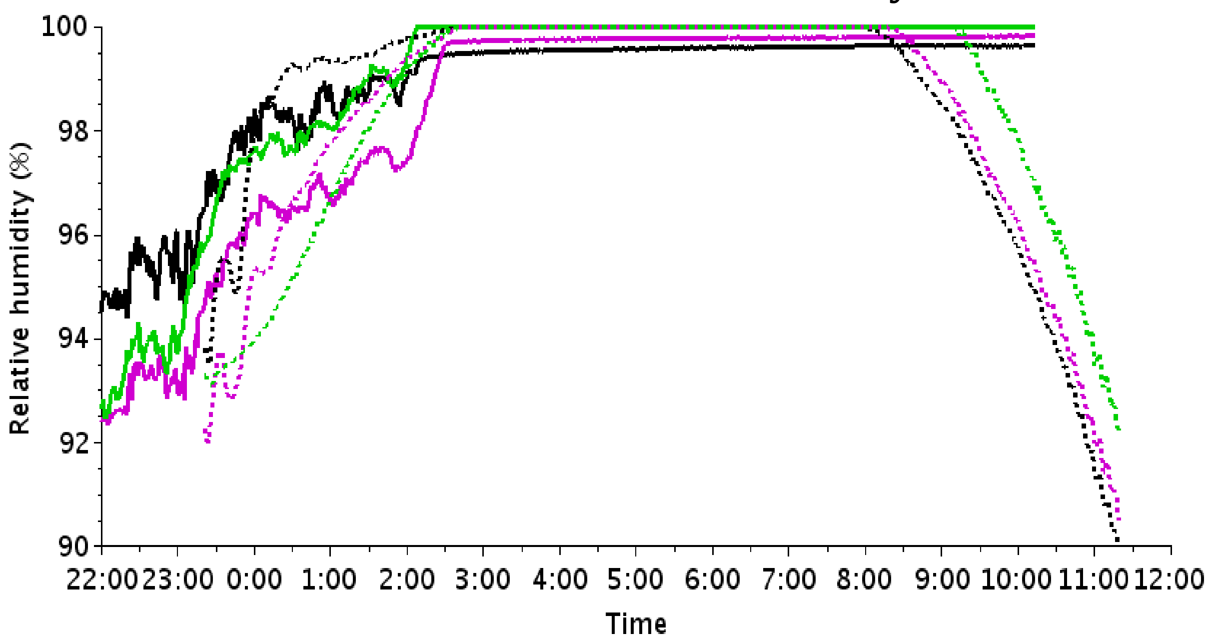
Temperature



OBS

REF

Relative humidity



Onset of fog at the ground:
02h30 in OBS and REF

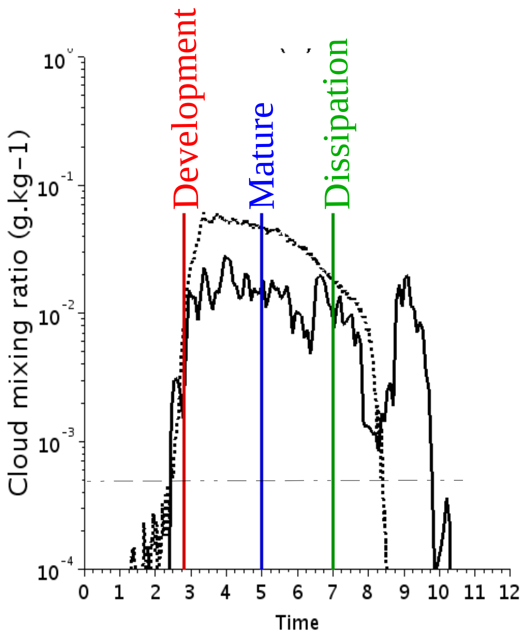
Dissipation at the ground :
10h in OBS
8h30 in REF

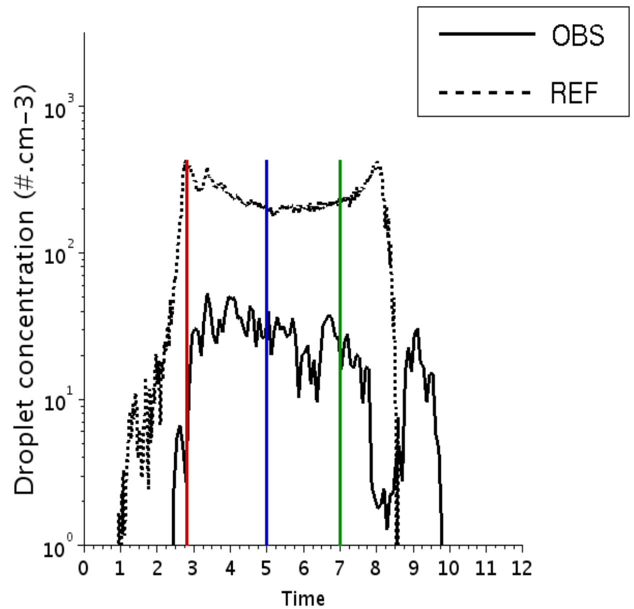
1. Microphysics at 3 m

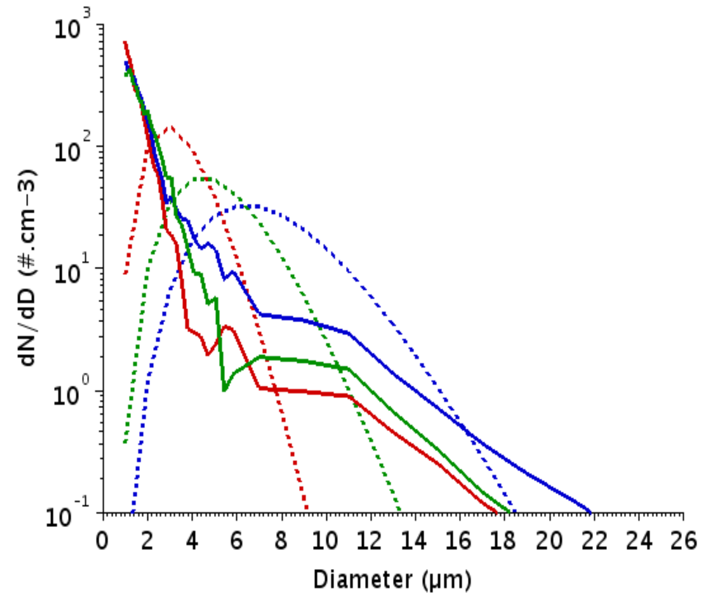
Droplet mixing ratio r_c

Droplet concentration Nc

Droplet Size Distribution







Low values of observed r_c and N_c

Max_OBS=0.03 g.kg^{-1}
Max_MNH=0.06 g.kg^{-1}

Max_OBS= 53 cm^{-3}
Max_MNH=350 cm^{-3}

Correct estimation of the mass and the life cycle (dissipation too early)
Overestimation of the number of droplets

Overestimation of the number of small droplets and underestimation of larger one
Limit of the monomodal distribution

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1. Diagnostic of visibility

The most often used in NWP models :

1. Using only **cloud mixing ratio**	2. Using **cloudmixing ratio** and **droplet concentration**
$VIS = a / (\rho_d . r_c)^b$	$VIS = c / (\rho_d . r_c . N_c)^d$
Kunkel (1984) a=0.027 b=0.88	Gultepe (2006) : c=1.002 d=0.6473 Zhang (2014) : c=0.187 d=0.34

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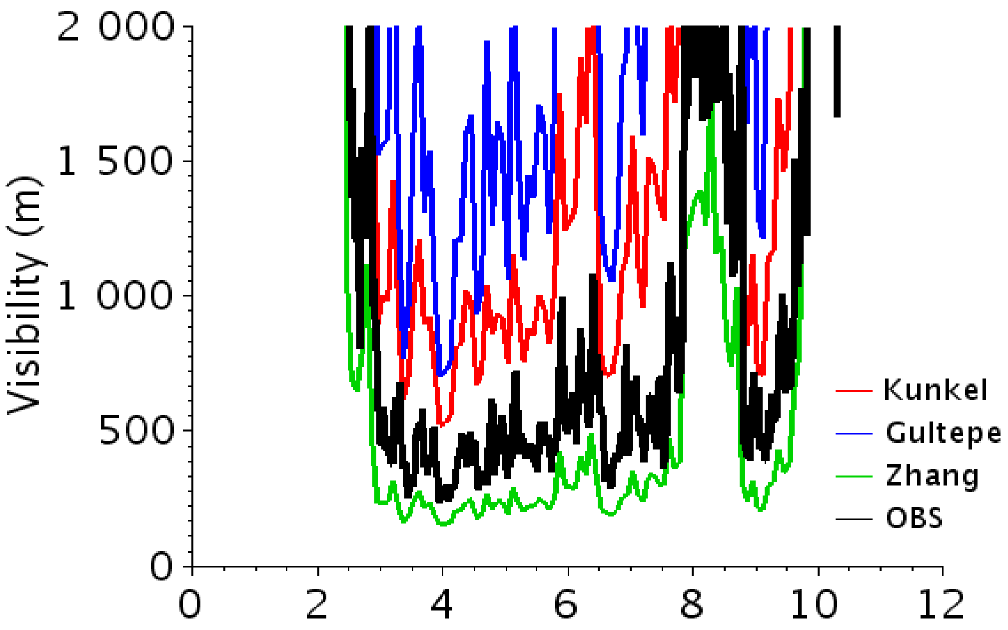
<u>From observations</u>



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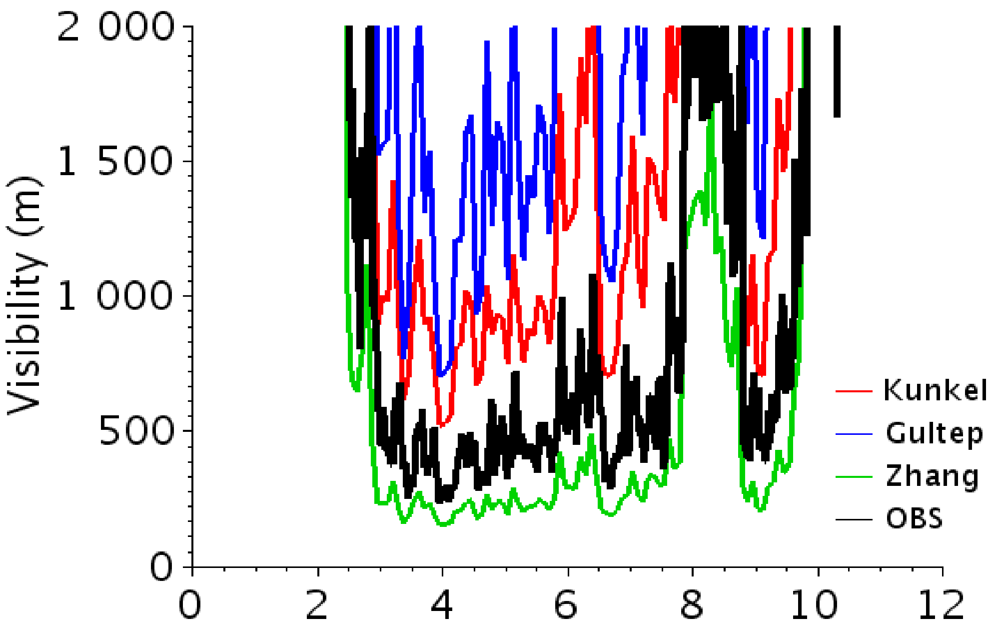
<u>From observations at 3m</u>



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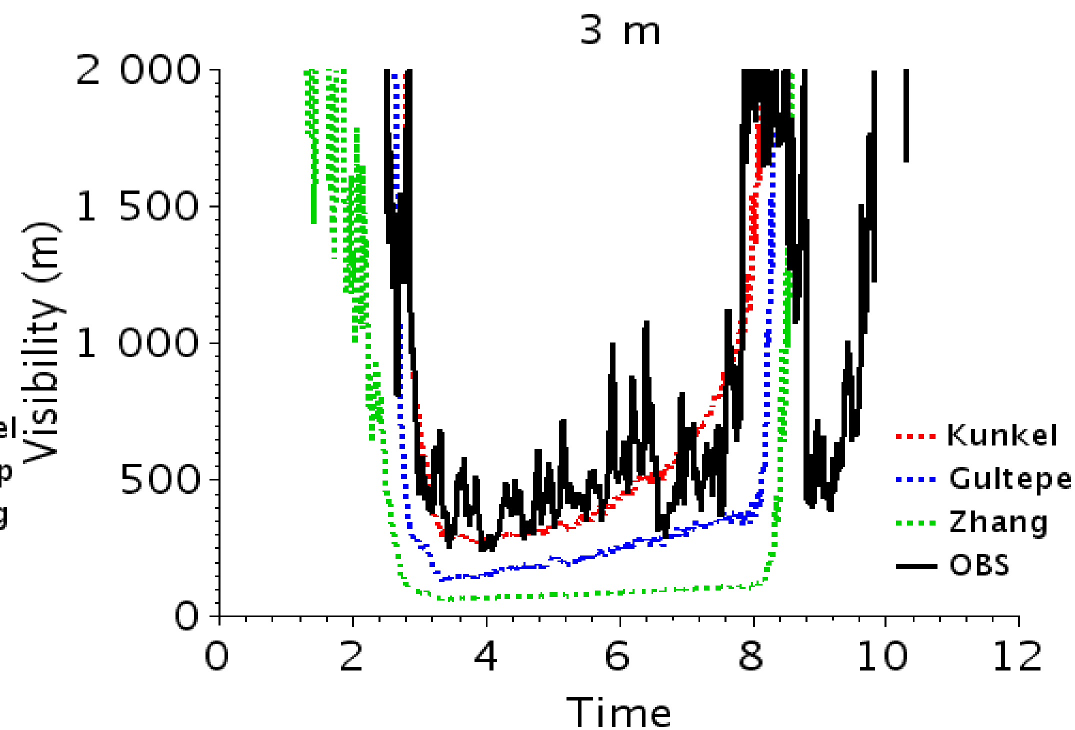
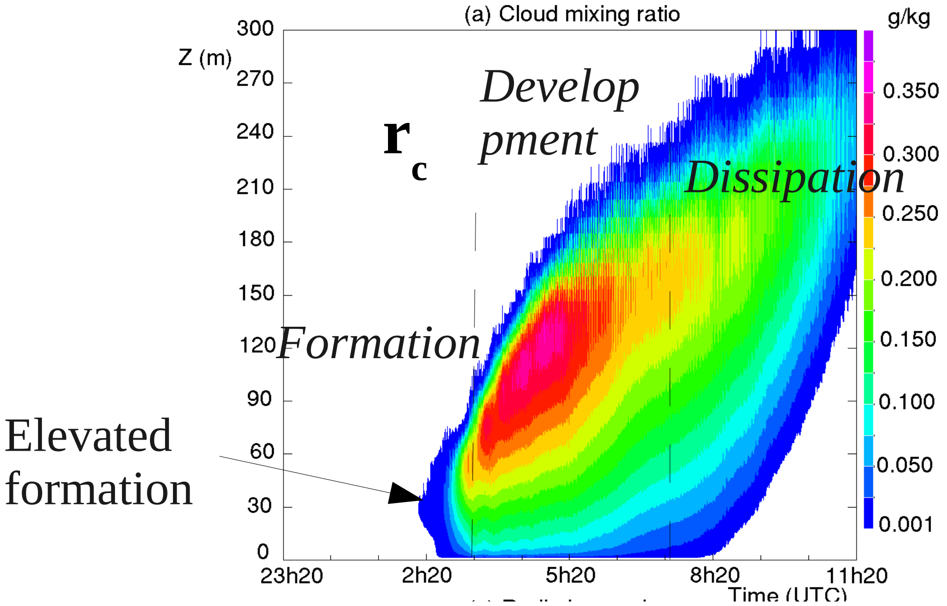
<u>Observation vs simulation</u>



Kunkel and Gultepe best adapted

2. Temporal evolution in the fog layer

$$\frac{dS}{dt} = \phi_1 w - \phi_2 \frac{dr_c}{dt} + \phi_3 \frac{dT}{dt}_{RAD}$$



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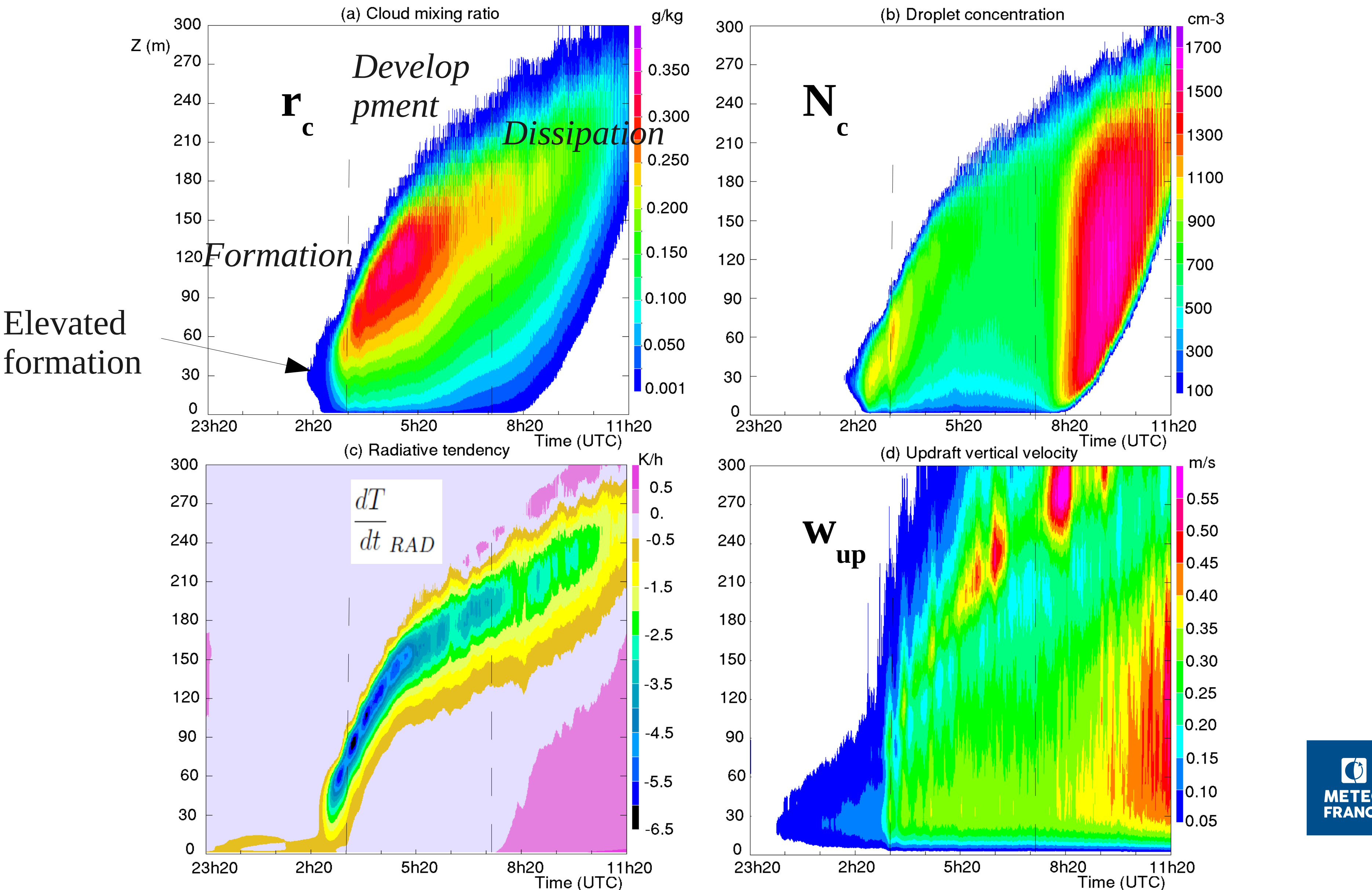

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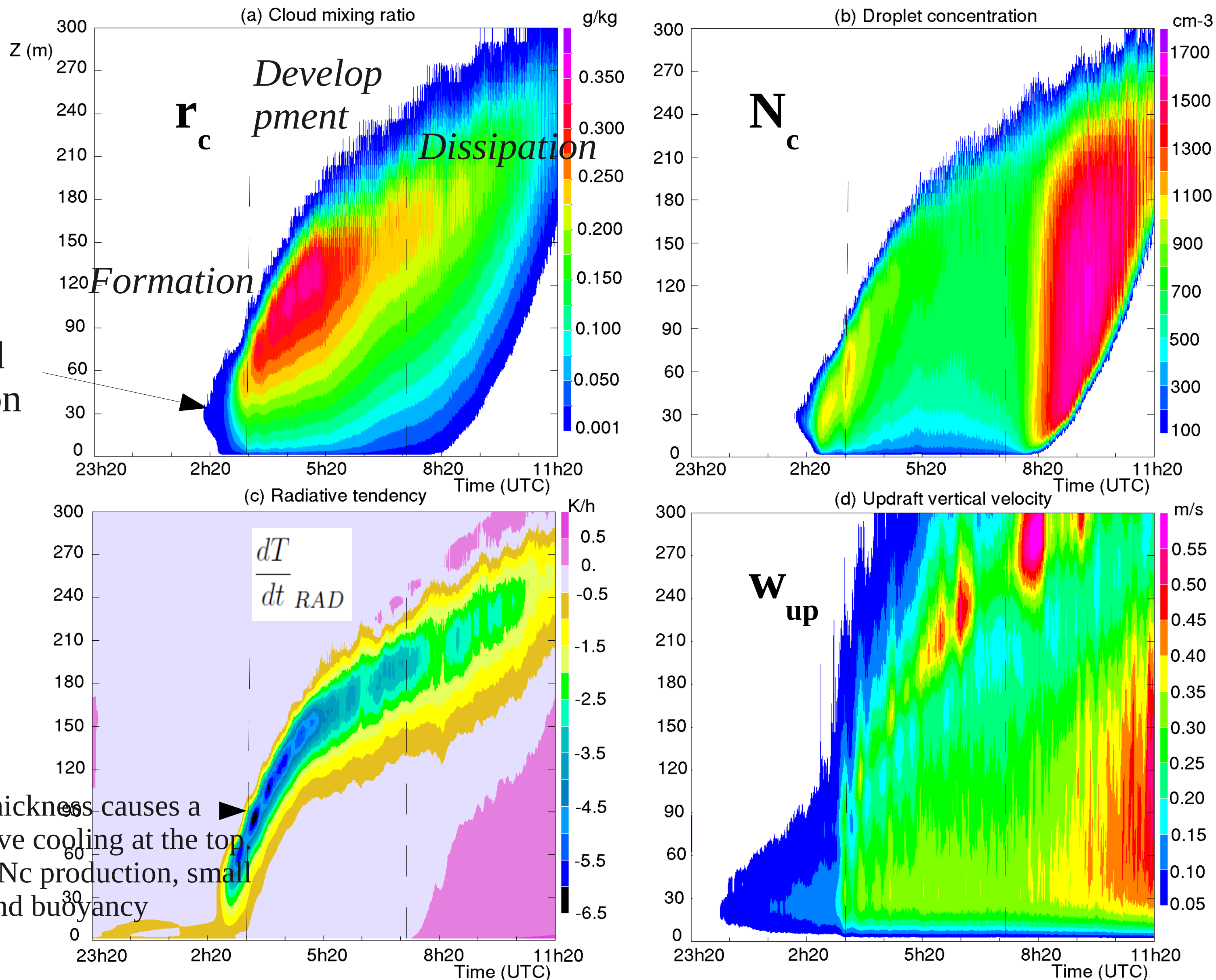
Elevated formation



The optical thickness causes a strong radiative cooling at the top. This induces Nc production, small downdrafts and buoyancy reversals.

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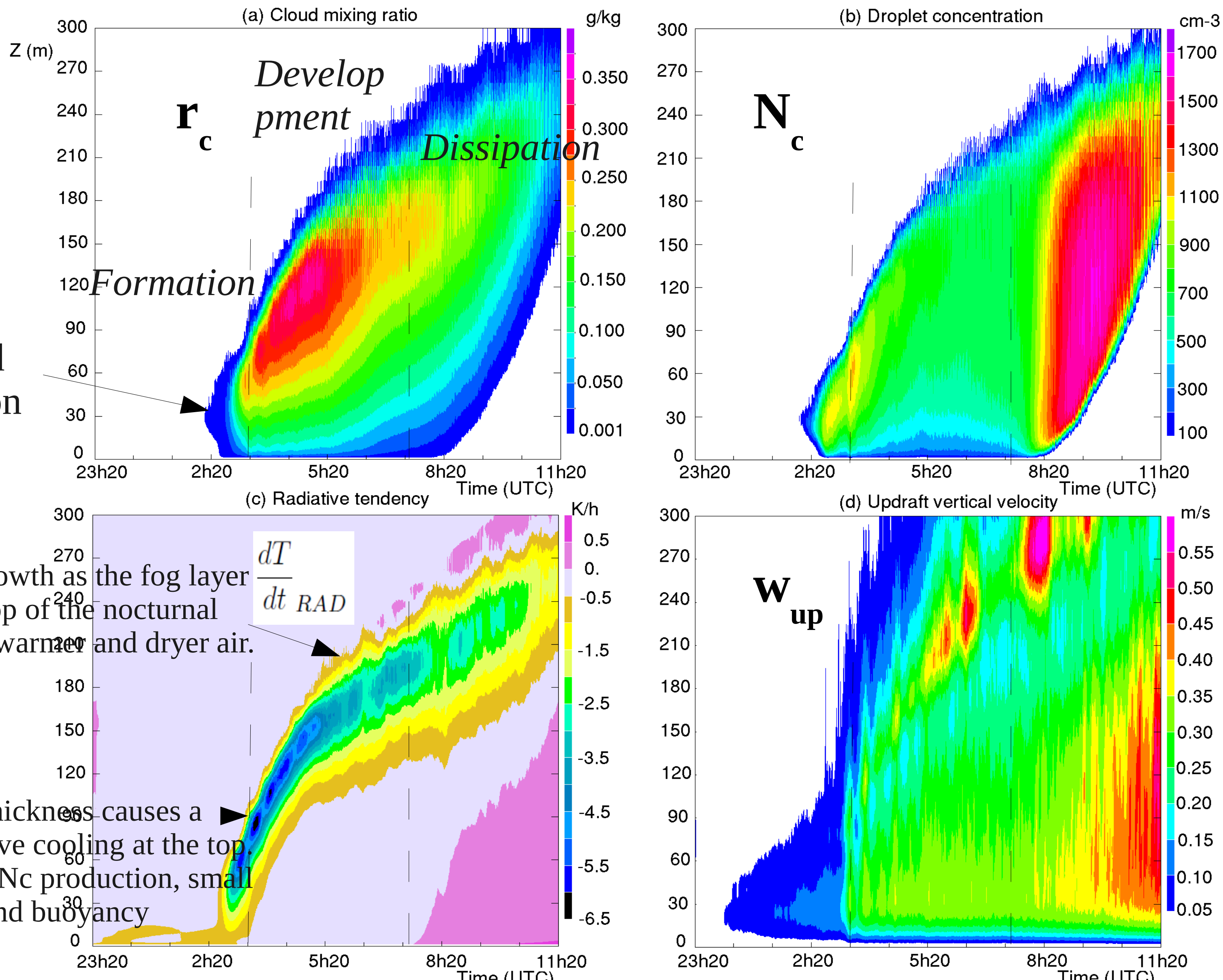

Elevated formation

Change of growth as the fog layer reaches the top of the nocturnal BL, meeting warmer and dryer air.

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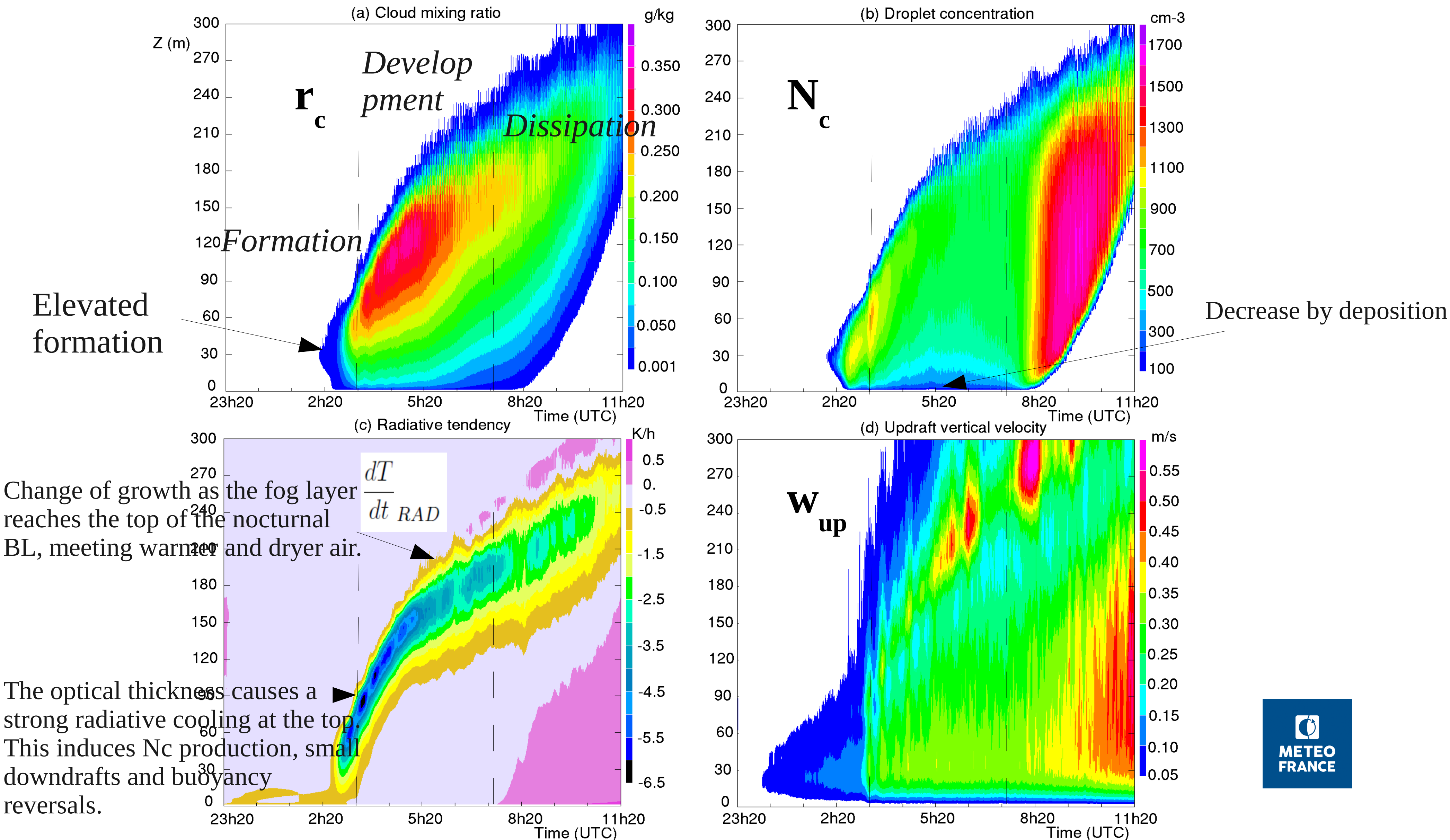

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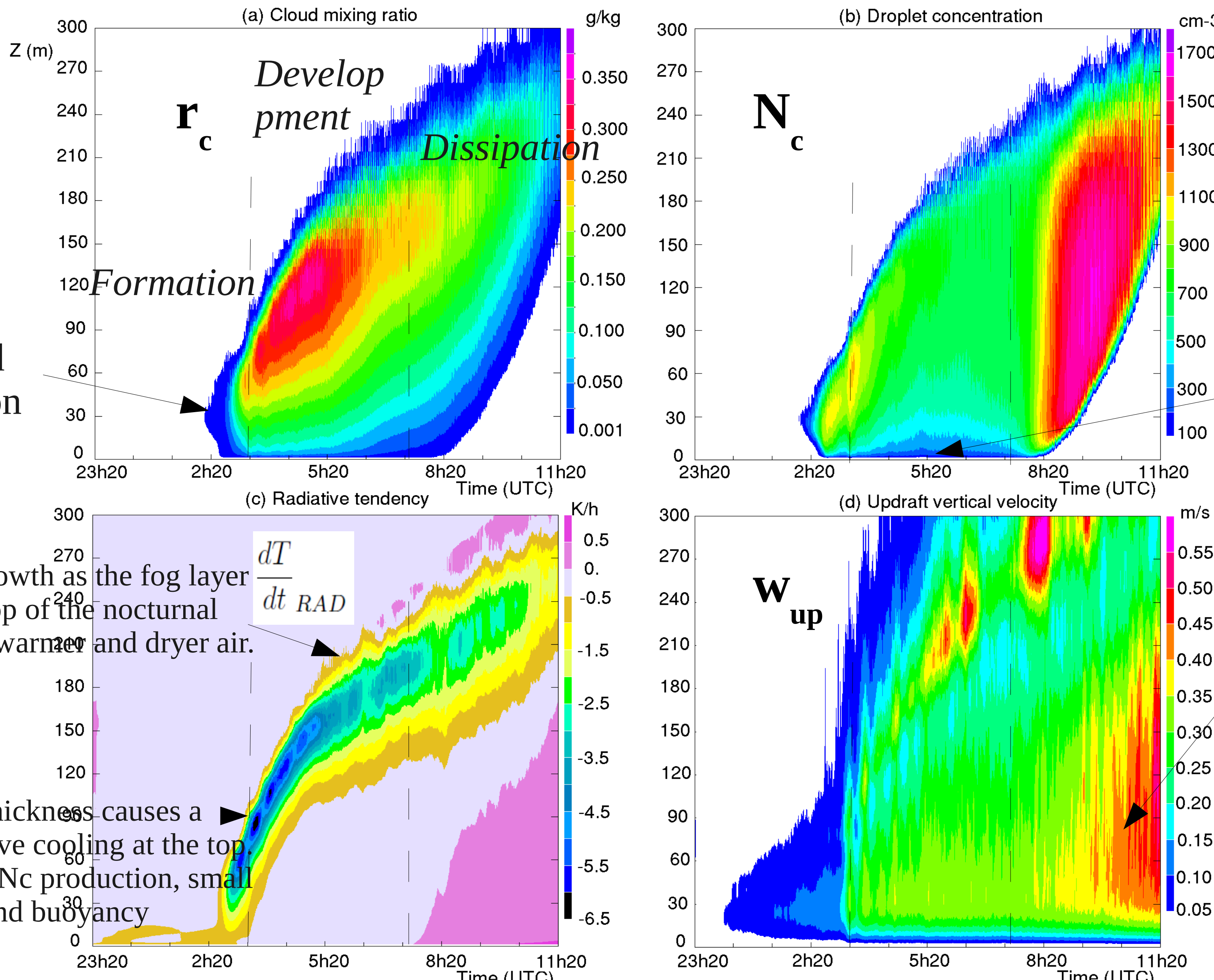

Elevated formation

Decrease by deposition

Change of growth as the fog layer reaches the top of the nocturnal BL, meeting warmer and dryer air.

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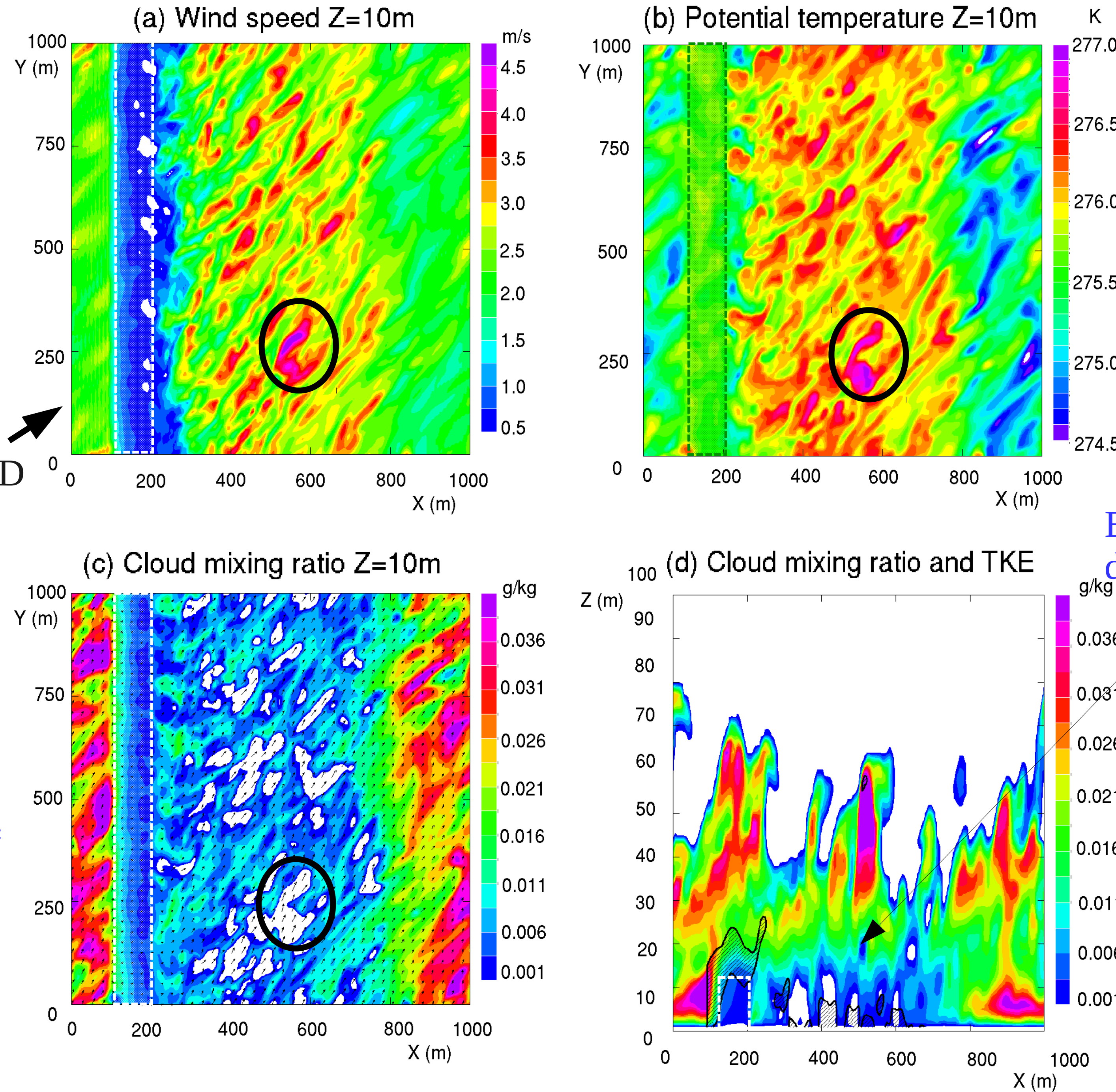
Stronger Wup Drives the production of Nc

2. Fog formation **(0240 UTC)**

Tree barrier -> blocking effect
Ascent upstream and subsidence downstream -> entrainment
Heterogeneity and Delay of fog formation

Turbulence due to the trees -> longitudinal structure in the direction of the wind

WIND



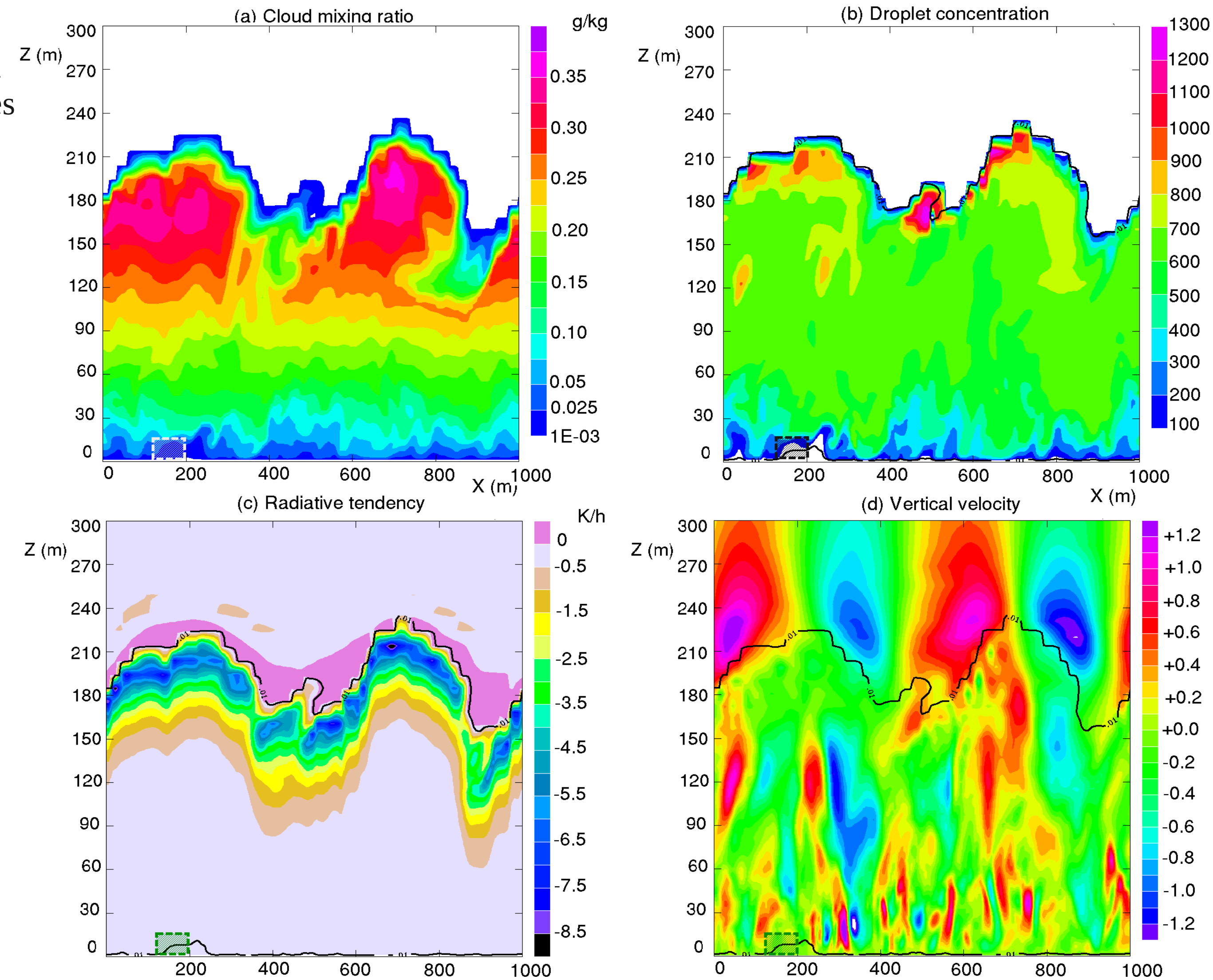
Elevated formation due to the trees

Duration of the fog formation at the ground = 1h

2. Mature phase of the fog **(0620 UTC)**

$$\frac{dS}{dt} = \phi_1 w - \phi_2 \frac{dr_c}{dt} + \phi_3 \frac{dT}{dt}_{RAD}$$

Horizontal rolls at the top : KH waves



Max of Nc in the radiative cooling layer and preferentially upstream the crest

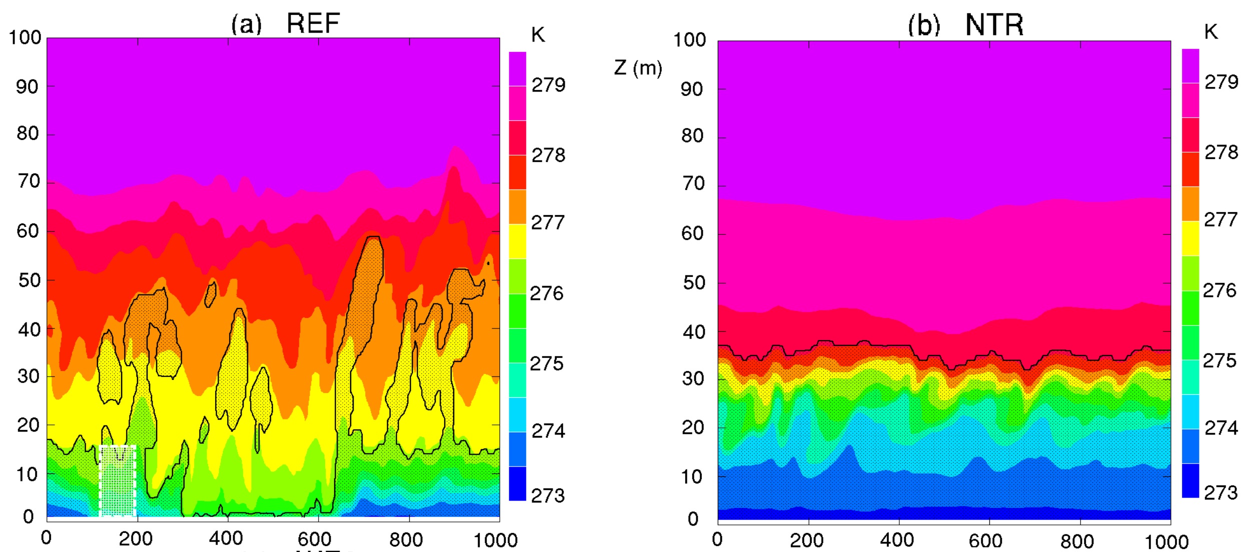
Updrafts upstream the crest and downdrafts downstream

Activation driven by vertical velocity and radiative cooling

3. Sensitivity test : Impact of the tree barrier

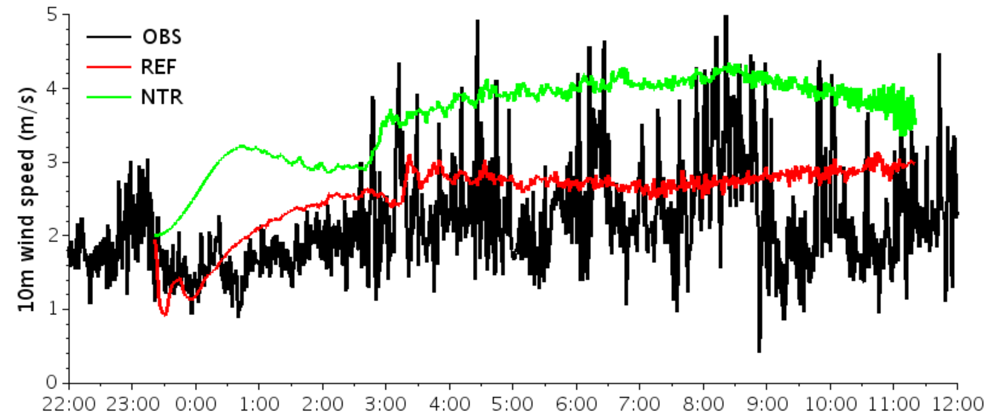
At the fog formation (0220 UTC)

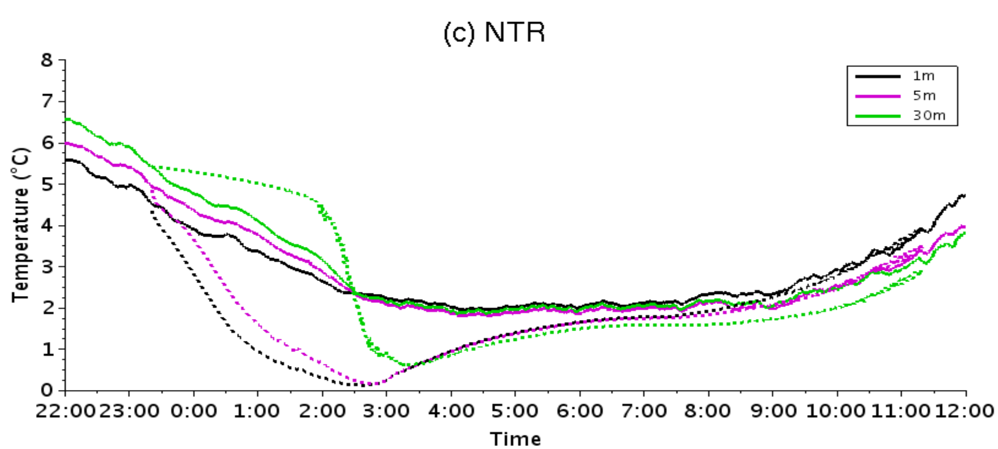
θ and rc



Without tree
Fog starts earlier without elevated fog formation

Without tree :
Too strong wind and cooling





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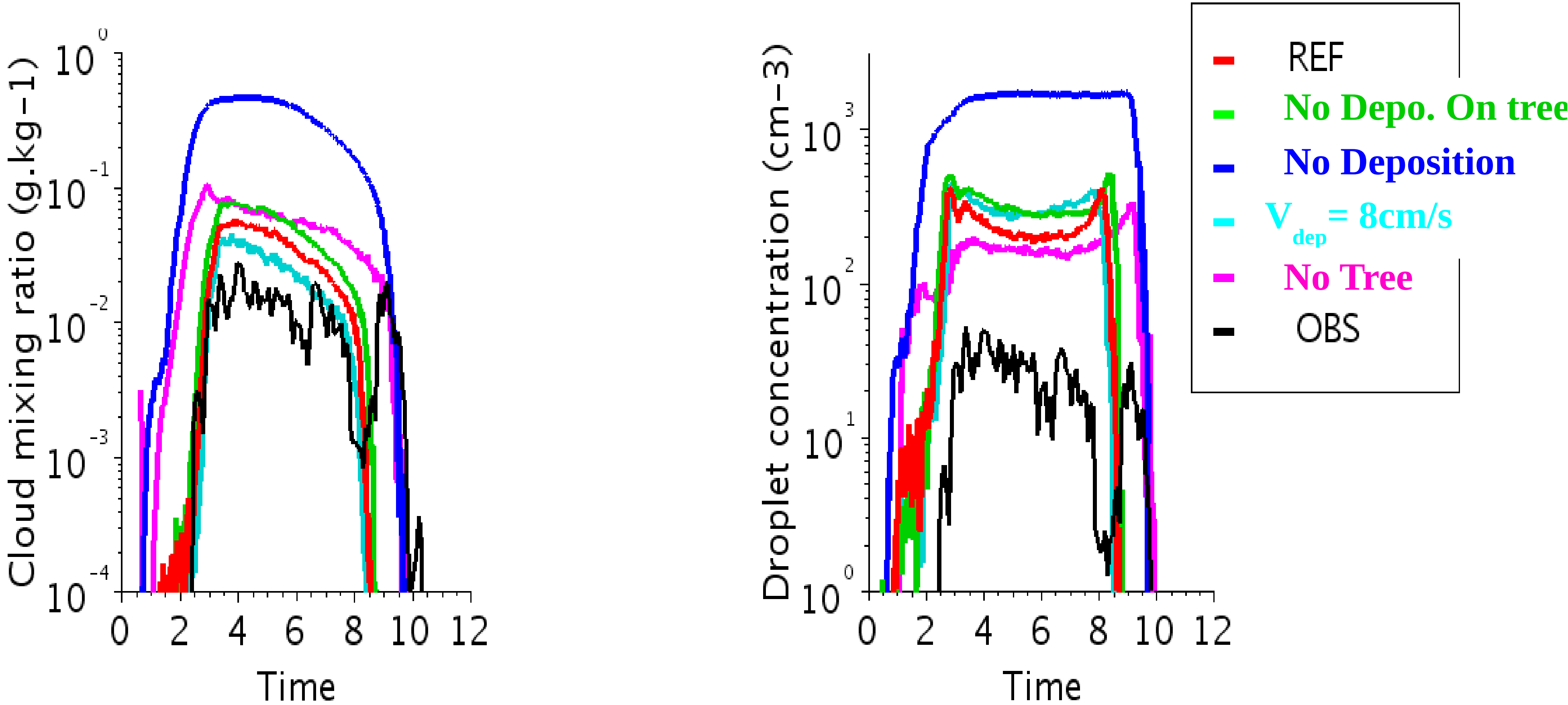
3. Sensitivity test : Impact of deposition



Deposition and tree drag effect are essential to capture the fog life cycle and the magnitude of microphysical fields.

4. Conclusion - Perspective

- Results in Mazoyer et al., 2017, ACPD
- Surface heretogeneities essential to reproduce the fog life cycle
- Deposition essential to limit the droplet mass and number

- Deposition currently tested in AROME (ENM course) on winter 2015-2016
- Parametrization of deposition to be improved : depends on wind speed, LAI …
- Droplet number overestimated : necessary to take into account the already condensed water as a sink of supersaturation in the activation process of 2-moment microphysical scheme (Thouron et al., 2012, GMD) : perspective for LIMA


Thank you for your attention