Formation of fog due to stratus lowering: experimental and numerical study of the life cycle

PHD defended on19April 2022
National Center for Meteorological Research

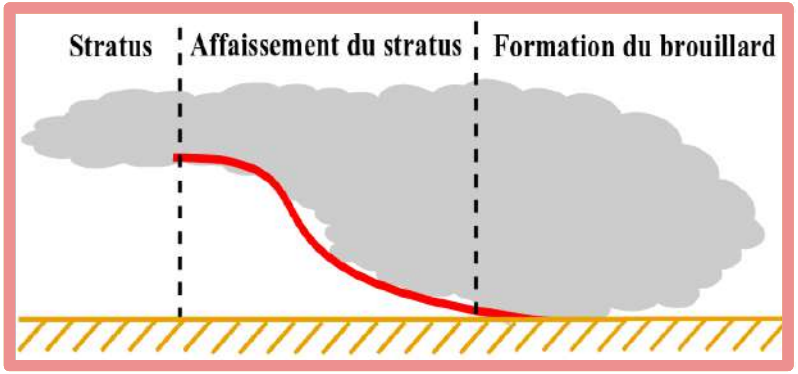
BURE, (F. Burnet)

Maroua Fathalli
supervised by Christine Lac & Frédéric Burnet

07/06/2022 - SOFOG3D meeting

GMEI/MNPCA & GMME

- **Fog STratus Lowering (FSTL)**



FSTL :
- poorly studied compared to **RAD**
- difficult to predict.

Numerical weather prediction (NWP):

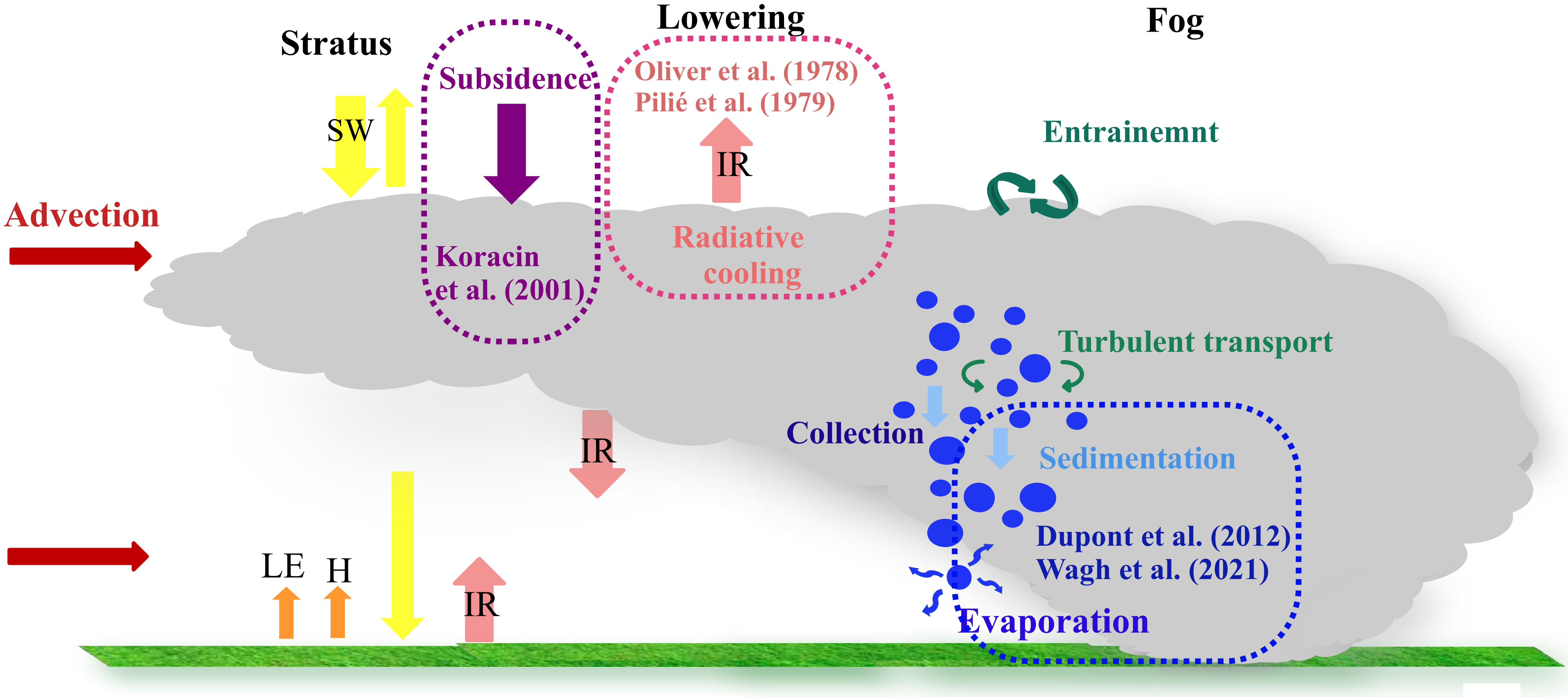
- **AROME** => difficulties to correctly forecast stratus lowering.

During winter 2011 at Paris-CDG, (17 RAD, **20 FSTL** et 3 ADV)

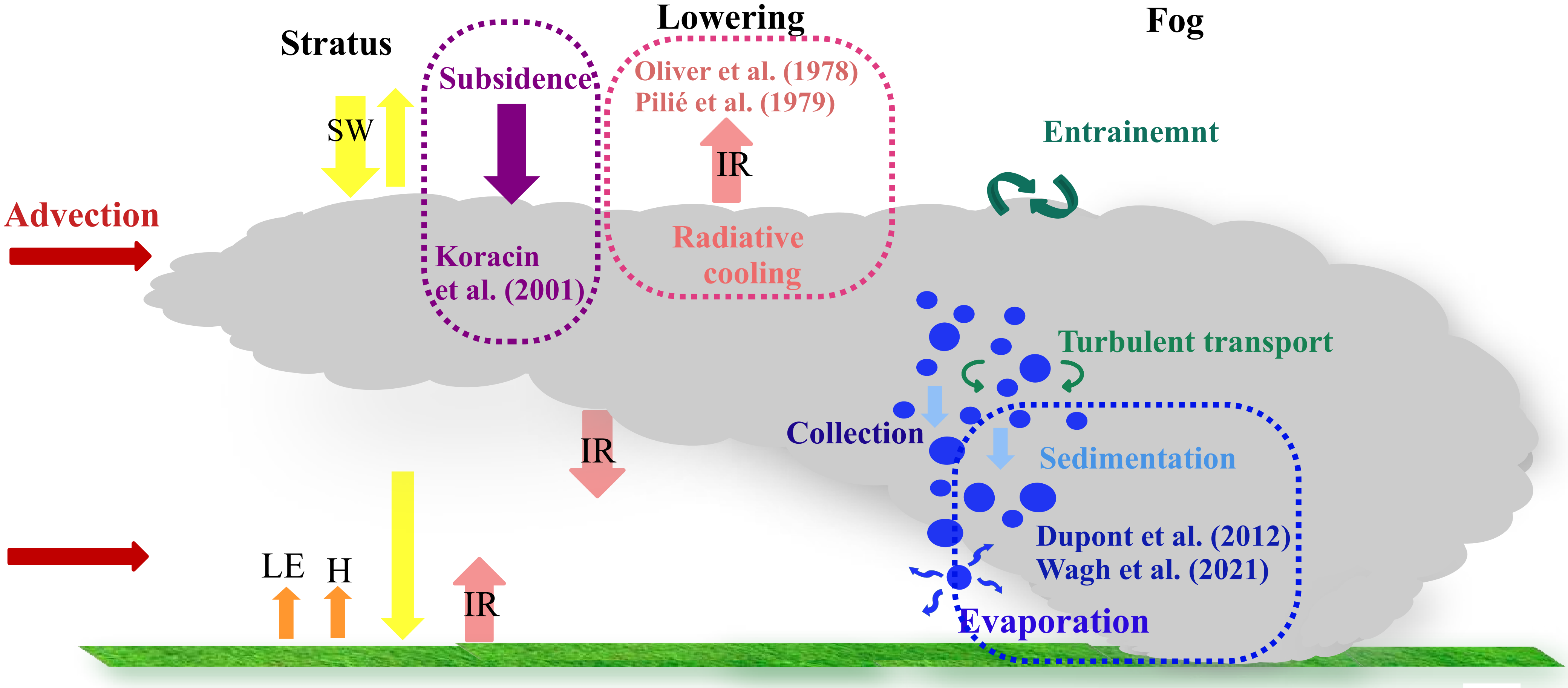
→ AROME simulated about 70 % RAD and **30 % FSTL** (Philip et al. (2016).

Better understanding for better forecasting. → What are the processes involved ?

Life cycle of a stratus lowering



Life cycle of a stratus lowering



What are the main processes leading to stratus lowering?

Objectives

Better understand the processes leading (or not) to stratus lowering.

1st objective

- Are stratus lowering driven primarily by local processes (such as microphysics) or non-local (large-scale conditions or mesoscale circulations) ?

2nd objective

- What are the main characteristics of stratus lowering fogs (thermodynamics, microphysics)?

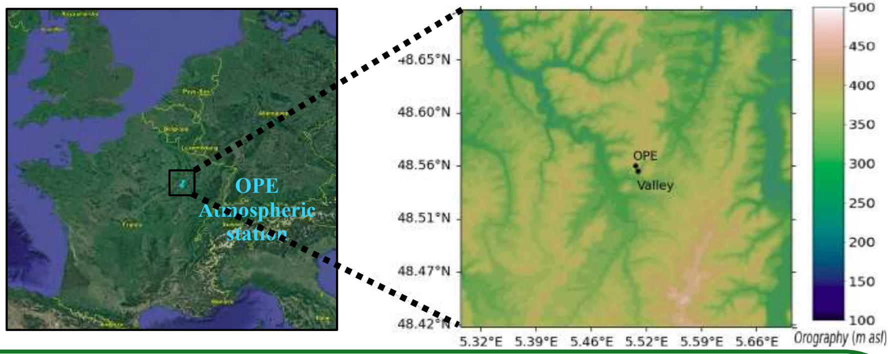
Methodology

Observations (BURE campaign)

Burnet et al.(2016)

- 2 winters 2015 et 2016
- Atmospheric station of the **OPE** (388 m) of ANDRA

*(**O**bservatoire **P**érenne de l'**E**nvironnement)*



✓**29 Radiative fog (RAD)**

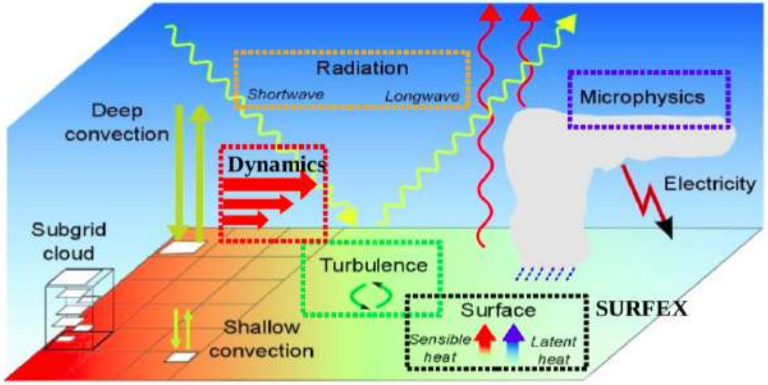
✓**18 Fog stratus lowering (FSTL)**

✓**19 No fog stratus lowering (NFSTL)**

Modeling

Meso-NH
mesoscale non-hydrostatic model

Lac et al.(2018)



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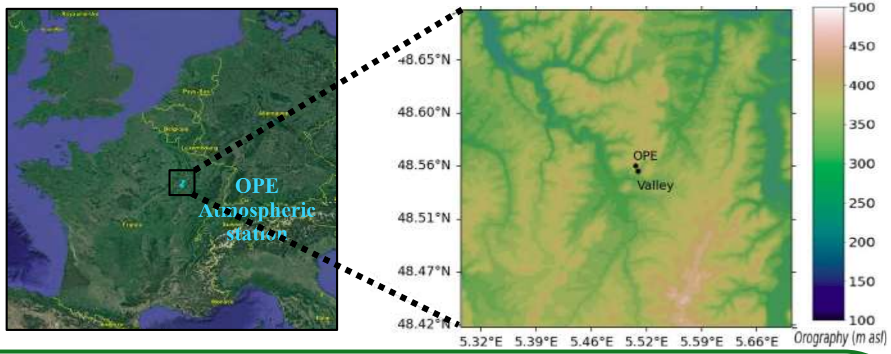

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- **IOP2** :One **FSTL** case sampled (1sd and 2nd December 2016)

Modeling

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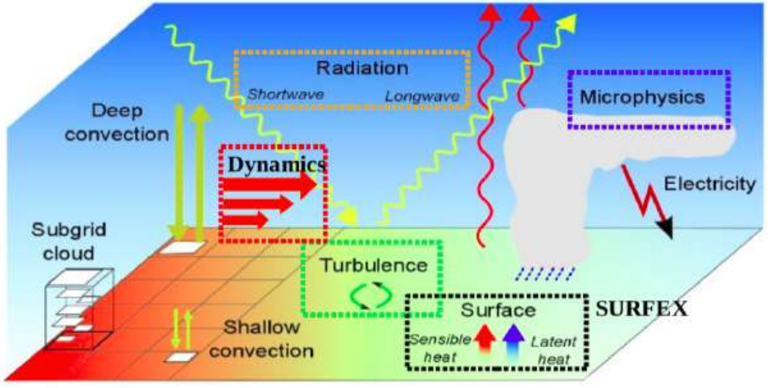

✓**LIMA** : 2-moment scheme (mixing ratios and prognostic droplet concentration) *Vié et al. (2016)*

- High resolution numerical simulation (**100m**) with **LIMA**
- Process study

Methodology

Observations (BURE campaign)

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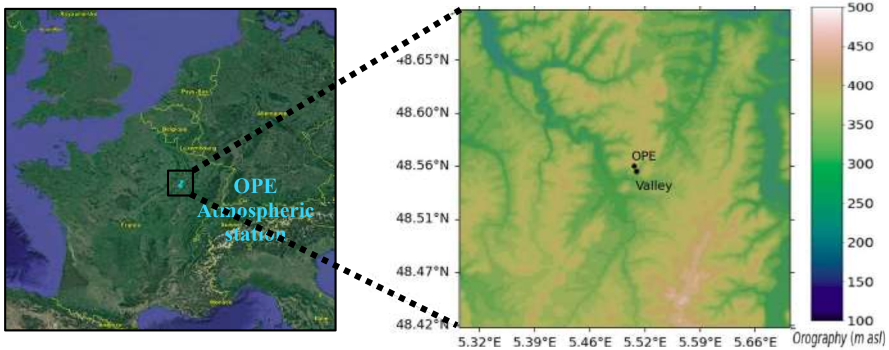

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- **IOP2** :One **FSTL** case sampled (1sd and 2nd December 2016)
- Statistical analysis of OPE events

Modeling

Meso-NH
mesoscale non-hydrostatic model

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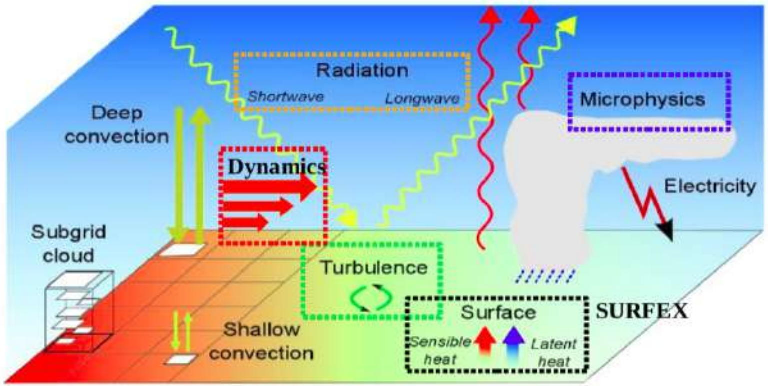

✓**LIMA** : 2-moment scheme (mixing ratios and prognostic droplet concentration)

Vié et al. (2016)

- High resolution numerical simulation (**100m**) with **LIMA**
- Process study

- Characterize the **FSTL**versus **NFSTL**

Presentation outline

1. Introduction

2. **Experimental** study of **IOP2** (**FSTL** observed December 1 - 2, 2016)

3. Numerical study of **IOP2**

4. Conclusion and perspectives

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1. Introduction
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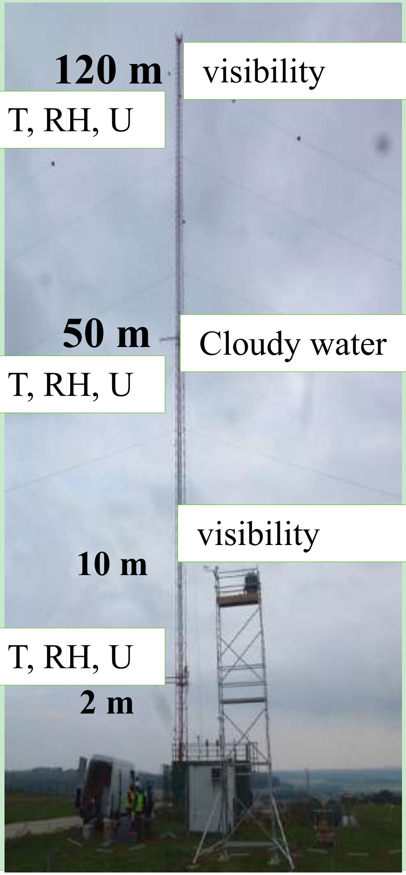
Overview of the case study: IOP2 1st and 2nd December 2016

In-situ measurements

Instrumented mast



120 m
visibility
T, RH, U
50 m
Cloudy water
T, RH, U
visibility
10 m
T, RH, U
2 m

Remote sensing

cloud base height

Integrated cloud water on the vertical

Martinet et al. (2020)

Turbulence

Deposition measurements

Tav et al. (2018)

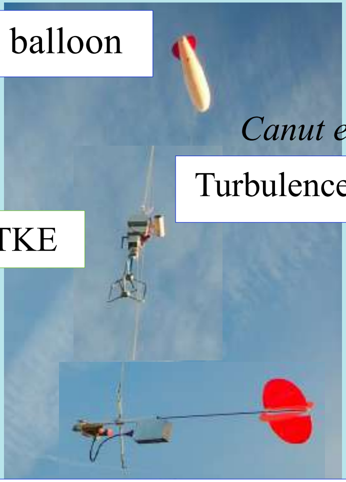
Intensive observation period

Tethered balloon

Canut et al. (2016)

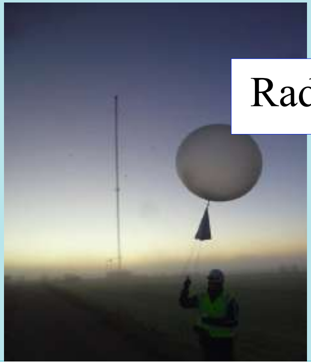
Turbulence probe

T, RH, U, TKE



CDP

Droplet size from 2 to 50 µm in diameter.



Radiosondes

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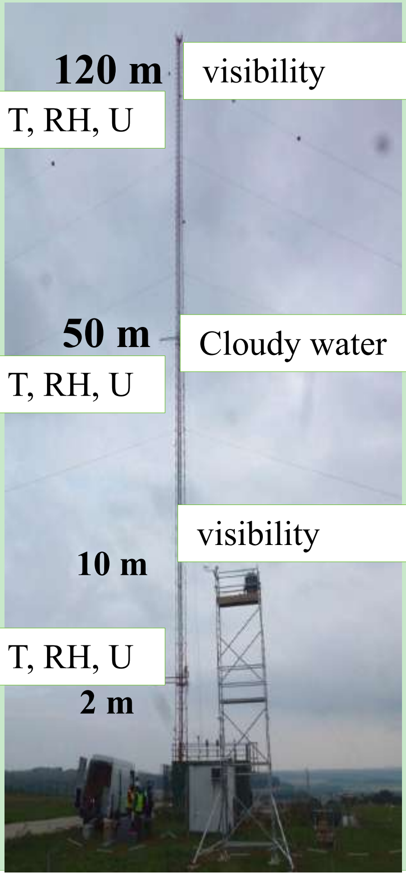

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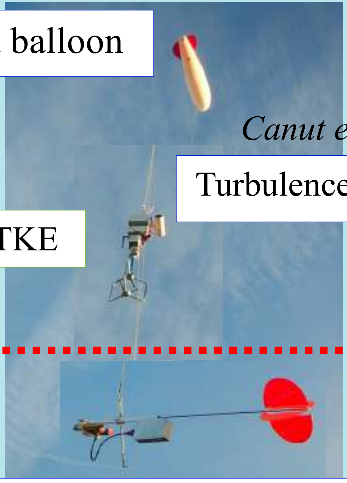

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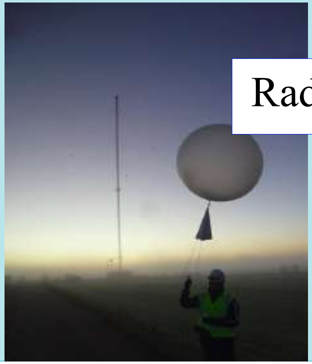
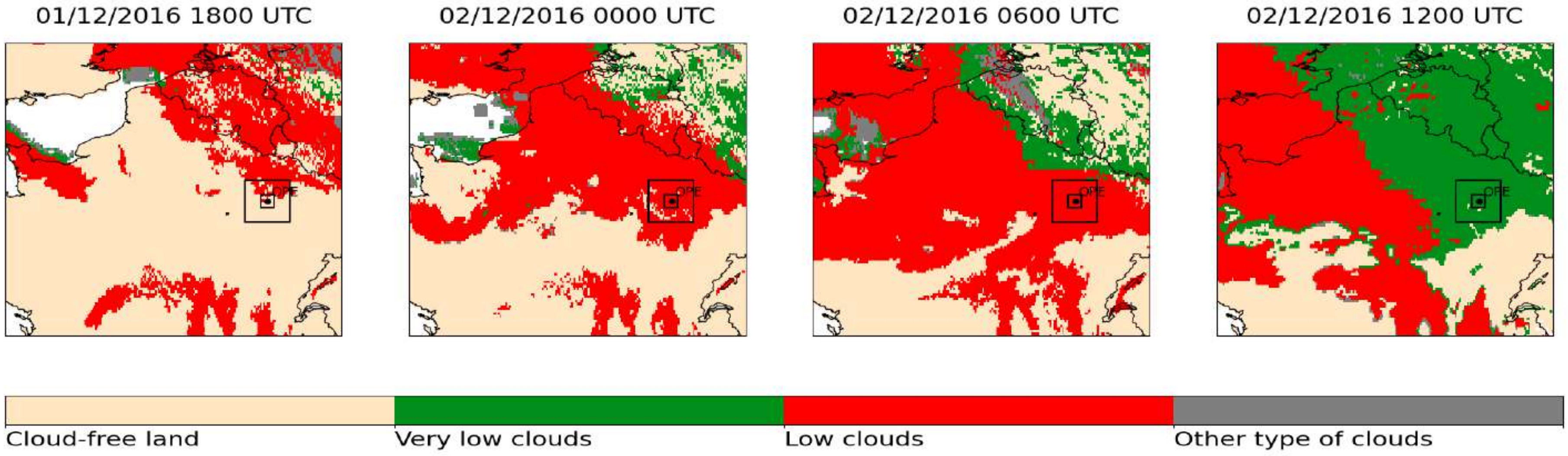


Overview of the case study: IOP2 1st and 2nd December 2016

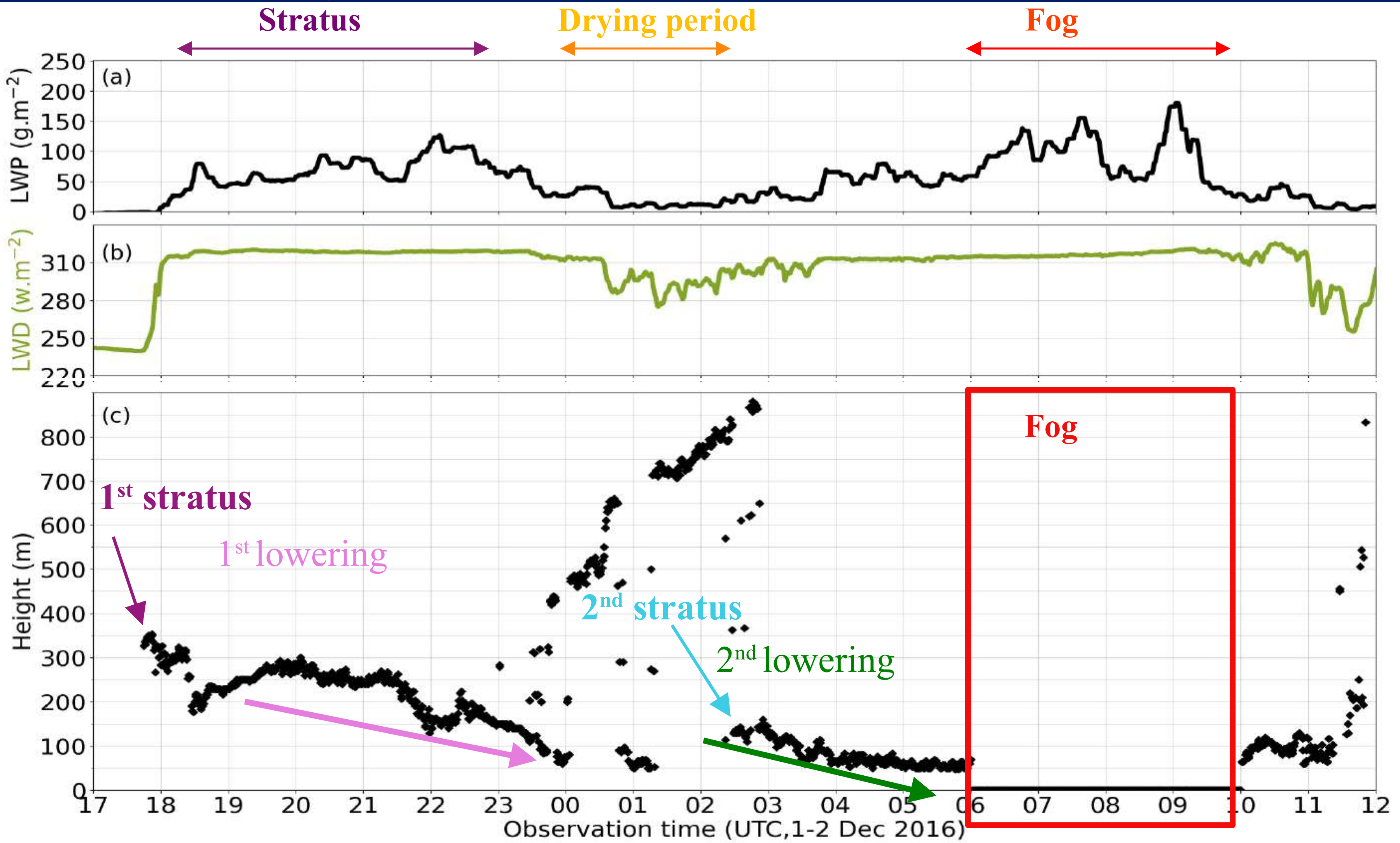
Satellite products

Cloud type



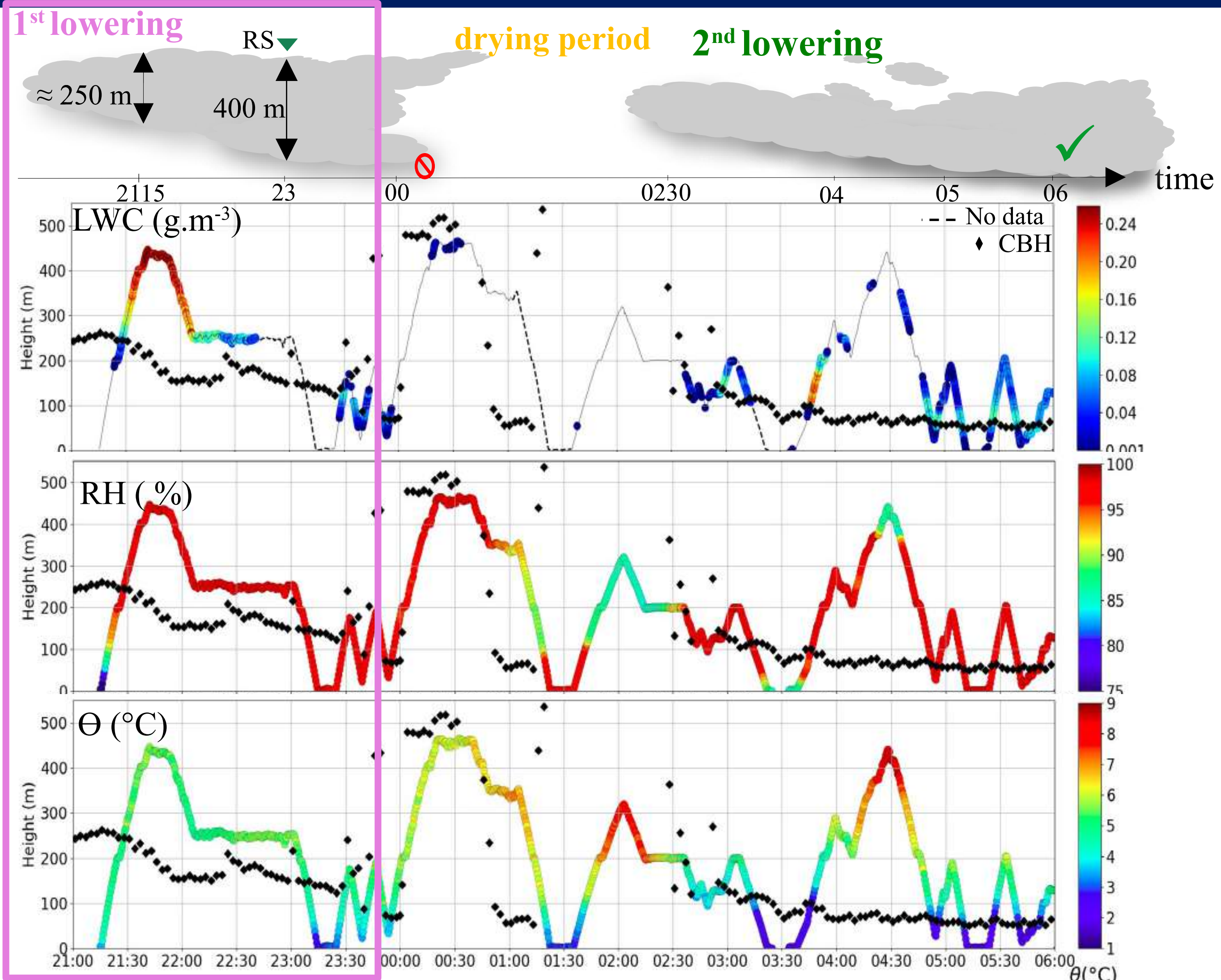
Source (E. Fontaine (CEMS))

Overview of the case study: IOP2 1st and 2nd December 2016



Analysis of stratus lowering

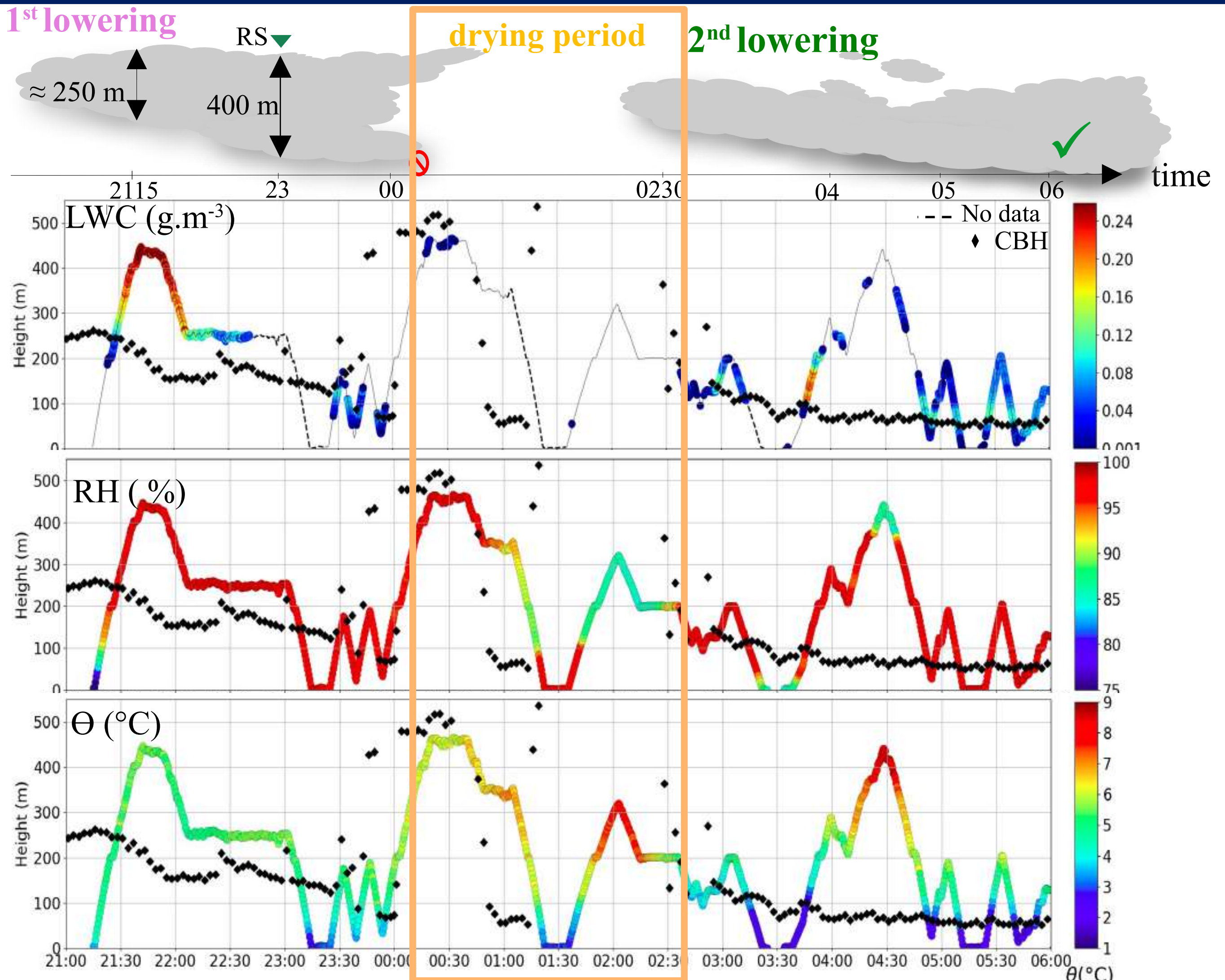
1st lowering



- Humidification ↗
- Cooling ↘

Analysis of stratus lowering

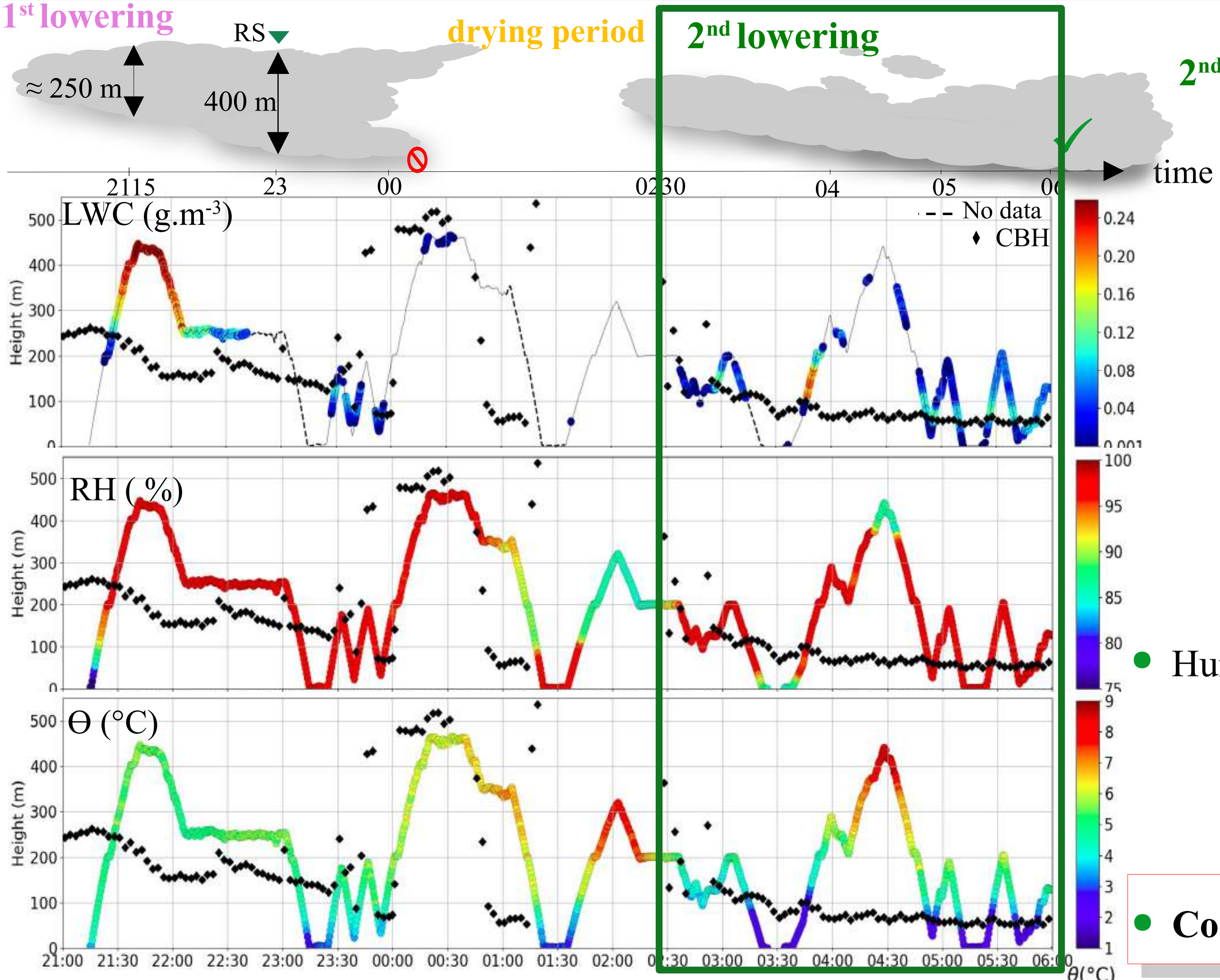
- Dissipation of stratus
- Drying
- Warming



Analysis of stratus lowering

1st lowering

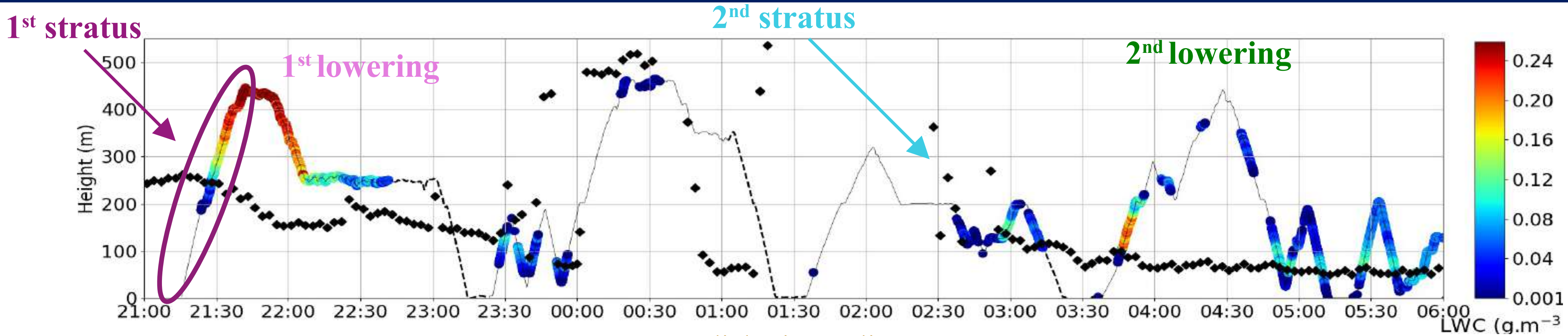
- Humidification
- Cooling



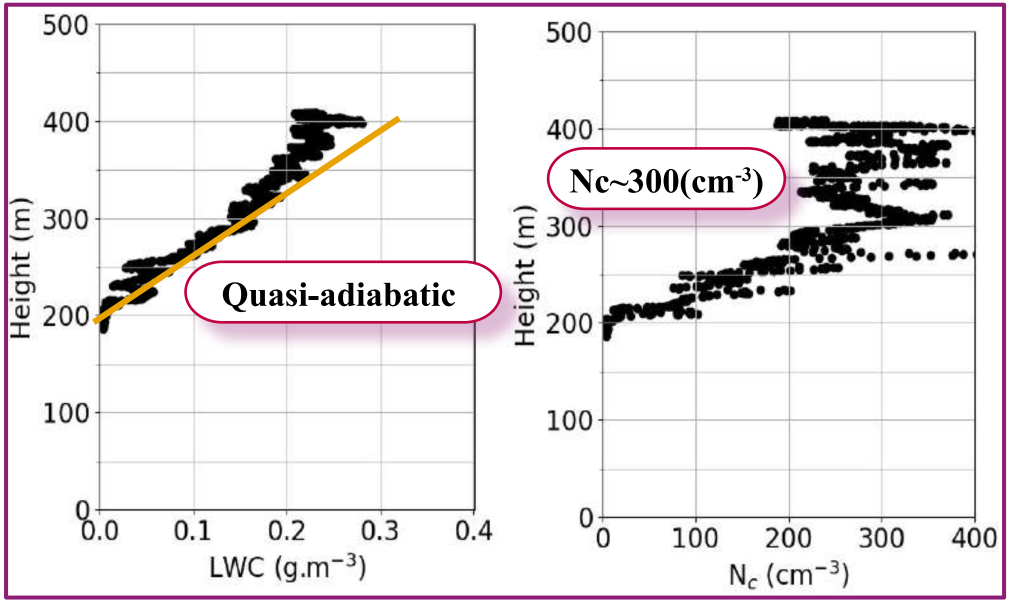
2nd lowering

- Humidification
- **Cooling**

Microphysical properties during lowering



— Adiabatic gradient



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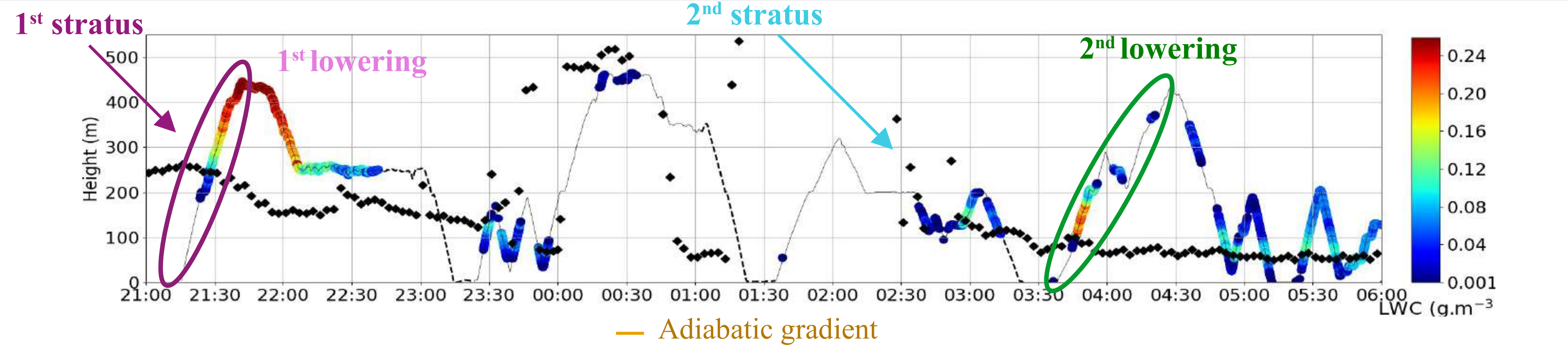

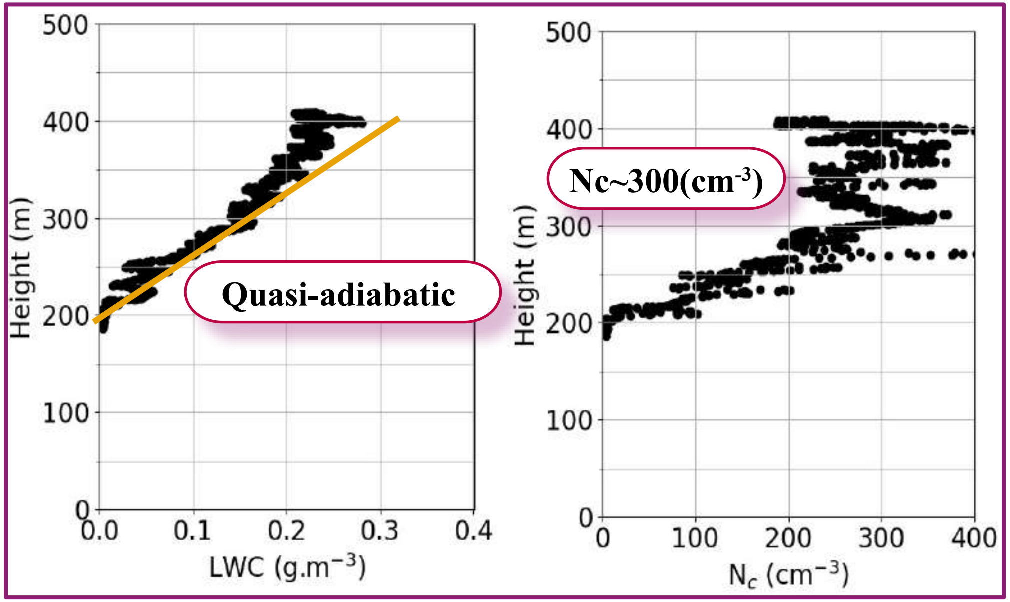

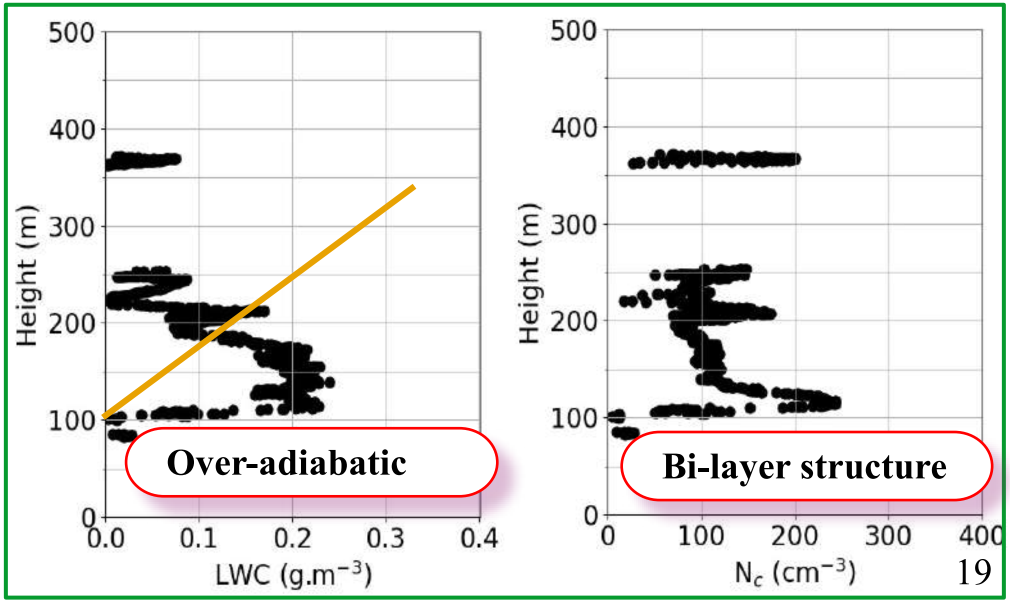

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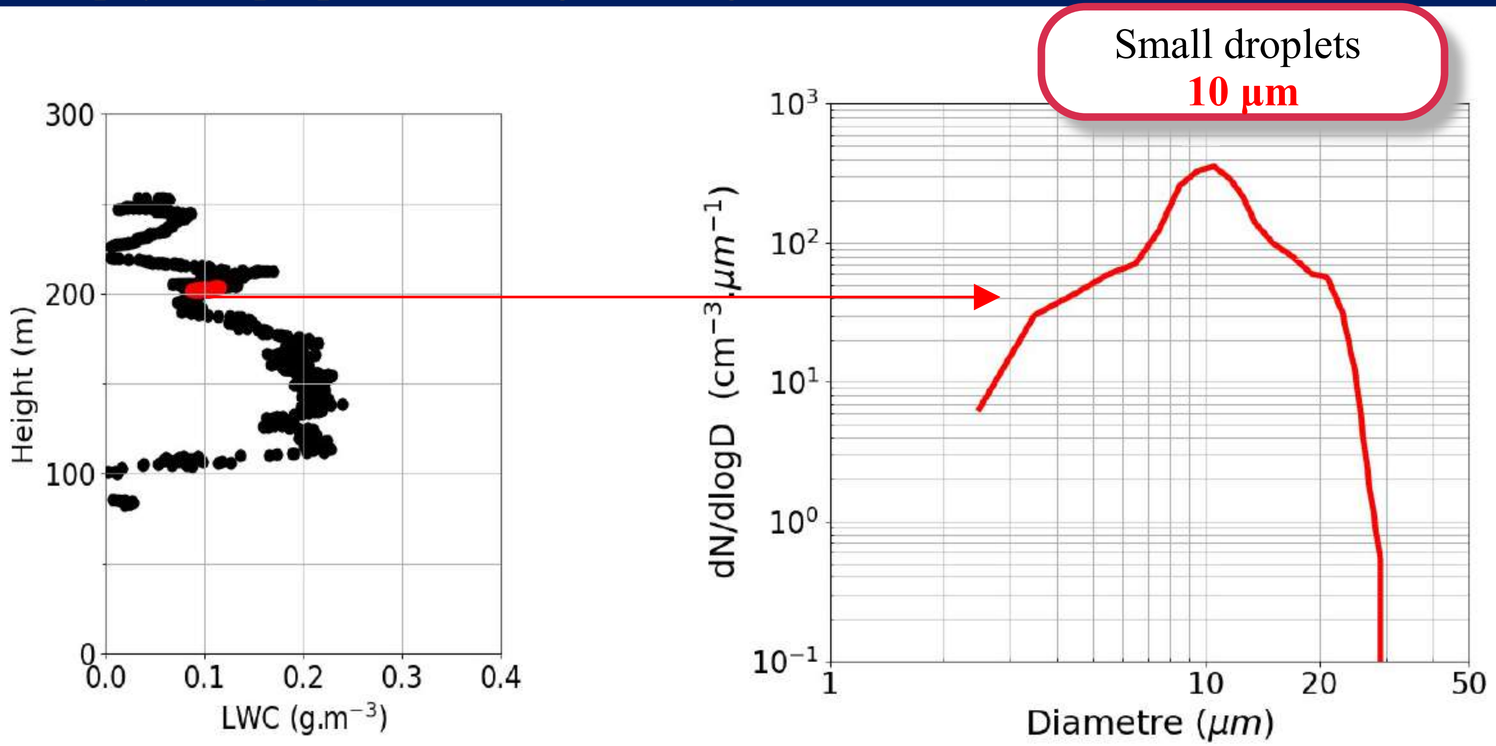

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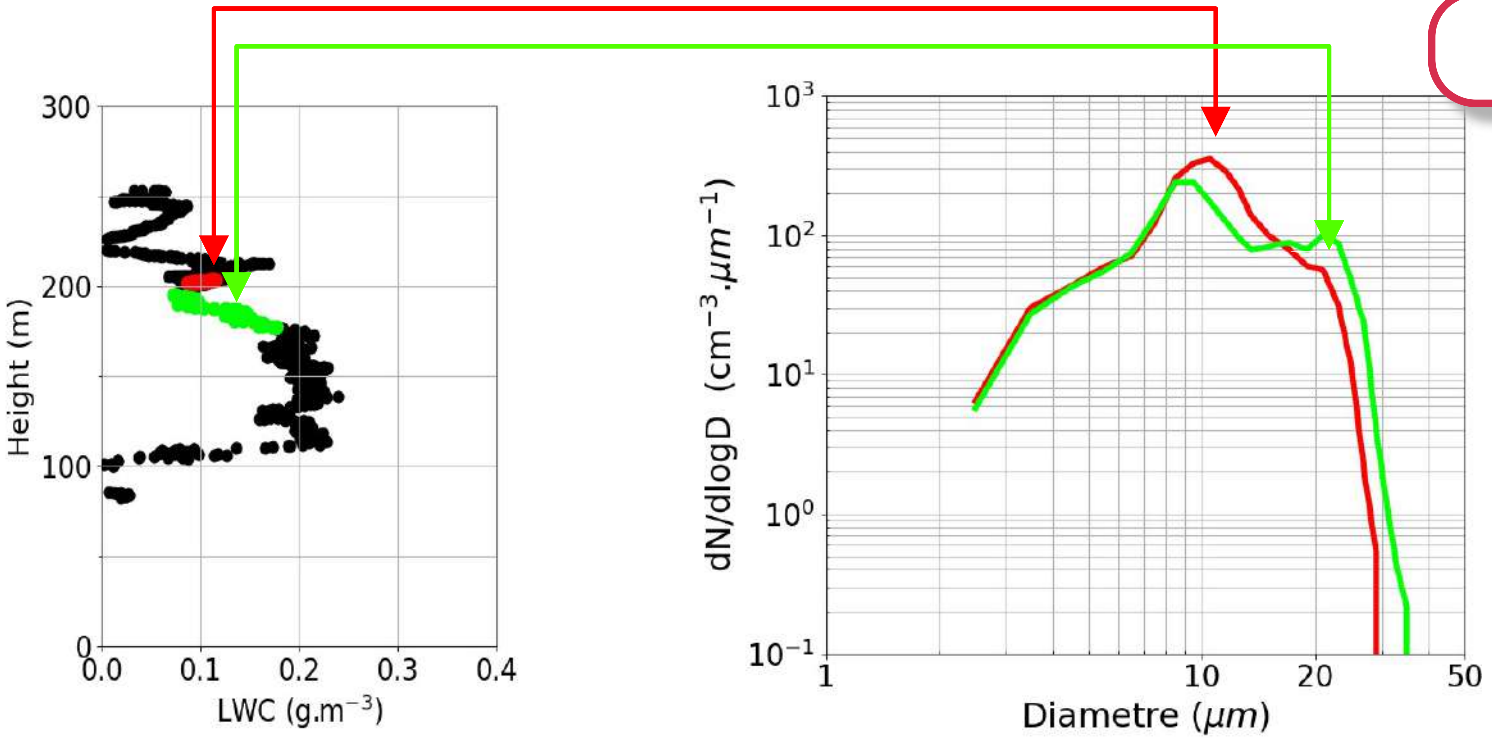
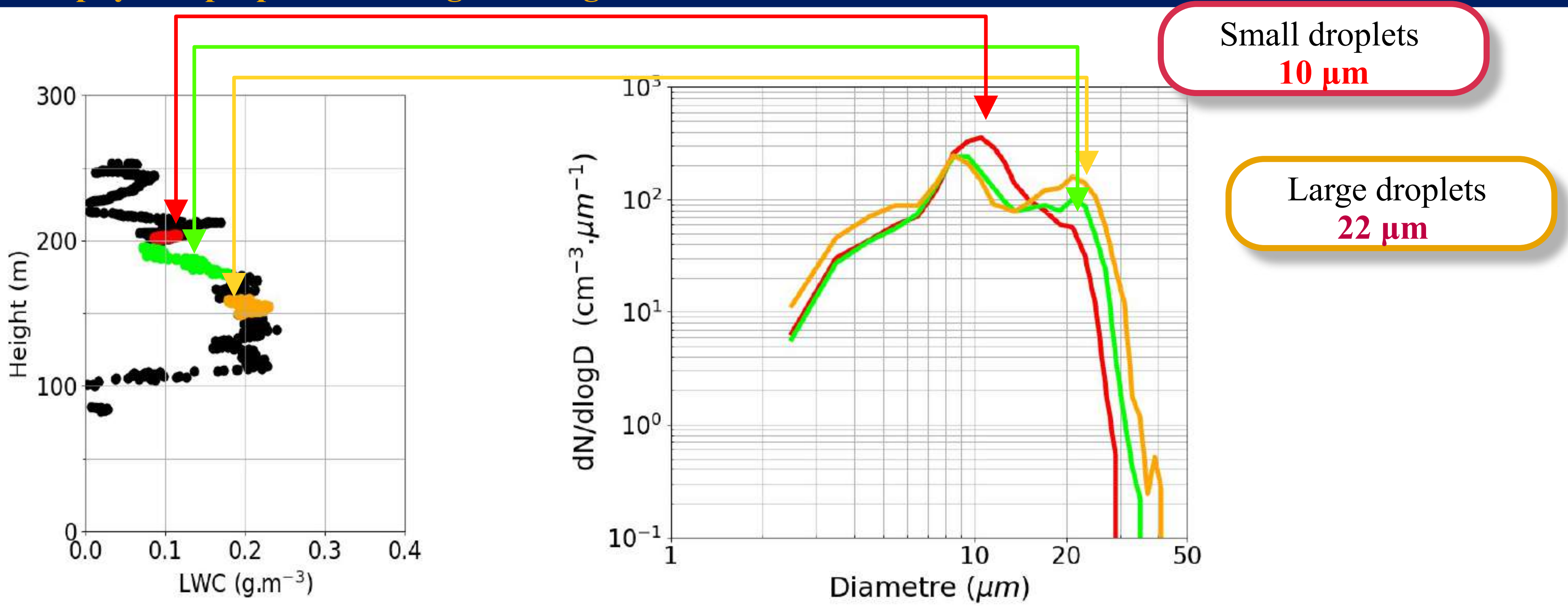


Small droplets
10 µm

Large droplets
22 µm

Microphysical properties during lowering



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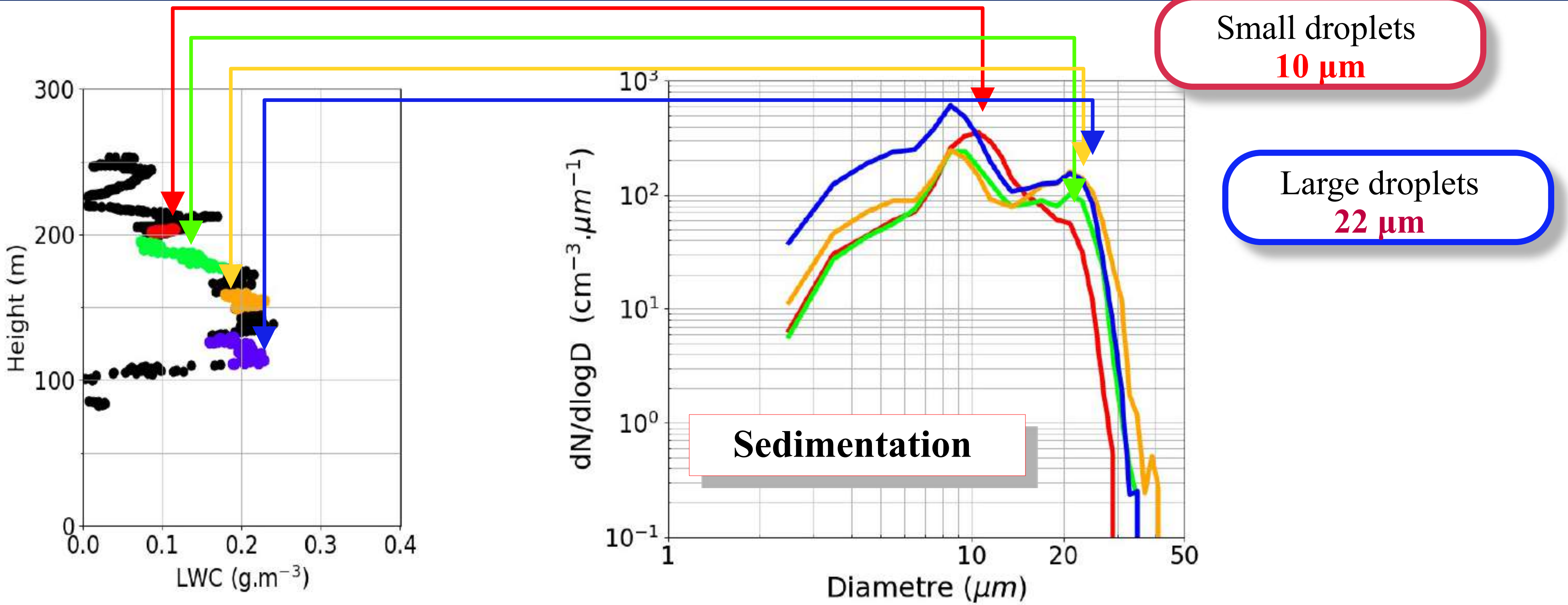

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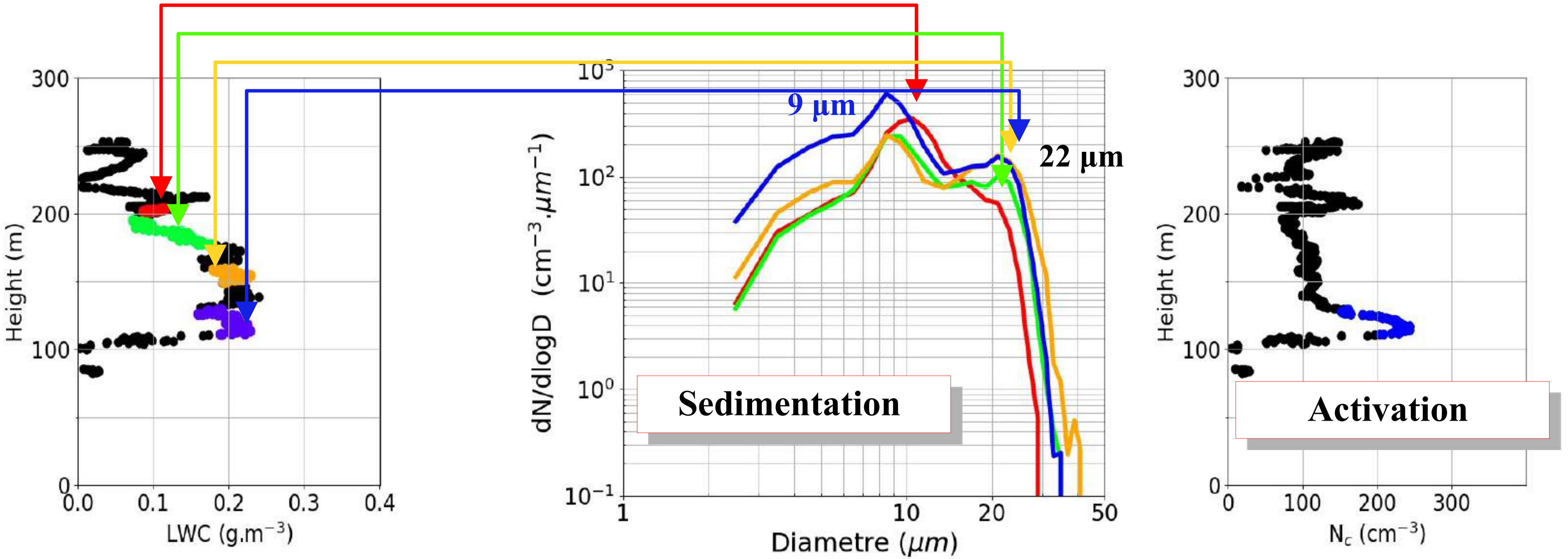
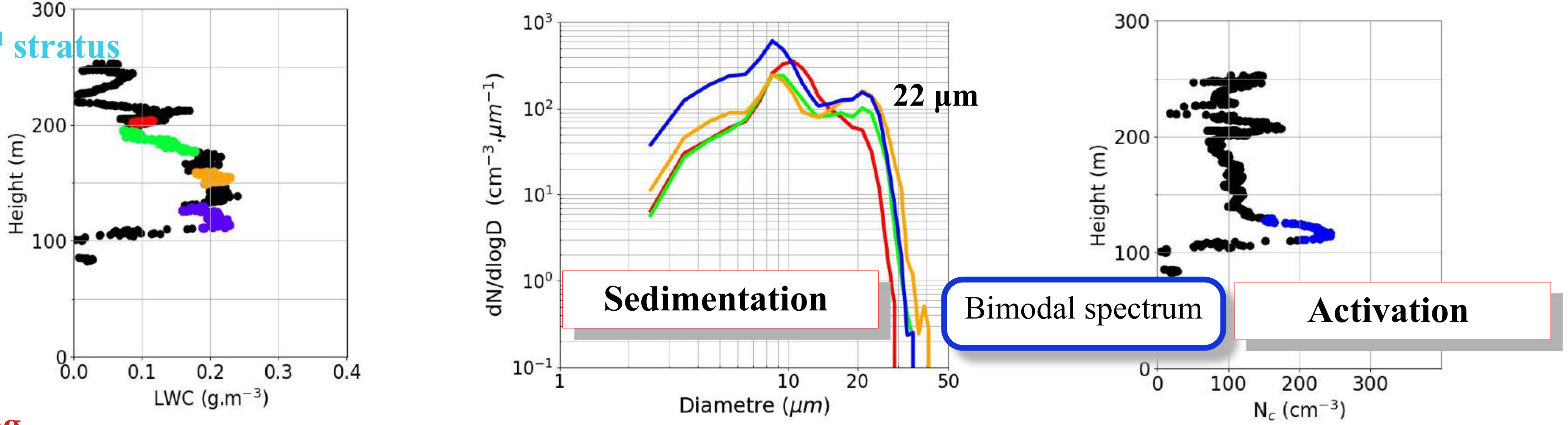
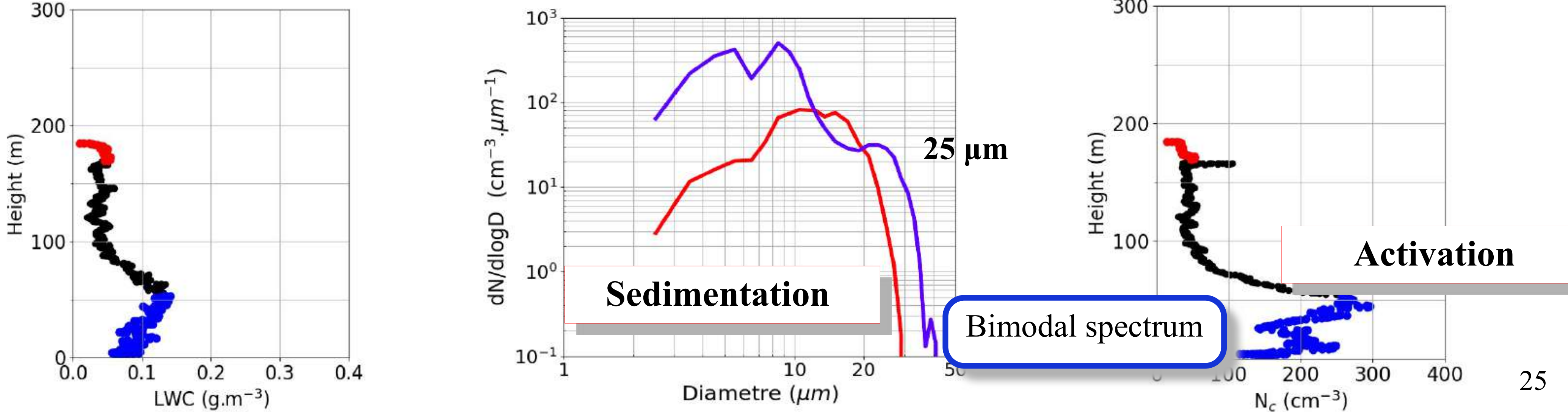


2nd stratus



Fog



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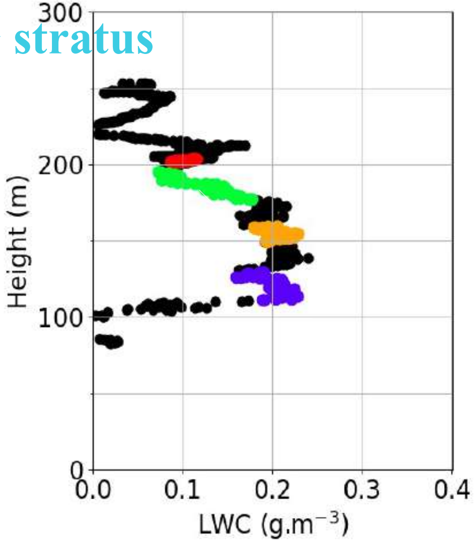
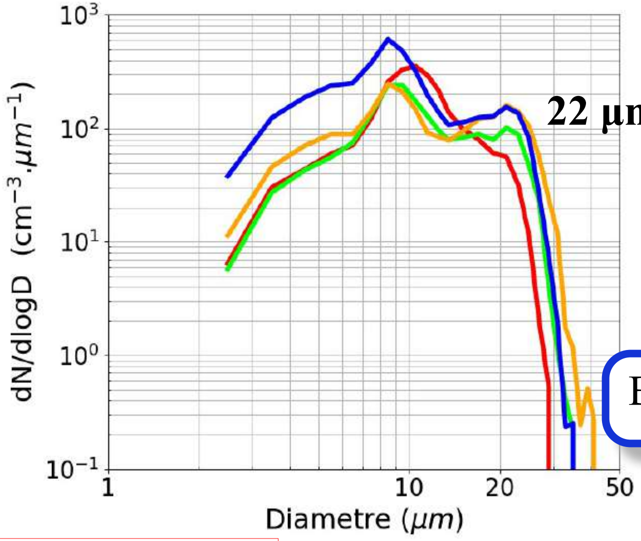
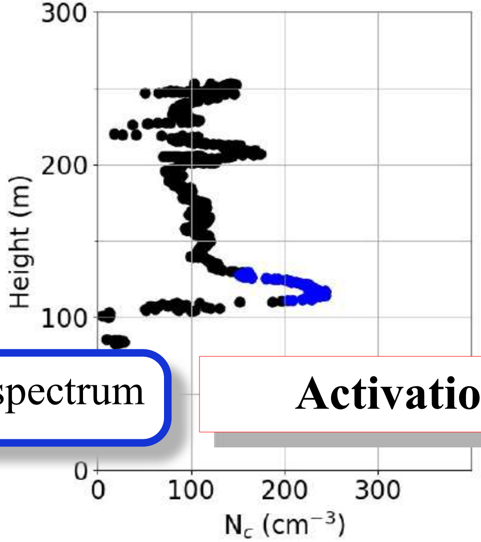




22 µm

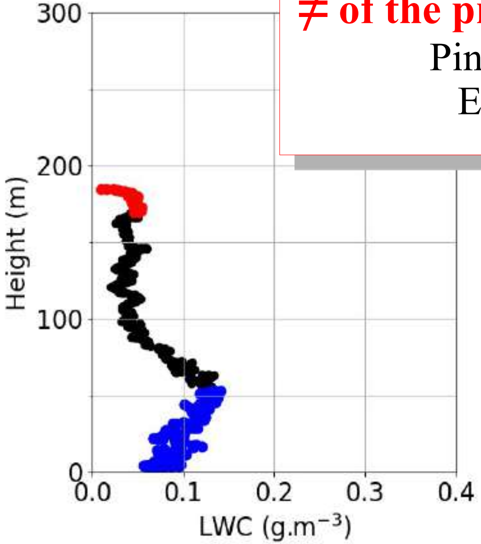
Bimodal spectrum

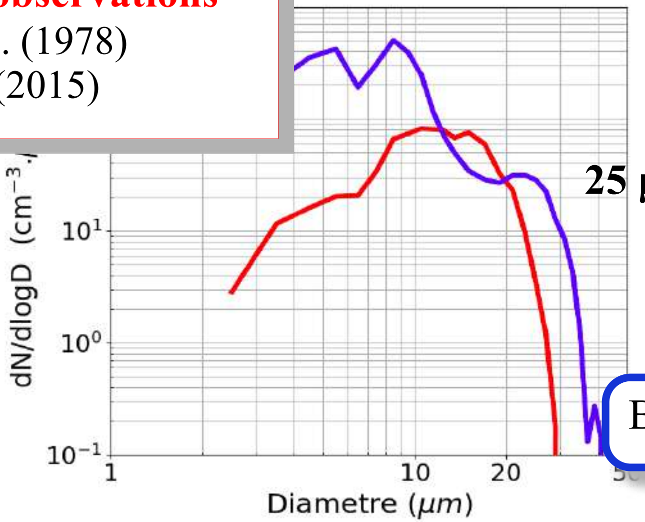


Activation

Fog

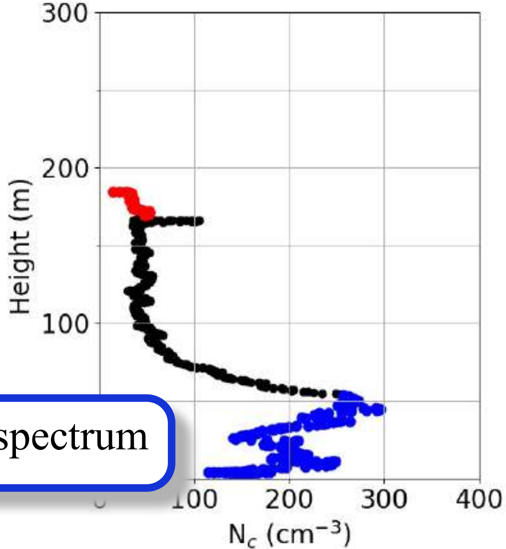
≠ of the previous observations
Pinnick et al. (1978)
Egli et al. (2015)



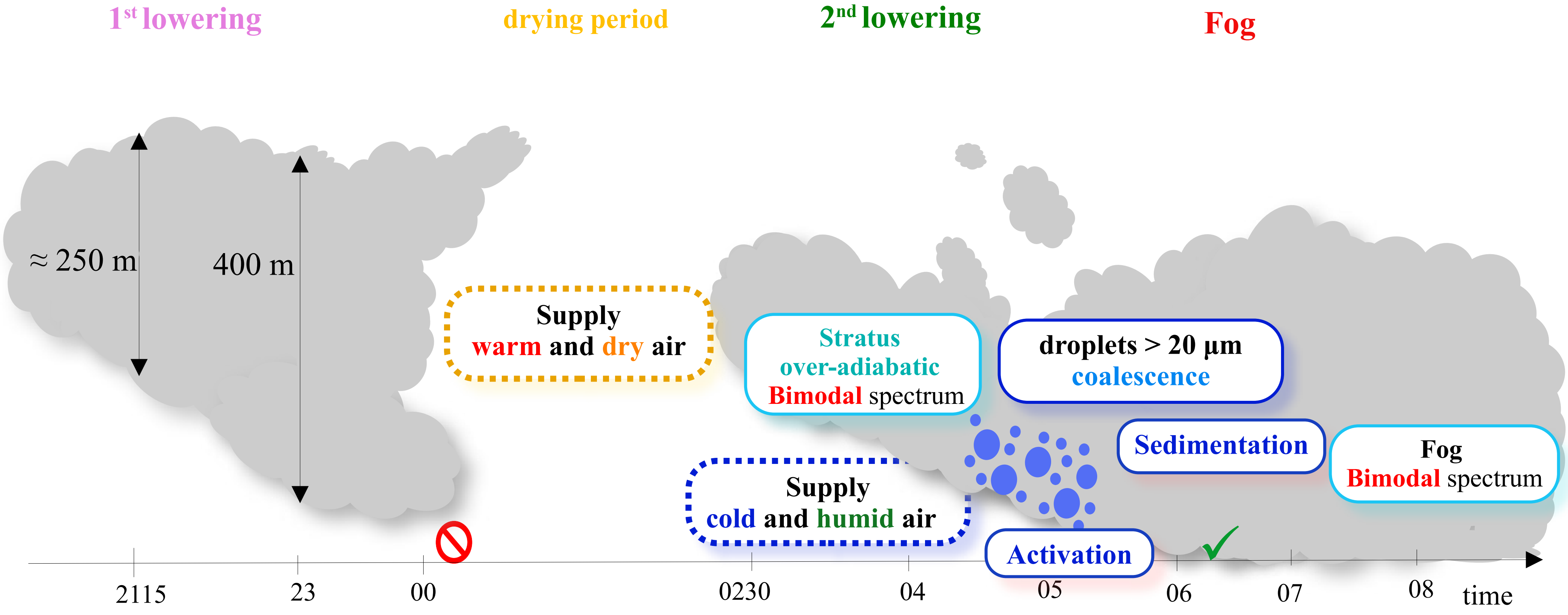


25 µm

Bimodal spectrum



Intermediate conclusion



Burnet et al, in prep

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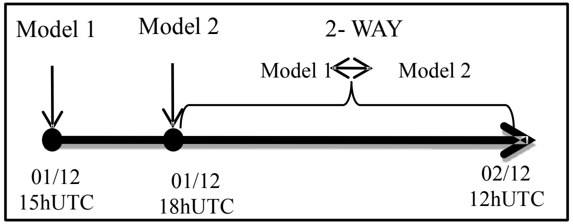
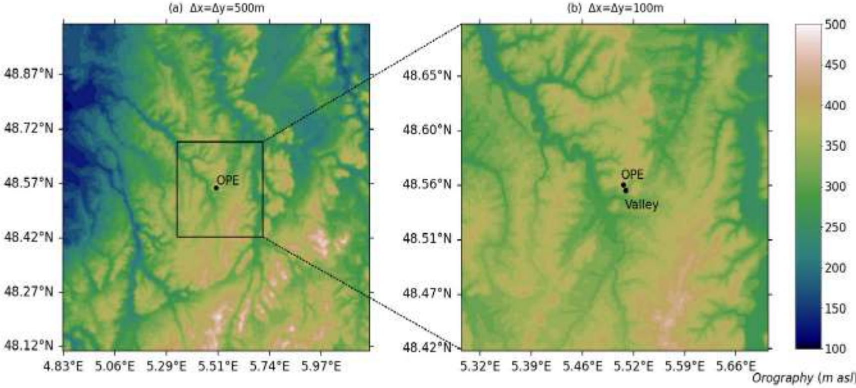
1. Introduction
2. **Experimental** study of **IOP2** (**FSTL** observed December 1 - 2, 2016)
3. **Numerical study of IOP2**
4. Conclusion and perspectives

Reference simulation with Meso-NH and LIMA at high resolution

- Horizontal grid resolution: 500 m et 100 m with two-way nested grids.
- 150 vertical levels : 0 to 3250 (from Δz = 1.5 to 50 m)
- Initial/coupling: AROME analysis.(1.3 km)

IOP 2 (BURE) - 1st and 2nd December 2016



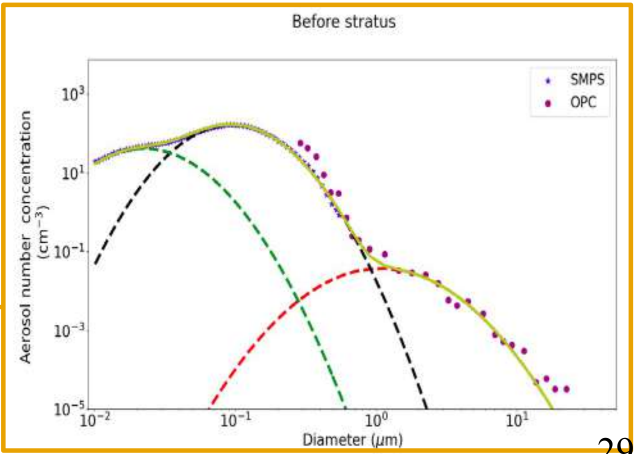


- Turbulence :
  1D at Δx=500m and mixing length **BL89**
  3D at Δx=100m and mixing length **DEAR**

  Prognostic equation for (Cuxart et al, 2000)

- Microphysics: **LIMA** (two-moment scheme)
- LIMA with modified activation according to Vié et al. (2022)

▪ Aerosol initialization from ground aerosol measurements (3 modes).
▪ Constant aerosol concentrations over the vertical.

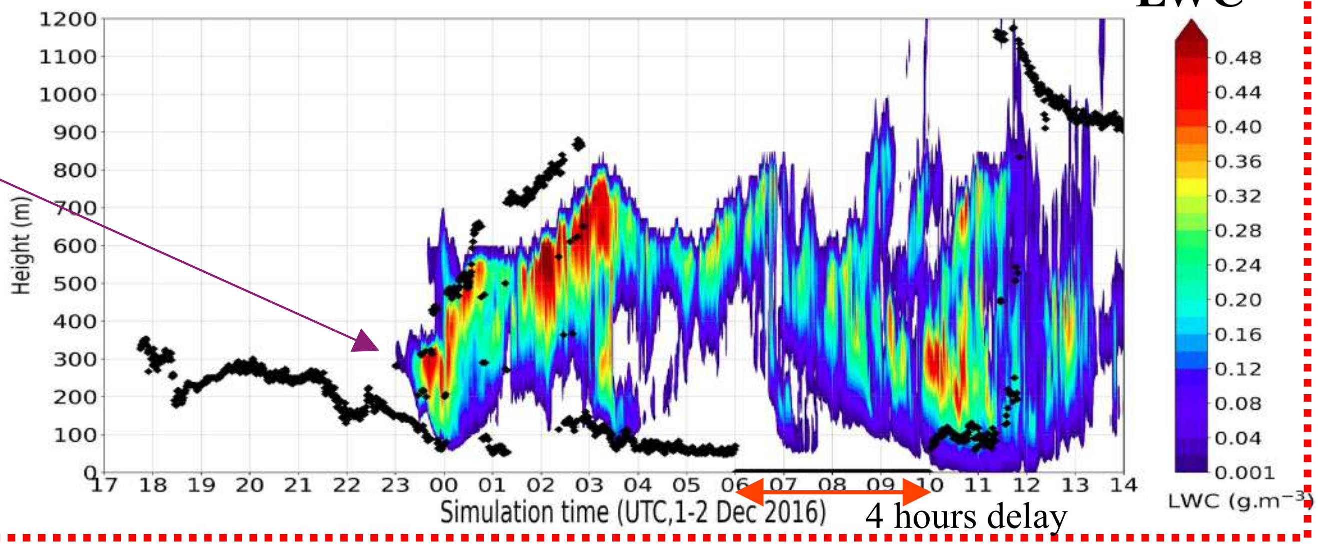


Validation of the reference simulation

OPE **CBH**

Stratus formation at **23** UTC instead of **18** UTC in the observations

Reference simulation



Delay of a few hours between the simulation and the observations.

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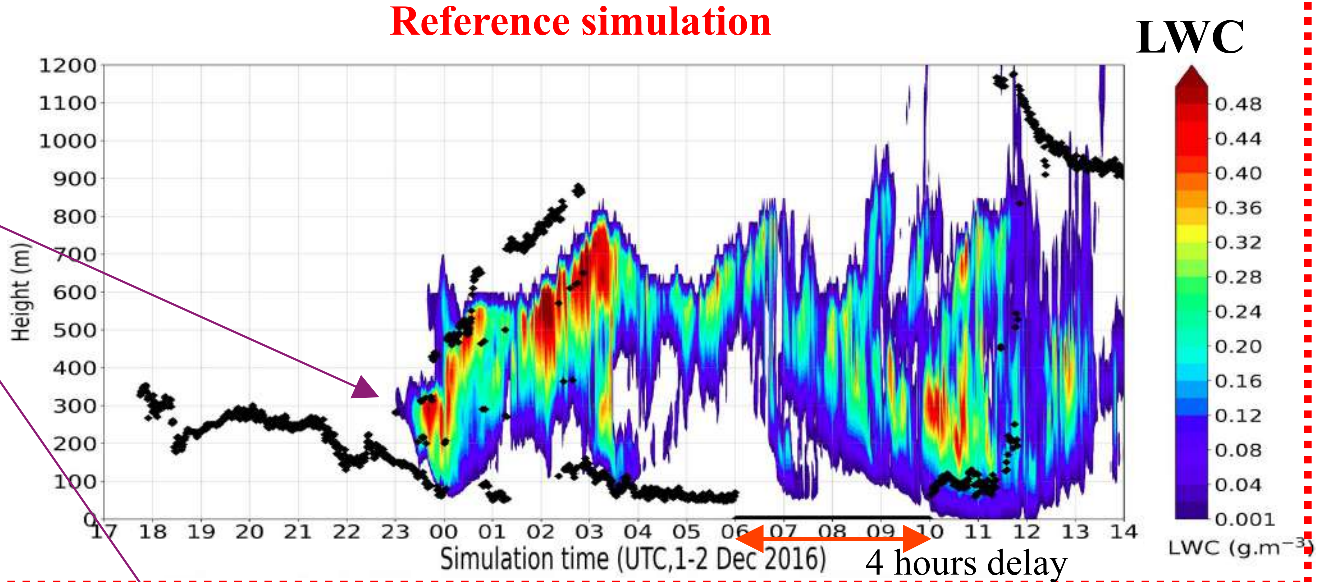

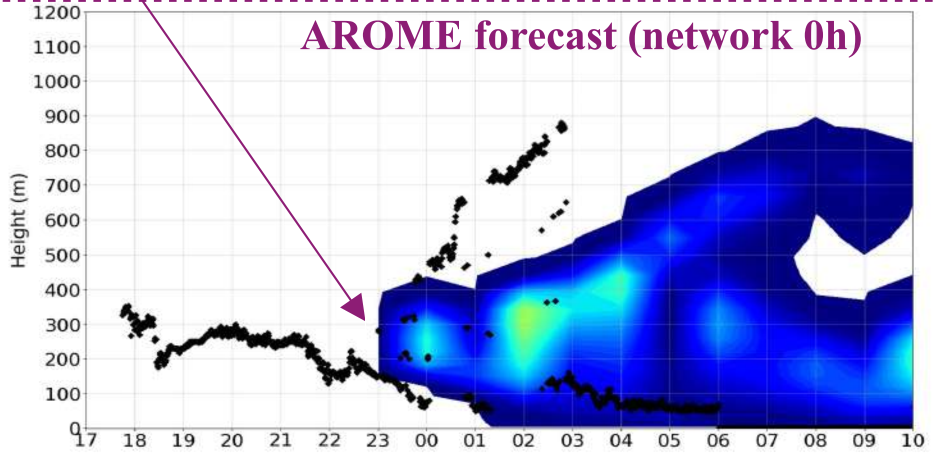

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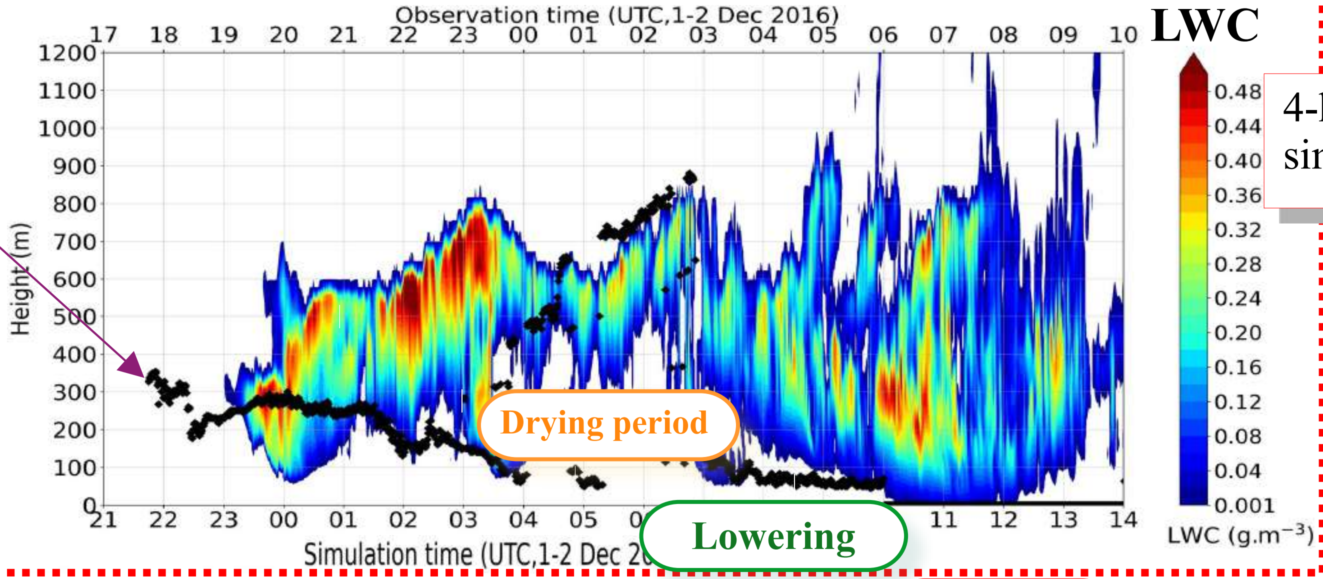
Validation of the reference simulation

OPE CBH

Stratus



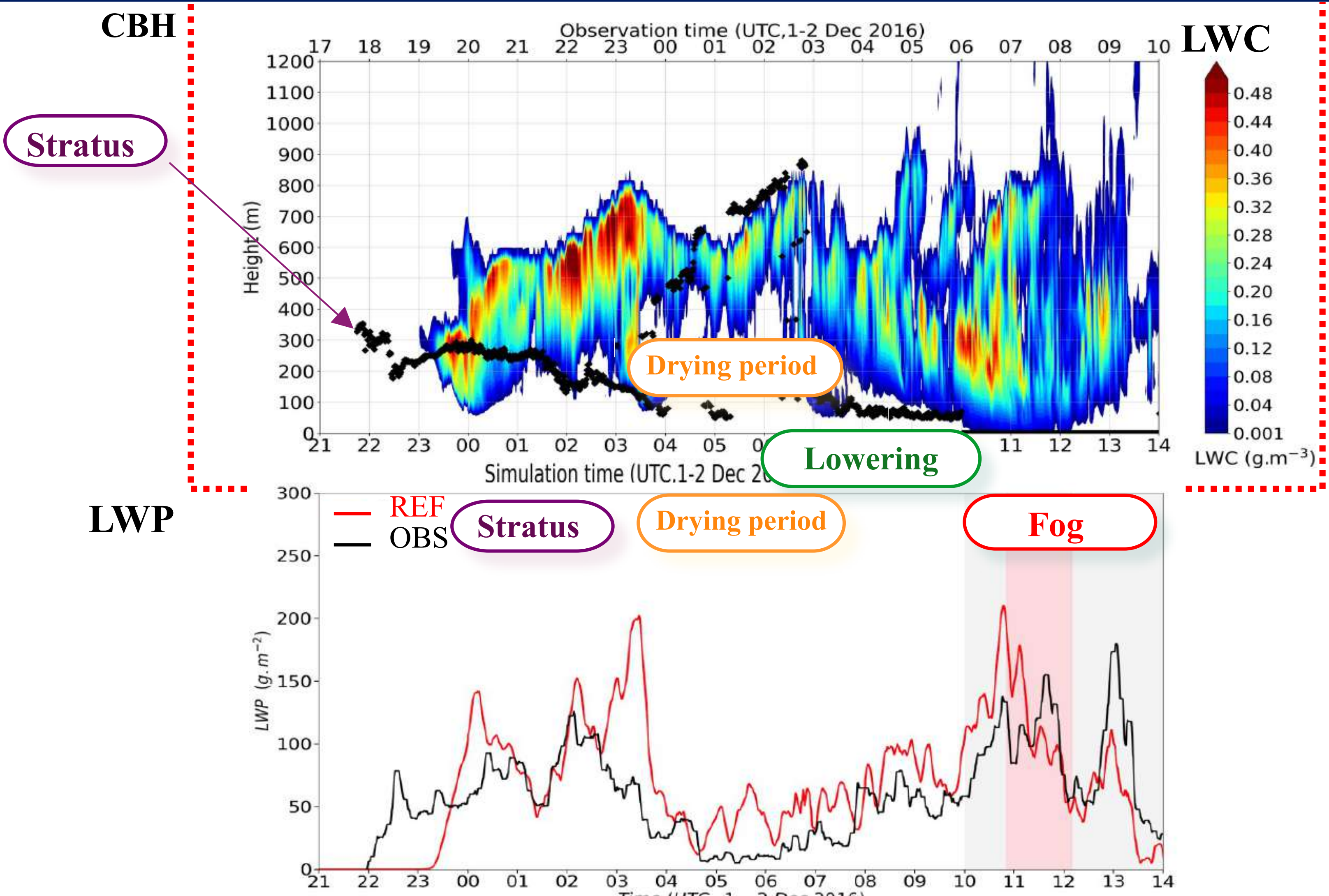
4-hour delay in the simulation

Fog

Validation of the reference simulation

OPE **CBH** **LWC**

LWP



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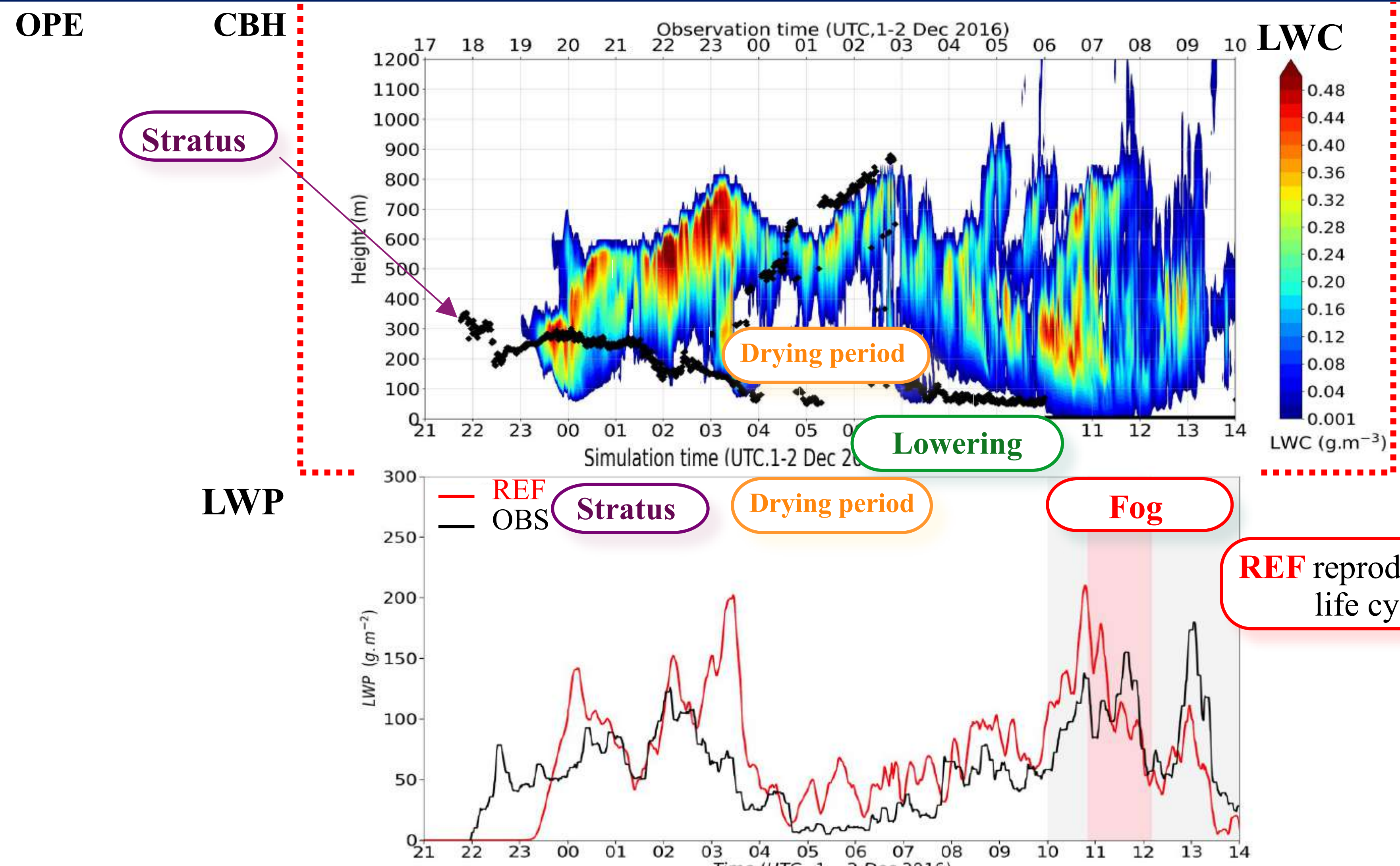
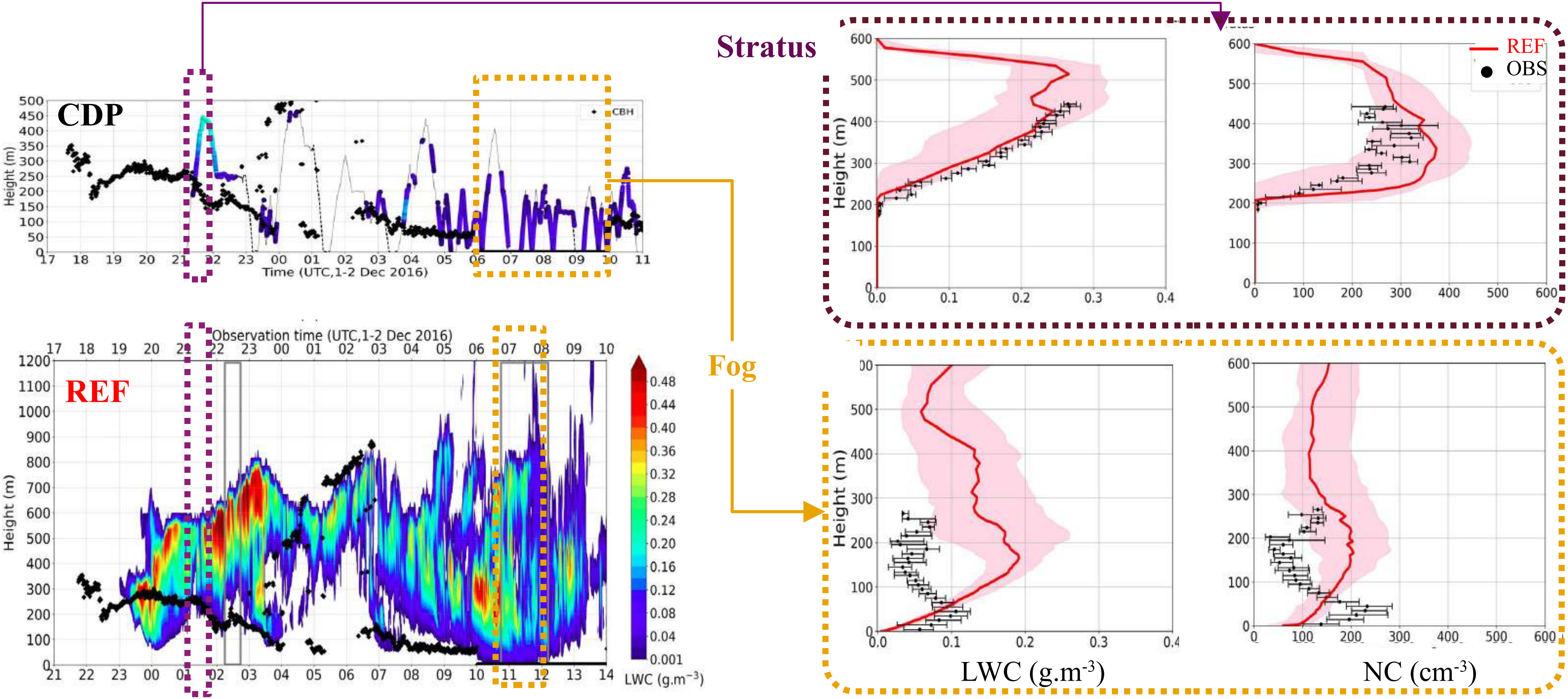


REF reproduces well the cloud life cycle (3 phases)

Validation of the reference simulation

Measurements with CDP under the tethered balloon

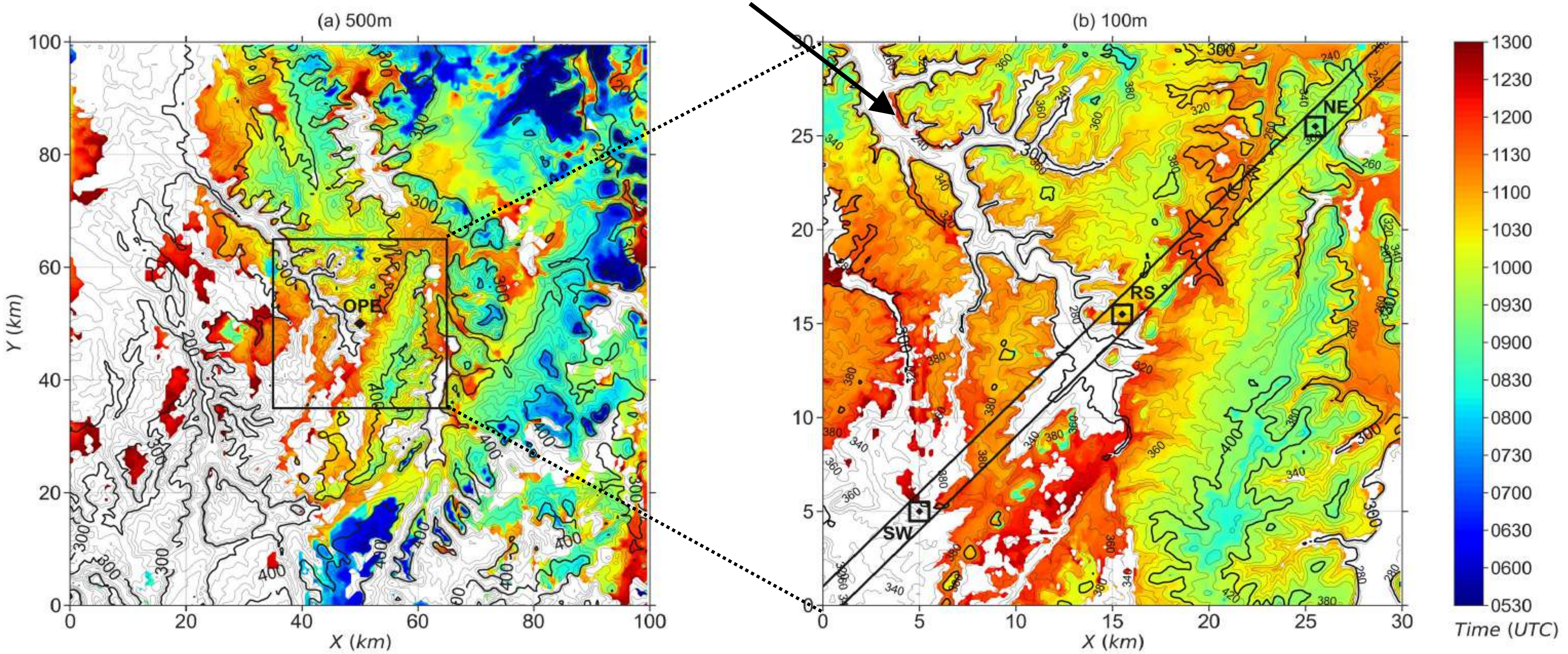


Differences between stratus and fog **fairly well reproduced**

Horizontal representation of stratus lowering

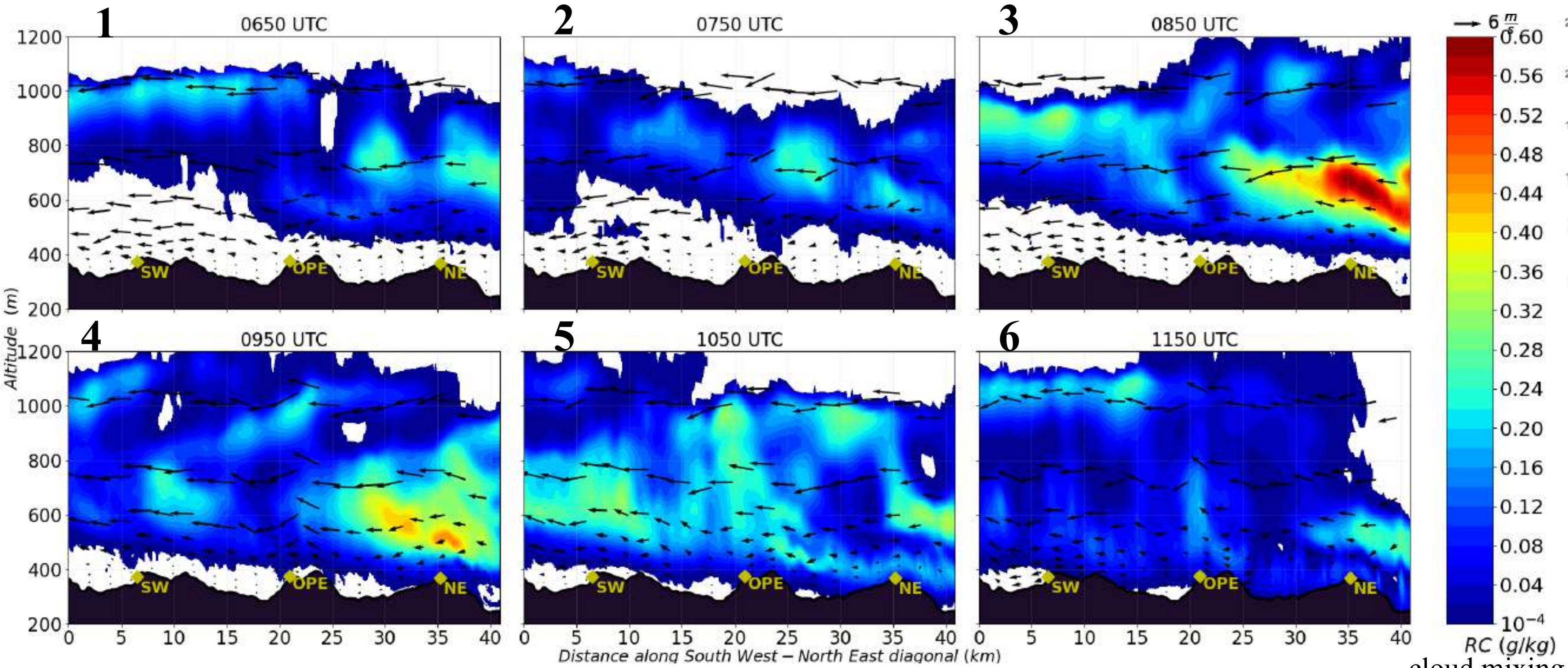
Hour fog formation

without fog

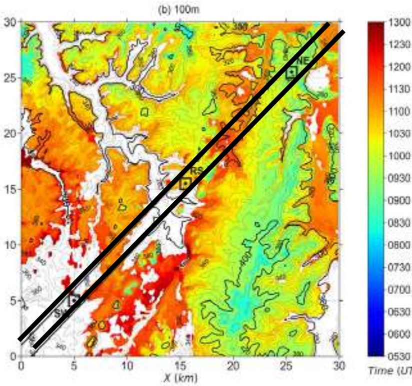


- Effect of advection (northeast to southwest).
- Effect of orography: late or no fog in the valleys.

Vertical representation of stratus lowering



cloud mixing ratio



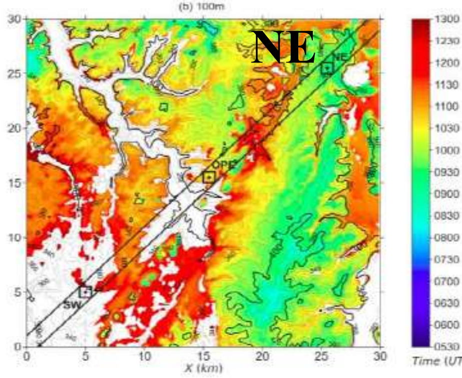
Alt_NE
Alt_OPE
Alt_SW
} = 380 m

Advection of stratus from northeast to southwest. .
Lowering: 1: NE, 2 : OPE, 3 : SW.

- Stratus progressively **thicker**.

Analysis of stratus cloud lowering

Budgets to better characterize the processes leading to stratus lowering



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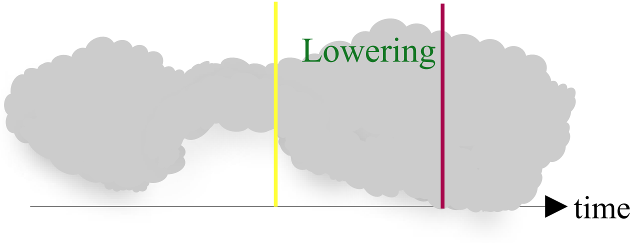
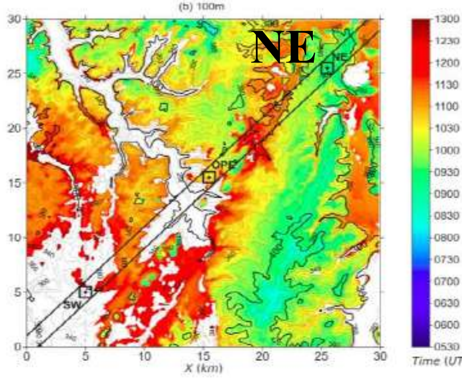
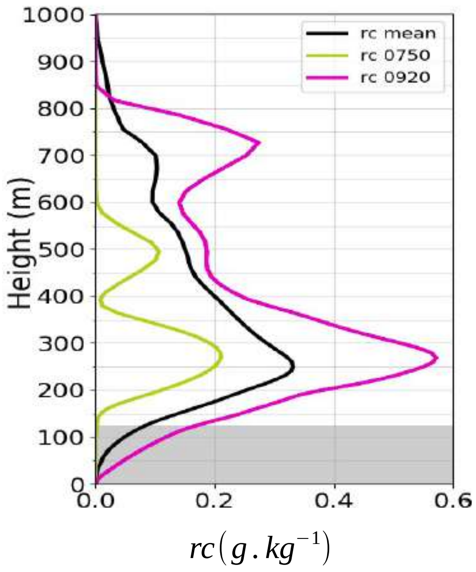




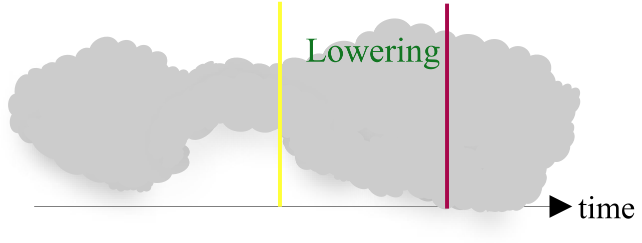


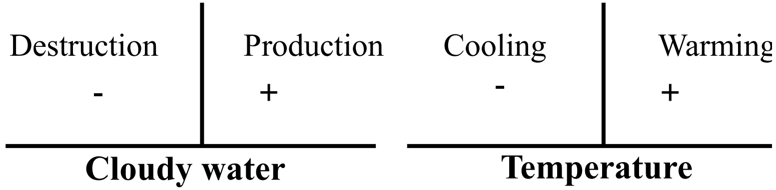
NE

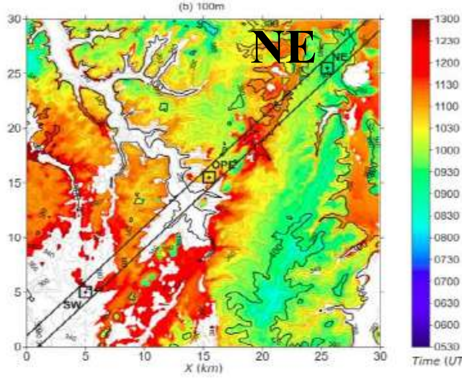
0750 UTC - 0920 UTC

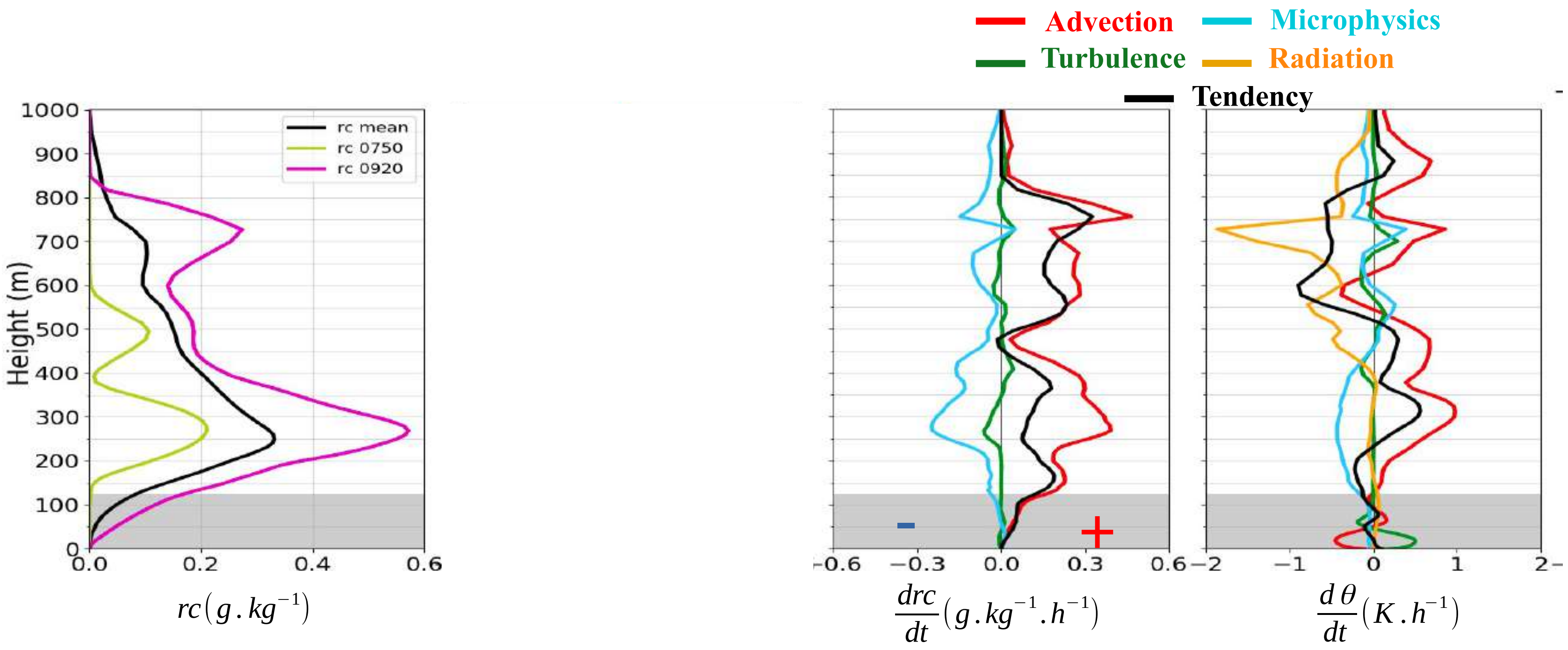
Analysis of stratus cloud lowering

Budgets to better characterize the processes leading to stratus lowering









NE
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Analysis of stratus cloud lowering

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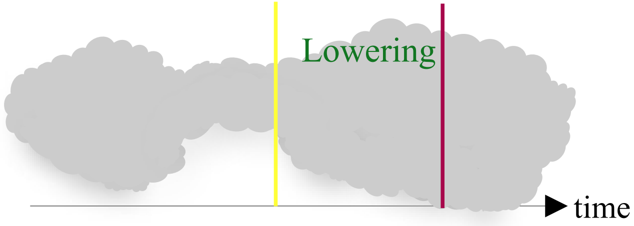
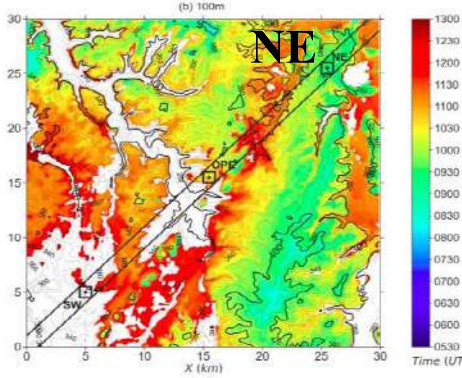
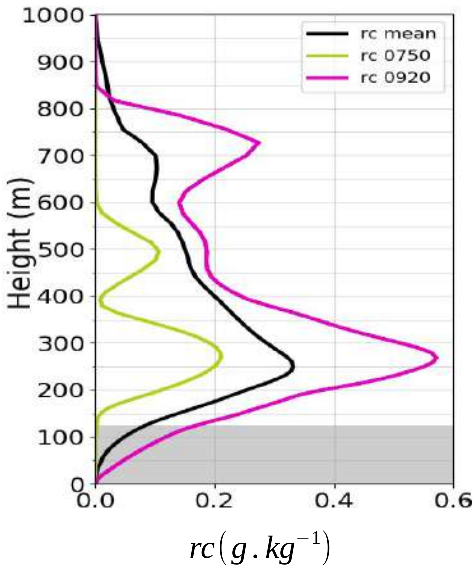
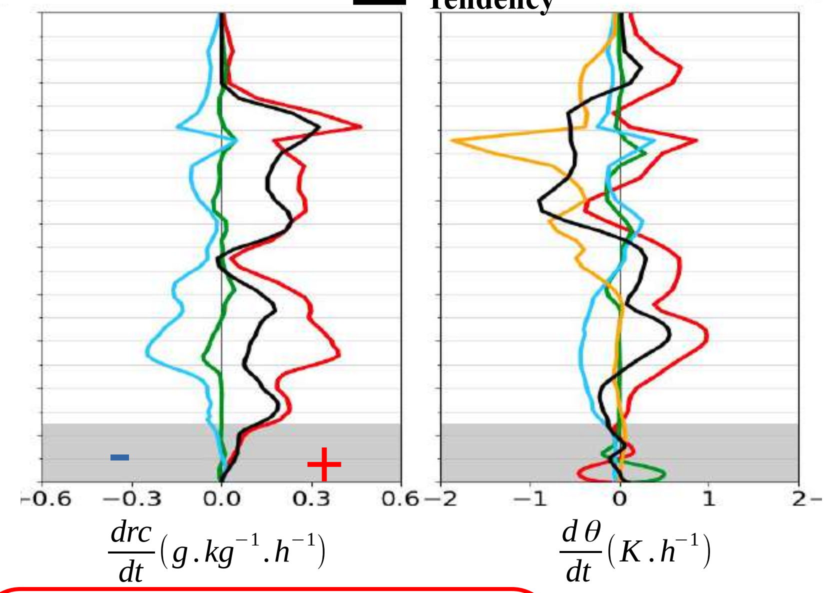




Destruction	Production	Cooling	Warming
-	+	-	+
Cloudy water		**Temperature**	

Advection **Microphysics**
Turbulence **Radiation**
Tendency



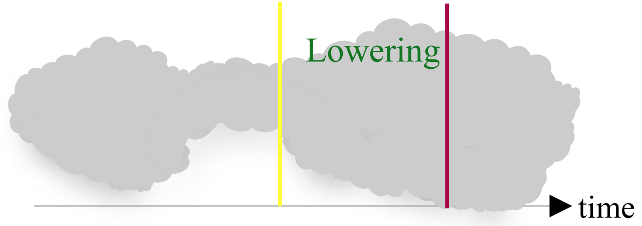


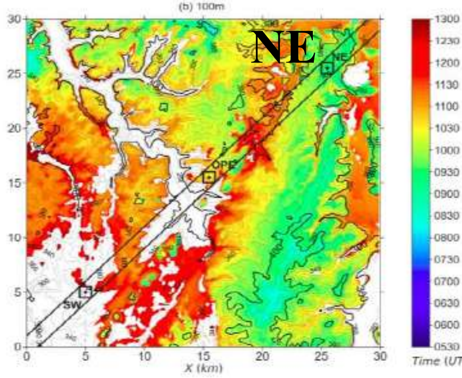
NE
0750 UTC - 0920 UTC

Advection of cloudy water

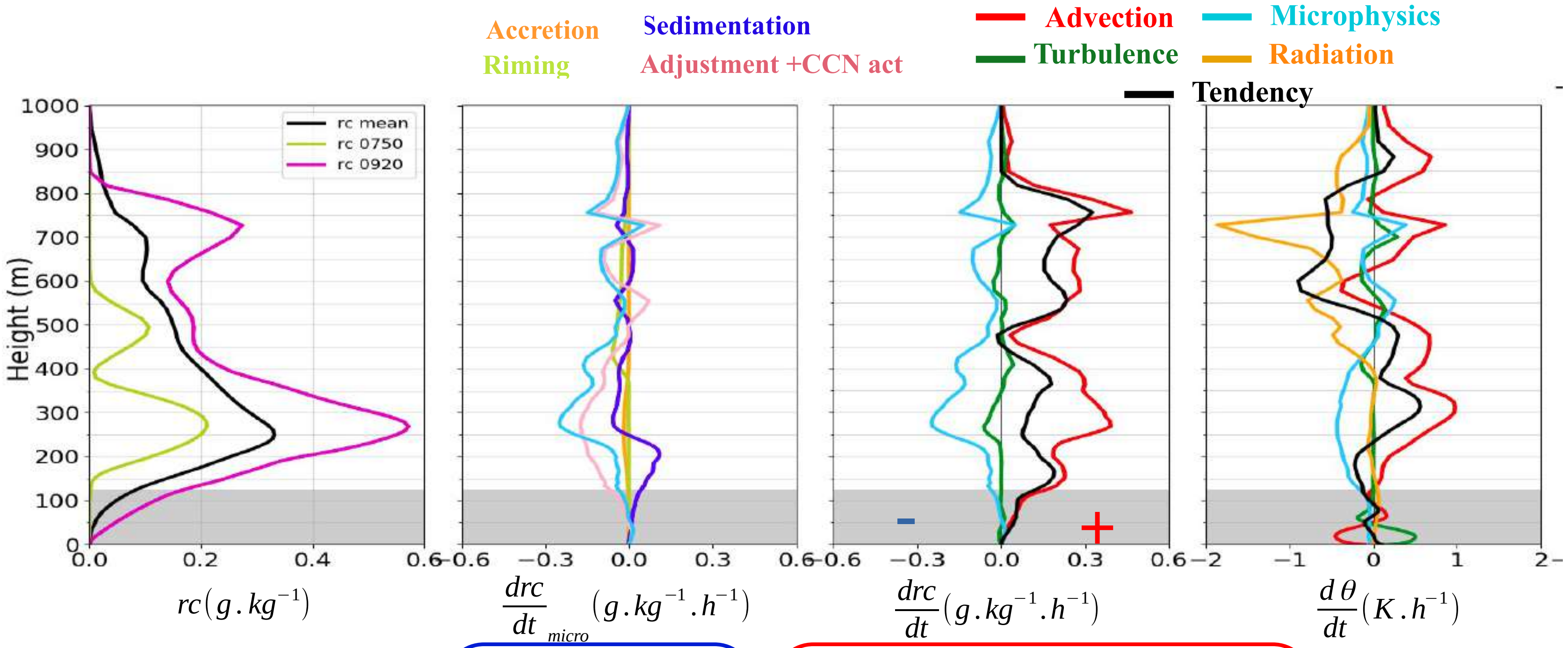
Analysis of stratus cloud lowering

Budgets to better characterize the processes leading to stratus lowering





Destruction	Production	Cooling	Warming
-	+	-	+
Cloudy water		**Temperature**	

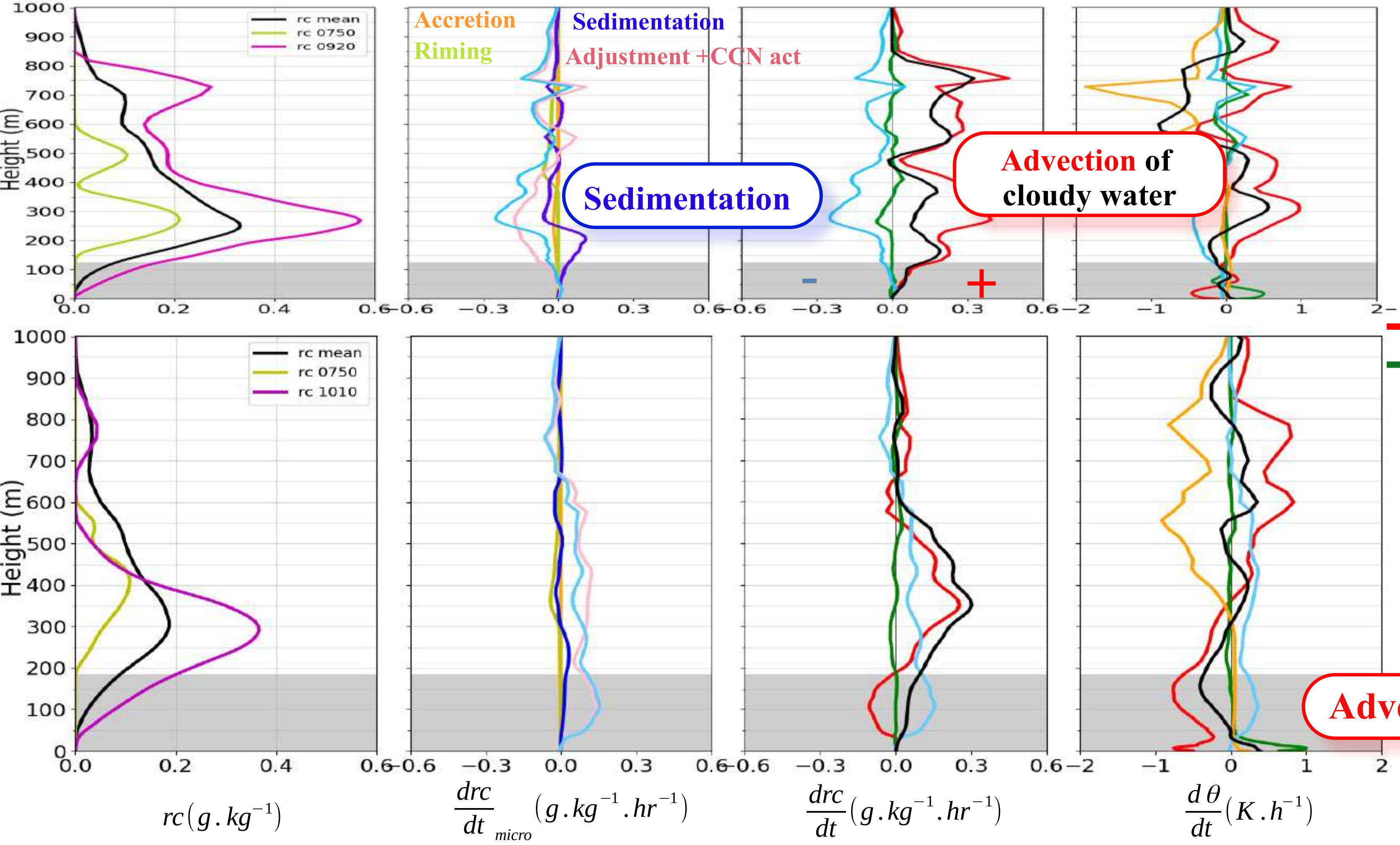


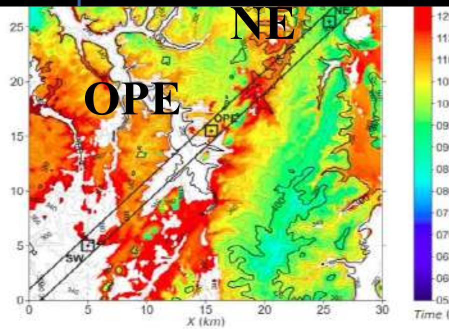
NE
0750 UTC - 0920 UTC

Sedimentation

Advection of cloudy water

Budgets to better characterize the processes leading to stratus lowering

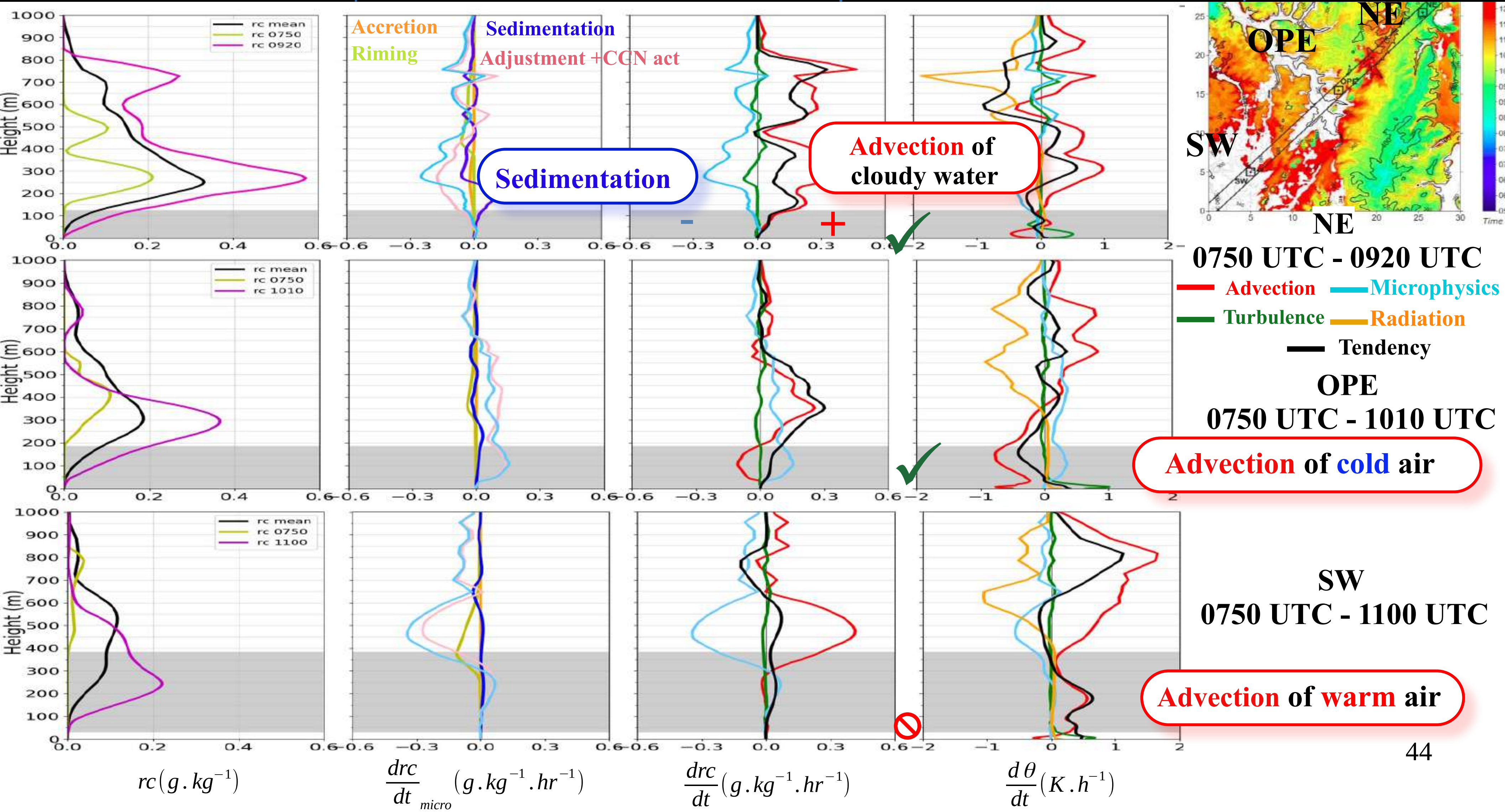




NE
0750 UTC - 0920 UTC

Advection
Microphysics
Turbulence
Radiation
Tendency

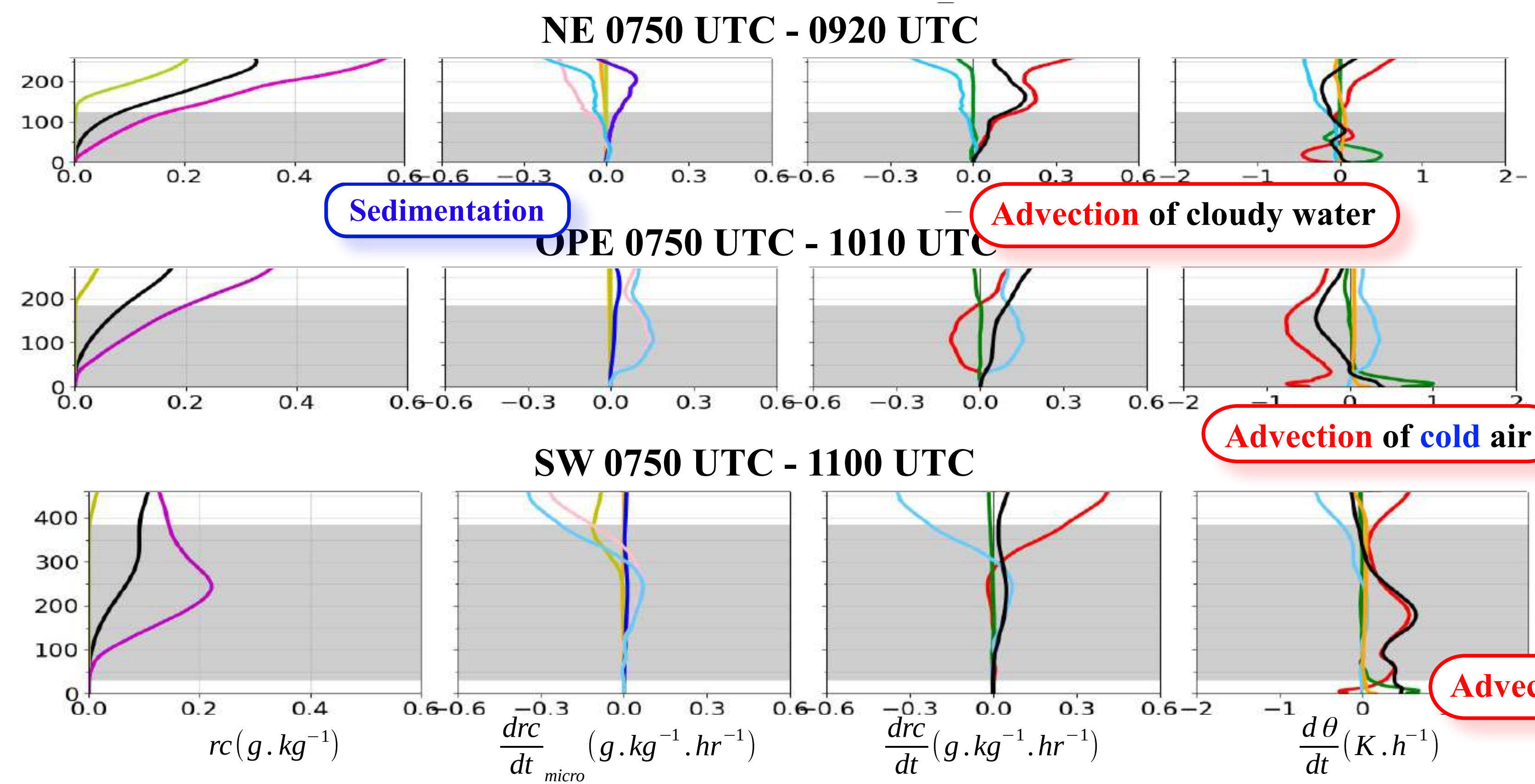
OPE
0750 UTC - 1010 UTC

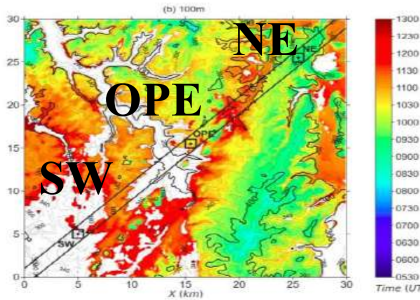


Accretion
Riming
Sedimentation
Adjustment +CCN act
Sedimentation
Advection of cloudy water
-
+
OPE
NE
SW
NE
0750 UTC - 0920 UTC
Advection
Microphysics
Turbulence
Radiation
Tendency
OPE
0750 UTC - 1010 UTC
Advection of cold air
SW
0750 UTC - 1100 UTC
Advection of warm air
rc mean
rc 0750
rc 0920
rc 1010
rc 1100
Height (m)
$rc(g.kg^{-1})$
$\frac{drc}{dt}_{micro}(g.kg^{-1}.hr^{-1})$
$\frac{drc}{dt}(g.kg^{-1}.hr^{-1})$
$\frac{d\theta}{dt}(K.h^{-1})$

Analysis of stratus cloud lowering

Budgets to better characterize the processes leading to stratus lowering





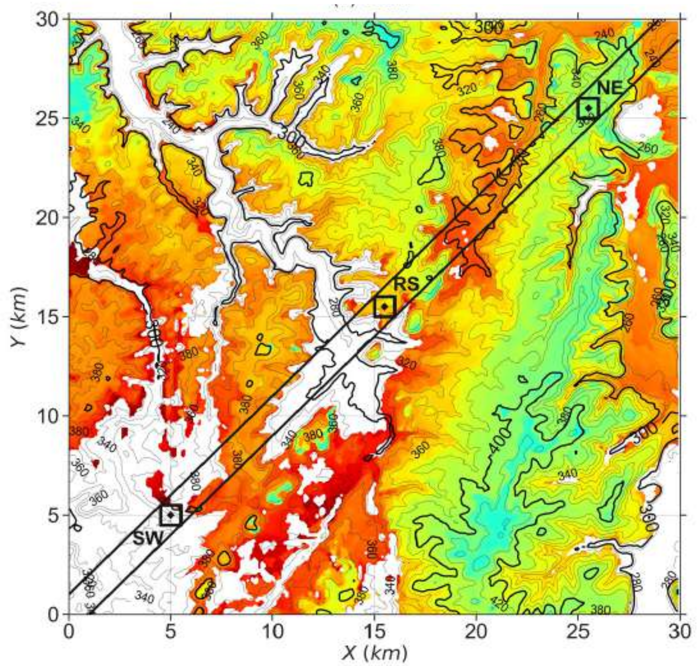
Advection is driven by **fine-scale orographic circulations.**

The **advection** of **cloud water** into stratus and cold air under stratus is **the primary process driving the STL on this case**.

Impact of microphysics

Hour fog formation

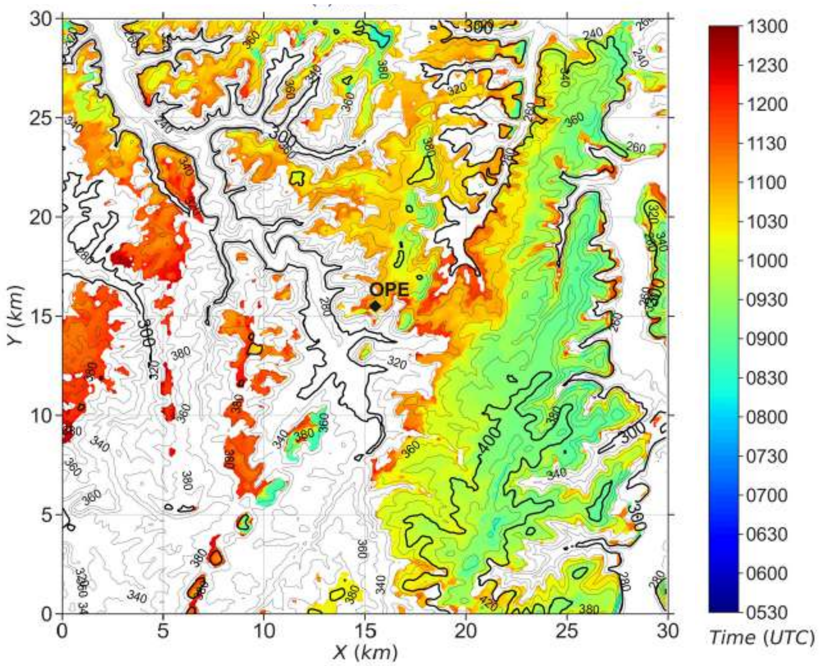
REF



72 % of the domain

NOSED

(Without droplet sedimentation)

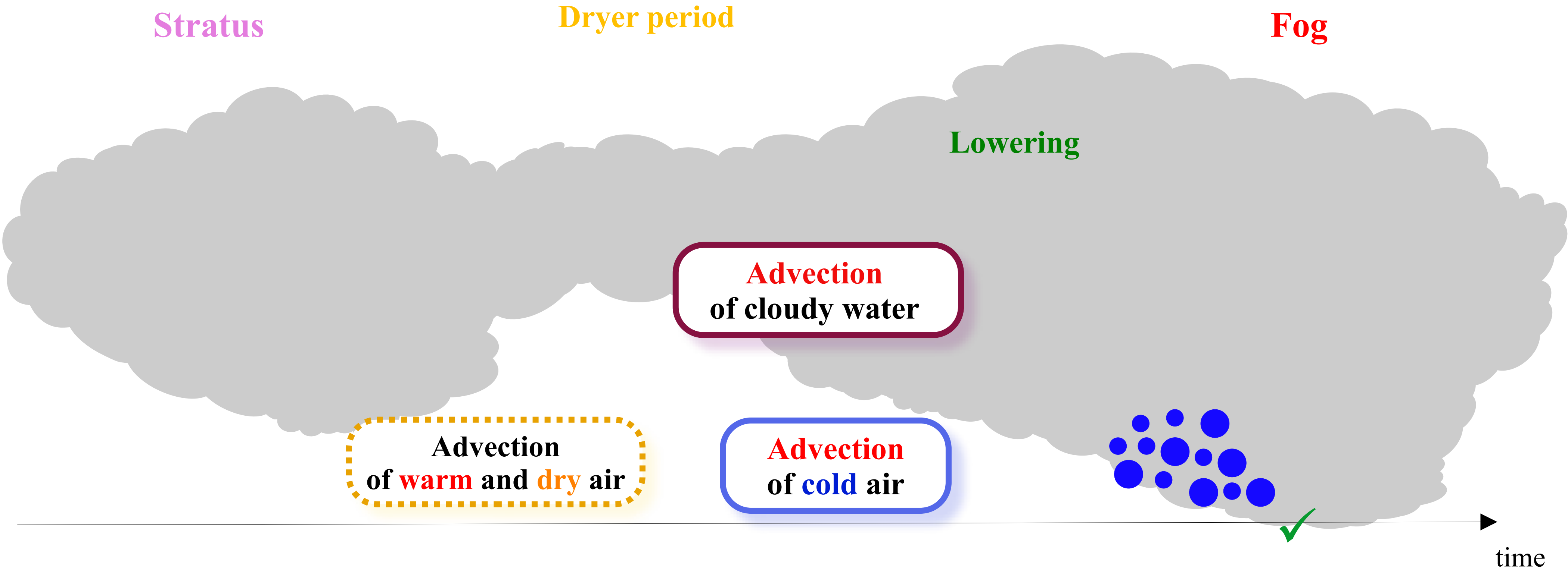


47 % of the domain

Sedimentation is **the second process that favors the stratus lowering**

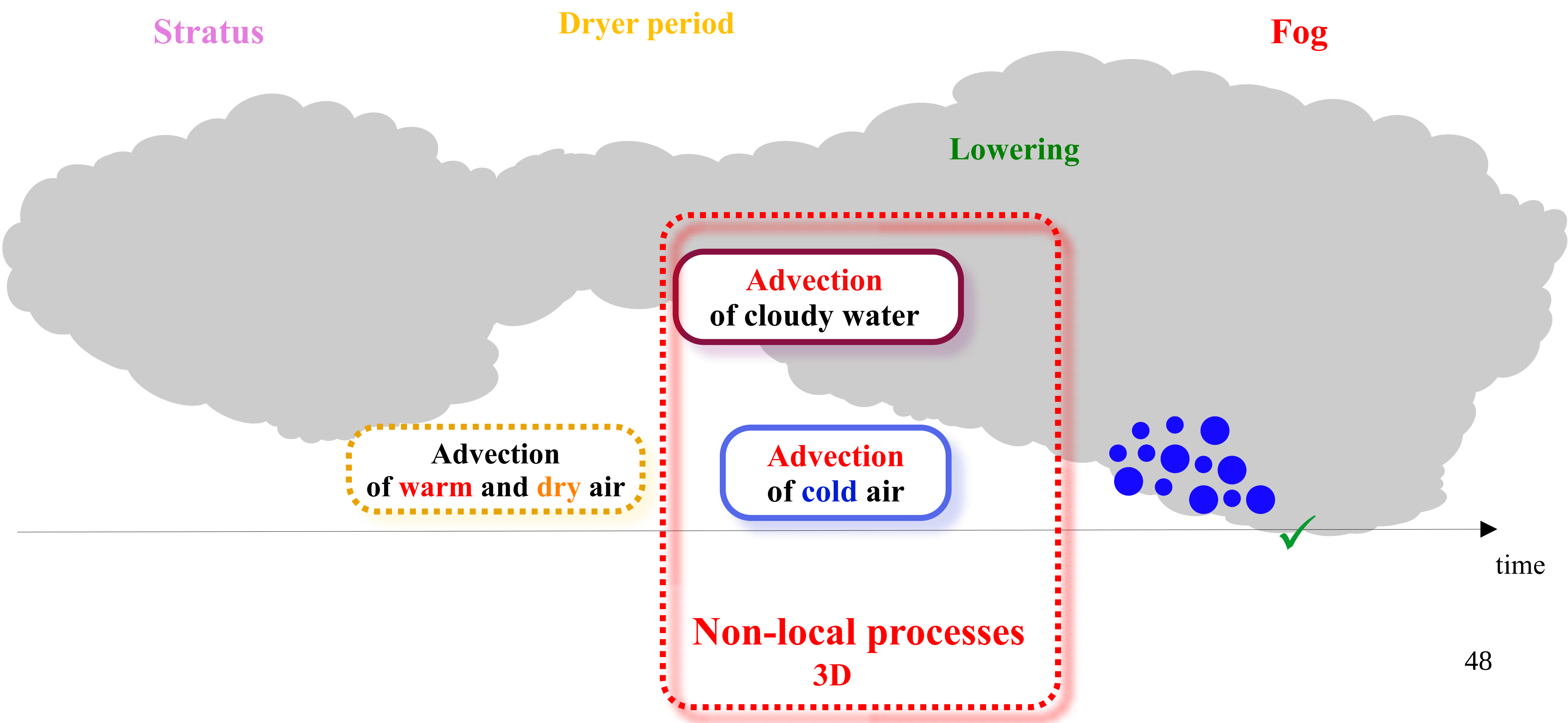
Better understand the processes leading (or not) to stratus lowering

Life cycle of stratus and its lowering



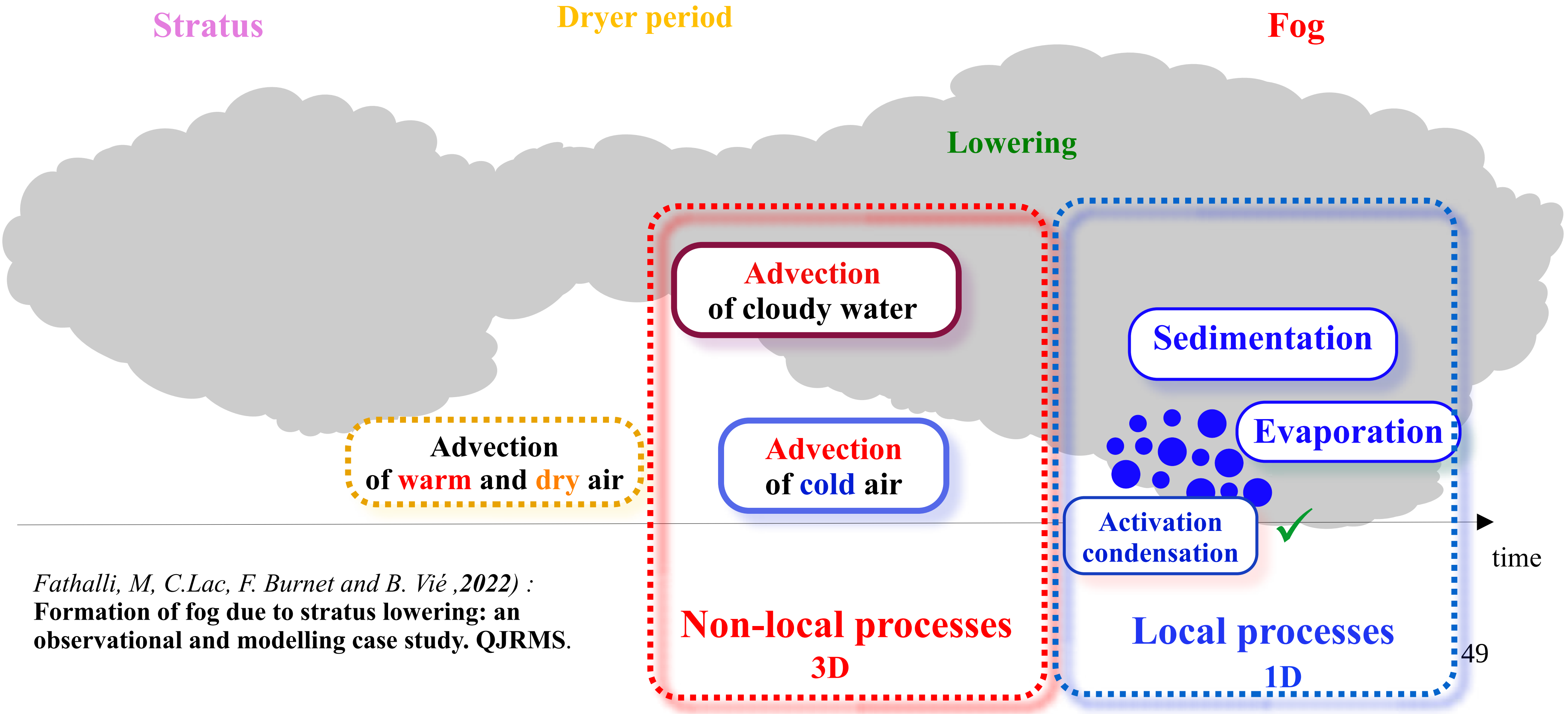
Better understand the processes leading (or not) to stratus lowering

Life cycle of stratus and its lowering



Better understand the processes leading (or not) to stratus lowering

Life cycle of stratus and its lowering

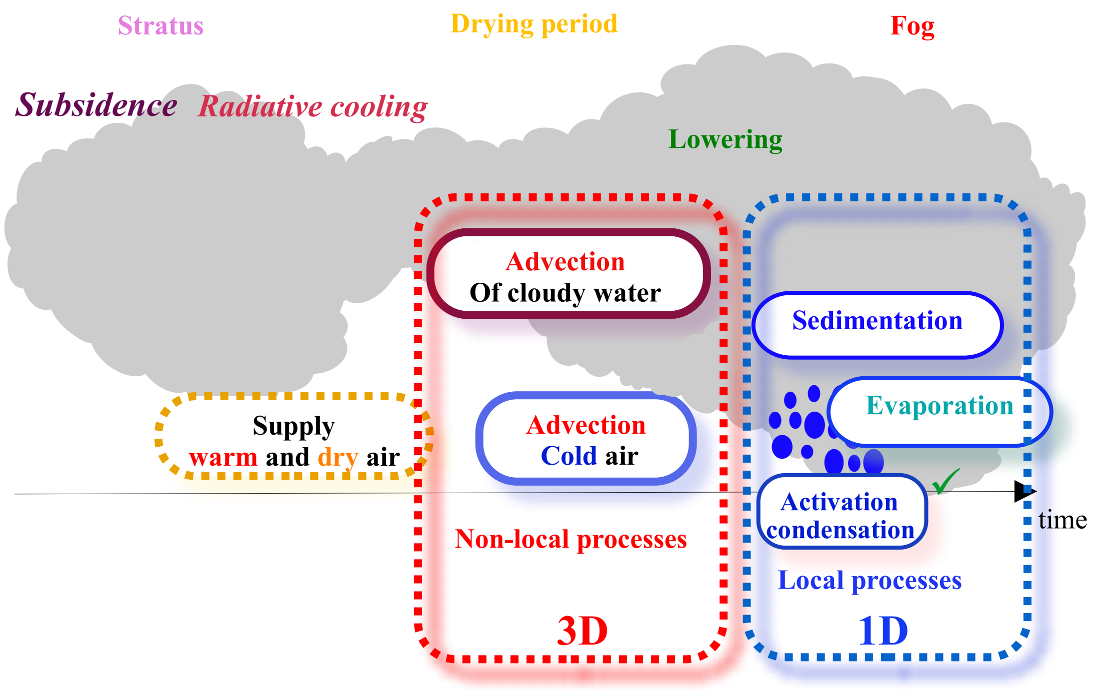


Fathalli, M, C.Lac, F. Burnet and B. Vié ,2022) :
Formation of fog due to stratus lowering: an observational and modelling case study. QJRMS.

Presentation outline

1^{er} objective

- **What are the main processes leading to stratus lowering?**



2^{eme} objective

- **What are the main characteristics of stratus lowering fogs?**

➢ Cloud water production in the fog phase.

➢ **Thicker** FSTL but with lower water content near the ground than RAD.

Post-doc: FSTL during SOFOG3D:

microphysical properties and processes study

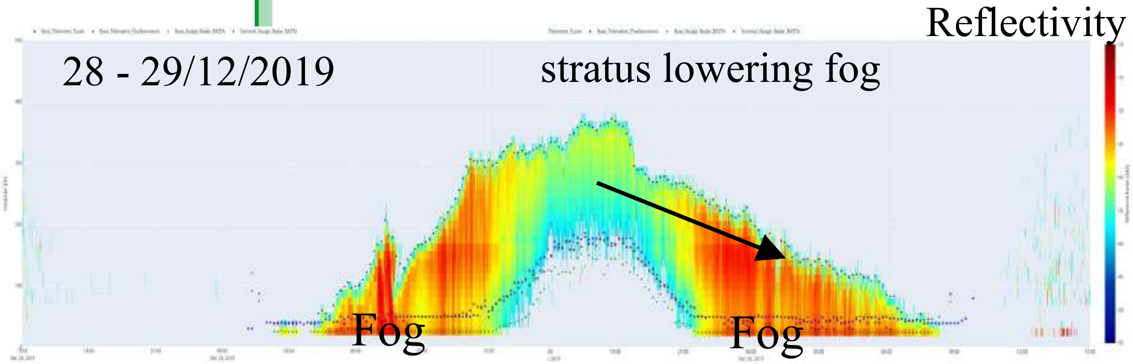
- Document the evolution of boundary layer properties during the stratus to fog event from in situ measurements and remote sensing.

- Perform numerical simulation of 2-3 case studies with the Meso-NH model in LES mode and validate with the available observation.

- Conduct budget analysis to investigate local and non local contributions of the processes leading to the fog formation by stratus lowering.

Post-doc: FSTL during SOFOG3D:

microphysical properties and processes study



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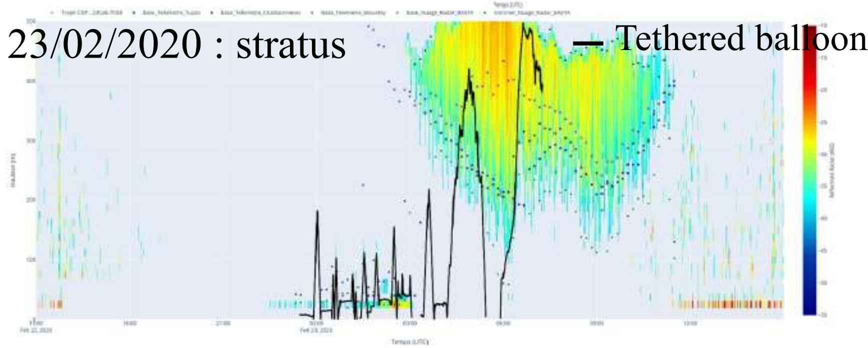
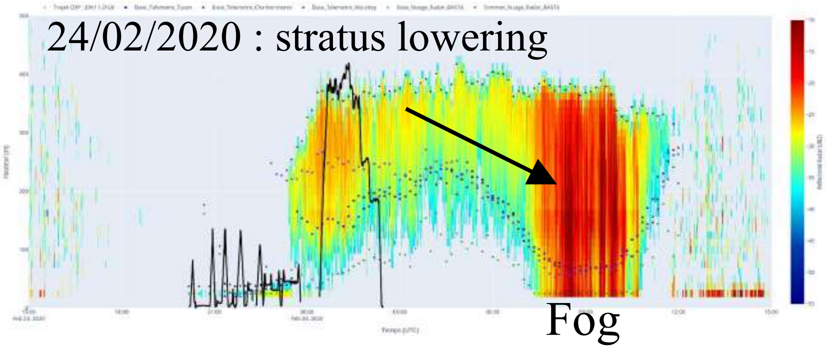
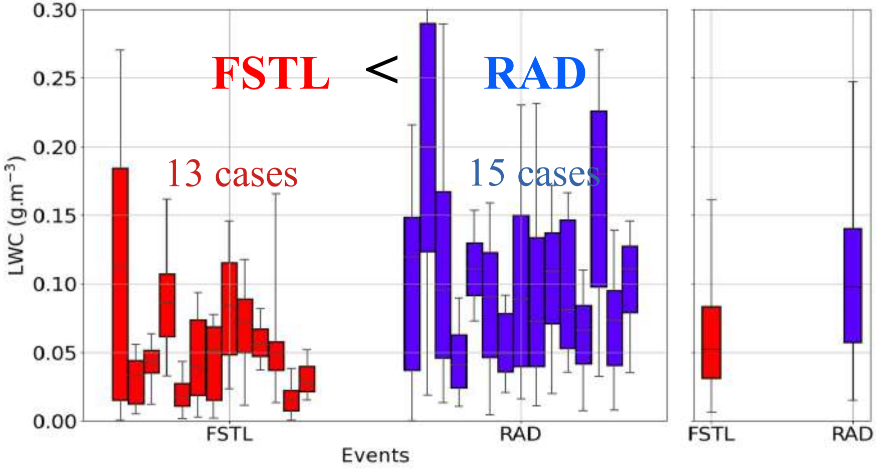




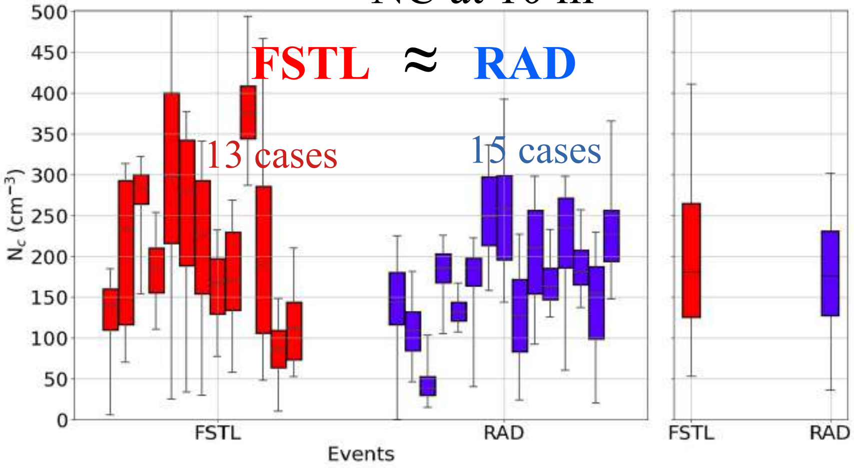

Thank you for your attention

Caractérisation des FSTL par rapport aux RAD

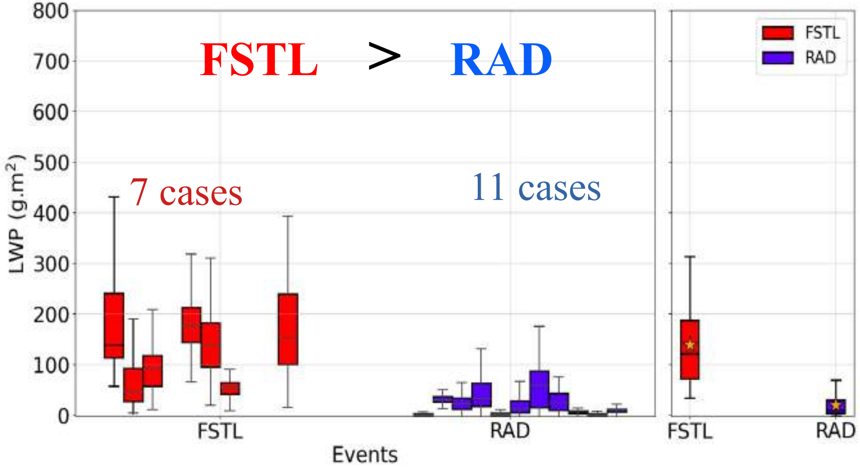
◆ LWC at 10 m



◆ NC at 10 m



◆ LWP



- Variability between the different cases of **FSTL** and **RAD**
- **FSTL** have **less liquid water on the ground** than **RAD**
- **FSTL** are **thicker** than **RAD**