Fog formed by stratus lowering: an observational and modeling case study from the SOFOG3D field campaign

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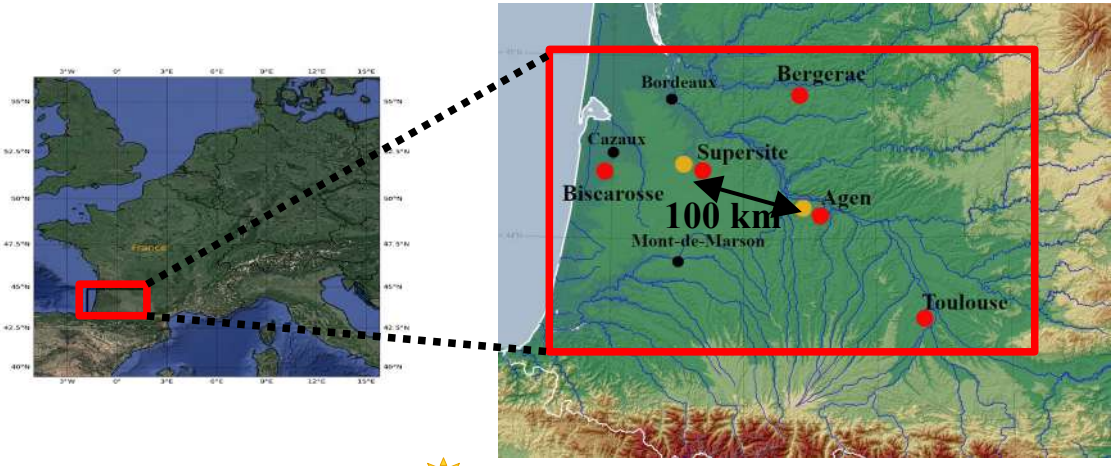
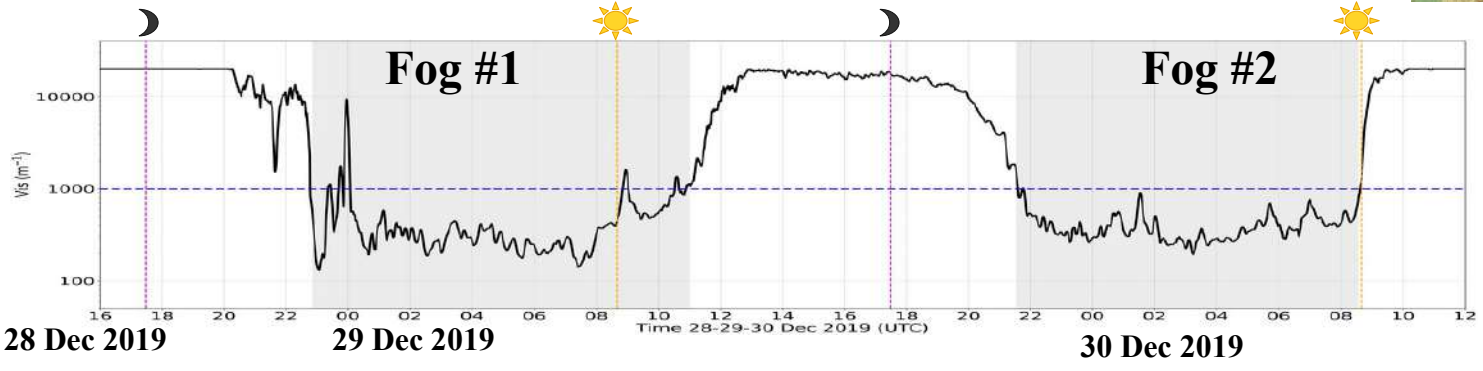
Context of the study

SOFOG3D field campaign (SOuth west FOGs 3D) (Burnet et al, 2023)

→ Aims to advance our understanding of the fog processes in order to improve forecasts of fog events by numerical weather prediction (NWP) models.





Cloud radar
Microwave radiometer(MWR)

==> Analysis of 3 days between 28 and 30 Dec 2019 characterized by different fog life cycles at regional scale with radiative and stratus lowering fogs.

Overview of large-scale case study (Satellite observations)

Suomi-NPP(Colored composition)

Fog/ stratus

Cirrus

MSG (HRV)

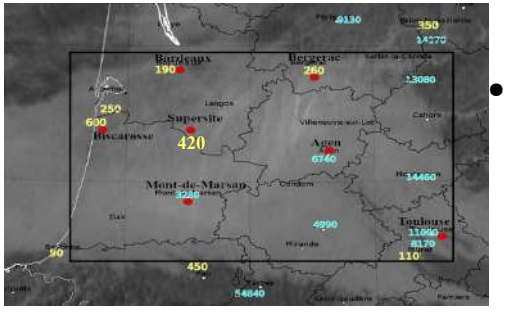
1 29 Dec at 0131 UTC

- Generalized radiative fog during the 1st night

Visibility values > 1 km

Visibility values < 1 km

2 29 Dec at 0830 UTC

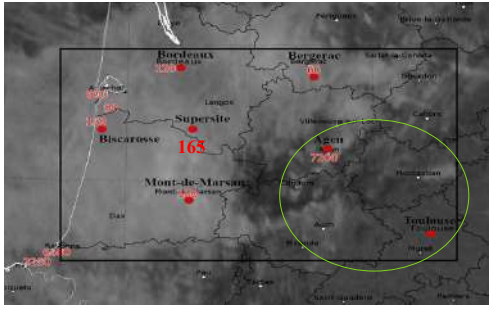


- Fog dissipation lifting in stratus on the southeast

3 29 Dec at 1258 UTC

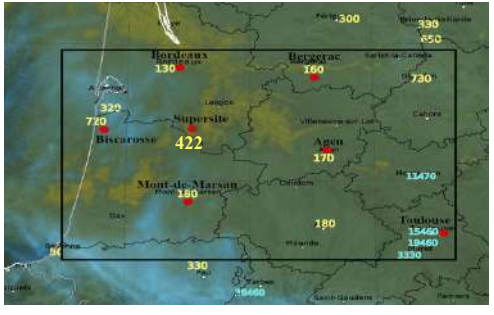
- Stratus dissipation on the southeast of the domain

4 29 Dec at 1500 UTC



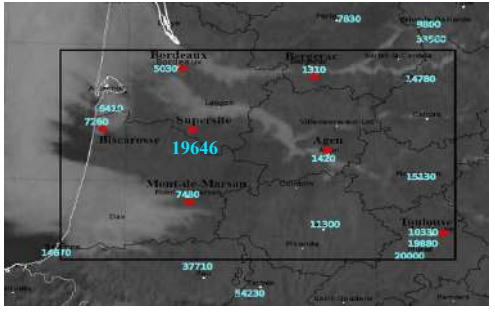
Cloud base height values

5 30 Dec at 0158 UTC



- Generalized stratus lowering fog during the 2nd night

6 30 Dec at 0930 UTC



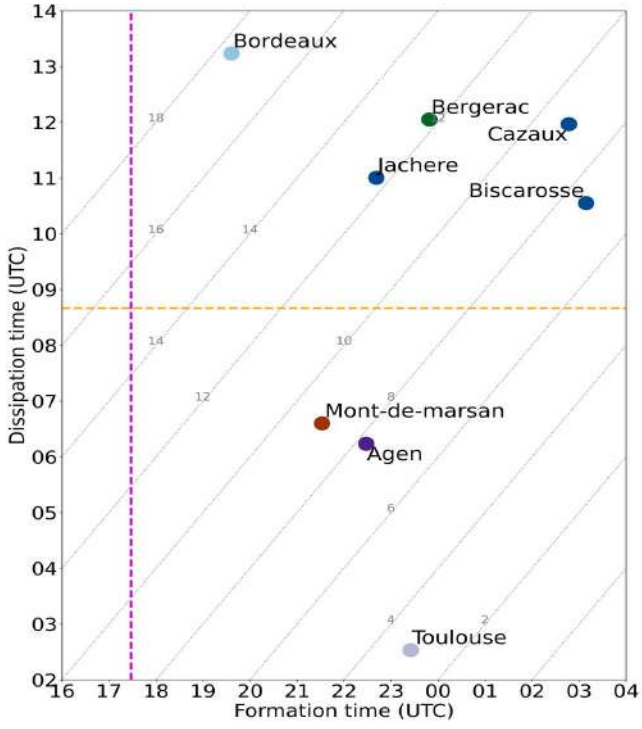
- Fog dissipation

Overview of large-scale case study

Fog time formation and dissipation

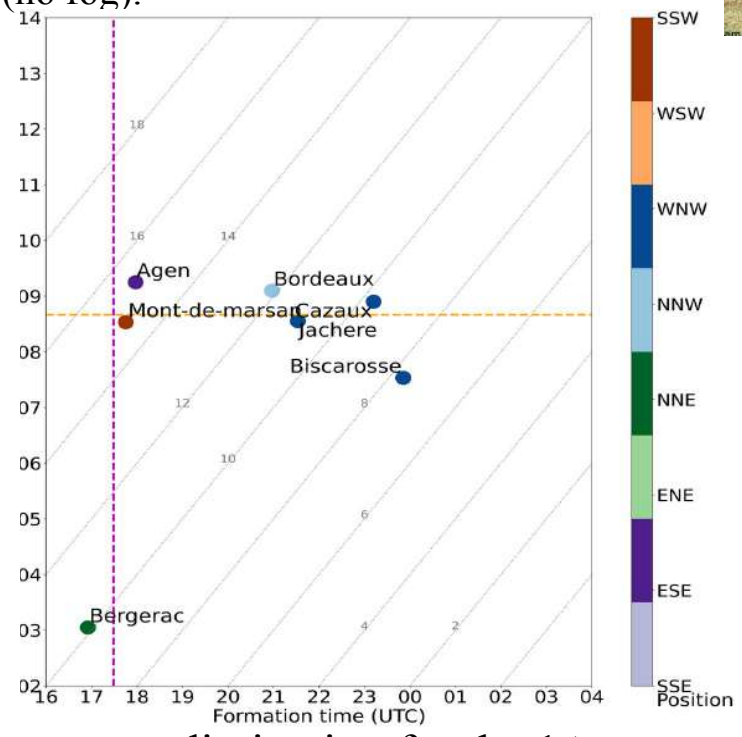
1st night : 28-29/12/2019

Generalized Radiative fog



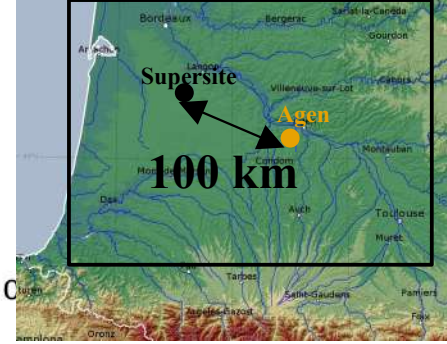
2nd night : 29-30/12/2019

Generalized stratus lowering fog, except in Agen (radiative fog) and Toulouse (no fog).



- Homogeneous formation, heterogenous dissipation for the 1st event
- Heterogenous formation, homogeneous dissipation for the 2sd event

Overview of the case study on two different sites



Fog development at 05 UTC

Cloud top lowering

Supersite (Jachere)

Fog #1:Radiative

Fog #2:Stratus lowering

Supers

CBH

Height (m)

LWP (g.m^{-2})

Agen

Fog #1: Thick radiative fog

Fog #2: Thin radiative fog

OBS

Time 28-29-30 Dec 2019 (UTC)

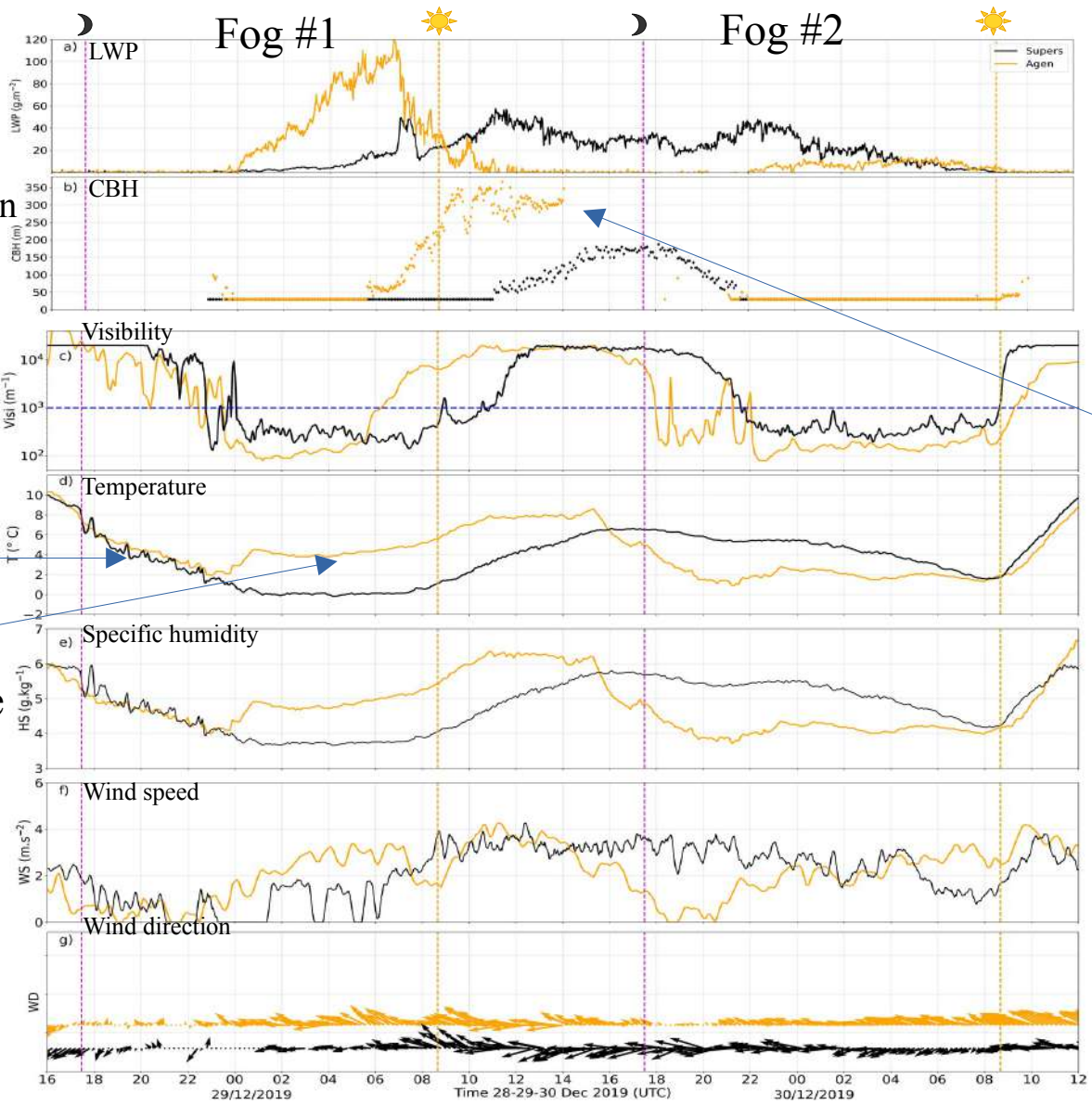
Dissipation by lifting

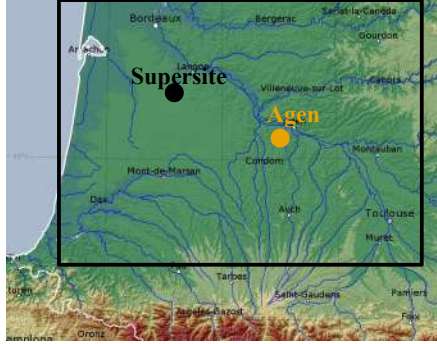
Ref (dbZ)

Cloud radar reflectivity

Spatial heterogeneity:
Supersite vs Agen

More developed fog at Agen





Radiative cooling

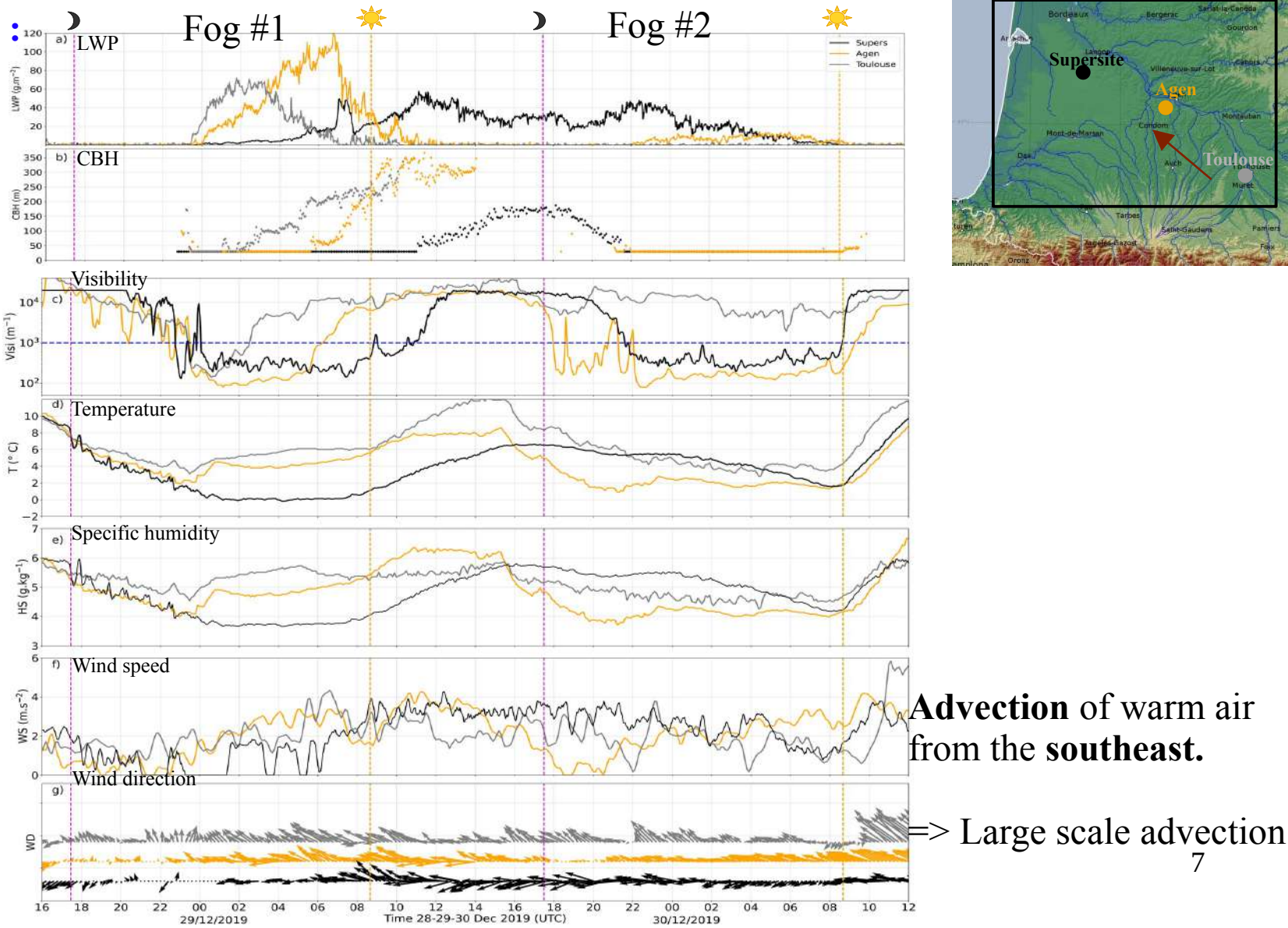
Temperature increase at Agen

Complete dissipation of stratus

Advection of warm air from the southeast.

Impact of the Garonne valley ?

Spatial heterogeneity :
Agen vs Toulouse (southeast)



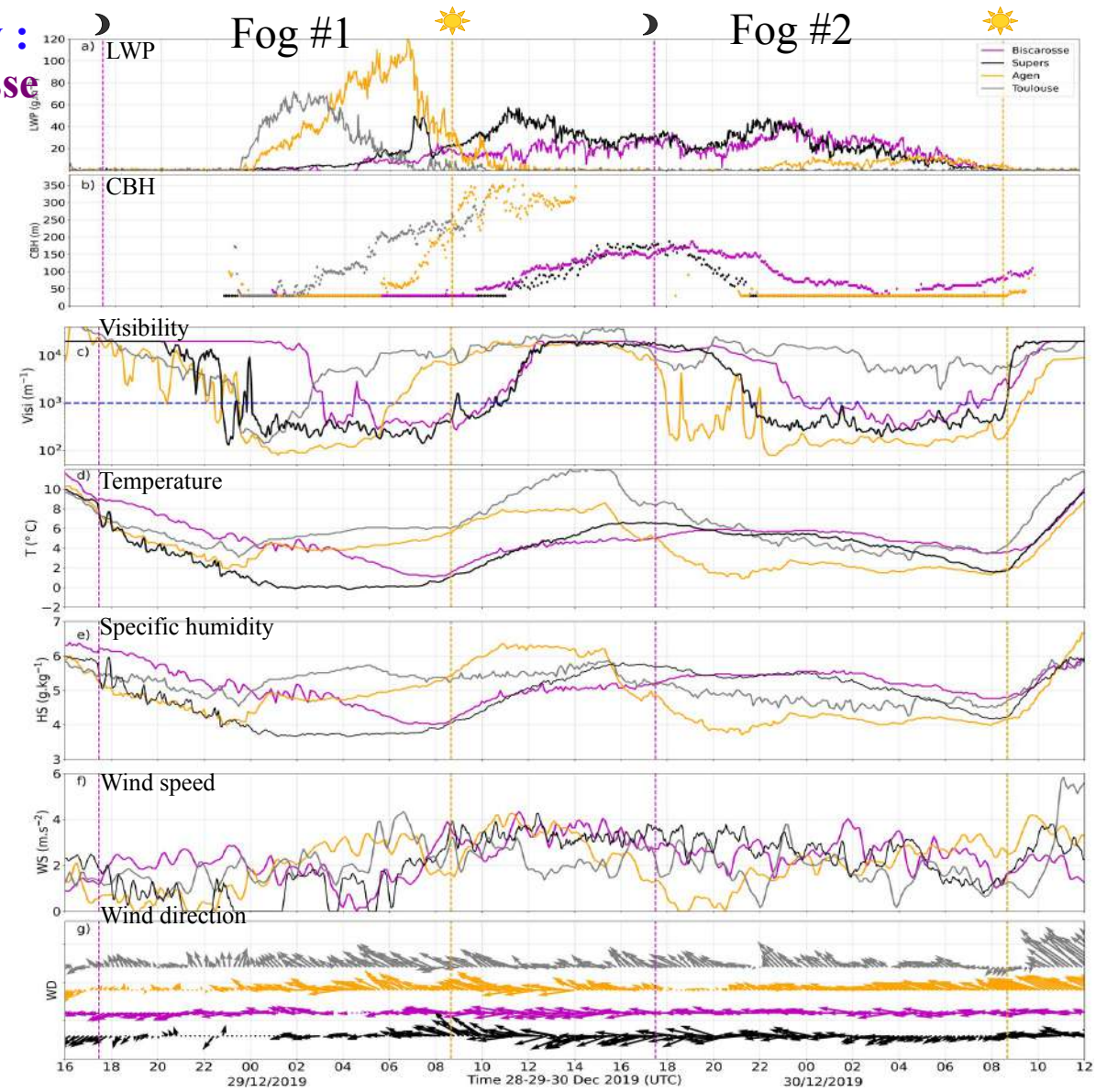
Same fog life cycle between Agen and Toulouse site during the 1st fog event.

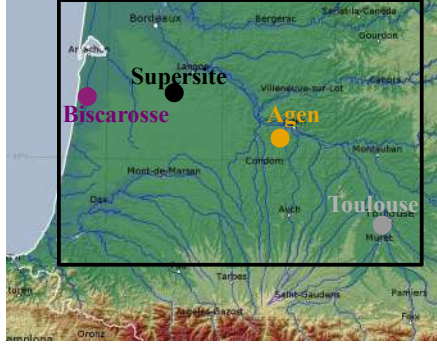
No fog formation at Toulouse during the second night.

Advection of warm air from the **southeast.**

=> Large scale advection

Spatial heterogeneity :
Supersite vs Biscarosse (Northwest)



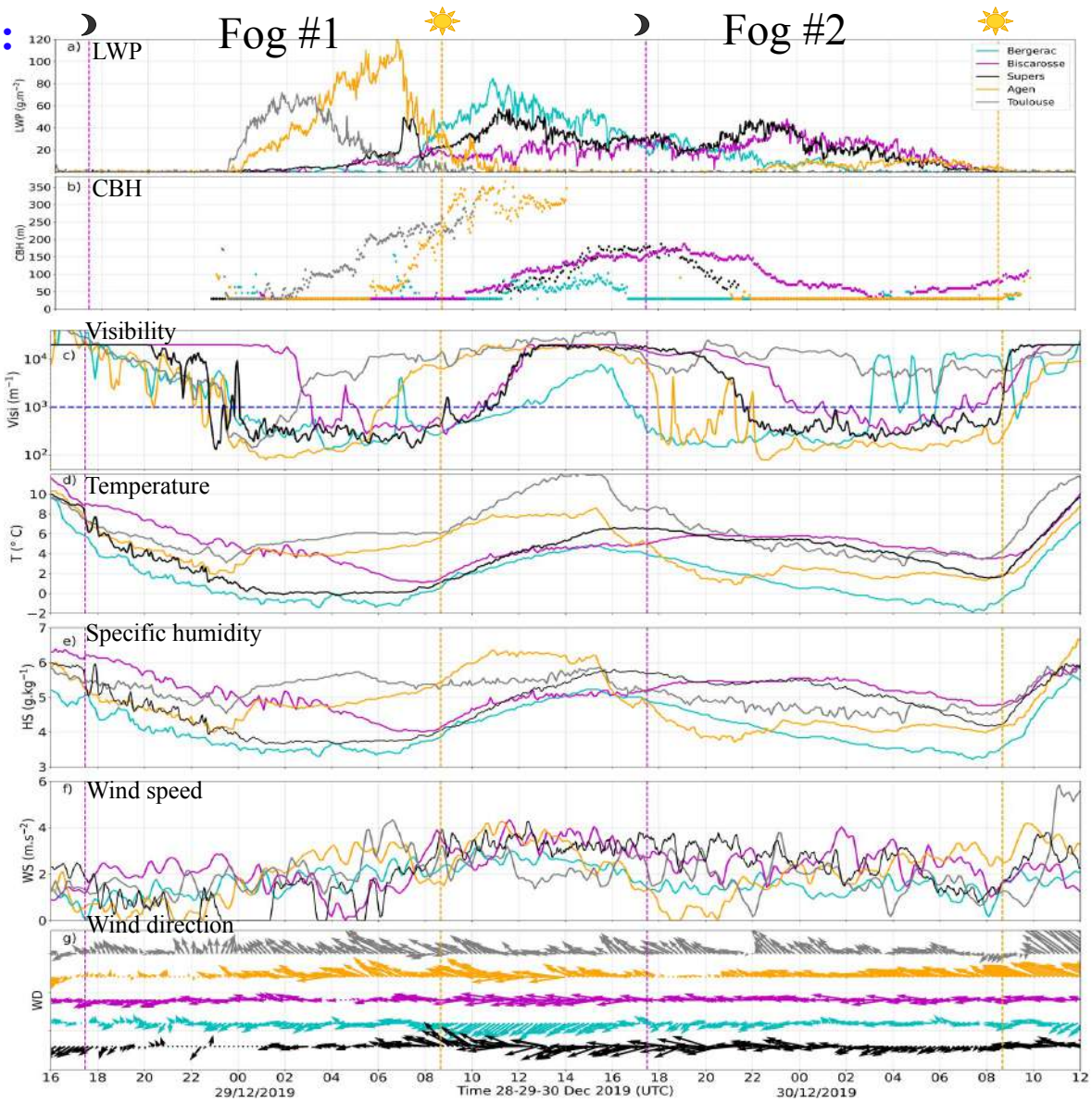


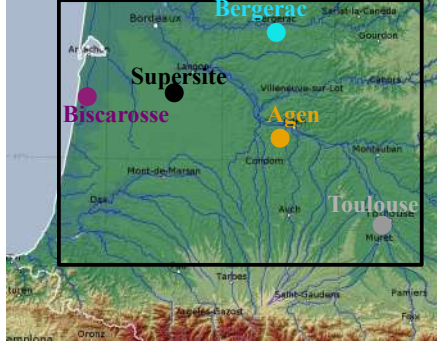
Late fog formation at Biscarosse

Same life cycle of LWP and CBH between Supersite and Biscarosse.

Advection from the East.

Spatial heterogeneity :
Supersite vs Bergerac (Northeast)





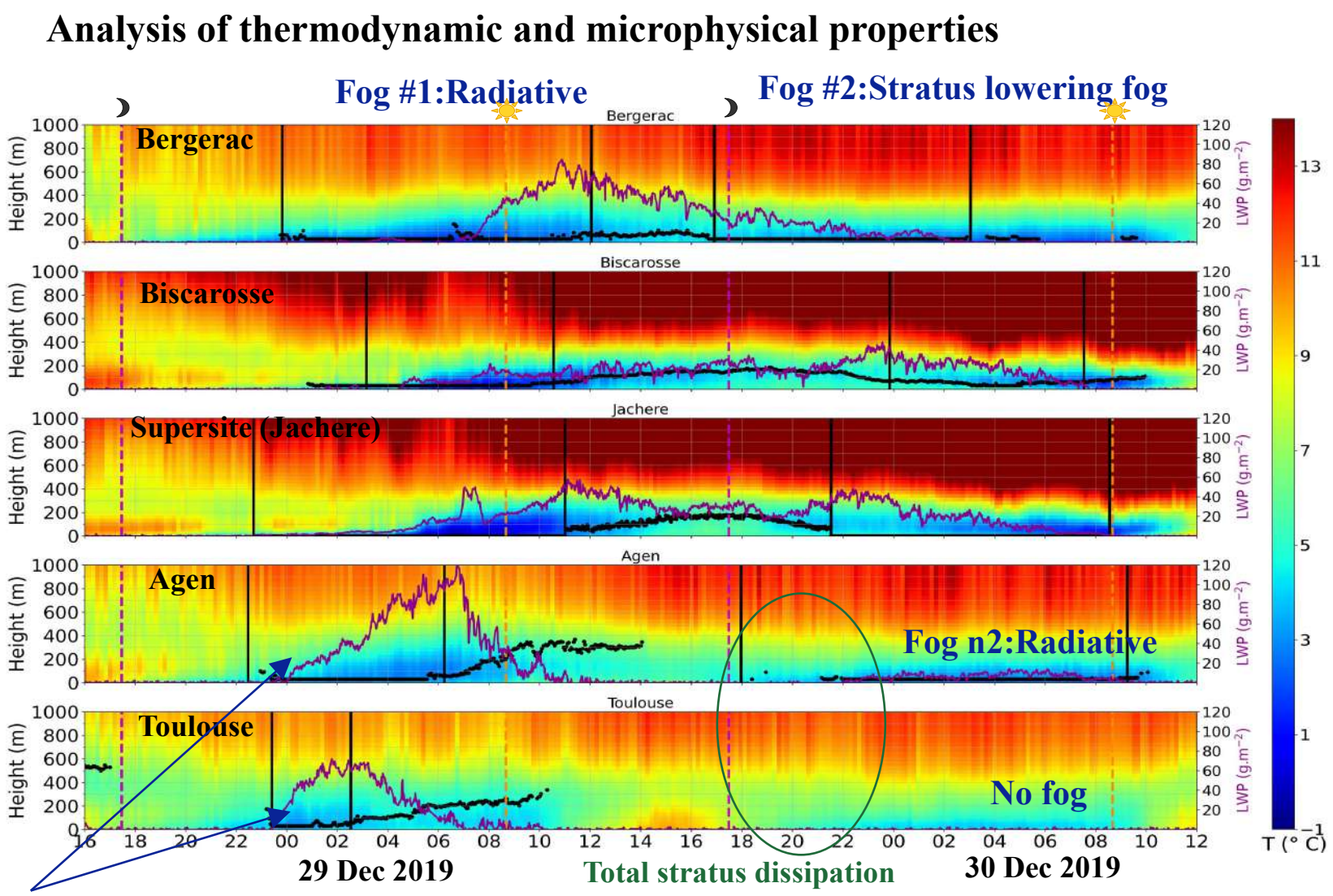
Early stratus lowering at Bergerac

Same temperature evolution during the 1st night.

Slight advection from the northeast.

=> Large variability of the fog life cycles on regional scale

Analysis of thermodynamic and microphysical properties



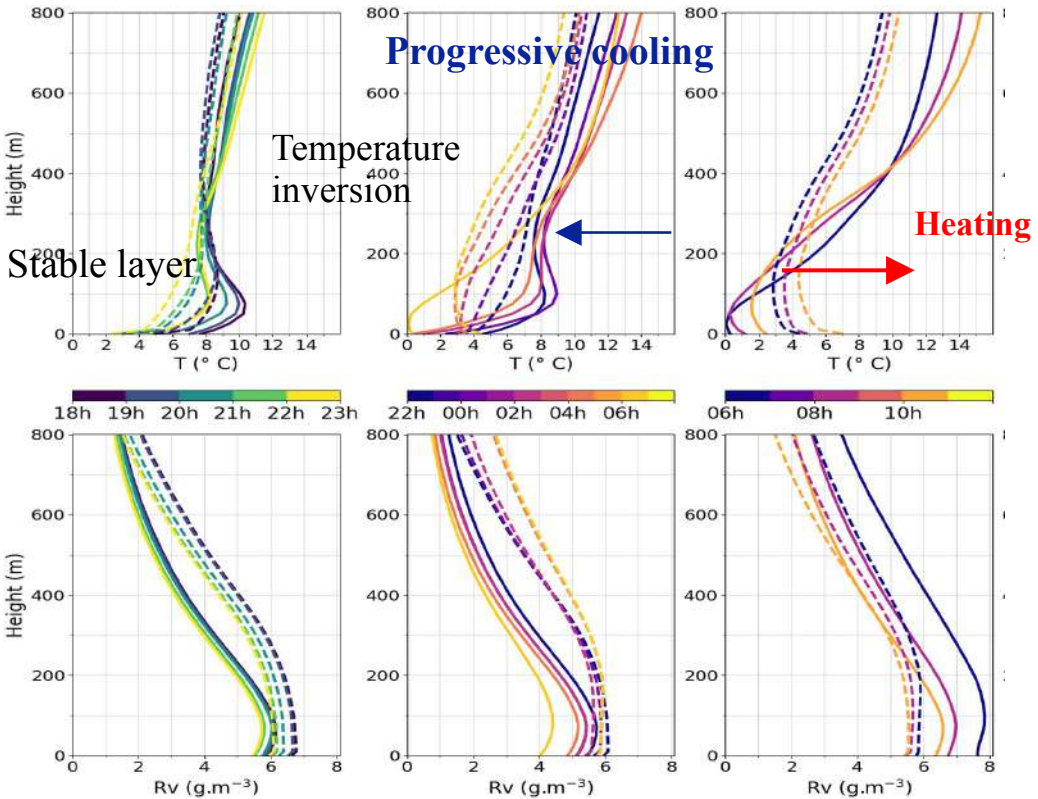
Lower altitude of the temperature inversion prevents the fog development

More developed fog at Agen and Toulouse (and Bergerac)

Vertical profiles of temperature and humidity at Agen (- -) and at Supersite (——)

Fog #1:Radiative fogs on both sites

Pre-fog conditions **Fog cycle**



Agen colder and moister up to 200m high => thick Fog
Dissipation : Radiative **heating** (supersite) and advection of warm air(Agen)

Vertical profiles of temperature and humidity at Agen (- -) and at Supersite (——)

Fog #1:Radiative fogs on both sites

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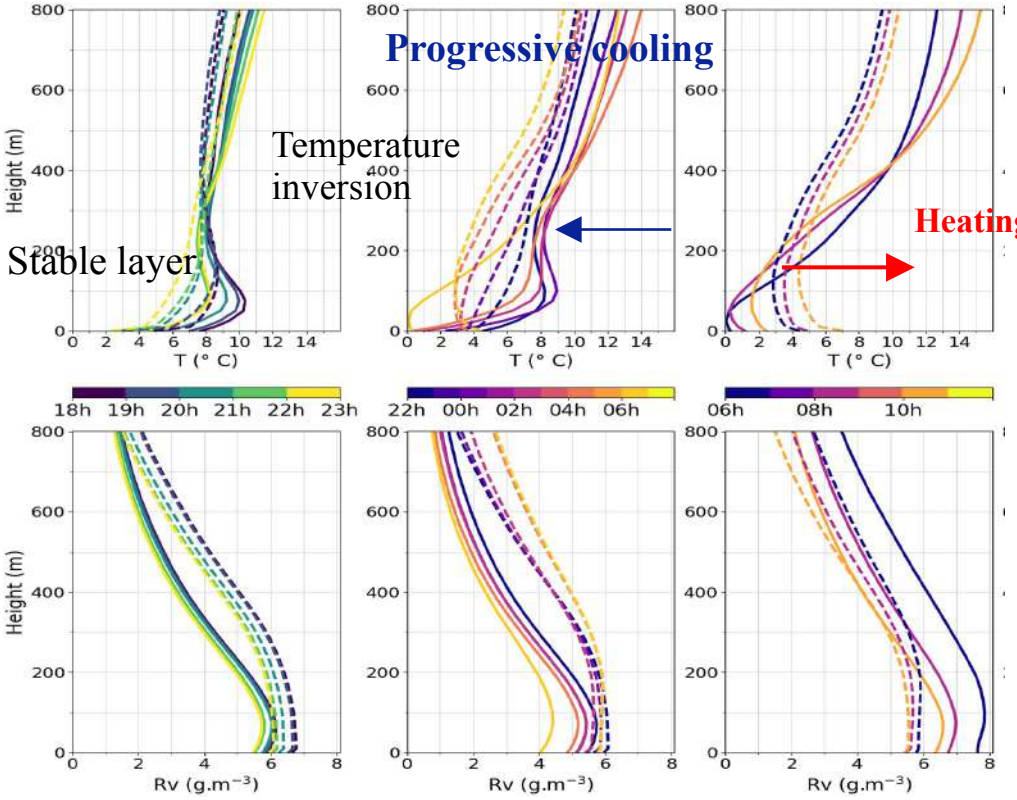
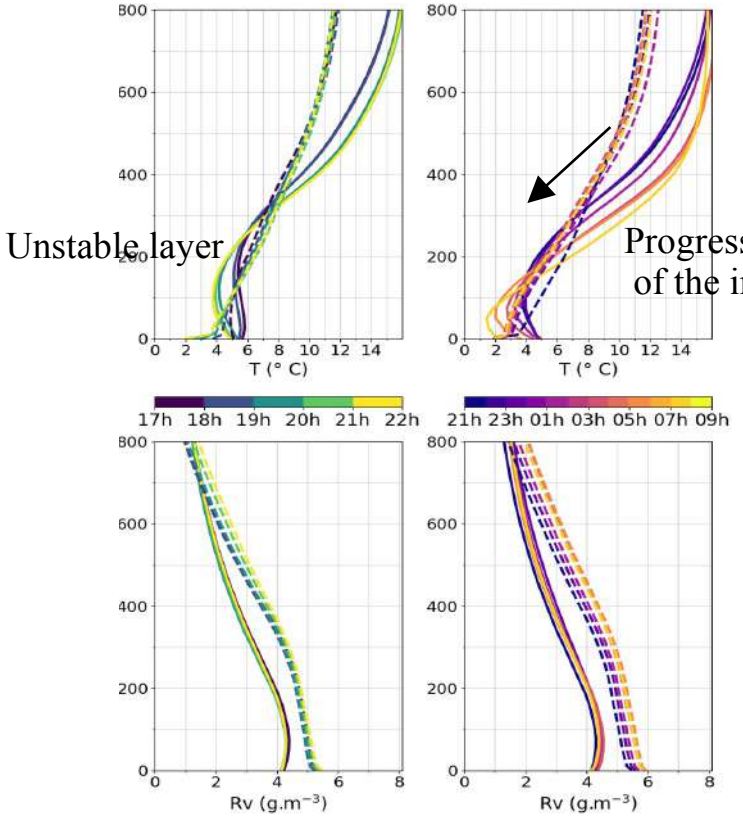
Fog cycle



Fog #2:Thin radiative fog (Agen), Stratus lowering fog (supersite)

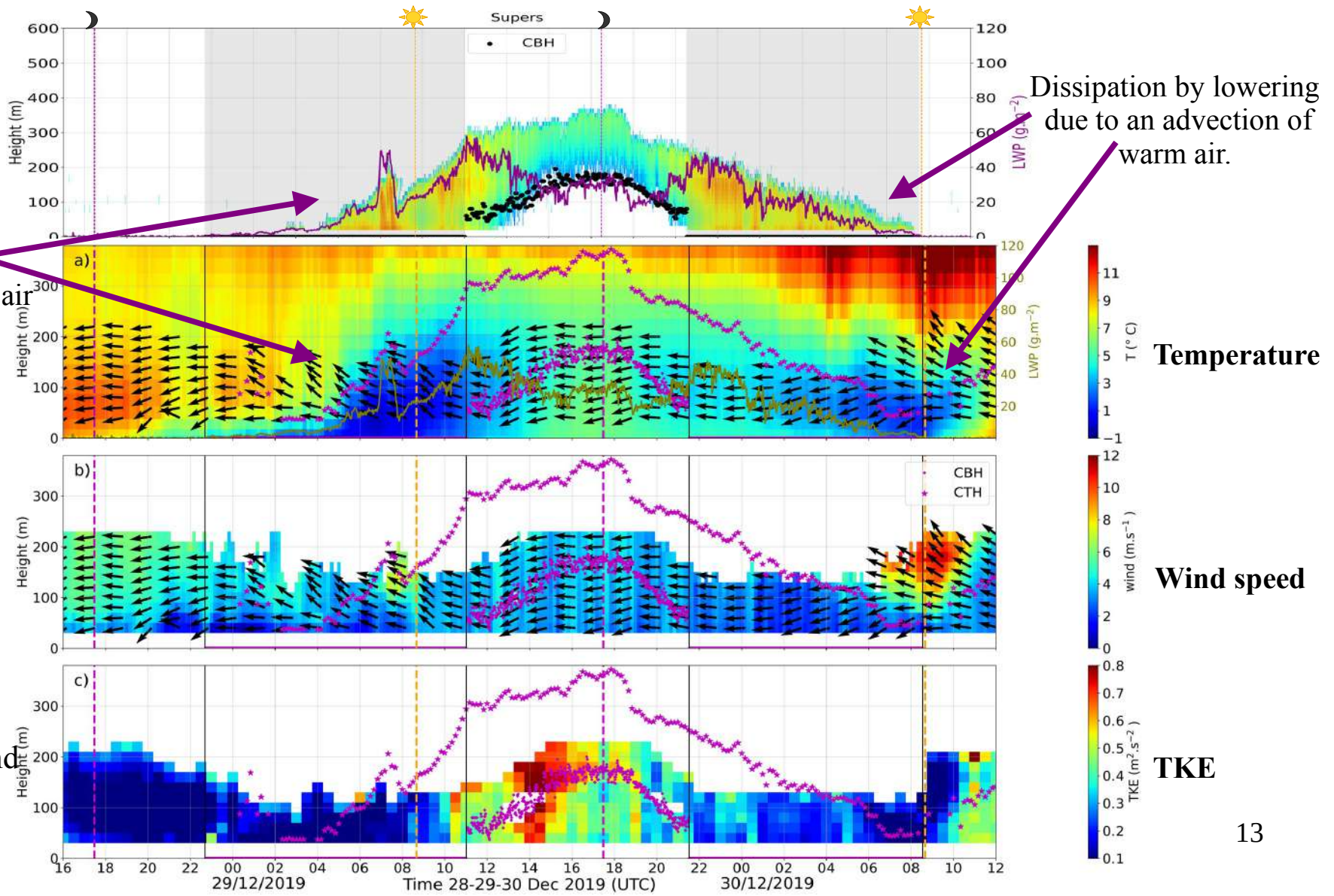
Pre-fog conditions

Fog cycle



Agen colder and moister up to 200m high => thick Fog
Dissipation : Radiative **heating** (supersite) and advection of warm air(Agen)

Humidity profiles are drier but they keep the same shape



Dissipation by lowering due to an advection of warm air.

Fog development at 05 UTCdue to advection of colder air from the southeast.

Temperature

Wind speed

TKE

Stratus lowering associated with TKE values around 0.3 m^2s^{-2}).

Complete stratus dissipation at Agen site ?

Radiative heating (thermal thermal) + mechanical turbulence.
High TKE values up to 0.4 $m^2 .s^{-2}$ => vertical mixing

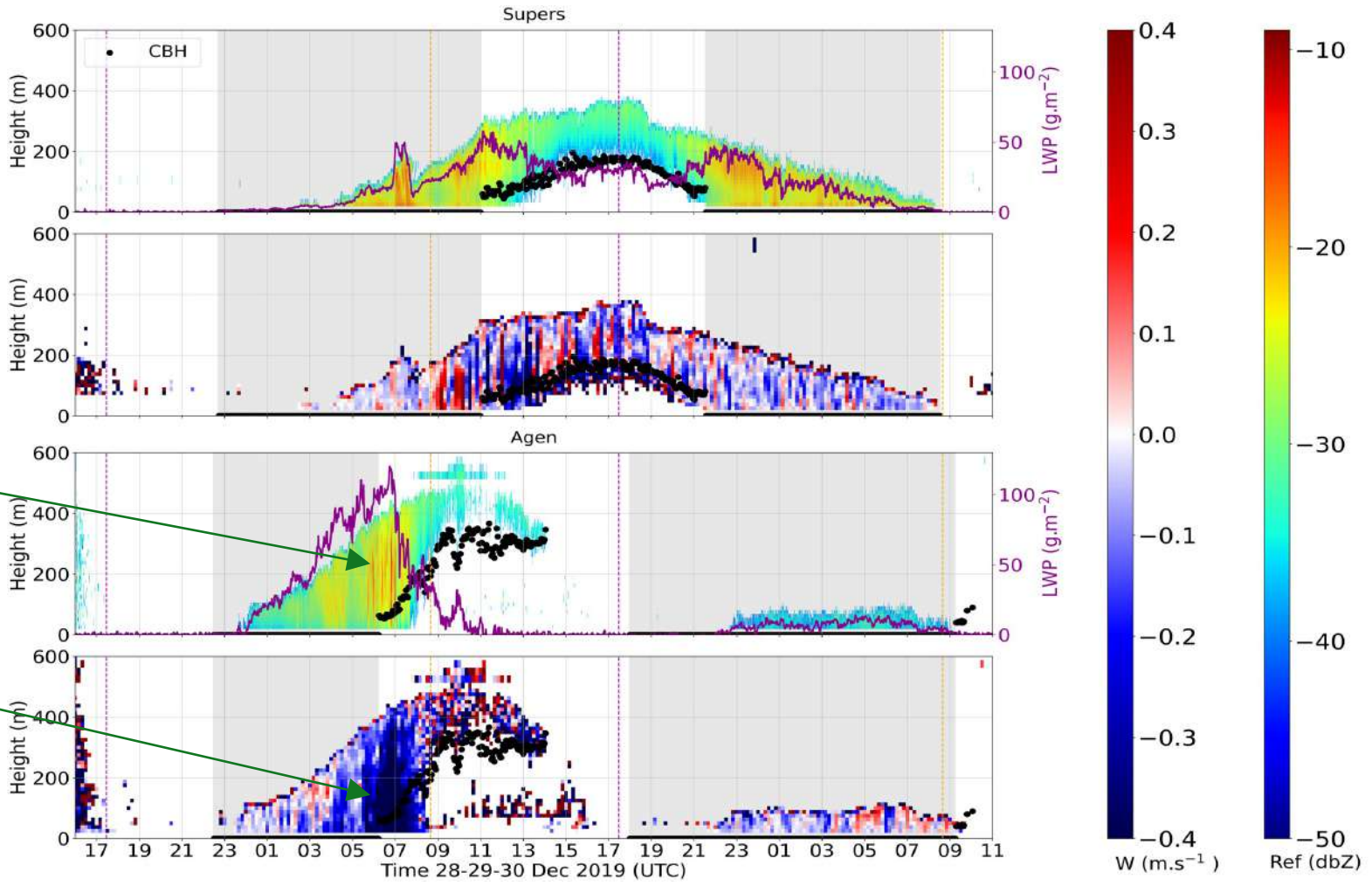
=>Fog dissipation at Supersite

High reflectivity values

High **negative** vertical wind speed up to -0.4 $m.s^{-1}$
=> droplet settling

+ advection of warm air

=>Fog dissipation at Agen site



Conclusion based on the observation analysis:

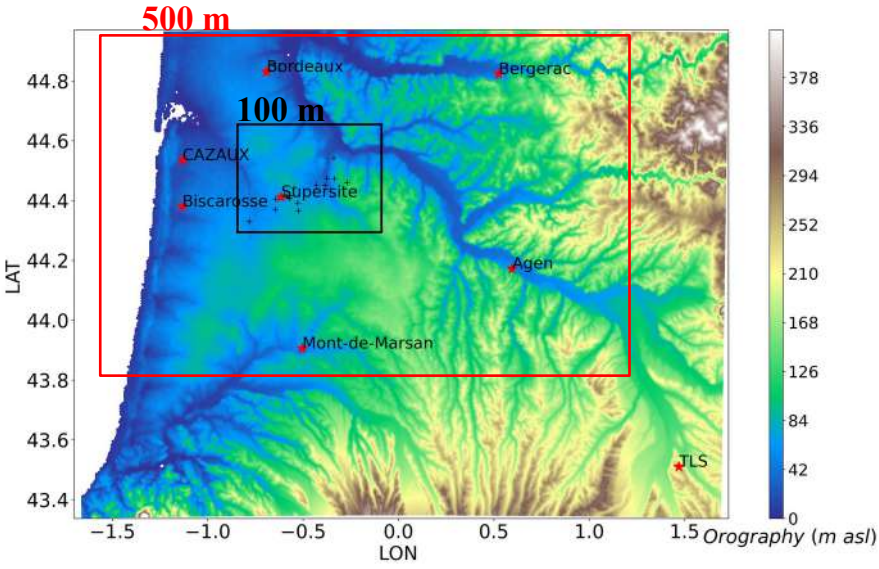
- Widespread **radiative fog** over the entire domain during the first night developed due to **cold air advection from the East** but **large variability** of the fog life cycles on regional scale.

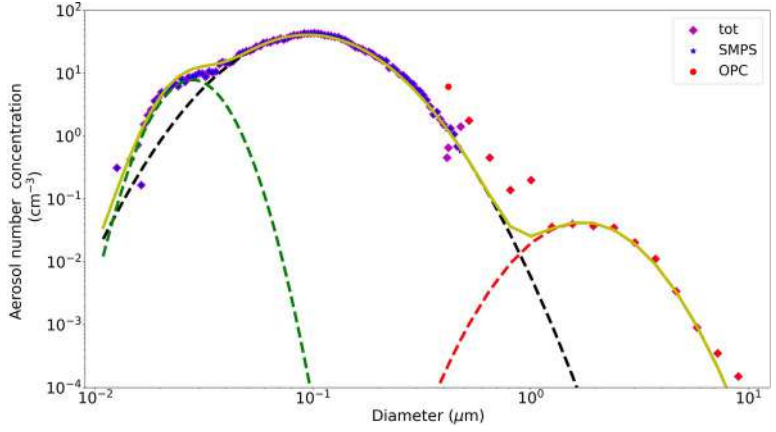
- **Complete dissipation** of stratus over the southern part of the domain due to **warm air advection**, while the stratus remains all the day on the northern part.

- For the second night, **stratus lowering fog** occurred in the North while radiative fog formed on the South, depending on **large scale advection** and **vertical structure of temperature and humidity**.

Numerical simulation with Meso-NH

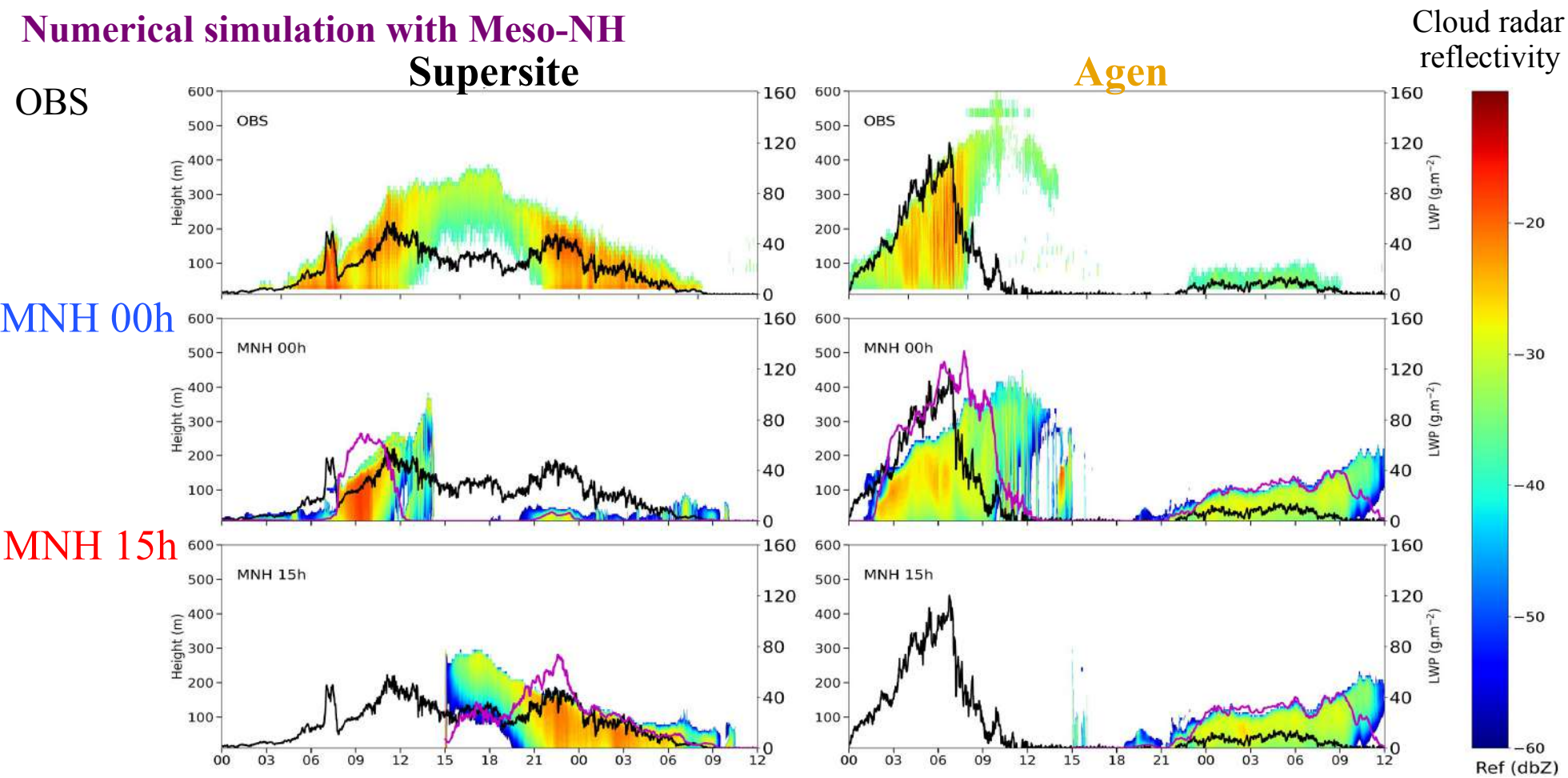
- **Initial/coupling conditions**: Analyses from AROME NWP model (1.3 km)
- **Horizontal grid resolution:** 500 m et 100 m with two-way nested grids.
- **Vertical grid resolution :**150 vertical levels (1.5 m first level).
- **Microphysics**: 2-moment (LIMA, Vié et al., 2016) with prognostic droplet and aerosol concentrations.
- Activation of 3 aerosol modes, initialized with in-situ measurement (OPC and SMPS)





MNH 00h : Meson-NH simulation initialized at **00h** with Arome Analyses.
MNH 15h : Meson-NH simulation initialized at **15h** with Arome Analyses.

Numerical simulation with Meso-NH



MNH15h reproduces the stratus lowering at Supersite and the contrast between Agen and Supersite, while MNH00h dissipates the stratus at SS as in Agen

Objective to better understand the differences between both simulations in order to characterize the ingredients favoring both scenarii.

Comparison with observations at the supersite

Temperature

Wind speed

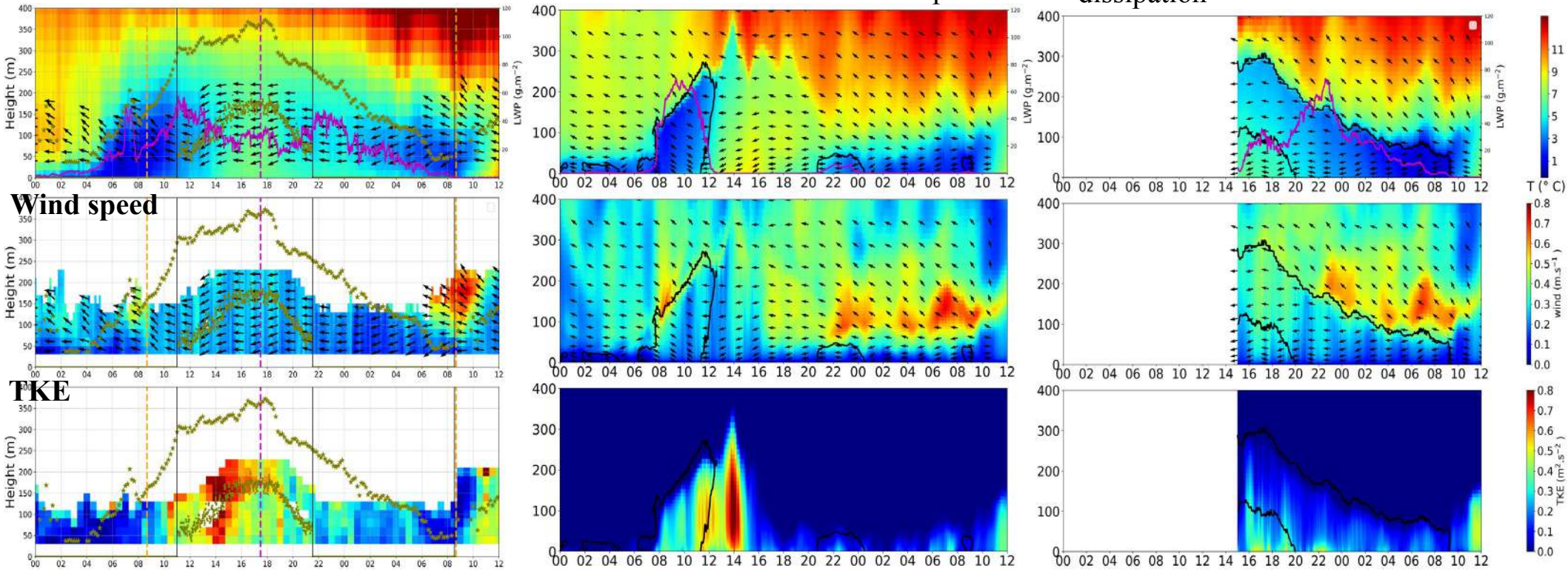
TKE

MNH 00H

Lower altitude of the temperature inversion favors stratus dissipation

MNH 15H

Good agreement on fog formation and dissipation



Complete stratus dissipation with MNH 00H : the fog forms late around 08h, which will be impacted by solar radiation just directly after its formation, and also the temperature inversion occurs at low altitude compared with obs.
Also MNH 00H produces too much water, which could explain the sudden dissipation.

Perspectives:

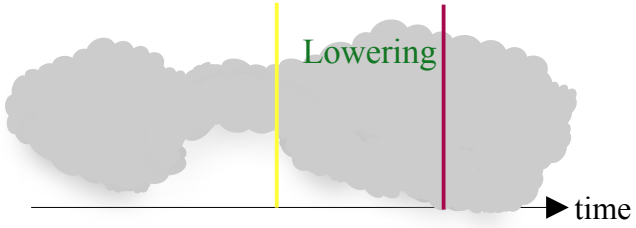
1. Further analysis of the differences between MNH00h/MNH15h and observations that guide the various scenarios.

2. A budget analysis as in Fathalli et al. (2022) to investigate the spatial heterogeneity of the fog event at the regional scale and to study the physical mechanisms involved in fog formed by stratus lowering.

Perspectives: Analysis of stratus cloud lowering

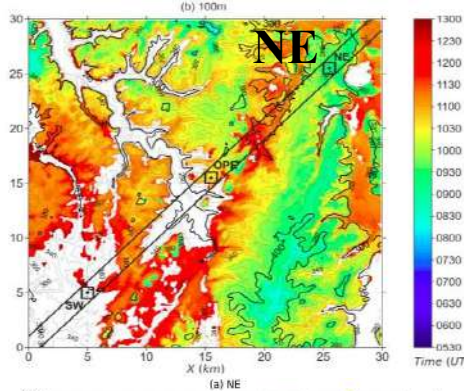
- Case study from the Bure field campaign (Fathalli et al, 2022)

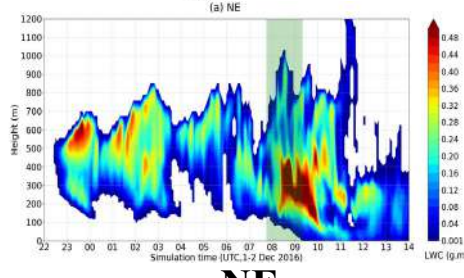
Budgets to better characterize the processes leading to stratus lowering



Destruction - | Production + | Cooling - | Warming +

Cloudy water | **Temperature**





NE

0750 UTC - 0920 UTC

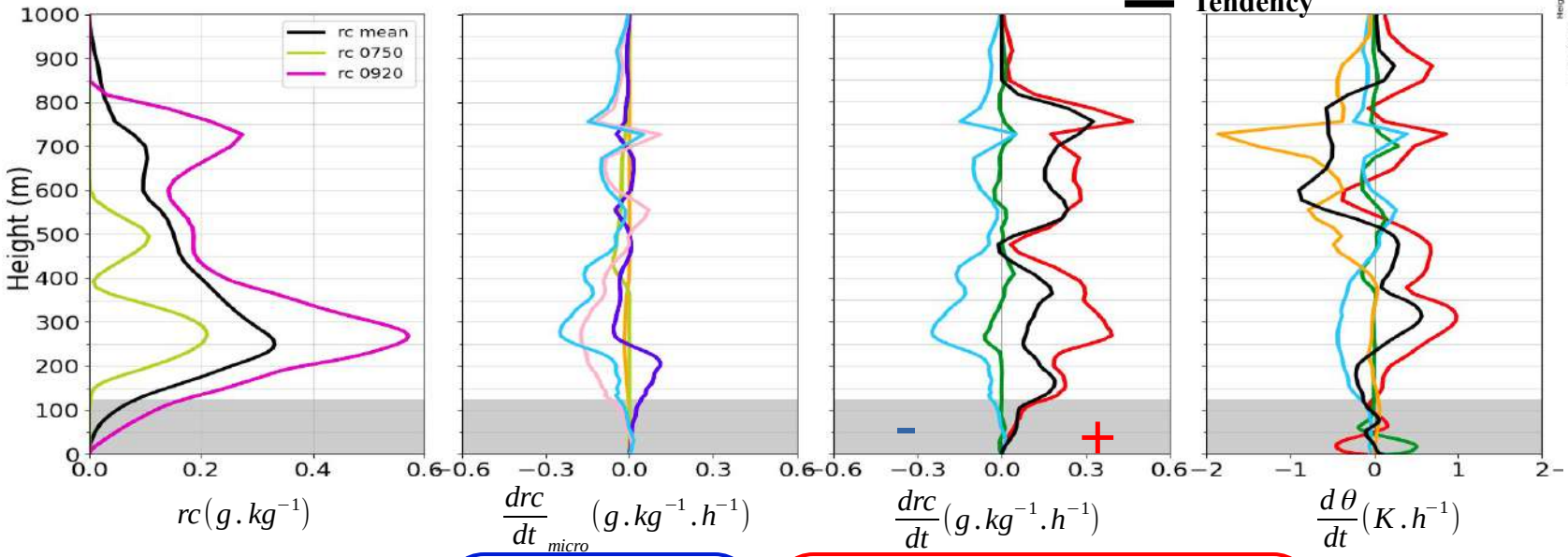
Accretion Sedimentation

Riming Adjustment +CCN act

Advection Microphysics

Turbulence Radiation

Tendency



Sedimentation **Advection of cloudy water**

Thank you for your attention

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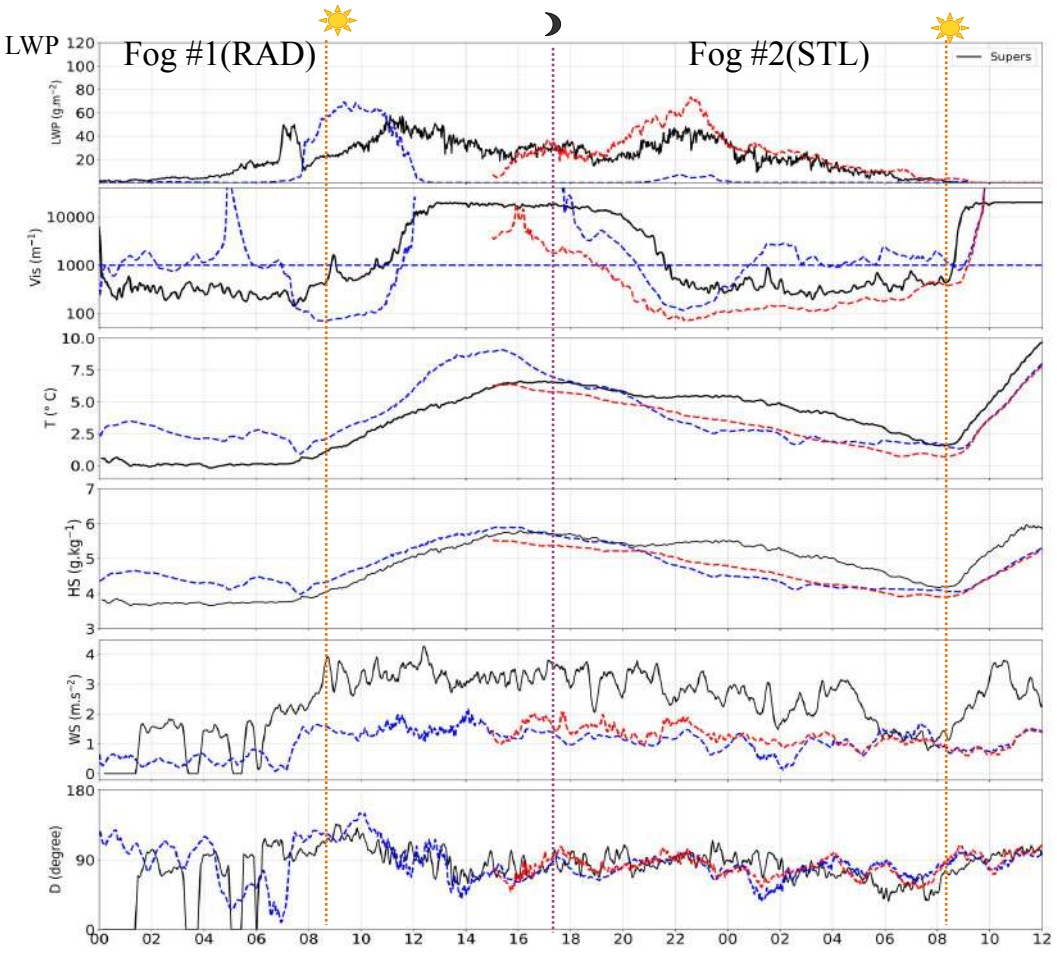
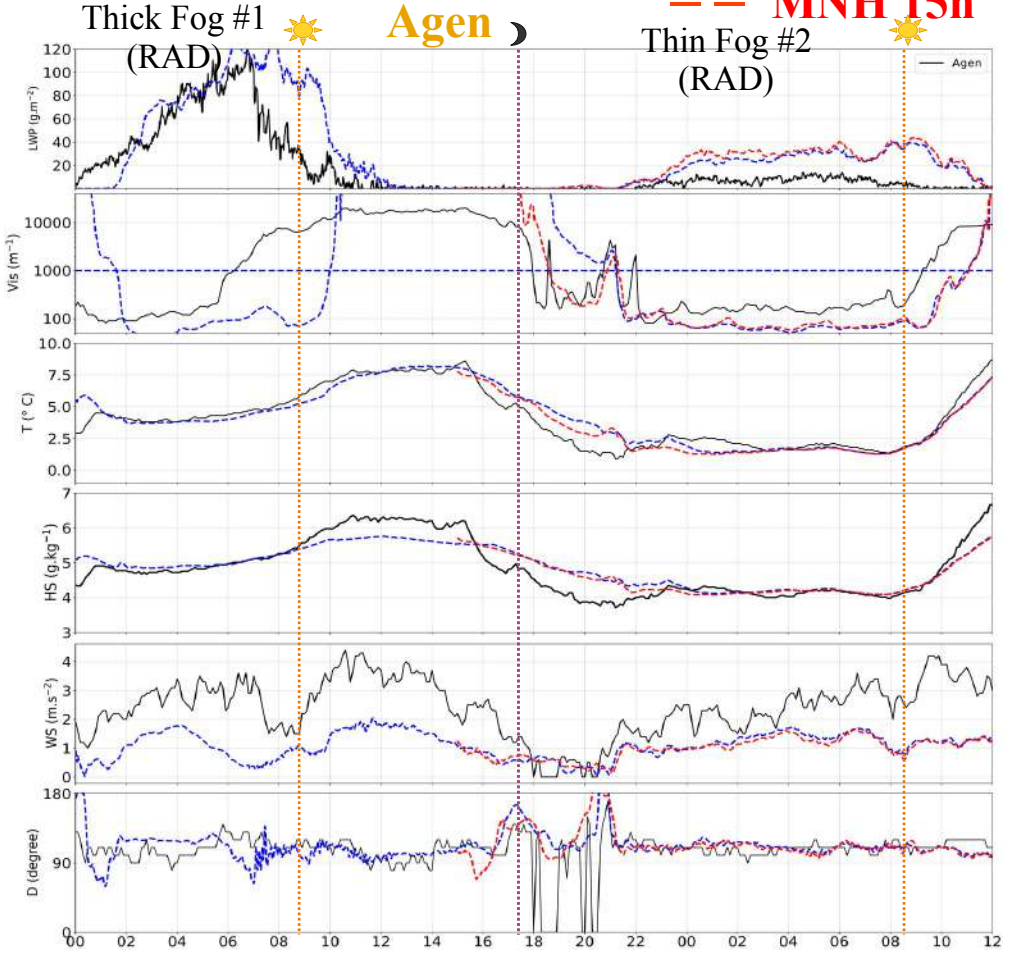
Comparison with observations

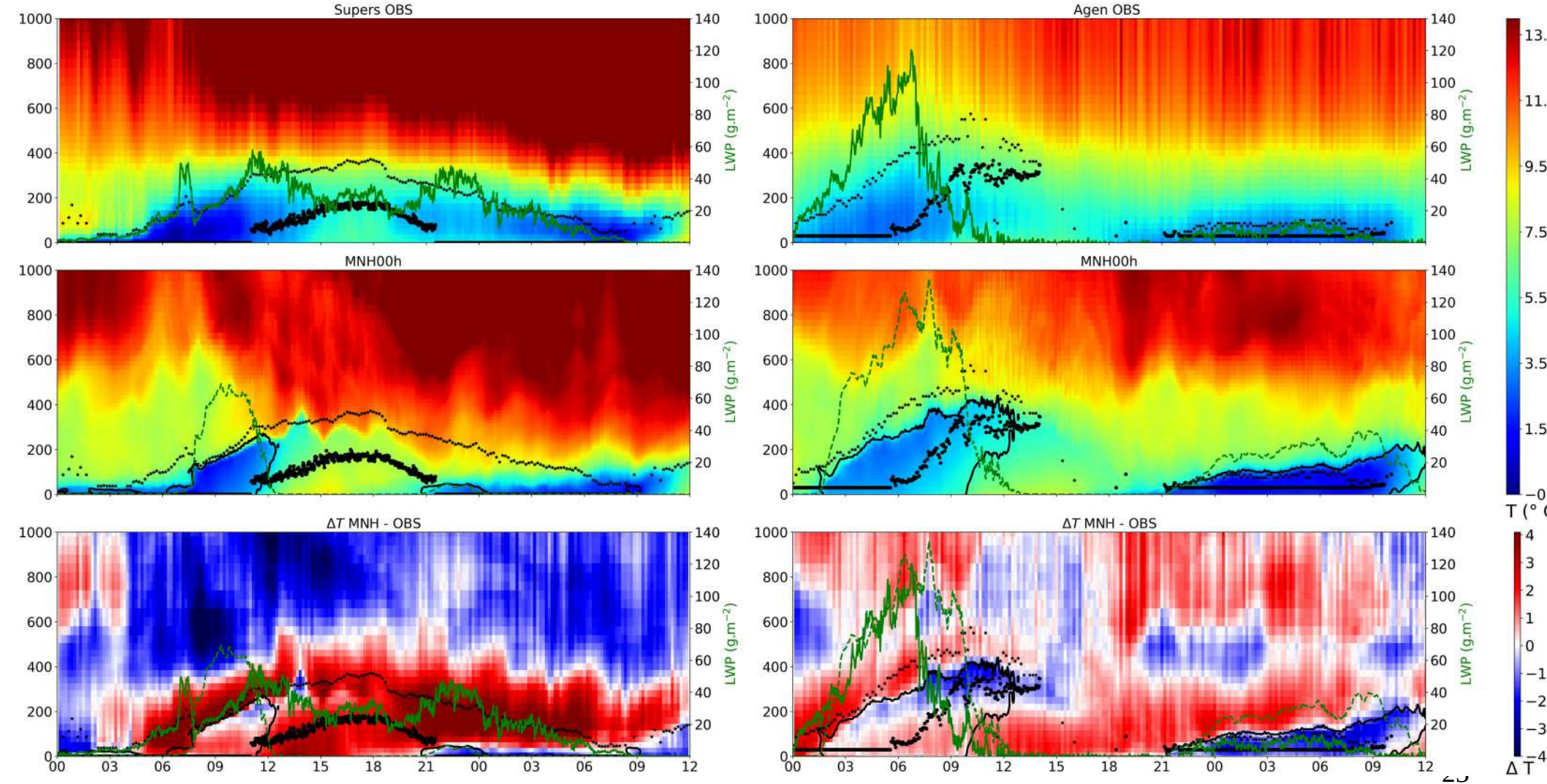
– – MNH 00h

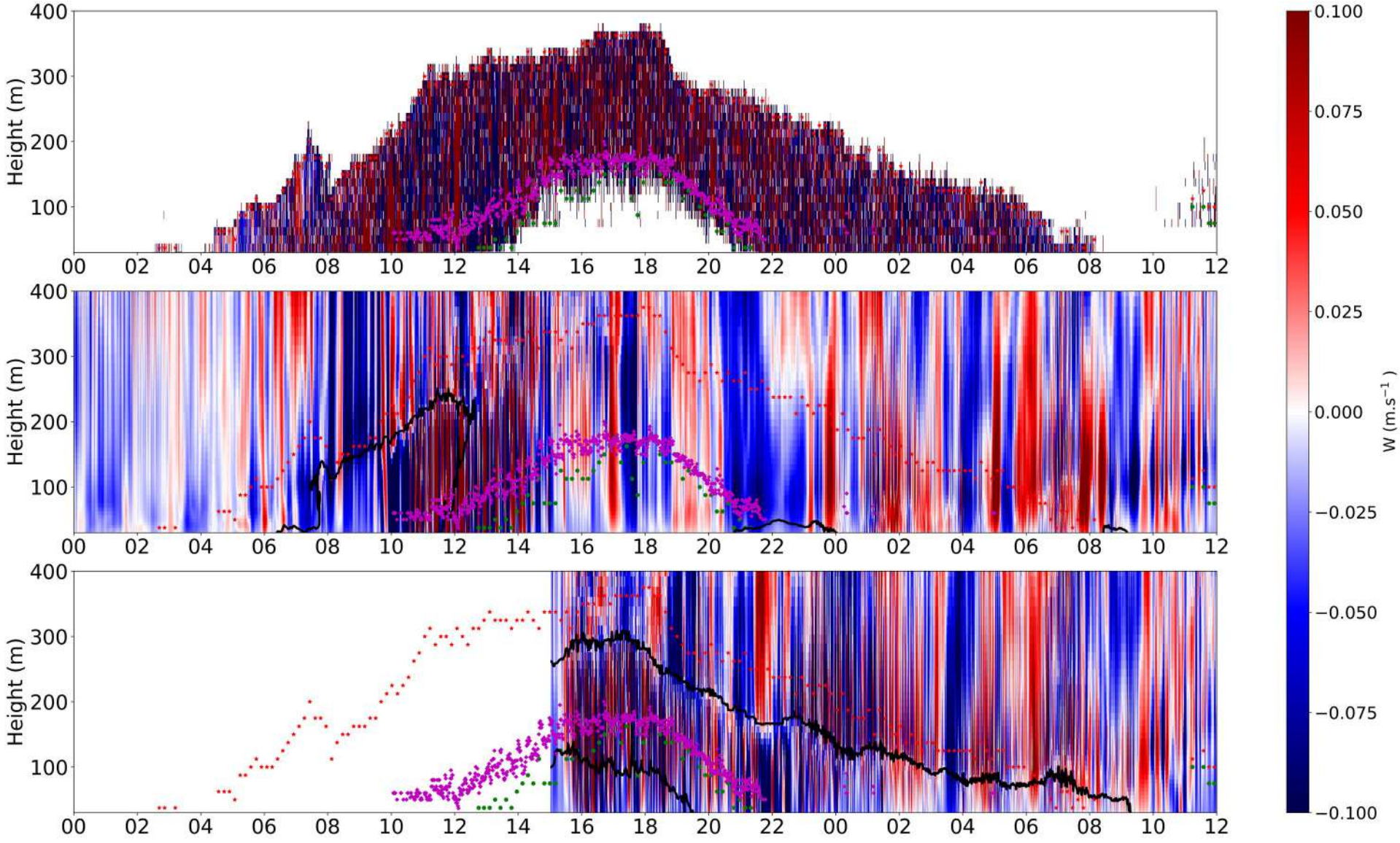
– – MNH 15h

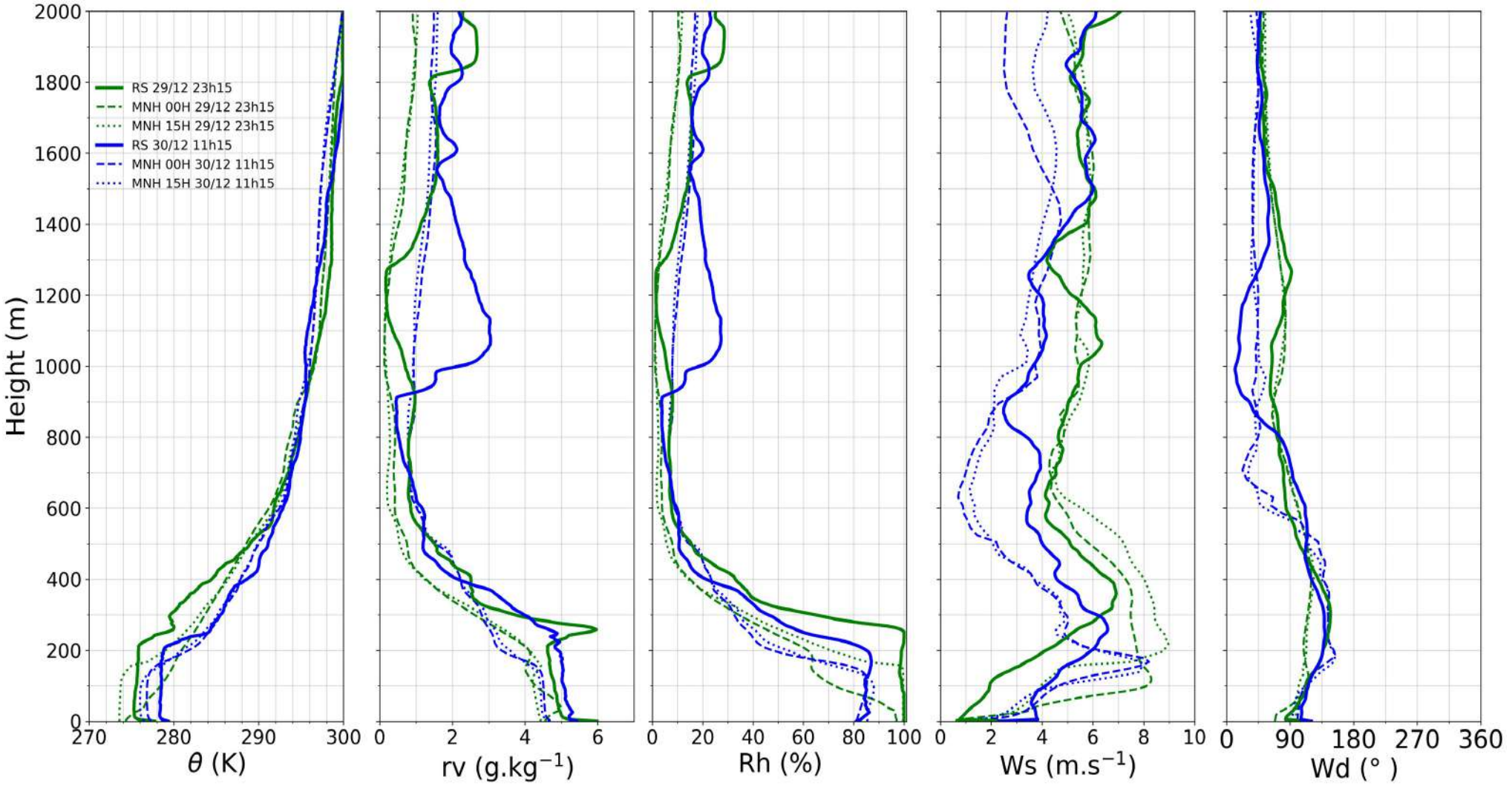




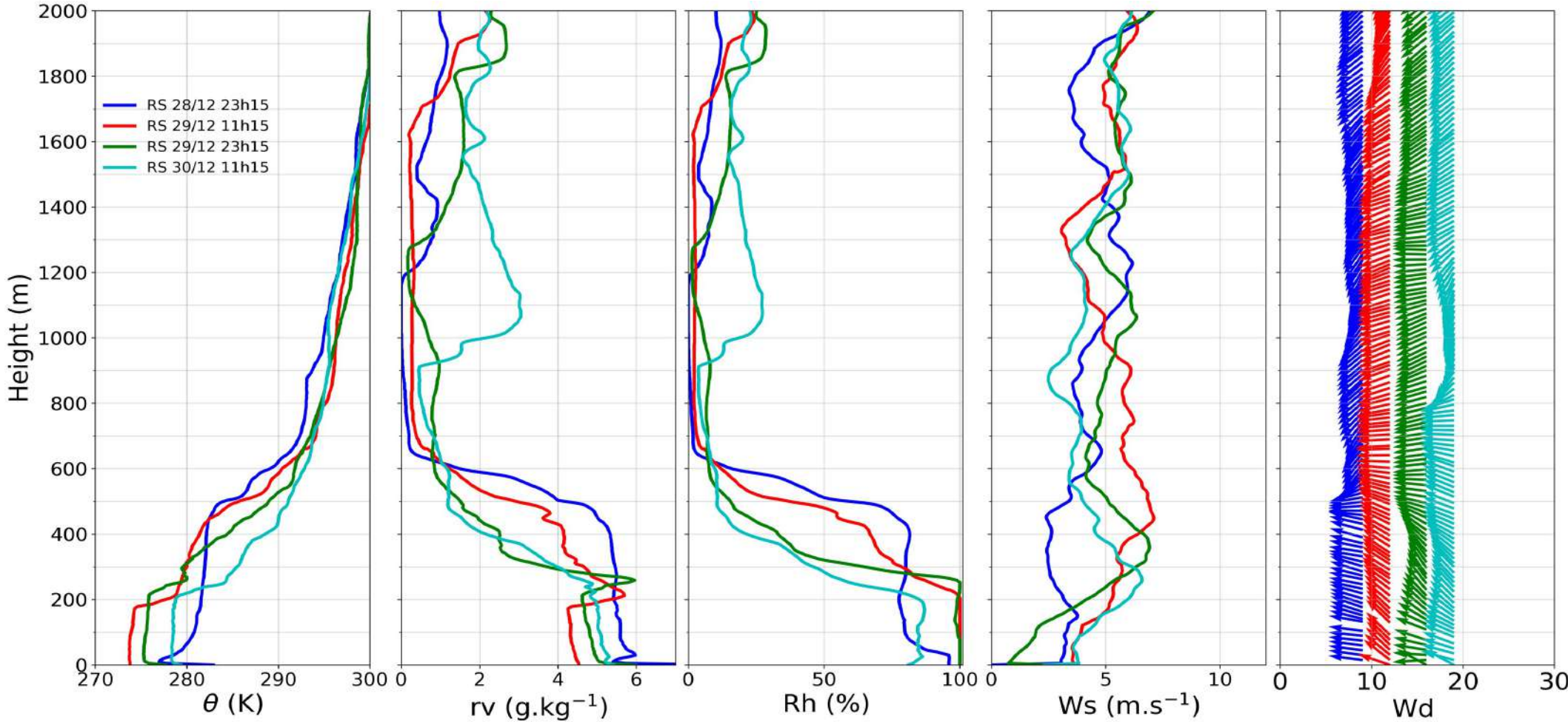
MNH 15H reproduces the stratus lowering as well as the LWP life cycle at the supersite.


Supers OBS
Agen OBS
MNH00h
MNH00h
ΔT MNH - OBS
ΔT MNH - OBS
LWP (g.m⁻²)
T (°
Δ T

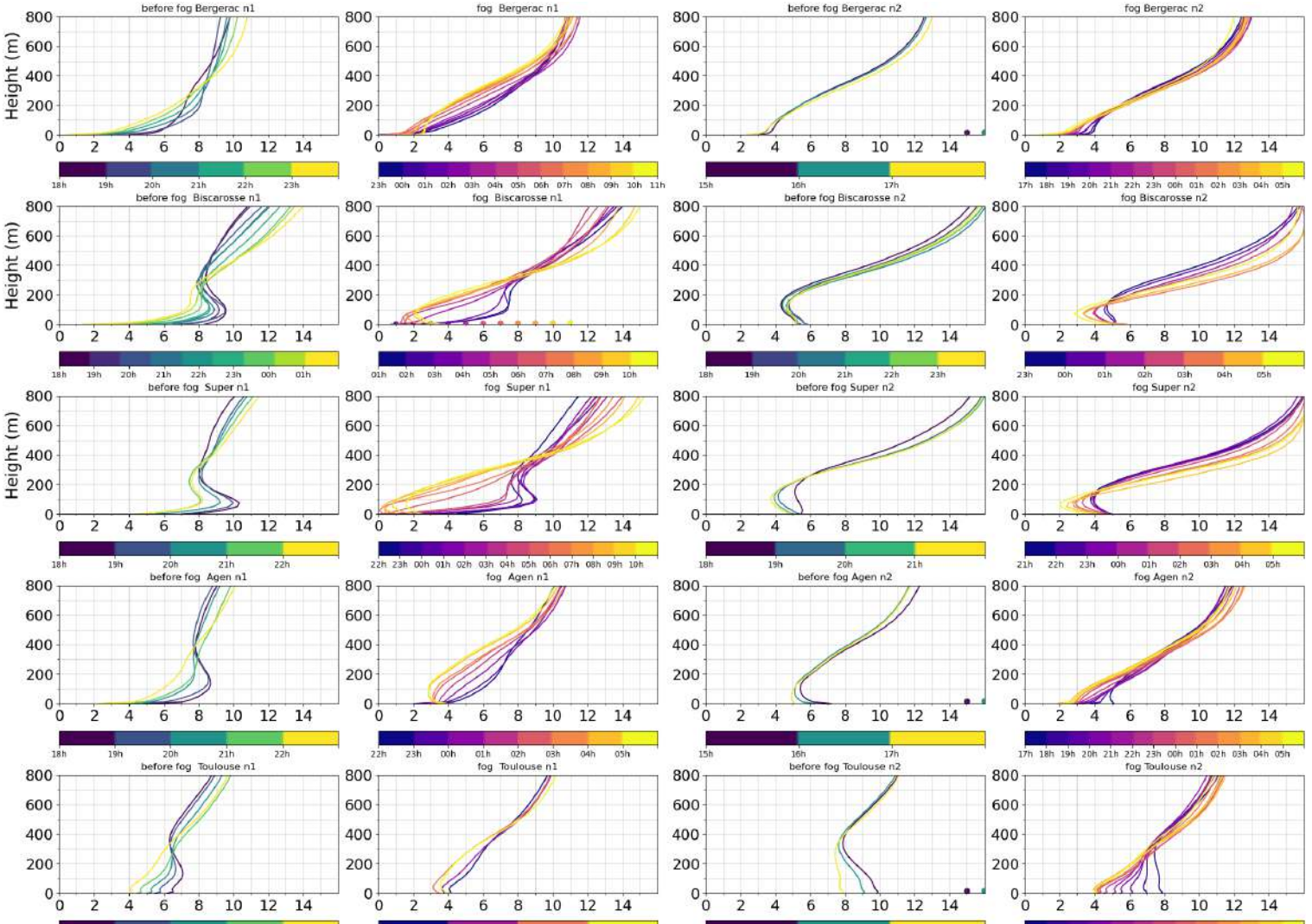

Height (m)
400
300
200
100
00
02
04
06
08
10
12
14
16
18
20
22
W (m.s^{-1})
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100


RS 29/12 23h15
MNH 00H 29/12 23h15
MNH 15H 29/12 23h15
RS 30/12 11h15
MNH 00H 30/12 11h15
MNH 15H 30/12 11h15
Height (m)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
270
280
290
300
θ (K)
0
2
4
6
rv (g.kg−1)
0
20
40
60
80
100
Rh (%)
0
2
4
6
8
10
Ws (m.s−1)
0
90
180
270
360
Wd (°)

Radiosondes at Bordeaux



- Cooling of 6K at 100m between 11pm on 28/12 (blue) and 11am on 29/12 (red).
- Advection of cold air from the southeast.


before fog Bergerac n1
fog Bergerac n1
before fog Bergerac n2
fog Bergerac n2
before fog Biscarosse n1
fog Biscarosse n1
before fog Biscarosse n2
fog Biscarosse n2
before fog Super n1
fog Super n1
before fog Super n2
fog Super n2
before fog Agen n1
fog Agen n1
before fog Agen n2
fog Agen n2
before fog Toulouse n1
fog Toulouse n1
before fog Toulouse n2
fog Toulouse n2
Height (m)