3D characterization of the fog microphysical properties during the SOFOG3D campaign and impacts on the fog life cycle : Observations and LES

PhD position Theophane Costabloz (May 2021 – 2024)

Supervision : F.Burnet, C.Lac

PhD Objectives

Main Objective : Characterize the microphysical heterogeneites within the fog layer during its life cycle

Experimental Part: Data Validation, Documentation and characterization of the fog microphysical properties

Modeling Part : High resolution simulations,validation, impacts of LIMA

Process studies to analyze the key processes that explain the microphysical evolution during the fog life cycle:

- **Role of microphysics during the transition between an optically thin and thick fog**
- **Impact of entrainment and turbulent mixing at the top of the fog layer**

Plan

I) Fog climatology and classification

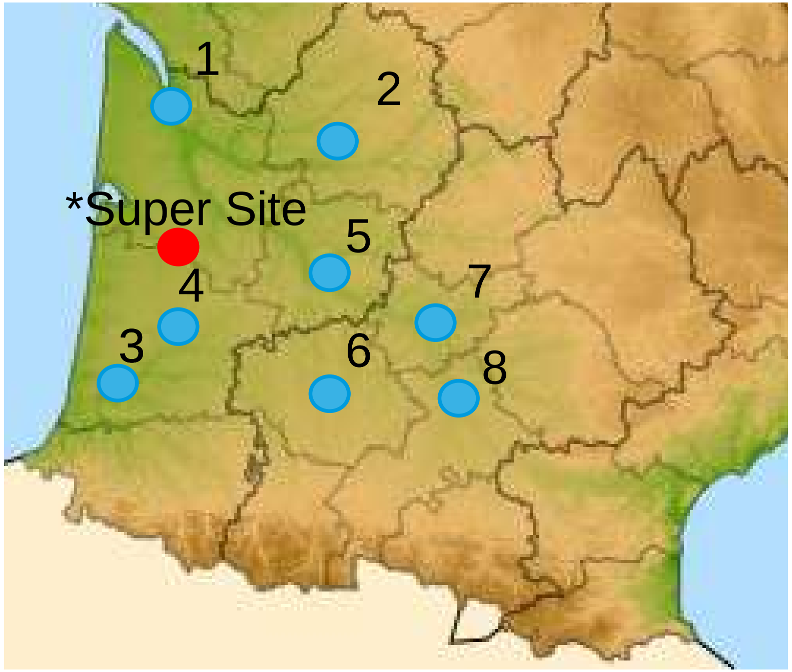
II) Measurements validation : Intercomparison

III) Methodology of microphysical properties

IV) Analysis of the fog thermodynamic and microphysical properties

V) Bias turbulence probe

I) Fog climatology in the South-West (1991-2022) and focus on SOFOG3D



8 Observations stations :

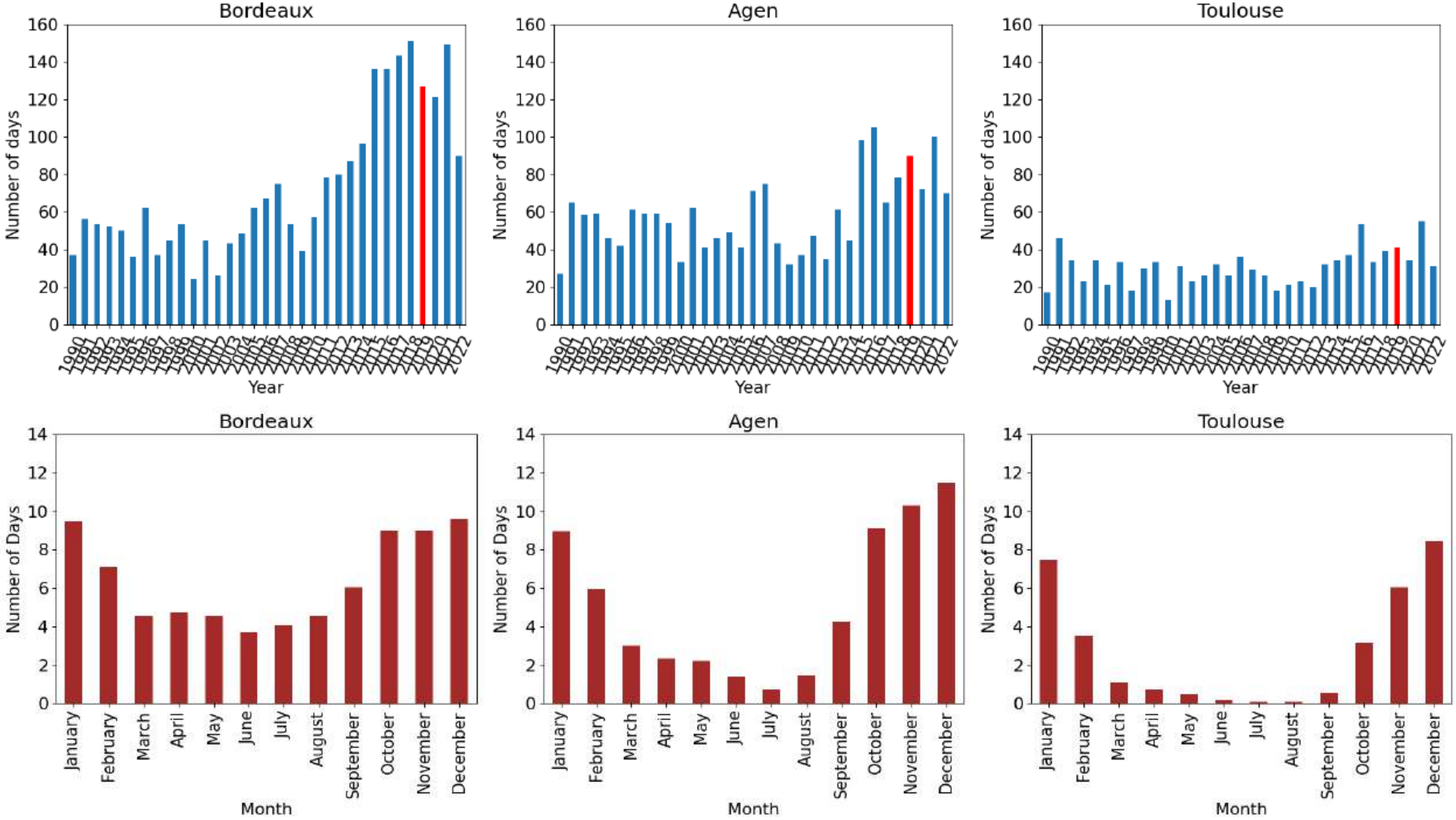
- 1 : Bordeaux (33)
- 2 : Bergerac (24)
- 3 : Dax (40)
- 4 : Mont-de-Marsan (40)
- 5 : Agen (47)
- 6 : Auch (32)
- 7 : Montauban (82)
- 8 : Toulouse (31)
- * : Super Site localisation

I) Climatology on 1991-2022 period : 2022 and 2023 added

Number of foggy days :

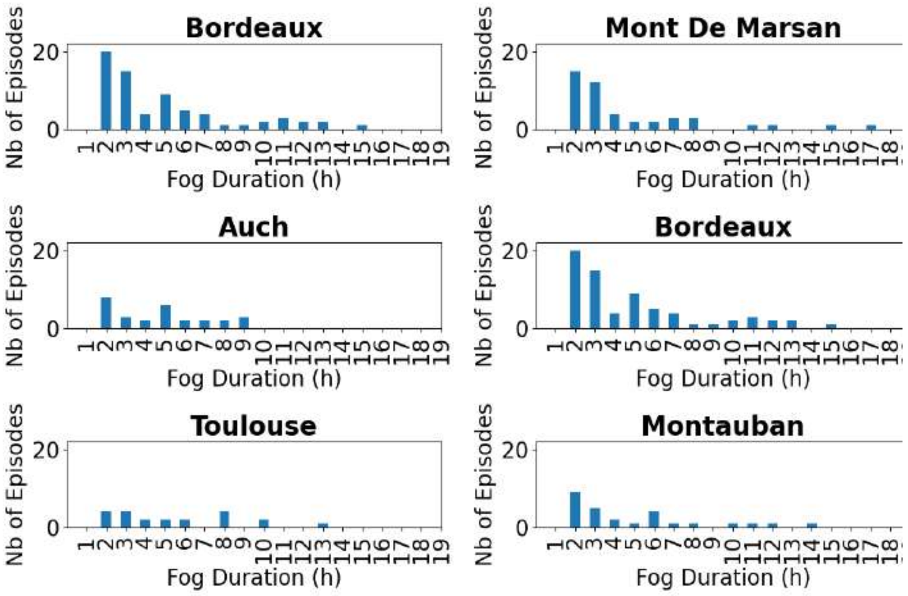
- Per winter

- Per month (mean)

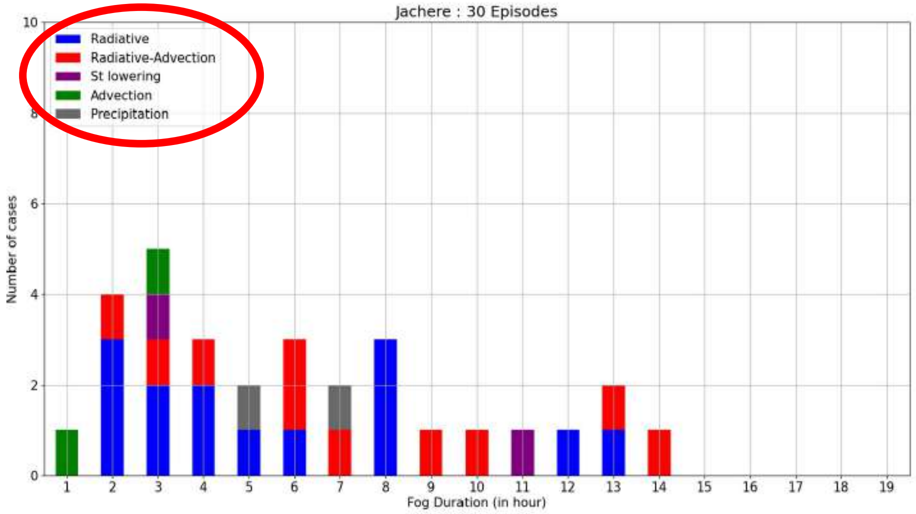


- Number of foggy days persistent with recent years in Toulouse and Bordeaux, higher in Agen
- Decreasing number of foggy days in summer westwards, higher in Bordeaux to very rare in Toulouse

I) Focus winter 2019/2020 : Monthly Fog duration



Meteo-France meteorological station



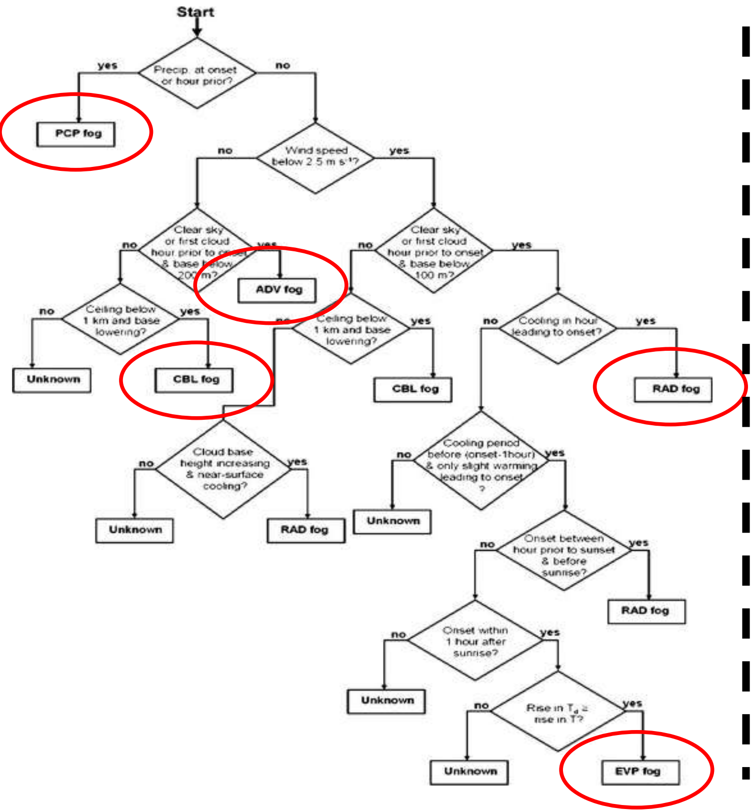
SOGOG3D Jachere site

1/3 non-persisting fogs (<2h) et 1/3 persisting fogs throughout the night (>8h)

I) Fog Classification : Methodology

Semi-automatic classification : combine

a) Tardiff and Rasmussen algorithm

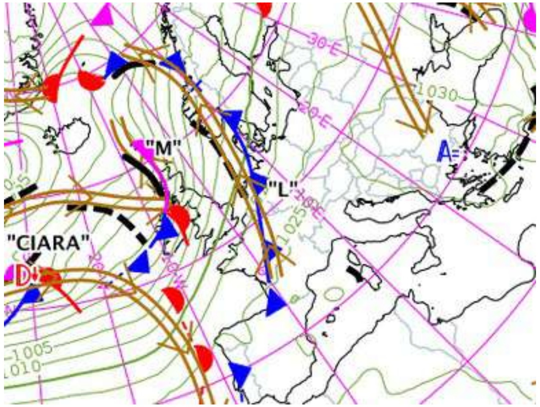


1) Large scale conditions

2) Analysis at thinner scale

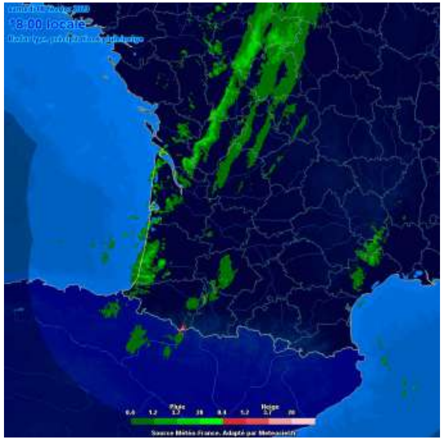
Adding Radiative-Advective fog type

b) Meteorological analysis

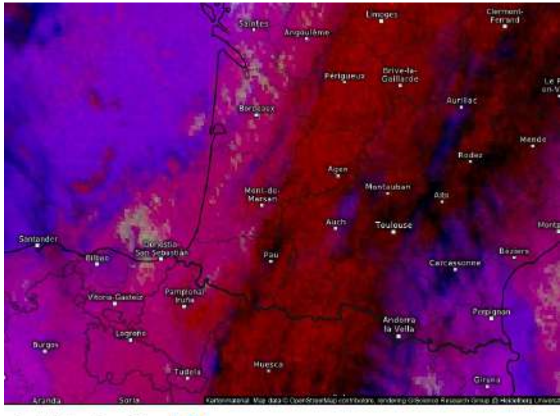


Anasyg

Radars



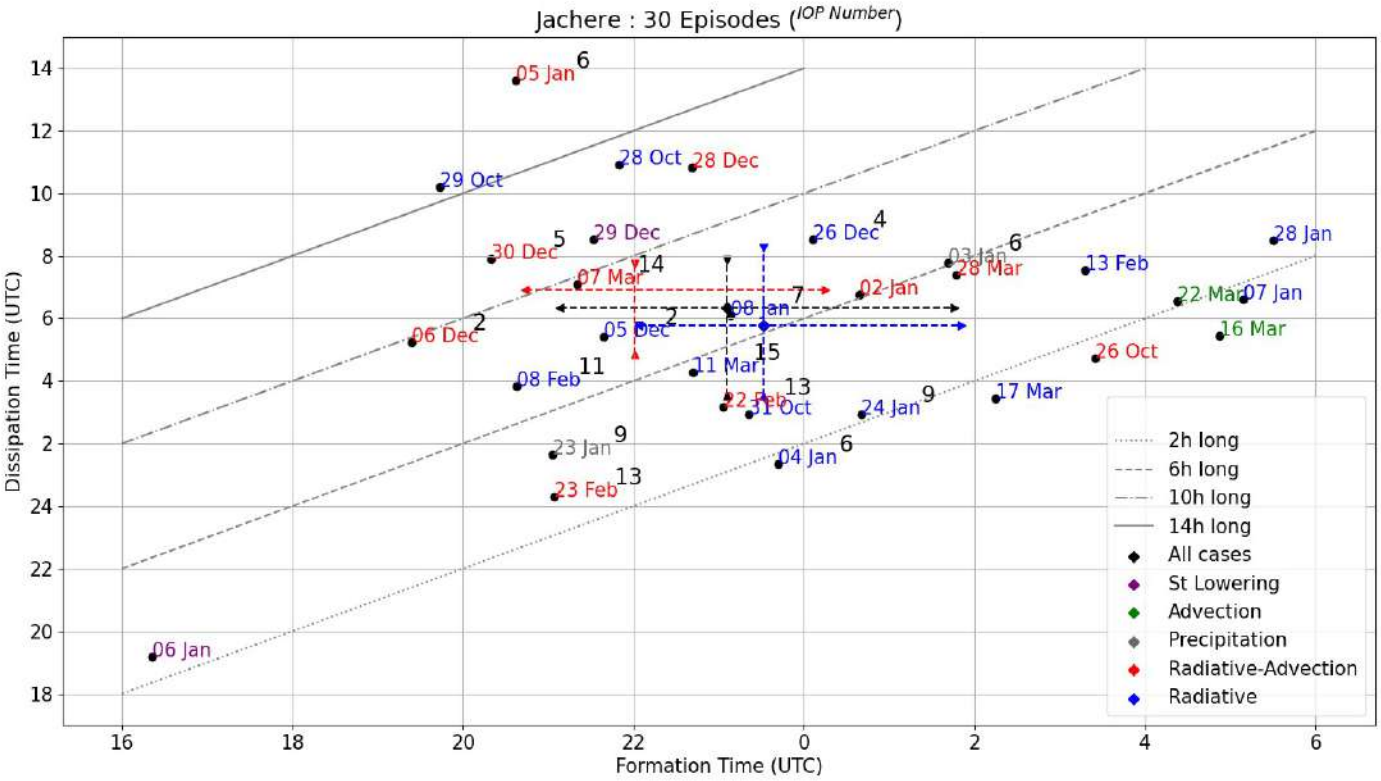
Satellites



Satellite Fog-Check

I) Classification : synthesis SOFOG3D

15 IOPs from November 29th 2019to March 11th 2020



30 episodes overall :

- 14 Radiative fogs
- 10 Radiative-Advective fogs
- 2 Advective fogs
- 2 Stratus Lowering
- 2 Precipitation fogs

Fog forms in general between 22h and 00h and dissipates between 6h et 8h

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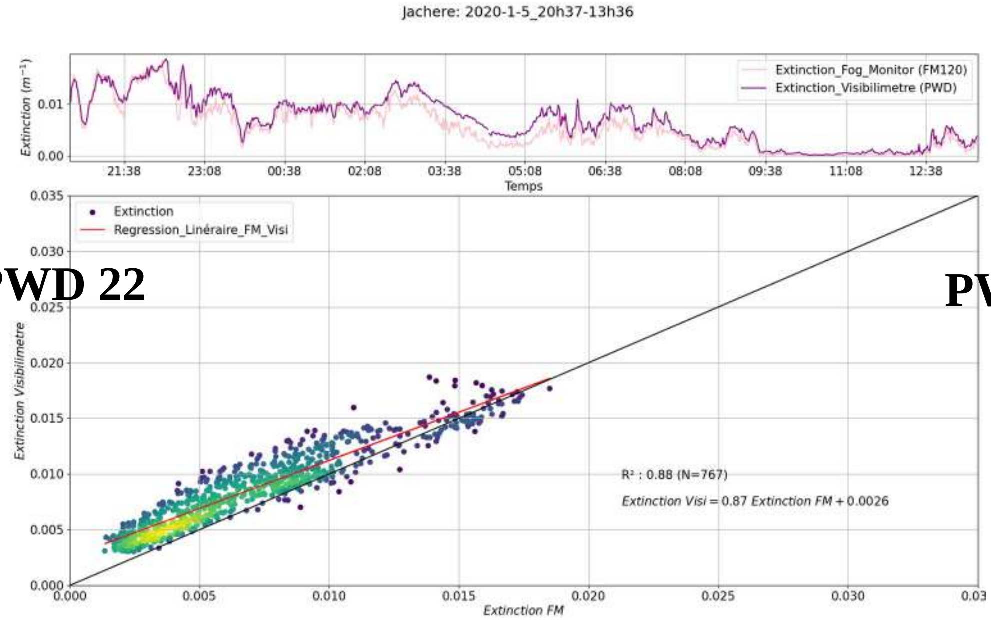
II) Measurements Validation

Ground validation : FM120 and PWD 22 visibilimeter (reference)

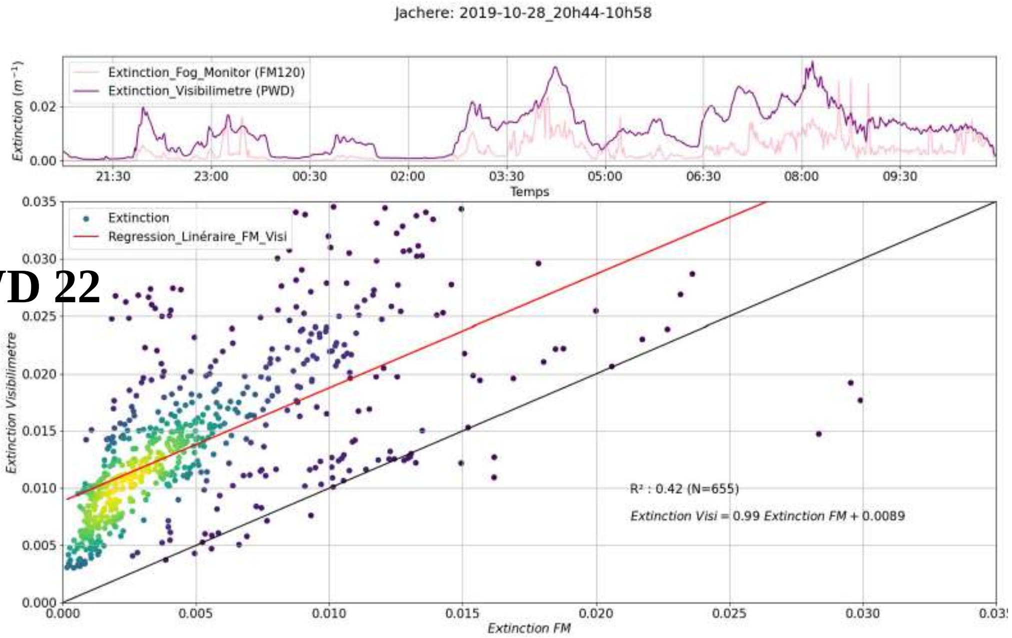


PWD 22

FM120

5/6 January 2020 (POI 6)

Validated case



PWD 22

FM120

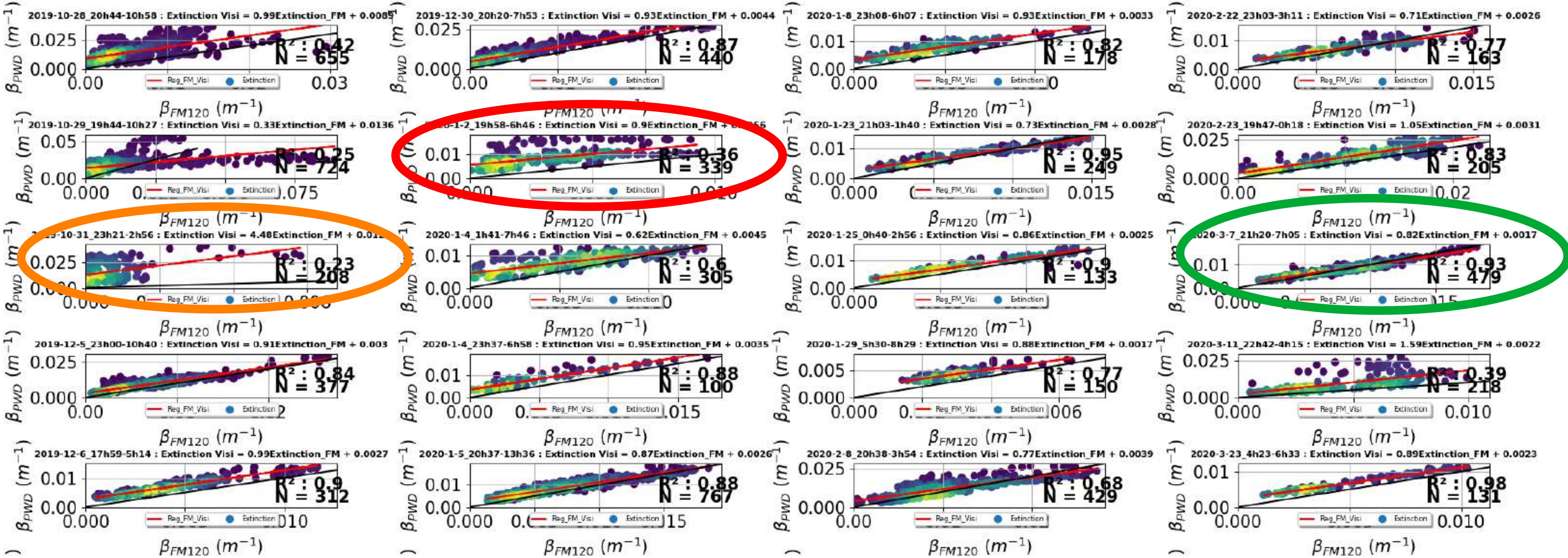
28/29 October 2019

Invalidated case

II) Measurements Validation

Ground validation : Overview

PWD



FM120

Intercomparison : 18 cases validated, 4 invalidated , 3 suspicious

II) Measurements Validation

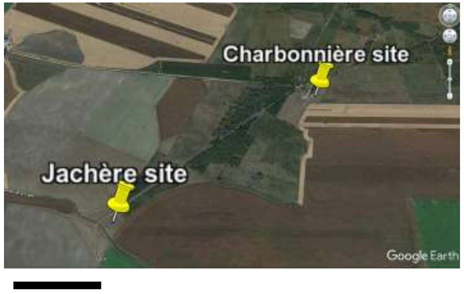
CDP validation : comparison with visibilimeter and FM120

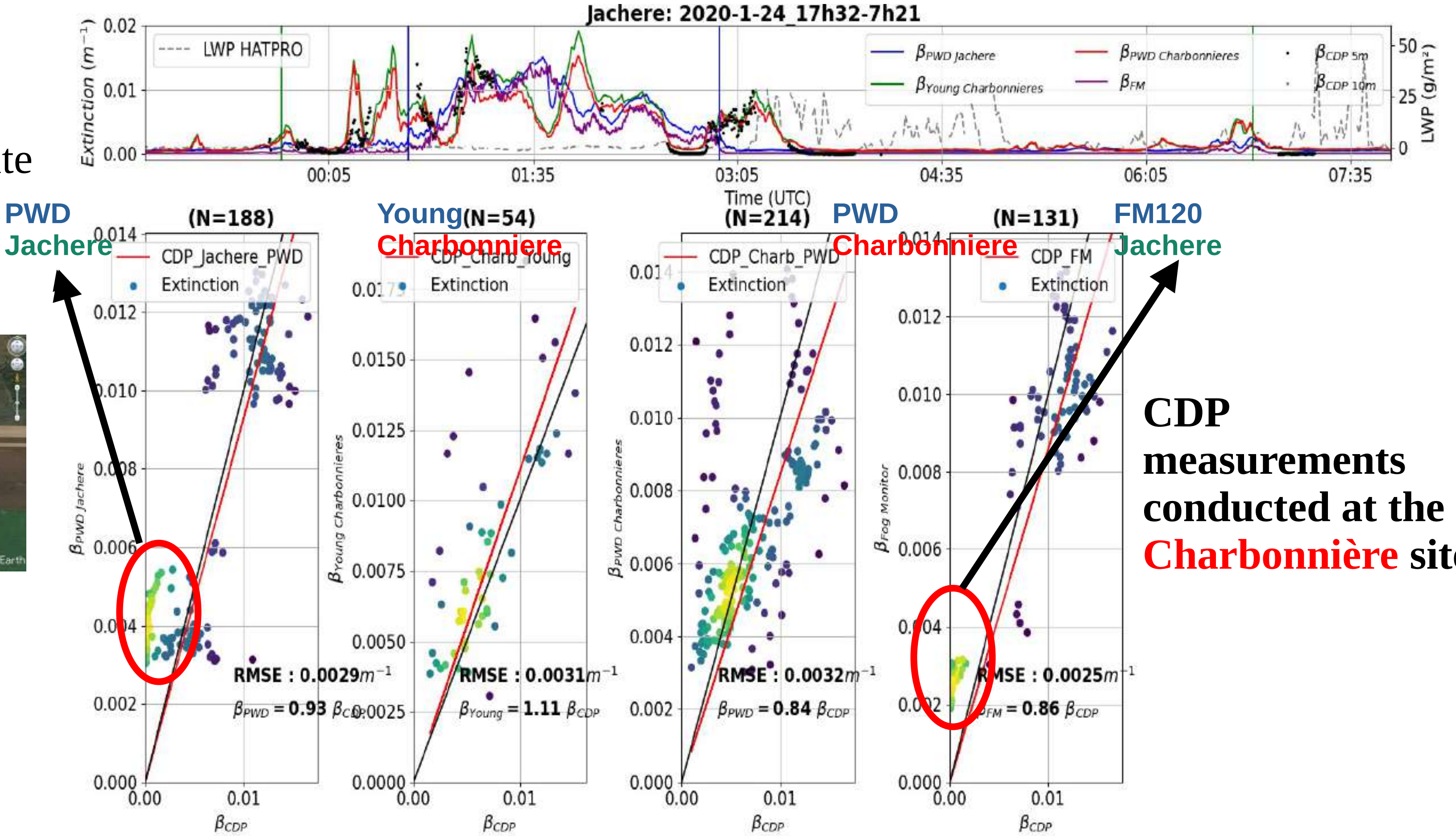
CDP Data near ground
- Charbonnière site

Ground

Charbonnière site

Jachere site





CDP measurements conducted at the Charbonnière site

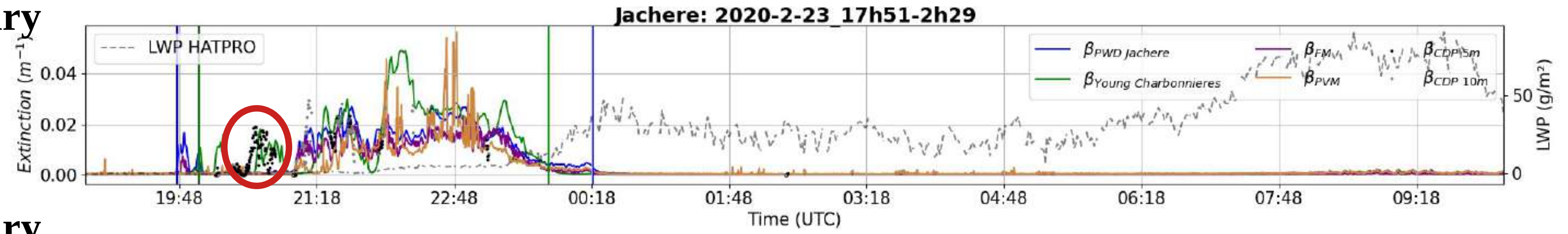
High microphysical heterogeneities between the two sites

II) Measurements Validation

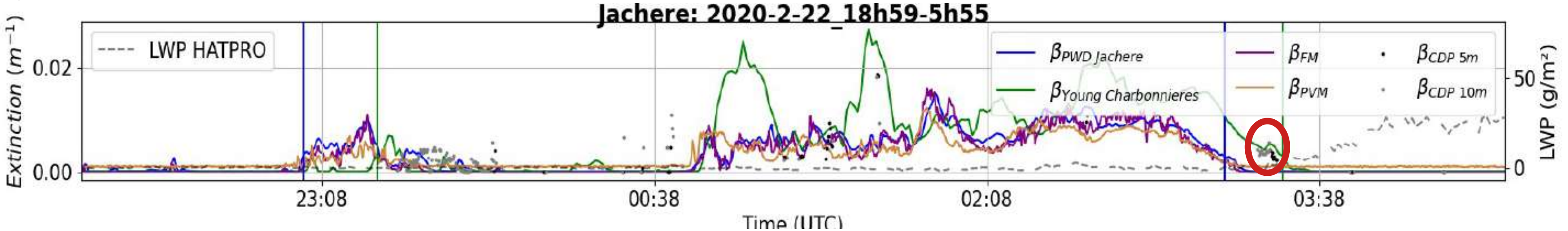
CDP validation : comparison with visibilimeter and FM120

24th January 2020

23th February 2020



22th February 2020



→ **Microphysical heterogeneities make difficult to compare CDP (aloft) and FM120 (ground) droplets distributions**

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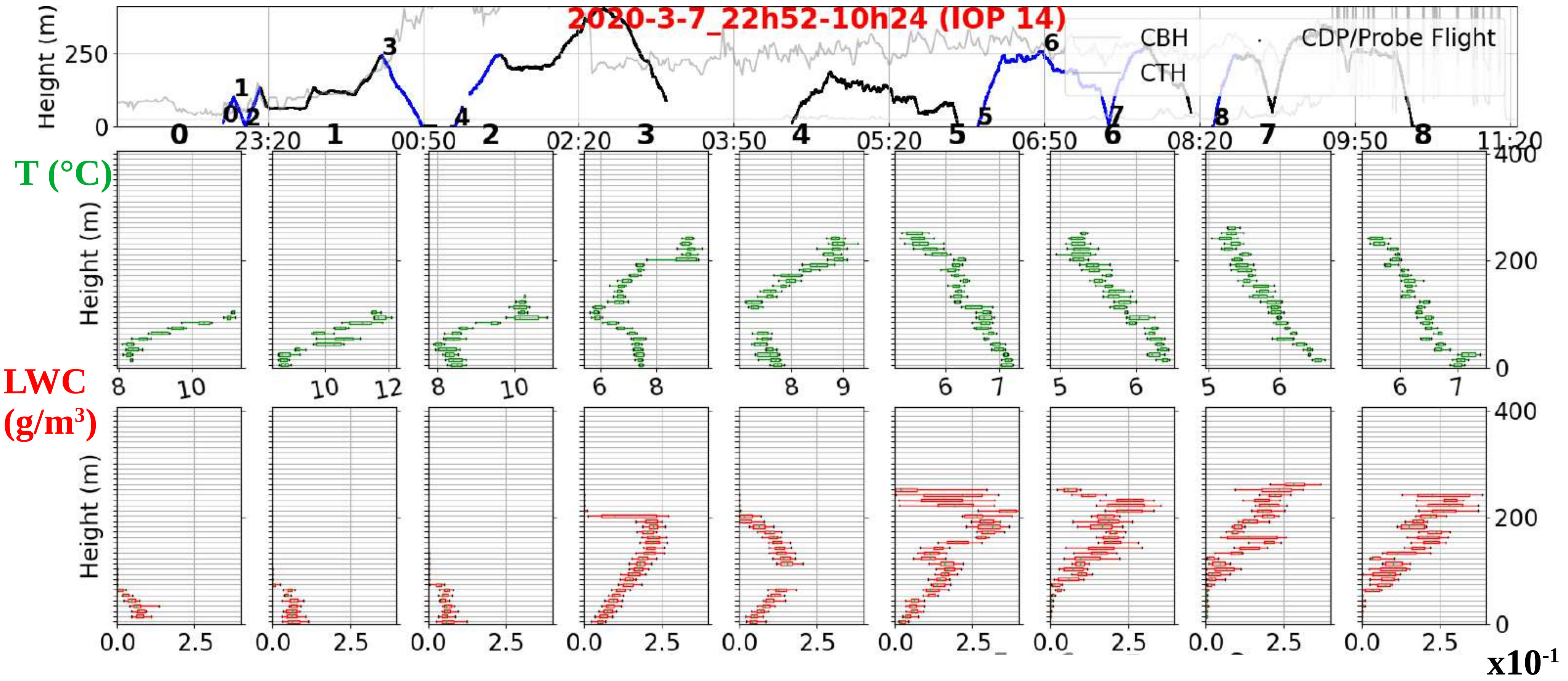
III) Methodology of microphysical properties : Introduction



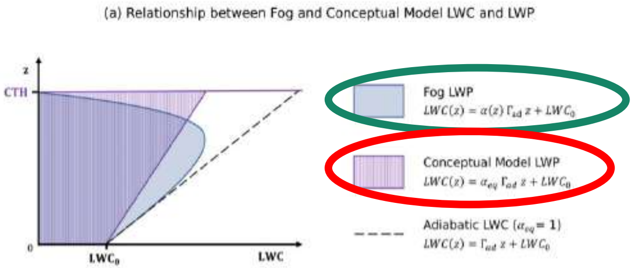
- High correlation between the vertical profiles of LWC and temperature
- Decreasing LWC values measured when the fog is optically thin

→ <u>Agreement with conceptual models ?</u>

III) Methodology of microphysical properties:
Conceptual models and observations

Conceptual models

<u>Without the knowledge of β, assumptions necessary</u>



$$LWC(z) = \alpha(z)\,\Gamma_{ad}(T,P)\,z + LWC_0$$

$$LWP = \int_{z=0}^{z=CTH} \left(\alpha(z)\,\Gamma_{ad}(T,P)\,z + LWC_0\right) dz$$

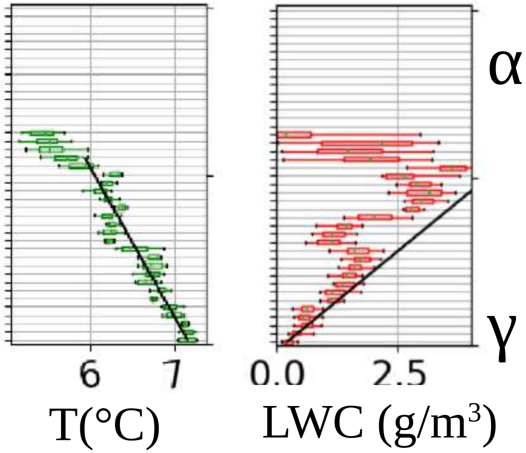
$$LWP = \frac{1}{2}\alpha_{eq}\,\Gamma_{ad}(T,P)\,CTH^2 + LWC_0\,CTH$$

$$\Rightarrow \alpha_{eq} = \frac{2\left(LWP - LWC_0 \times CTH\right)}{\beta_{ad} \times CTH^2}$$

Radiometer (→ LWP), *Visi* (→ LWC_0), *BASTA* (→ CTH)

Toledo et al, 2021

Observations



$$\alpha = \frac{\frac{dLWC}{dz}}{\left(\frac{dLWC}{dz}\right)_{ad}} = \frac{\beta}{\beta_{ad}}$$

Local adiabaticity (→ β)

Adiabaticity fraction

$$\gamma = \frac{\frac{dT}{dz}}{\left(\frac{dT}{dz}\right)_{ad}} = \frac{\Gamma}{\Gamma_{wet\ ad}}$$

Local lapse rate (→ Γ)

Lapse rate fraction

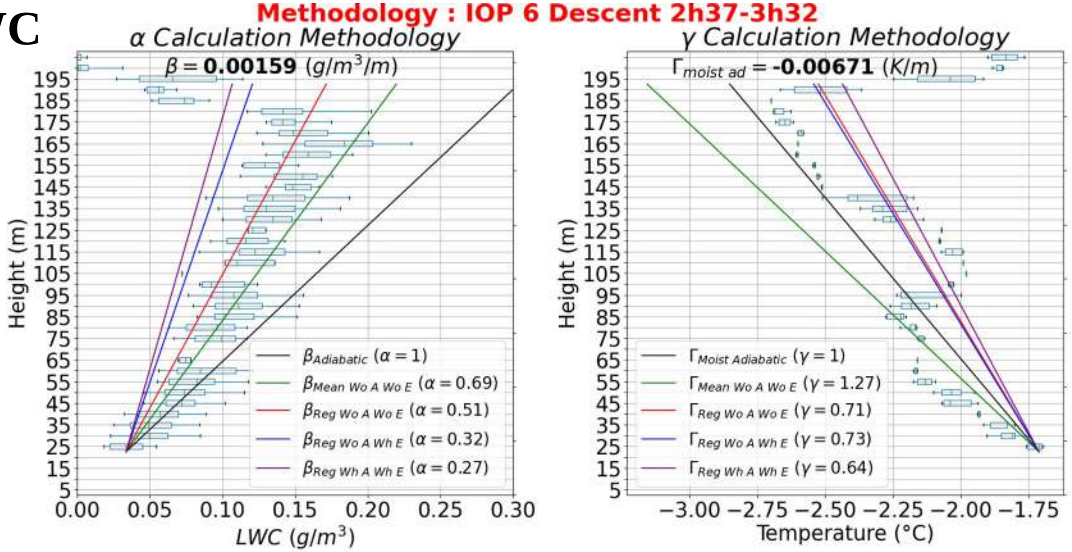
III) Methodology of microphysical properties : β and Γ calculation

LWC

T

a) Adiabatic Vertical Profile

a)



With activation, with Eentrainment

Without activation, with entrainment

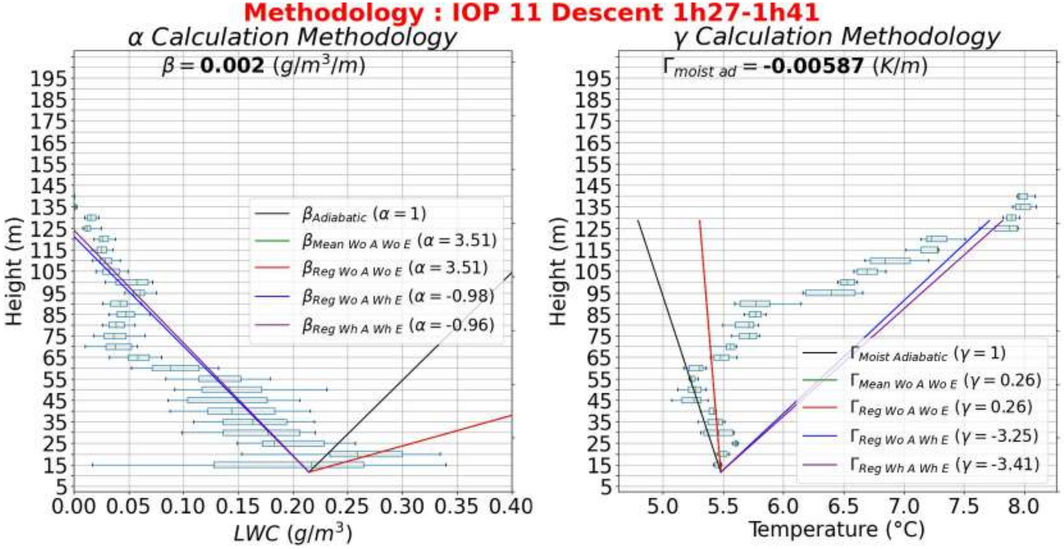
Without activation, without entrainment
Regression

Without activation, without entrainment
Mean Gradient

Theoretical adiabaticity

b) Inverted LWC vertical profile

b)



Necessity to take into account :

- **Activation at the fog top and entrainment**
- **Entrainment within the fog layer when the fog is optically thick**

III) Methodology of microphysical properties:

SOFOG3D

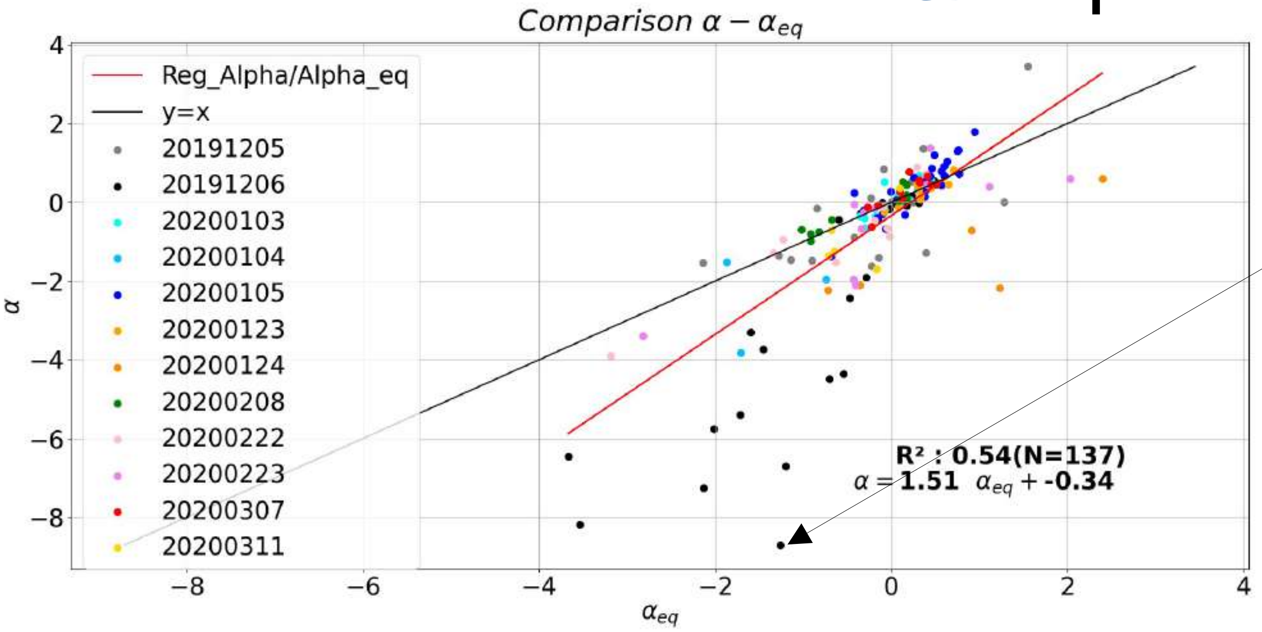
Conceptual model validation

$$\alpha_{eq} = \frac{2\left(LWP - LWC_0 \times (CTH - CBH)\right)}{\beta_{ad} \times \left(CTH^2 - CBH^2\right)}$$

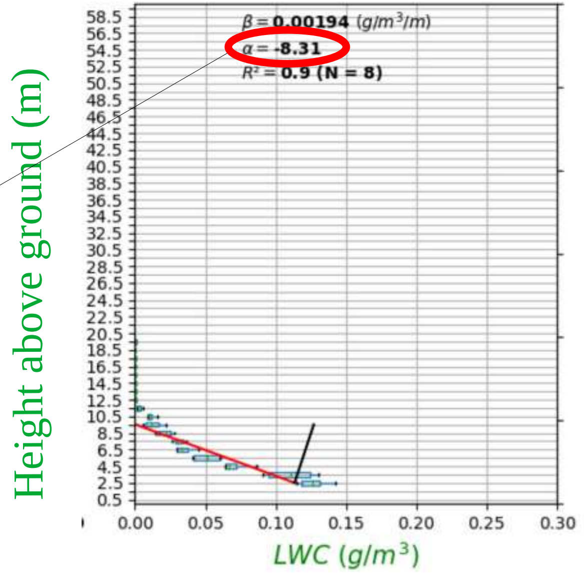
CDP (LWP) — CDP (LWC_0) — CDP (CTH)

$$\alpha = \frac{\beta}{\beta_{ad}}$$

Linear regression (β)



Descent 0336-0339UTC

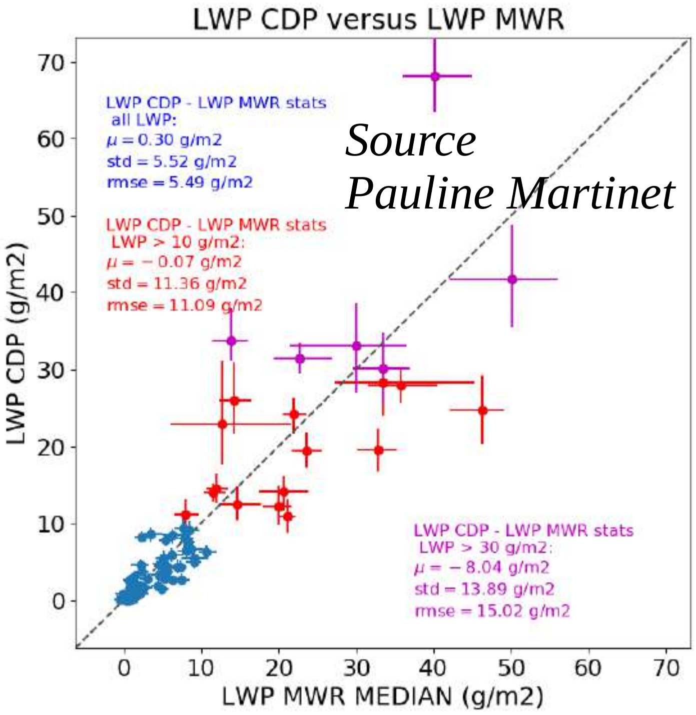


Larger differences for negative α values ➡ **Conceptual model not designed for very thin fogs (α<-1)**

III) Methodology of microphysical properties:

Conceptual model validation

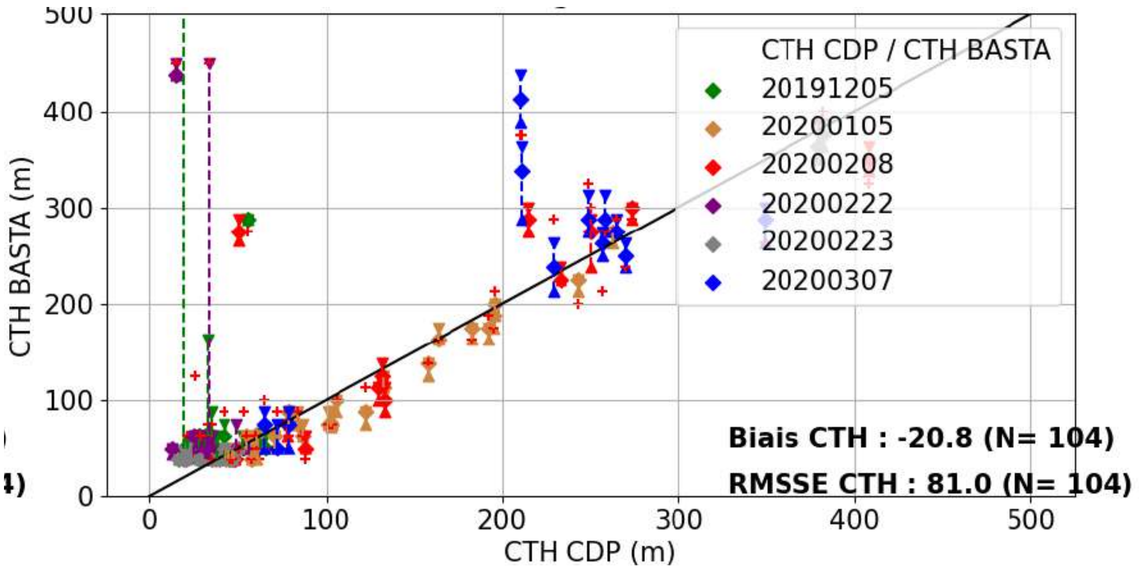
LWP Closure : HATPRO/CDP



Source Pauline Martinet

LWP : errors within the incertitude range of 10/20 g/m².
Larger discrepencies for the highest LWPs

CTH Closure : BASTA/CDP



CTH : Good agreement except for some cases due to BASTA CTH detection algorithm

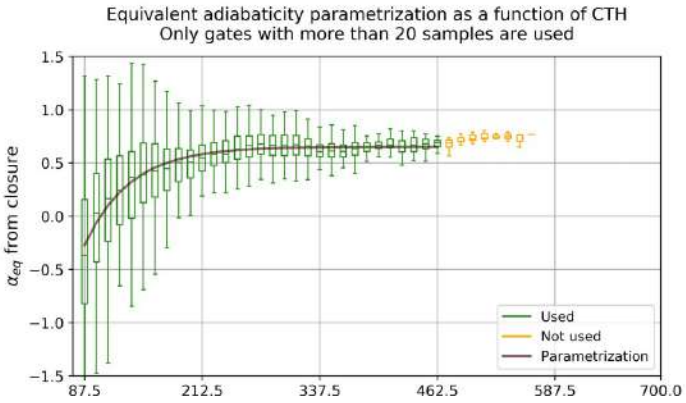
Overall, CDP LWP and CDP CTH consistent with remote sensing instruments.

→ **Low impacts on the computation of α_{eq} using CDP data**

III) Methodology of microphysical properties:

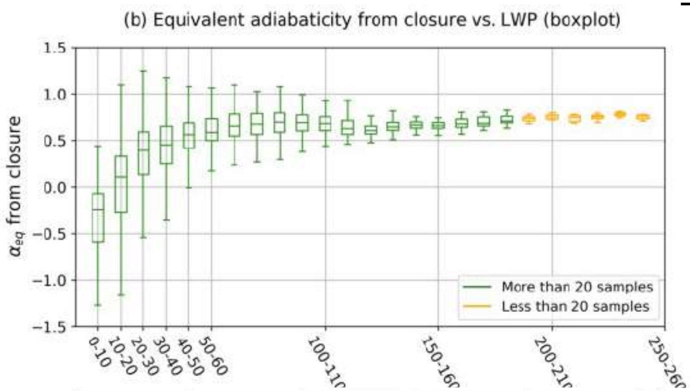
Conceptual model validation

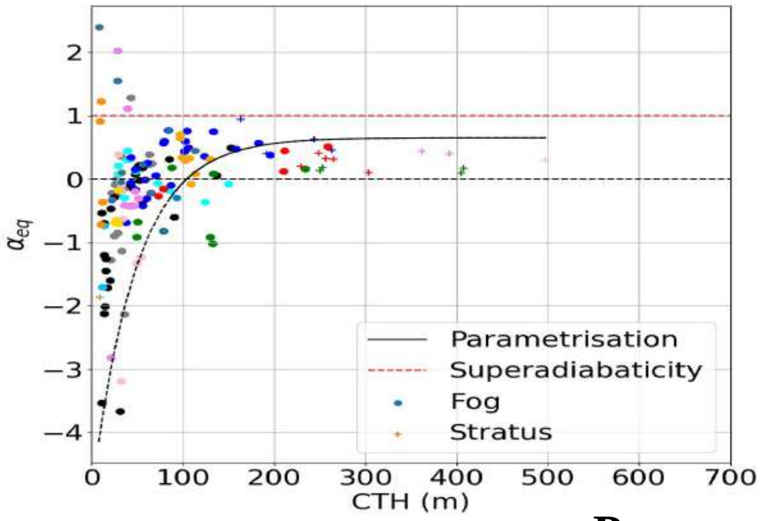
CTH



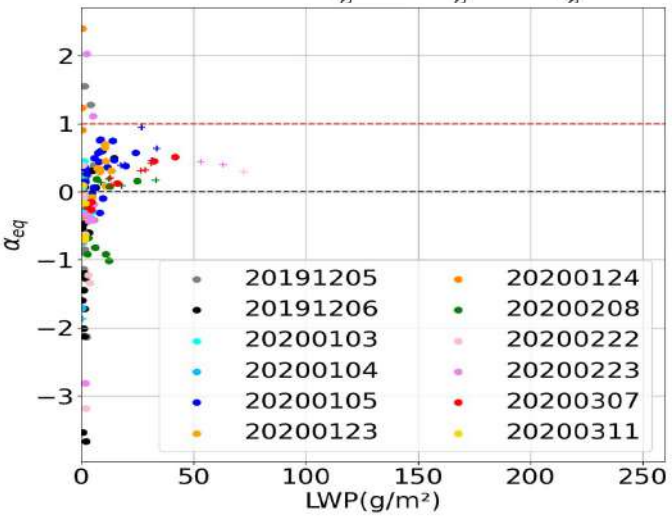
Toledo et al, 2021

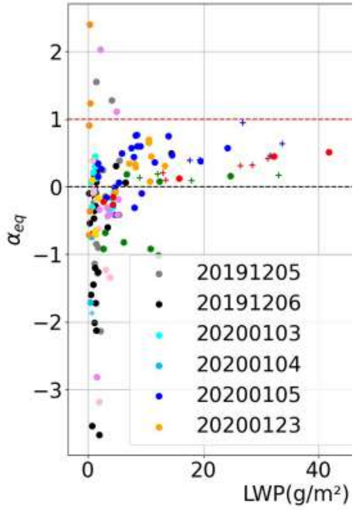
LWP





SOFOG3D



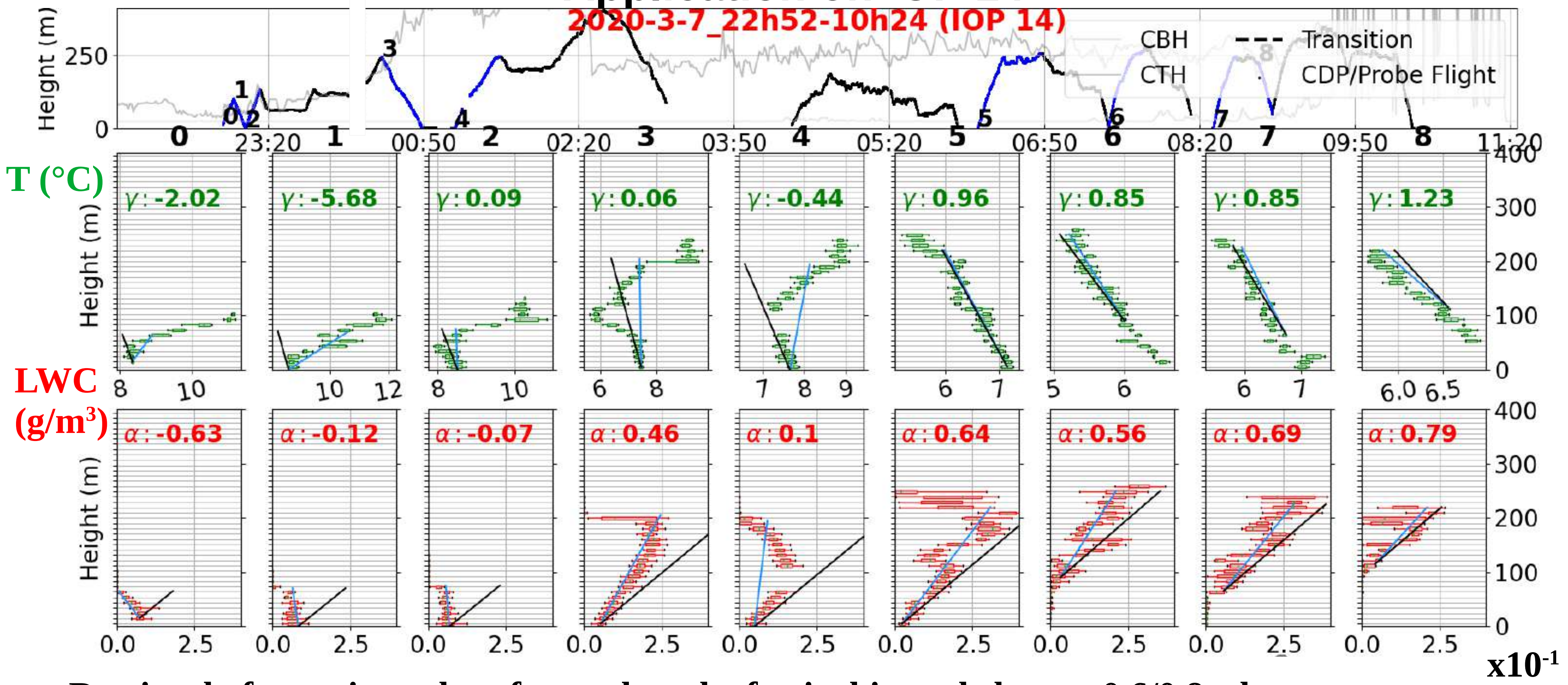


Parametrisation underestimated for lower CTH

→ Detection threshold BASTA Radar 85m

III) Methodology of microphysical properties:

Application on IOP 14



Retrieval of negative values for α when the fog is thin and close to 0,6/0,8 when more adiabatic

<u>Need to determine the time of transition from optically thin to optically thick fog</u>

III) Methodology of microphysical properties: :

Determination of the transition from optically thin to thick fog

Definition :

$LW_{UP} - LW_{DOWN} < 5\ W/m^2$

Other thresholds :

a) TKE Threshold :

TKE > 0,2m²/s²

(Dhangar 2021)

b) $Grad_{T\ 25\text{-}50m}$ Threshold :

GradT 25-50m < 0°C/m²

(Dupont 2015)

c) LWP Threshold :

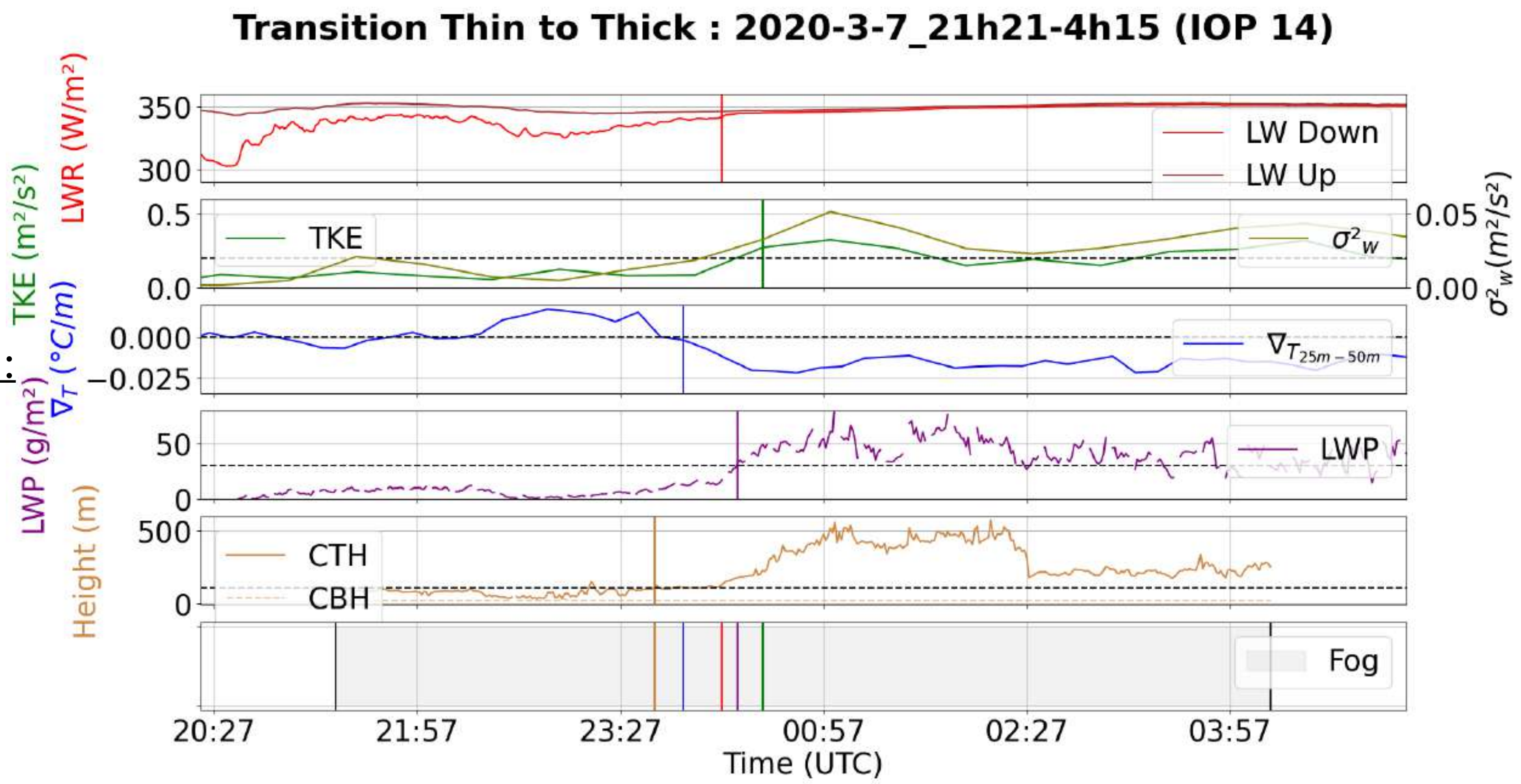
LWP > 30 g/m²

(Waersted et al, 2017)

d) CTH Threshold :

CTH> 110m

(from Waersted et al, 2017)



Consistency for the determination of the transition time between the definition and other thresholds in this case

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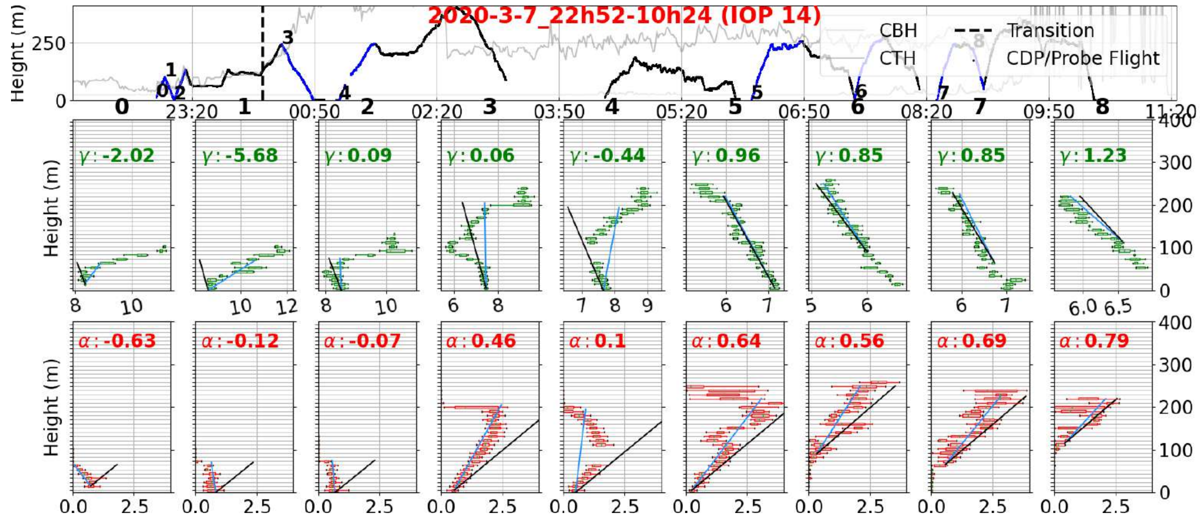
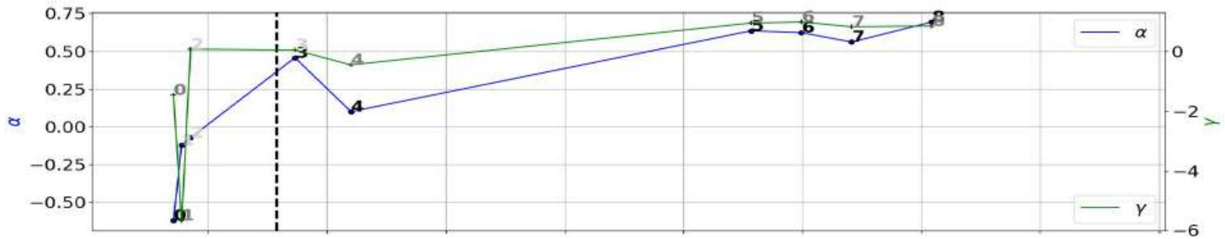
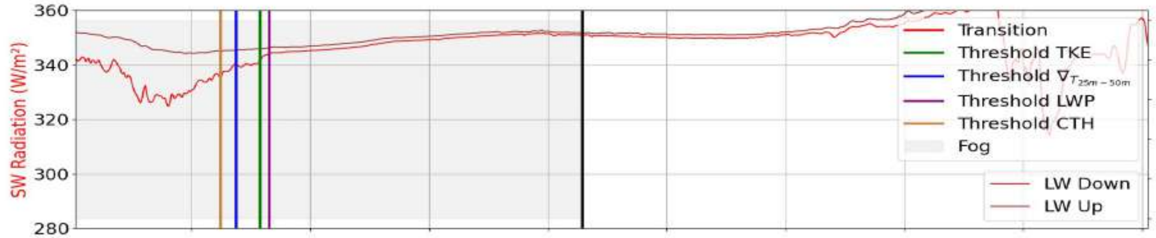
IV) Analysis of the microphysical and thermodynamic properties

IOP 14







-α and γ negative before the transition at 0012UTC

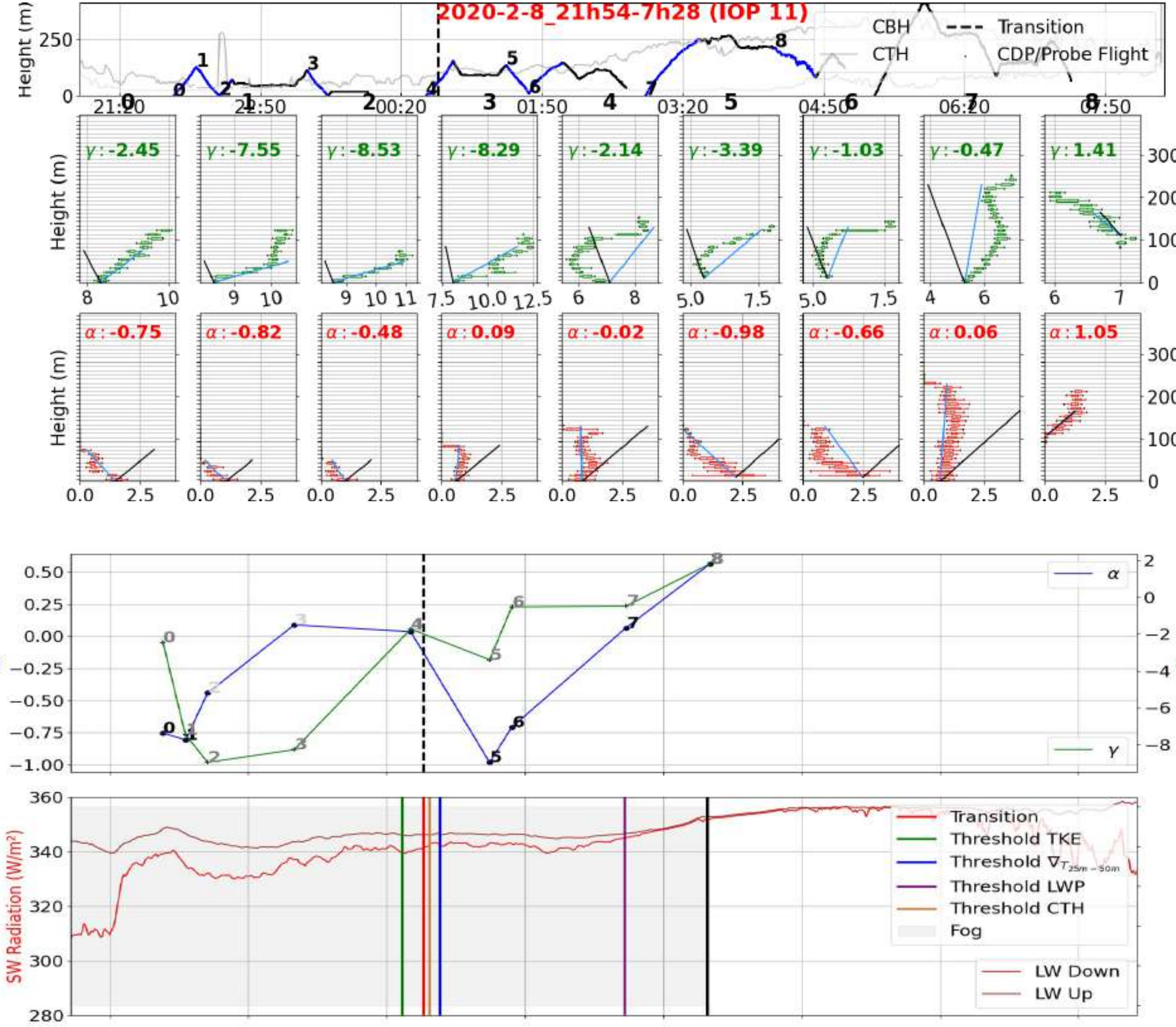
-α and γ positive after the transition occured

α [-0,7 ;0,8]

- Progressive transition from optically thin to thick fog in this case

IV) Analysis of the microphysical and thermodynamic properties

IOP 11



- Transition time at 0044UTC consistent between definition and thresholds except for LWP

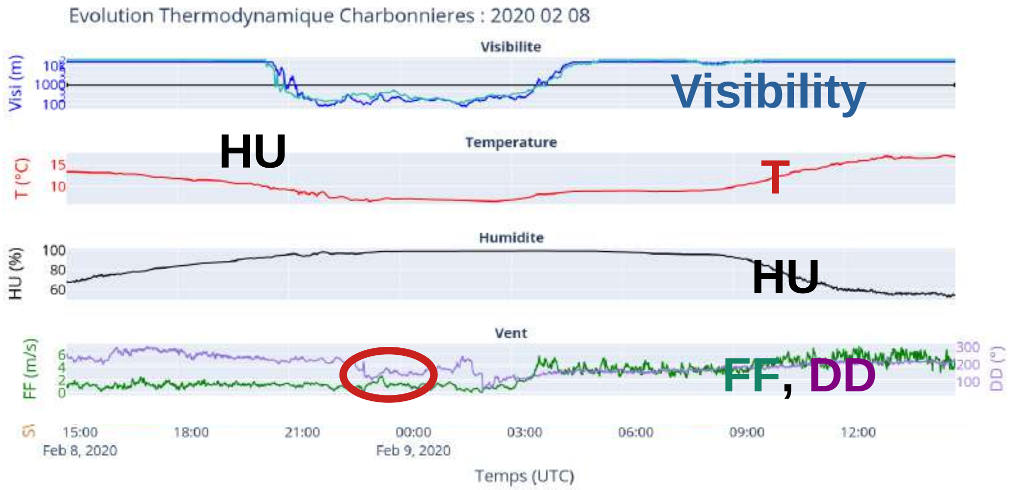
-α negative before and after the transition.Only positive after fog lifted into Stratus.
α [-1 ;1]

- Transition from optically thin to thick fog non-linear in this case

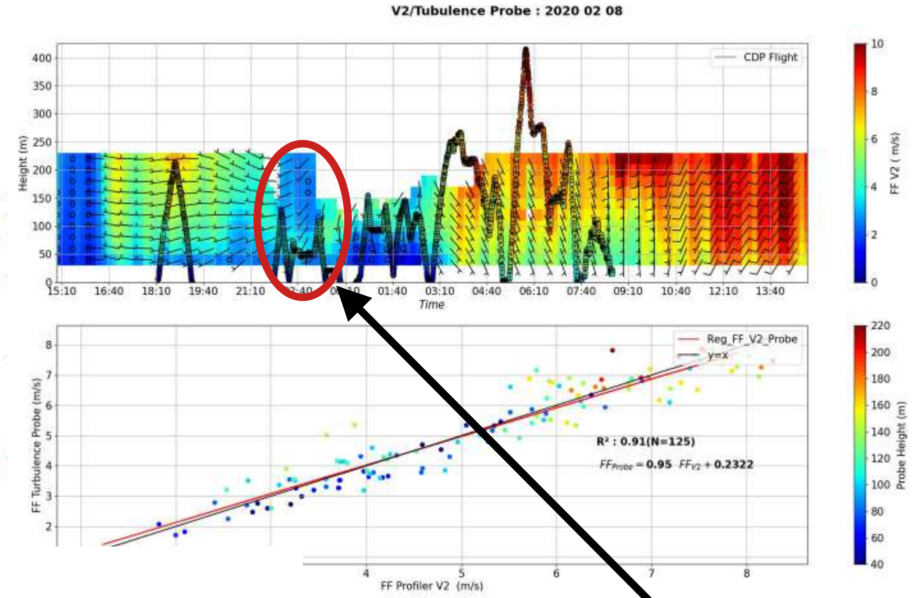
Impacts of non-local processes during the fog life cycle

IV) Analysis of the microphysical and thermodynamic properties

Impact of non-local processes



Meteorological Station Charbonnière



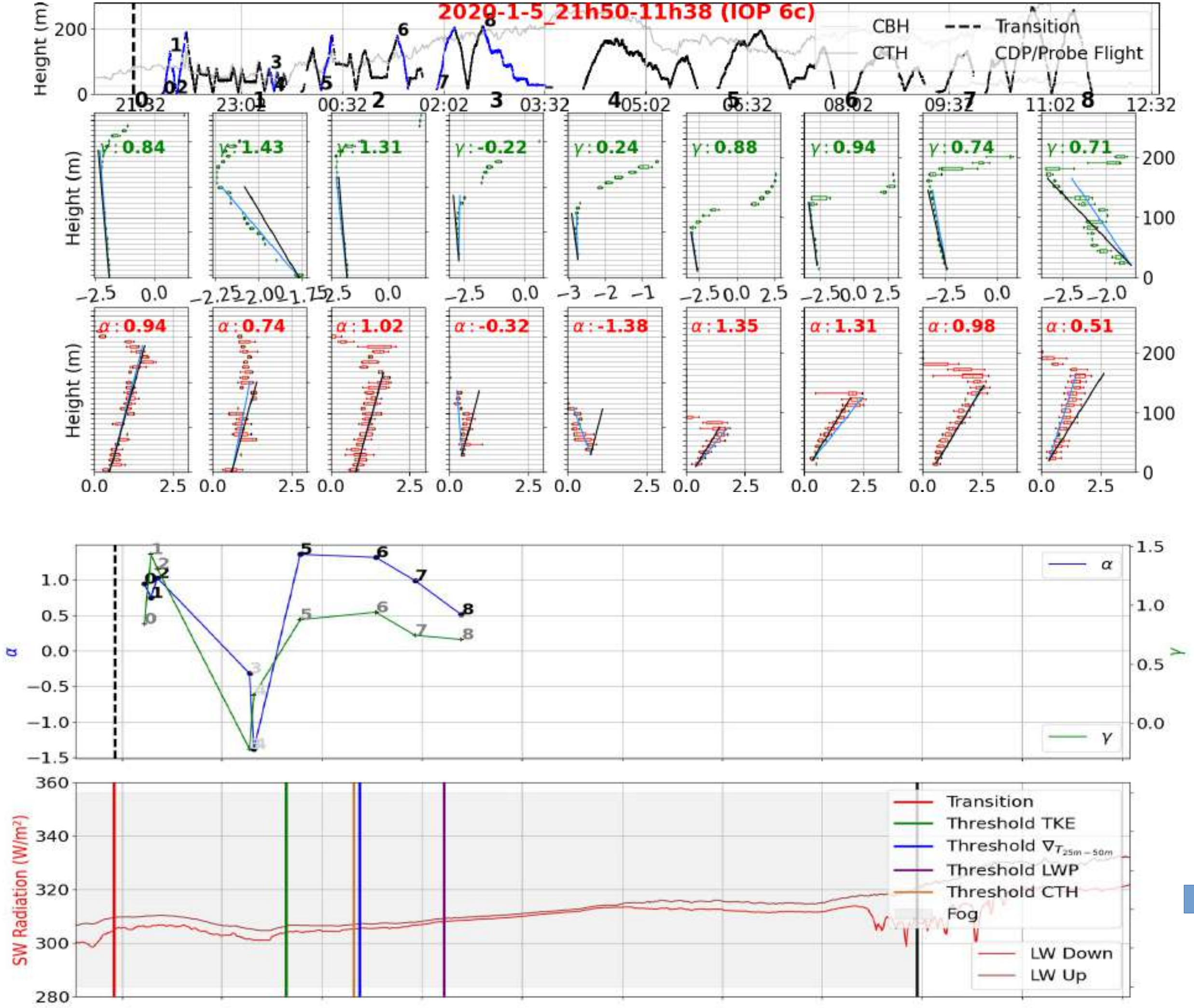
V2 Charbonnière

Ascent n°3

Establishment of a southerly wind starting from 00/01UTC that may explain the non linear transition to optically thick fog

IV) Analysis of the microphysical and thermodynamic properties

IOP 6



- Transition time at 2126 UTC due to advetive processes. Inconsistent with other thresholds

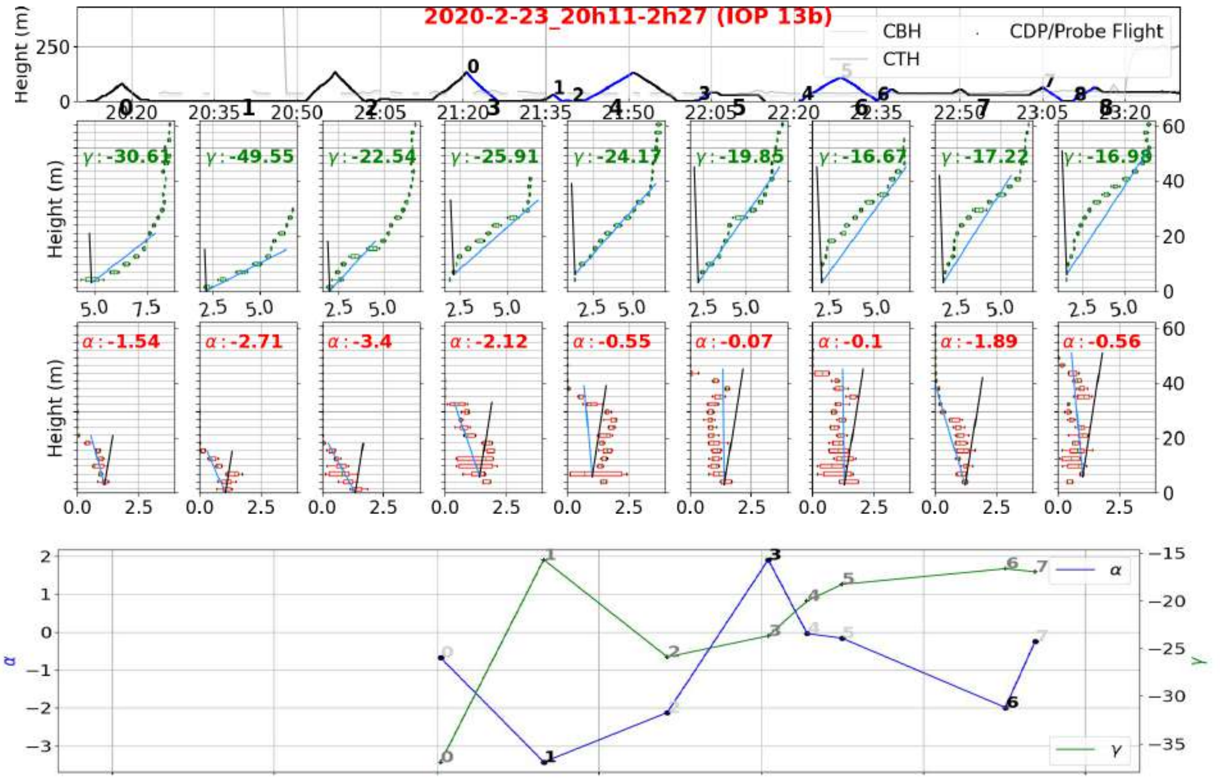
- Due to advective processes, α positive at the fog formation and after deepening at 00UTC. α only negative when the fog is thinner at 23UTC
α [-1,4 ;1,3]

- Difficult case in terms of transition due to advective processes

Impacts of non-local processes during the fog life cycle

IV) Analysis of the microphysical and thermodynamic properties

IOP 13b Thin case



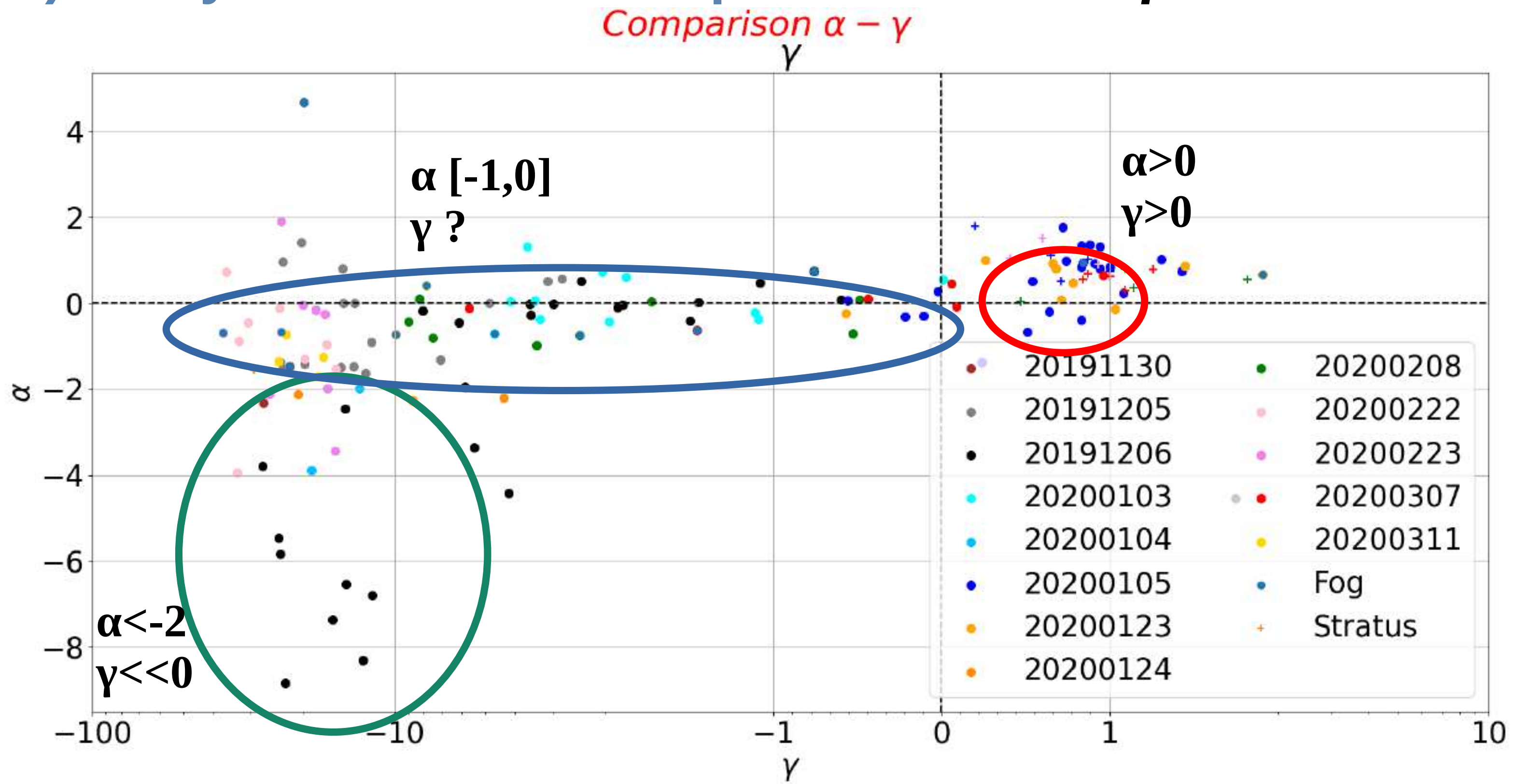
α values always negative associated with strong negative γ values

α [-3,4 ;0] > α_{thin to thick fogs}

γ [-50 ;-15] >> γ_{thin to thick fogs}

For a thin fog, negative α and γ values throughout the night, strongly lower than for thin to thick fogs

III) Analysis of the vertical profiles : α and γ correlation



Correlation between the amplitude of the radiative cooling and the amount liquid water content near the ground :
- When fog is very stable (α<-2)
- After the transition to optically thick fog occured (α>0)
- Less correlation when α slightly negative

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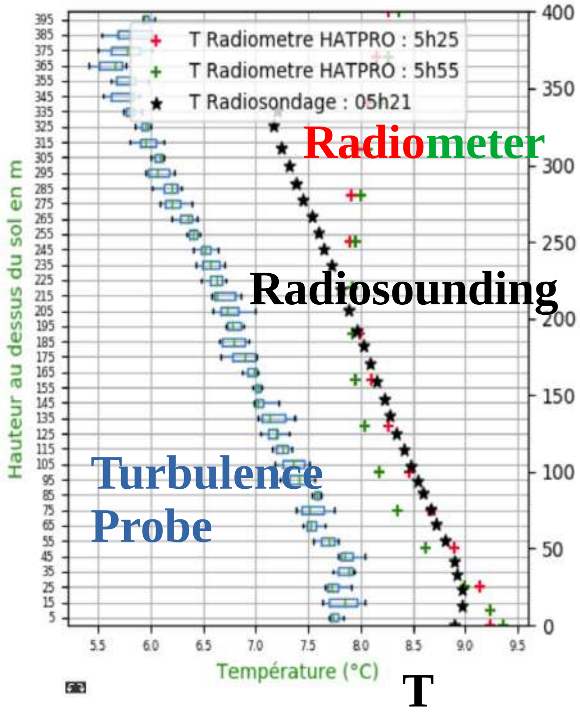
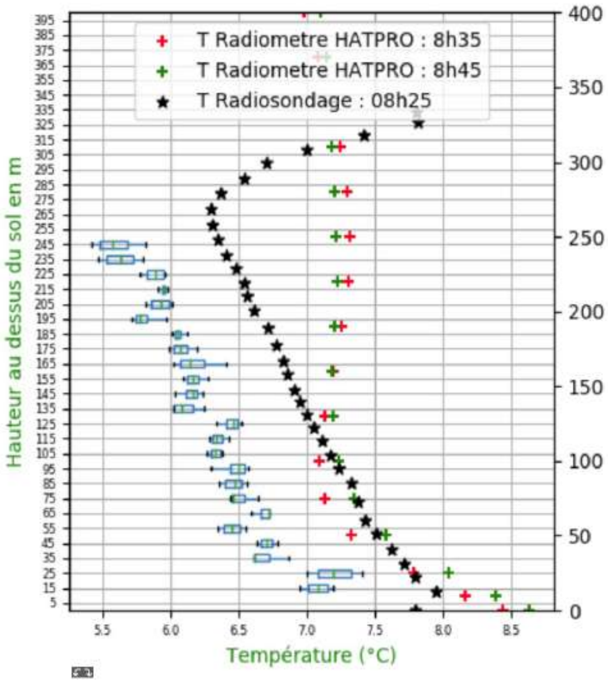
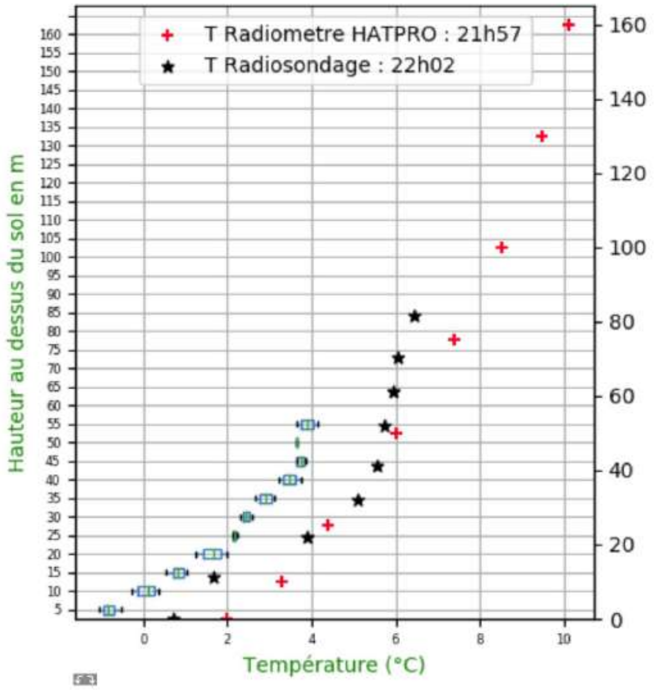
V) Bias Turbulence Probe : **Introduction**



IOP 11 : Ascent 5h22/5h54



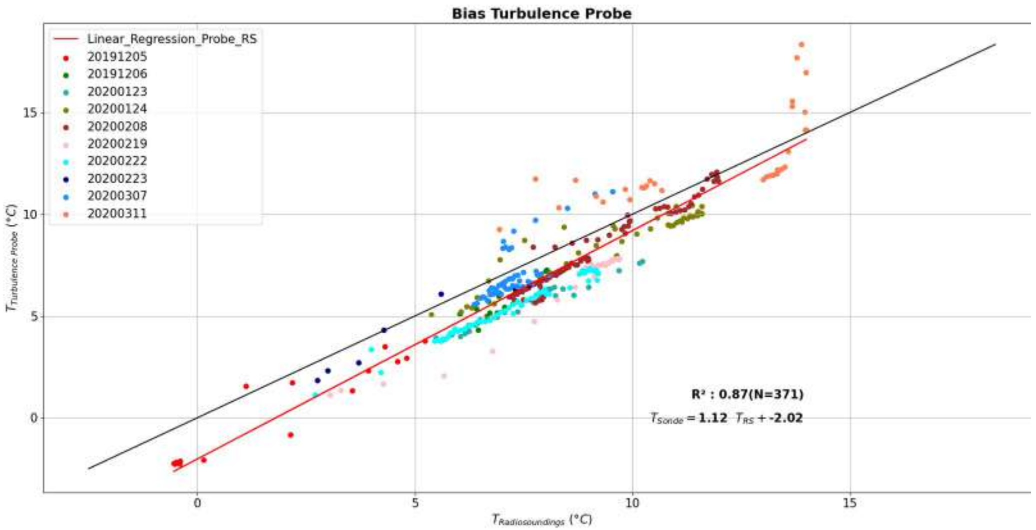
IOP 14 : Ascent 8h28/8h41



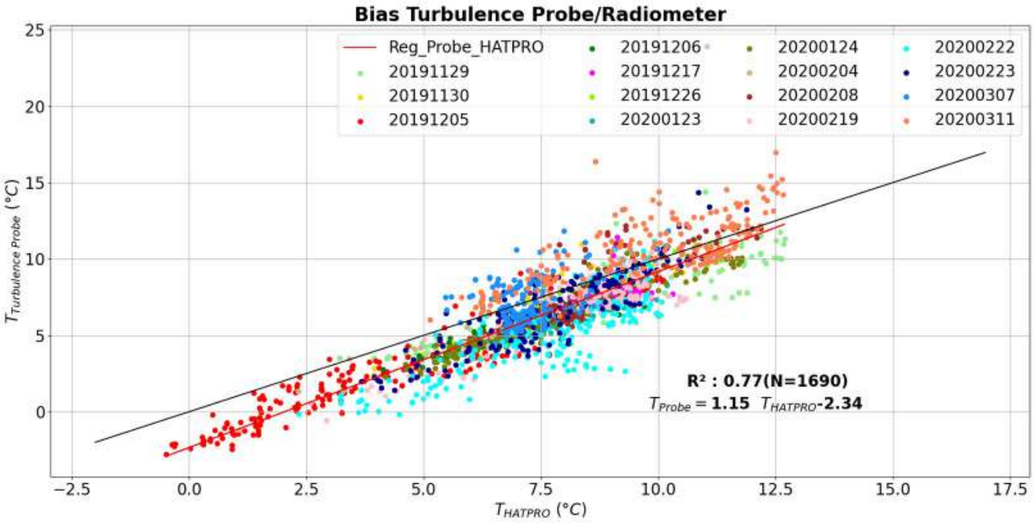
IOP 2 : Ascent 21h50/21h53

Negative bias from the turbulence probe

V) Bias Turbulence Probe :
Comparison with Radiosoundings and Radiometer



Radiosoundings

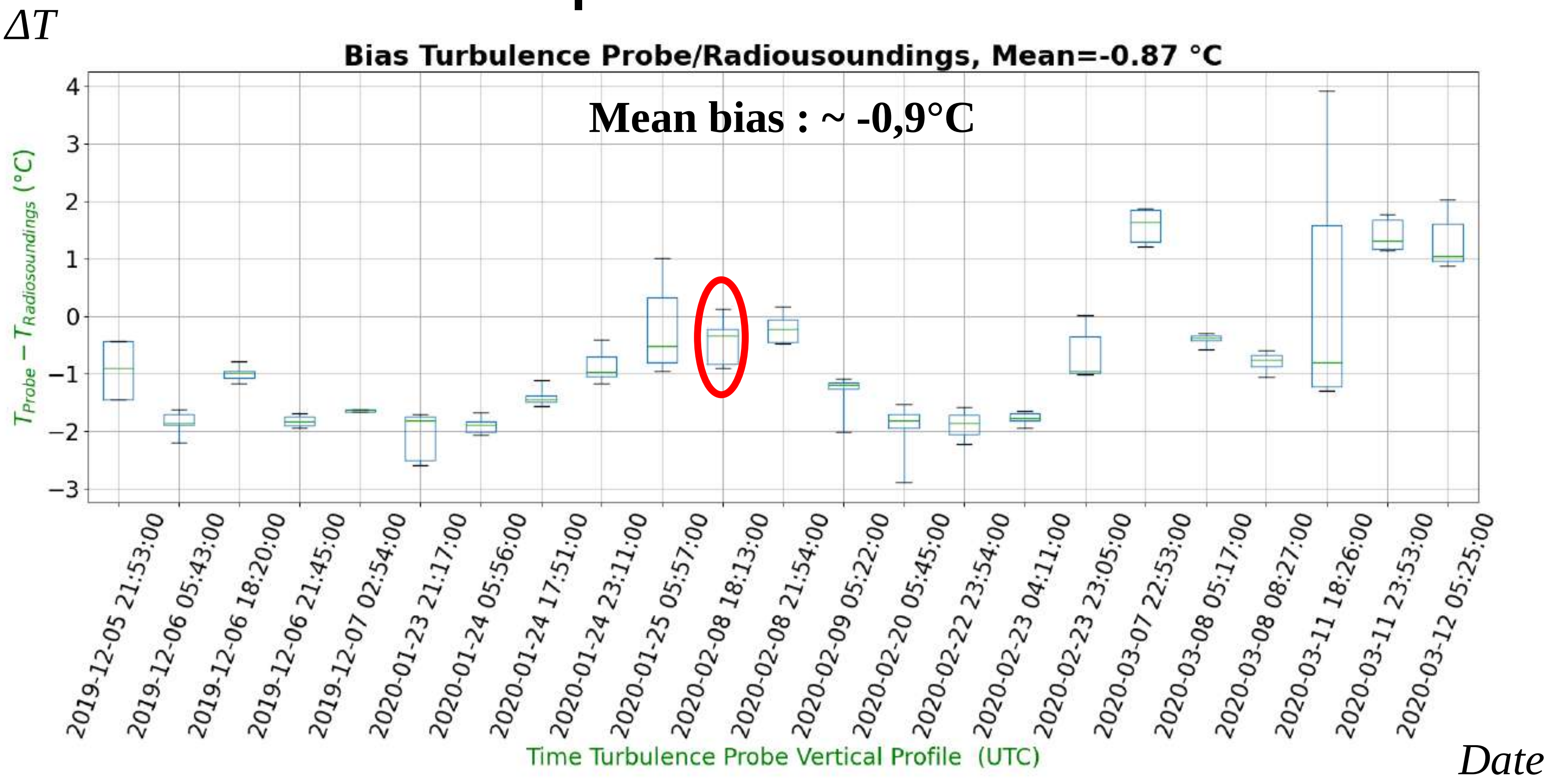


Radiometer

Negative Bias almost systematic with an offset of ~ -2°C

IV) Bias Turbulence Probe :

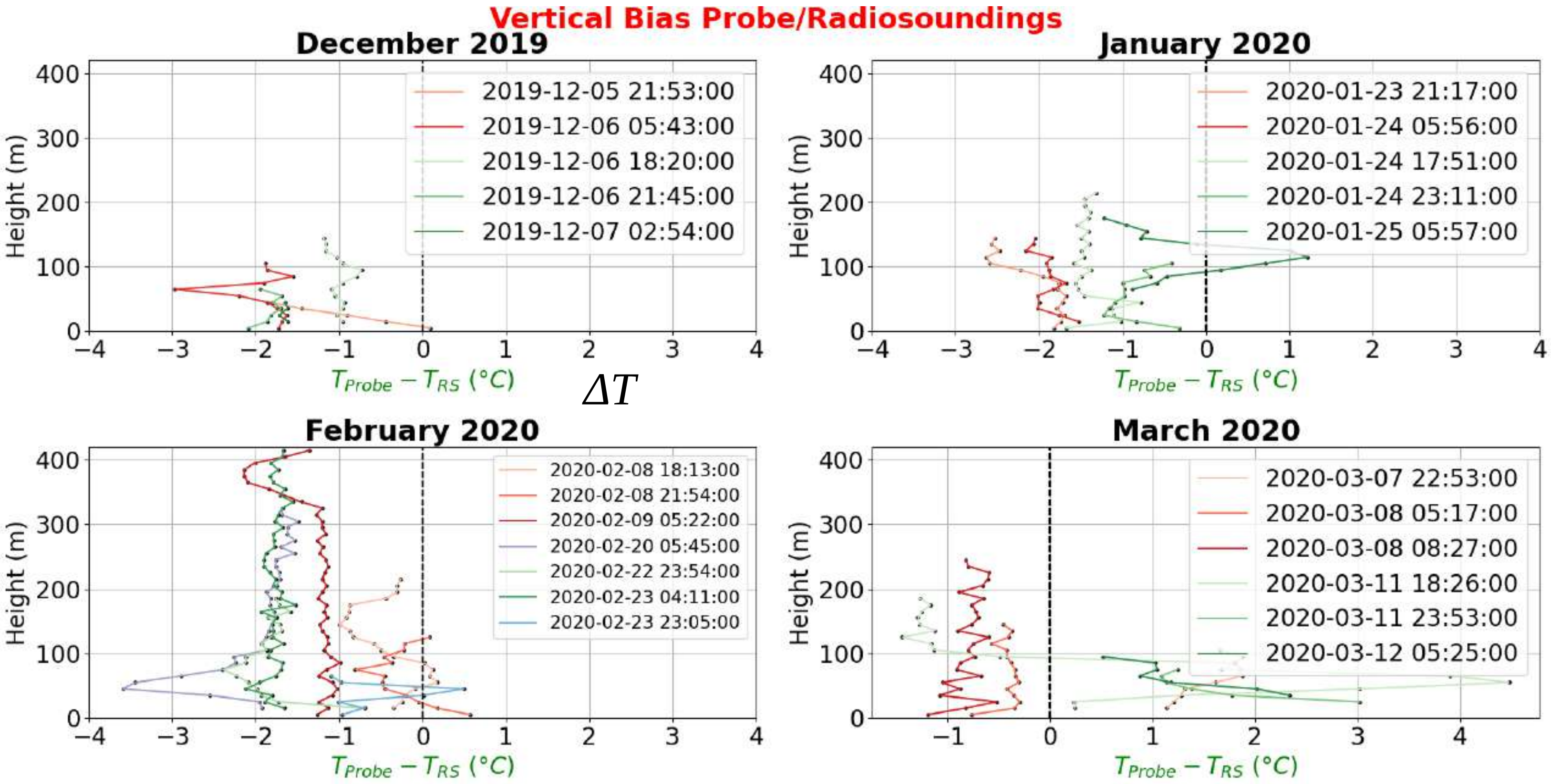
Temporal Bias



Before Fog

- No sign of temporal drift but positive bias for IOP 14 and 15
- Negative bias even without foggy conditions

IV) Bias Turbulence Probe :
Vertical Bias



Bias quite homogeneous vertically except near the ground and close to the cloud top height.

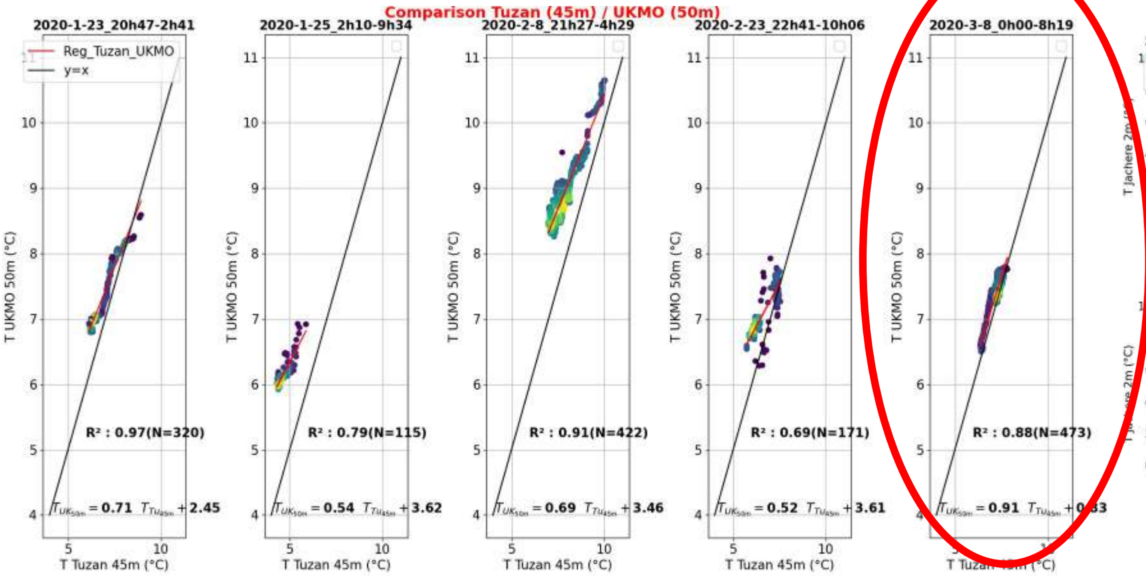
V) Bias Turbulence Probe :

Comparison with towers at Jachere (10m) , Tuzan (45m) and UKMO (50m) sites

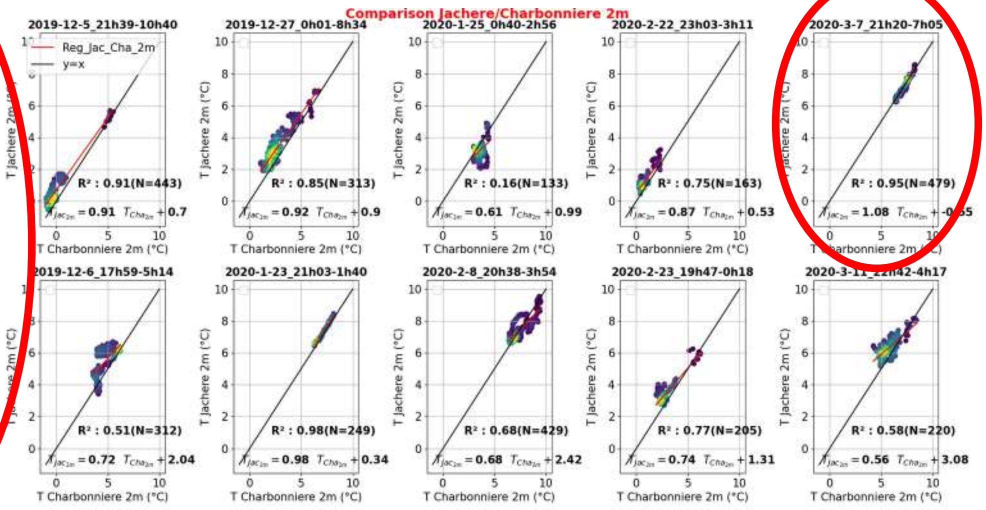
Methodology : Intercomparison between the turbulence probe and towers when :

- $T_{2m\ Charbonniere} \sim T_{2m\ Jachere}$ and $T_{45m\ Tuzan} \sim T_{50m\ UKMO}$

$T_{45m\ Tuzan}$ / $T_{50m\ UKMO}$

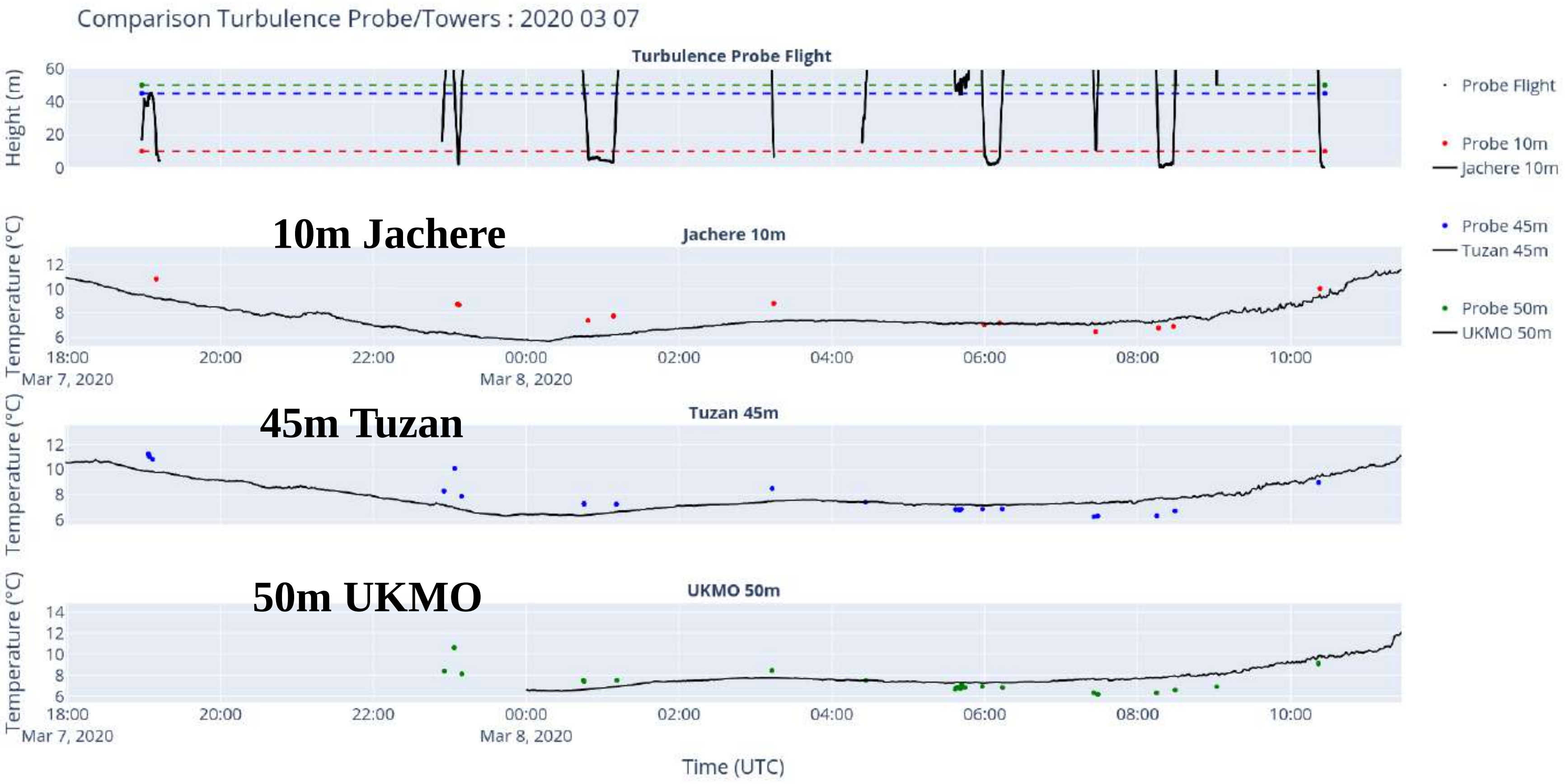


$T_{2m\ Jachere}$ / $T_{2m\ Charbonniere}$



Night of 7/8 March 2020 (IOP14) homogeneous temperatures between different sites at different heights

V) Bias Turbulence Probe :
Comparison IOP 14



Variable bias while conditions are homogeneous throughout the night

→ **Negative bias not systematic**

Summary :

- Climatology and Classification : 30 episodes classified at the Jachere site mainly radiative and radiative-advective.

- Measurements validation : - Ground : Satisfying between FM120 and PWD 22

  - Aloft : CDP validation more difficult due to surface hetorogeneities

- Methodology : - Computation of the adiabticity and lapse rate fractions with activation and entrainment within the fog layer taken into account. Inconsistent with previous conceptual models for thin fog

  - Determination of the transition from optically thin to optically thick fog with radiative measurements. Consistent with other thresholds except LWP

- Vertical profiles: - significant vertical variability between stable (High LWC values near the ground, $\alpha<0$ $\gamma<0$) and mature phases (more adiabatic LWC profile, $\alpha>0$ $\gamma>0$)

  - transition to optically thick fog not likely linear, highly dependant on non-local processes.

  - Correlation between α and γ when fog is very stable ($\alpha<-2$) and adiabatic ($\alpha>0$)

- Bias turbulence probe : Bias of ~ -2°C not systematic. No temporal drift observed and bias quite homogeneous vertically except near the ground and the cloud top height.

Future works

- Document the variability of the droplets distribution at a temporal scale
  Constant height sections.

- Study of the microphysical processes involved in the fog life cycle
  - Droplets Distribution
  - Turbulent mixing at the fog top (Doppler RADAR, V2)

- Link the fog microphysical properties between ground (FM120) and aloft (CDP)

- Evaluation of the microphysics of High Resolution simulation (100m) from Taufour et al. with LIMA (IOP6 first)
  Sensitivity tests on the activation process (prognostic supersaturation ...)