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)

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PhD Objectives

<u>Main Objective</u> : Characterize the microphysical heterogeneites within the fog layer during its life cycle

<u>Experimental Part</u>: Data Validation, Documentation of the fog microphysical properties

<u>Modeling Part</u> : LES Simulations,Validation, Impacts of LIMA

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

- **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

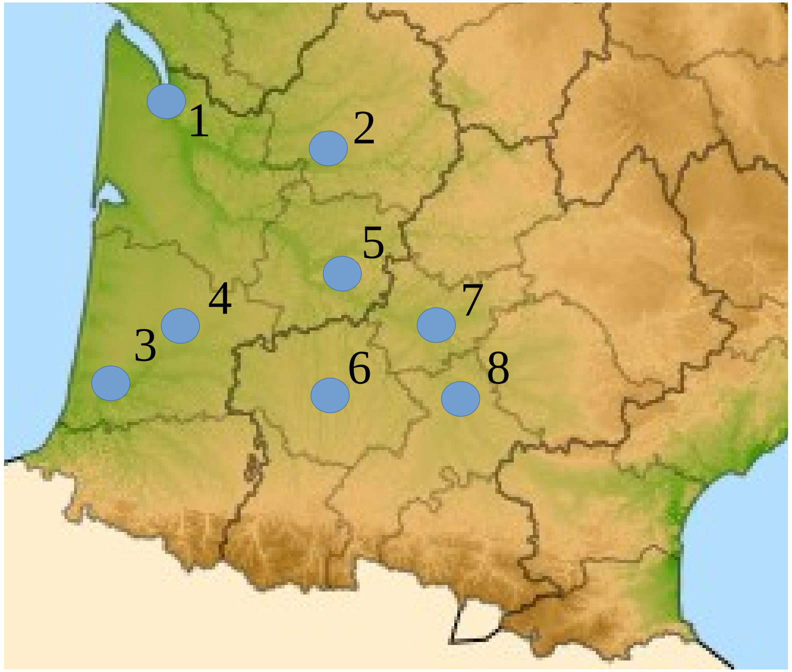
II) Measurements Validation : Intercomparison of ground data and microphysical statistics

III) Characterization of the transition between optically thin and thick fog

IV) Microphysical Vertical Profiles

V) Bias Turbulence Probe

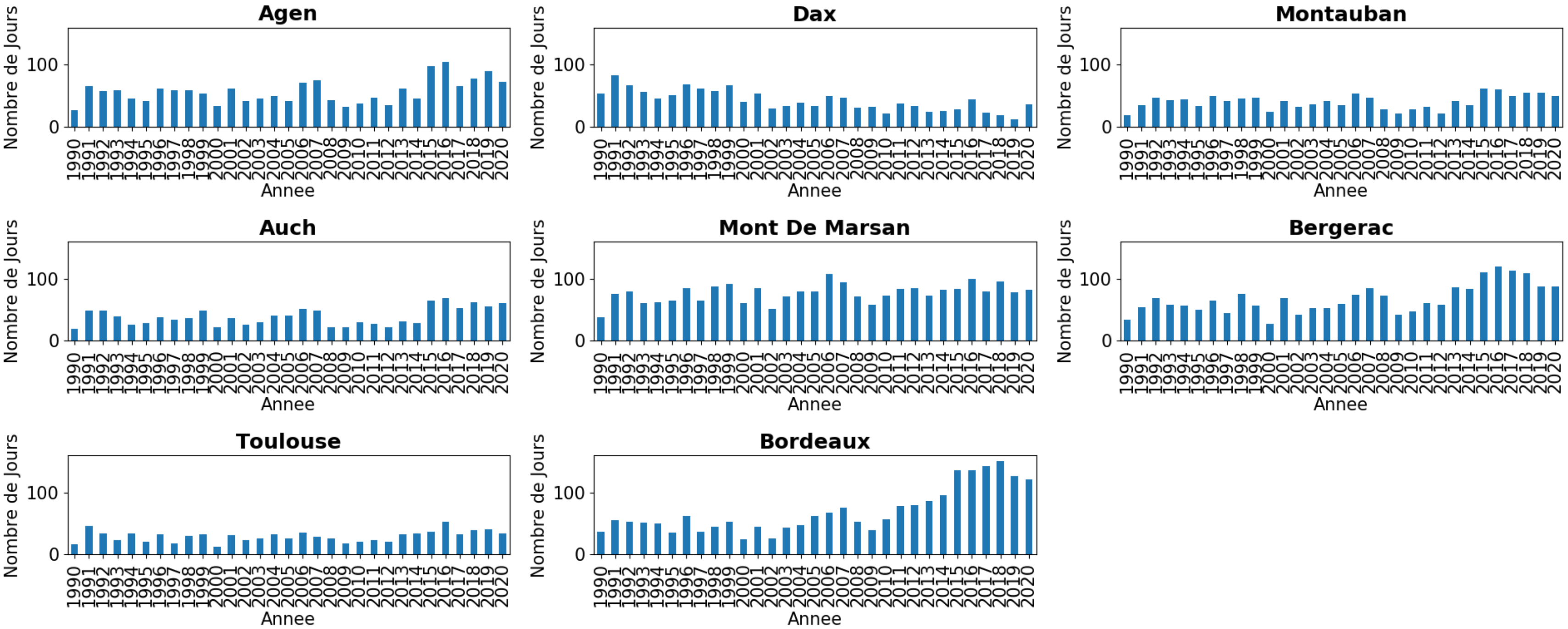
I) Fog Climatology in the South West of France (1991/2020) and focus on winter 2019/2020



7 Observation 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)

I) Climatology of the Number of foggy days per winter (1991/2020)

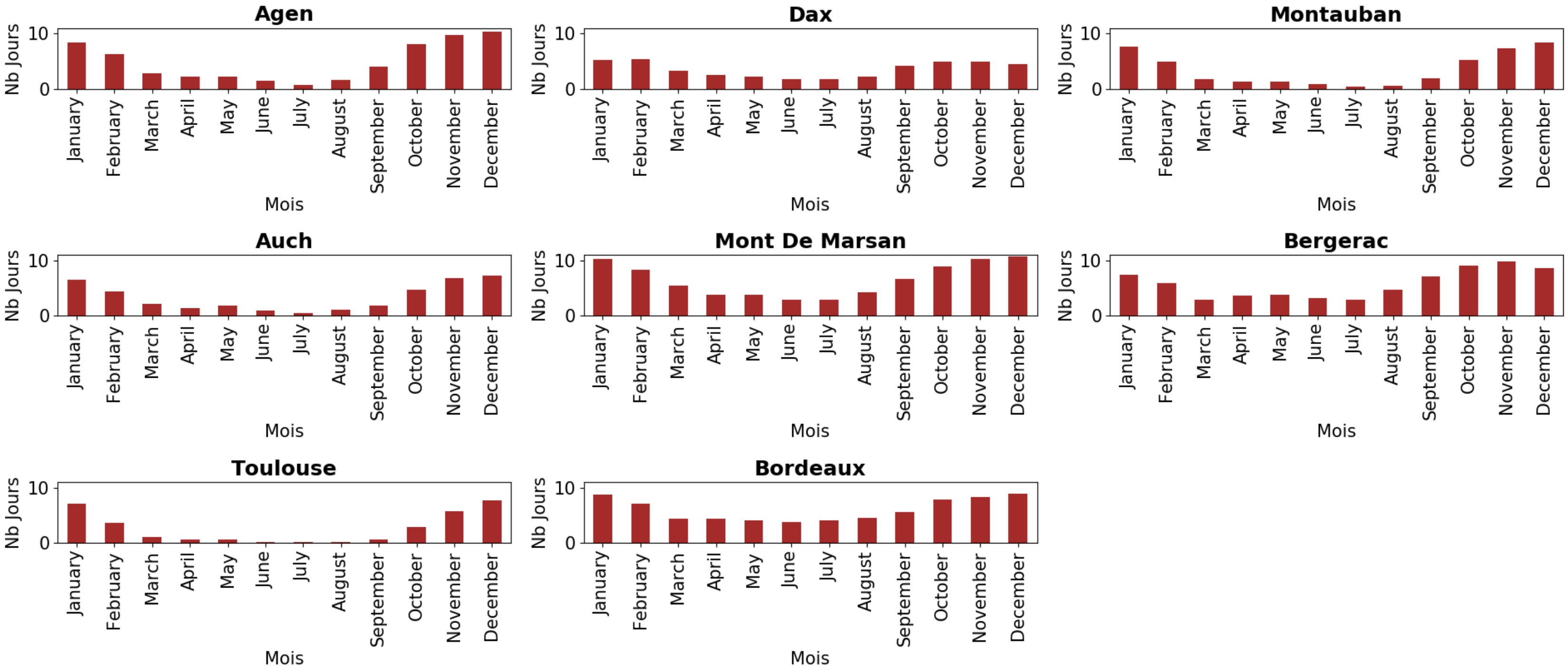


Climatology of the number of foggy days per winter (1990-2020)

Tendency :

- Decrease at Dax
- Almost constant at Mont de Marsan
- Increase for some other cities, especially Bordeaux (nearly 150 days per winter since 2015/2016)

I) Annual Distribution of the mean number of foggy days (1991/2020)



Annual Repartition of the mean number of foggy days (1990-2020)

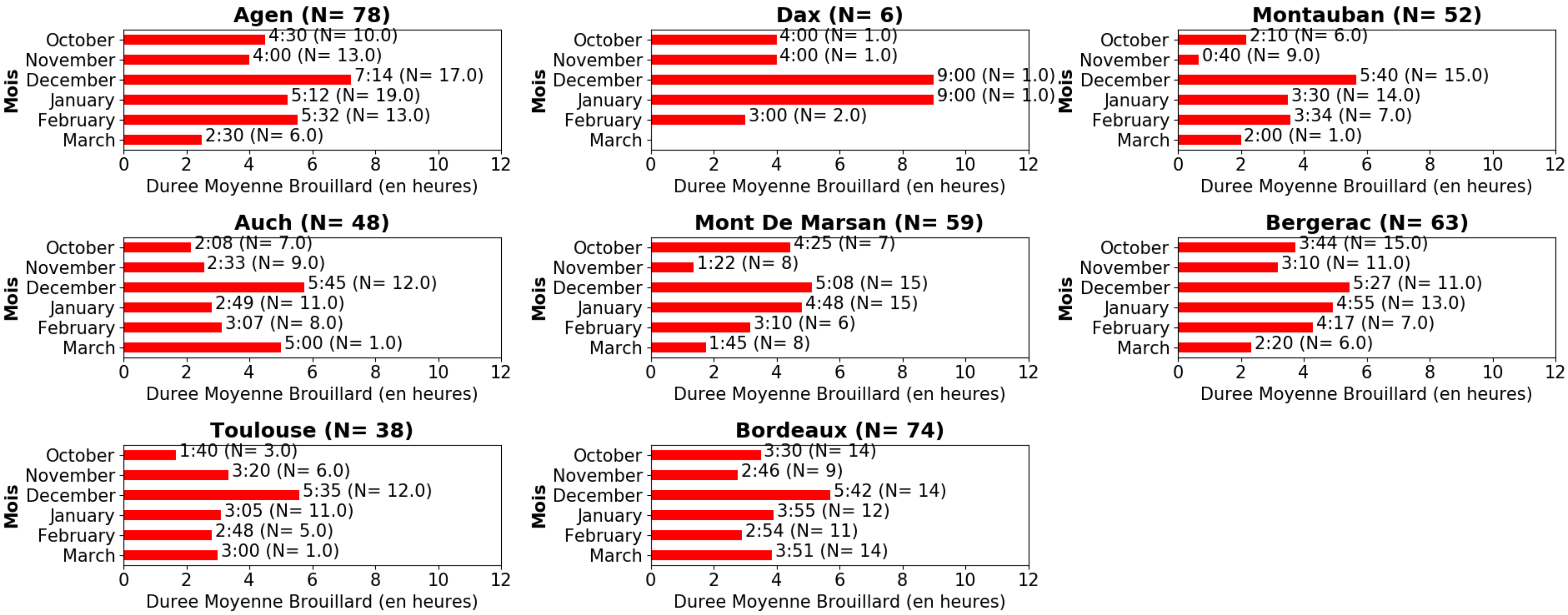
Tendency :

- Fogs more regular in fall and winter, especially in Agen, Mont-de-Marsan and Bergerac

- Rare in summer and even inexistent (Toulouse) but still present near coasts (Bordeaux, Mont de Marsan, Dax)

Advection Fog/ Sea Fog ?

I) Focus SOFOG3D : Distribution of the mean fog lifespan



Distribution of the mean fog lifespan during winter 2019/2020

Tendency :

- For the most stastistically significant stations, fogs are more persistent in late fall, early winter and can last from 5h (Mont de Marsan) to 7h (Agen)

I) Fog Classification : R. Tardif et R. Rasmussen Algorithm

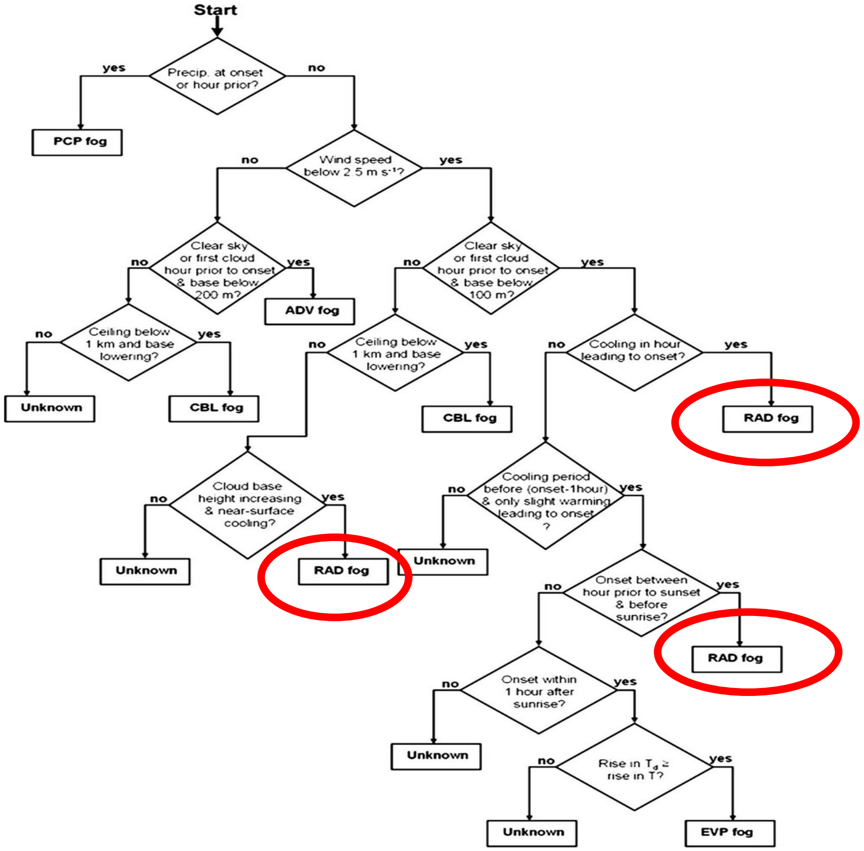


TABLE 2. List of fog types used in the classification algorithm and associated primary mechanisms, as well as definitions based on the morphology of fog formation.

Fog type	Primary physical mechanism	Definition/morphology of fog formation	References
Precipitation (PCP)	Thermodynamical influence of evaporating precipitation	Precipitation observed at the onset of fog or the hour prior	Petterssen (1969)
Radiation (RAD)	Radiative cooling over land	Onset during the night with an observed wind speed below 2.5 m s^{-1} and cooling during the hour prior in absence of a cloud ceiling, or with a cloud base rising concurrently or slight warming in the hour leading to onset if preceded by cooling period (e.g., fog forming between two hourly observations) or cloud ceiling below 100 m if followed shortly by fog at surface (e.g., elevated fog formation)	Taylor (1917), Pilié et al. (1975), Roach et al. (1976), Roach (1995a), Meyer et al. (1986), Meyer and Lala (1990), Baker et al. (2002)
Advection (ADV)	Shear-induced mixing of air parcels of contrasting temperatures as moist, warm air flows over a colder (water, land, or snow) surface	Onset as a "wall" of fog reaches a station, with an observed wind speed greater than 2.5 m s^{-1} and an associated sudden decrease in visibility or sudden appearance of a cloud ceiling below 200 m, followed by fog onset within next 2 h	Roach (1995b), Baars et al. (2003)
Cloud-base lowering (CBL)	Moistening and/or cooling of the layer below boundary layer stratiform clouds and/or prolonged subsidence	Gradual lowering of a cloud ceiling within a 5-h period prior to fog onset, with initial ceiling height below 1 km	Petterssen (1940), Oliver et al. (1978), Pilié et al. (1979), Duynkerke and Hignett (1993), Koračin et al. (2001), Baker et al. (2002)
Morning evaporation (EVP)	Evaporation of surface water and mixing in the surface layer	Increasing temperature and greater increase in dewpoint leading to saturation, within 1 h of sunrise	Arya (2001), Brutsaert (1982)*

* These references do not specifically discuss the formation of fog under the influence of evaporation at sunrise, but rather present comprehensive discussions on the evaporation of water at the earth's surface.

Tardif and Rasmussen Algorithm (2007)

I) Fog Classification SOFOG3D

Synthesis :

- 30 Fog episodes in Jachere, 33 on UKMO site between October 2019 and March 2020

- 72 % radiative fogs

- Somes cases difficult to classify : - 4 unknown cases

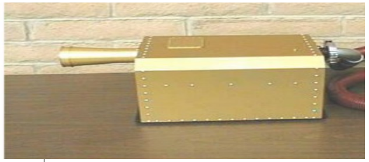
  - Stratus possibly formed by turbulence (IOP 14)

II) Measurements Validation : Ground Intercomparison

Microphysical Instruments based on Mie Scattering

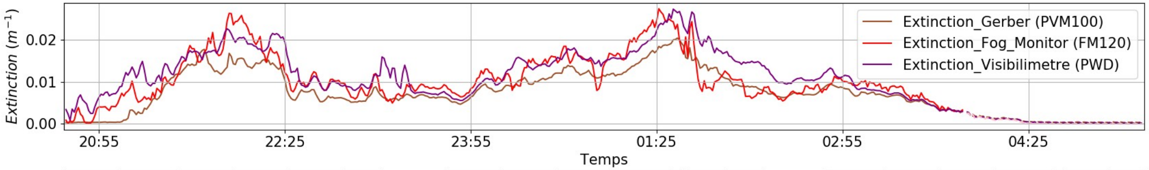
Visibilimeter PWD

Fog Monitor FM120

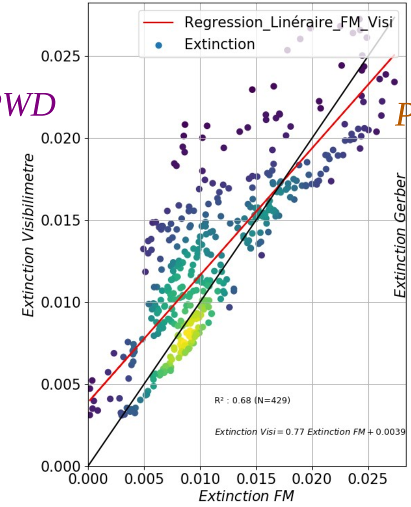


Gerber PVM100

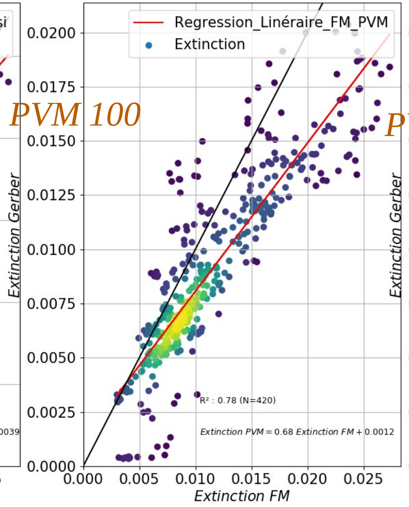
Extinction



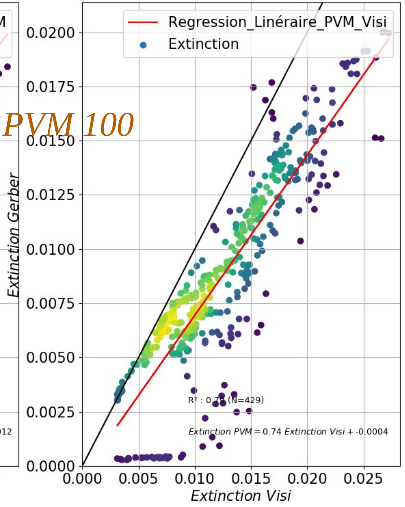
Jachere IOP 11:
Ground Intercomparison
FM120, PVM 100
Visibilimeter PWD



FM120



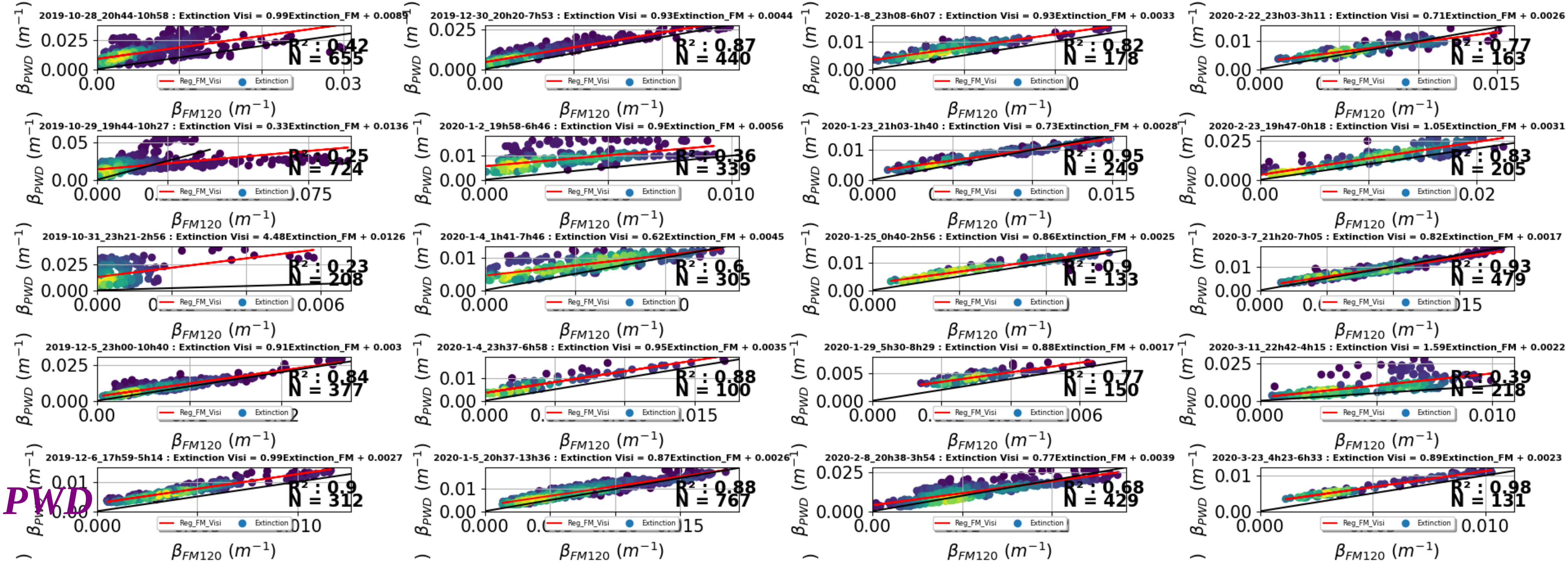
FM120



PWD

II) Measurements Validation : Overview of the Campaign

Intercomparison Fog Monitor FM120/Visibilimeter (PWD)

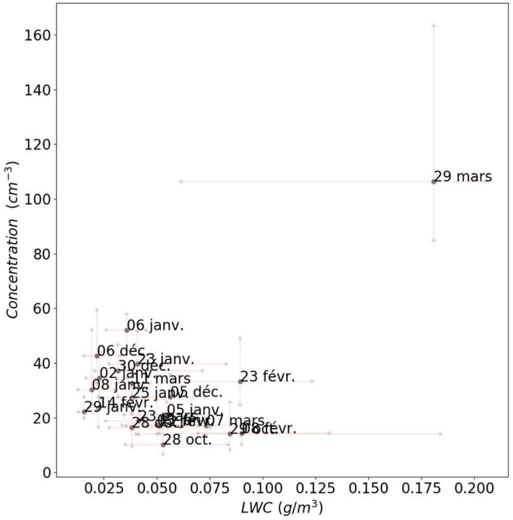


FM120

Validation still in progress

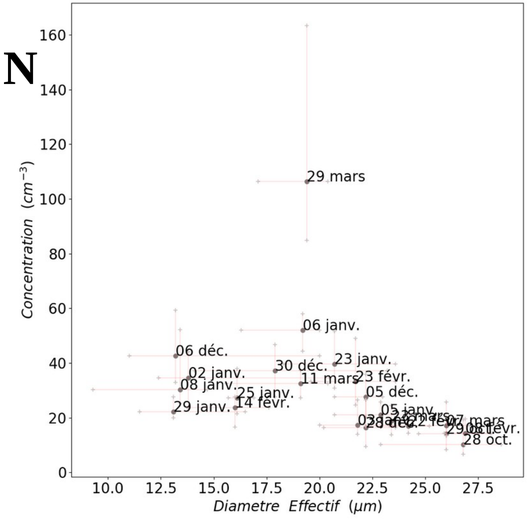
II) Measurements Validation : Statistics on Microphysical Variables

N



LWC

N



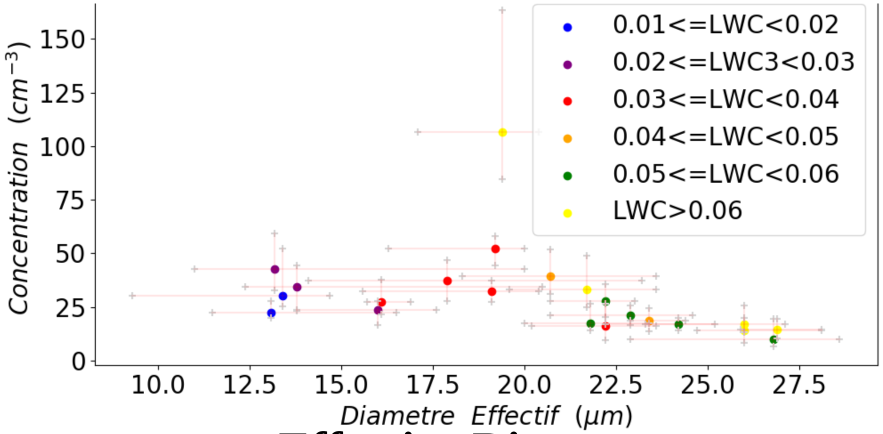
Effective Diameter

N ~ [20 ; 60 /cm³]

LWC ~ [0.025 ; 0.075] g/m³

Effective Diameter ~ [13;27] µm

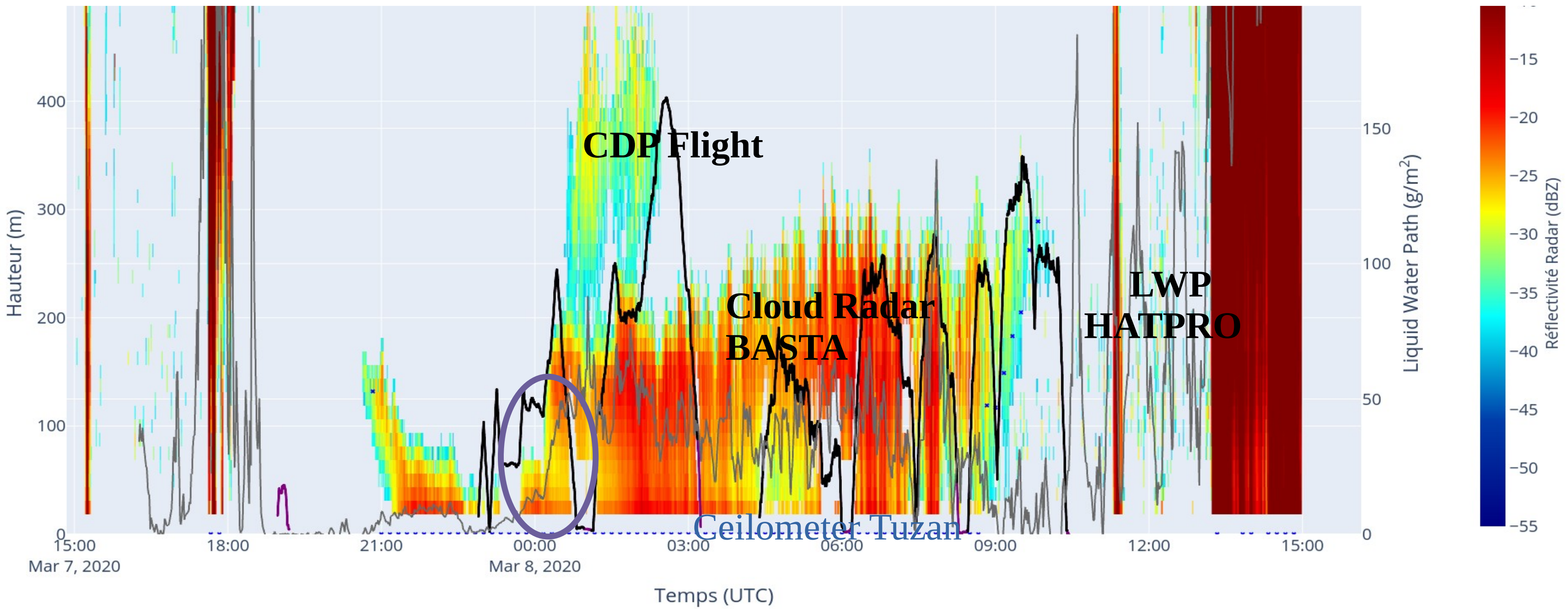
Concentration



Effective Diameter

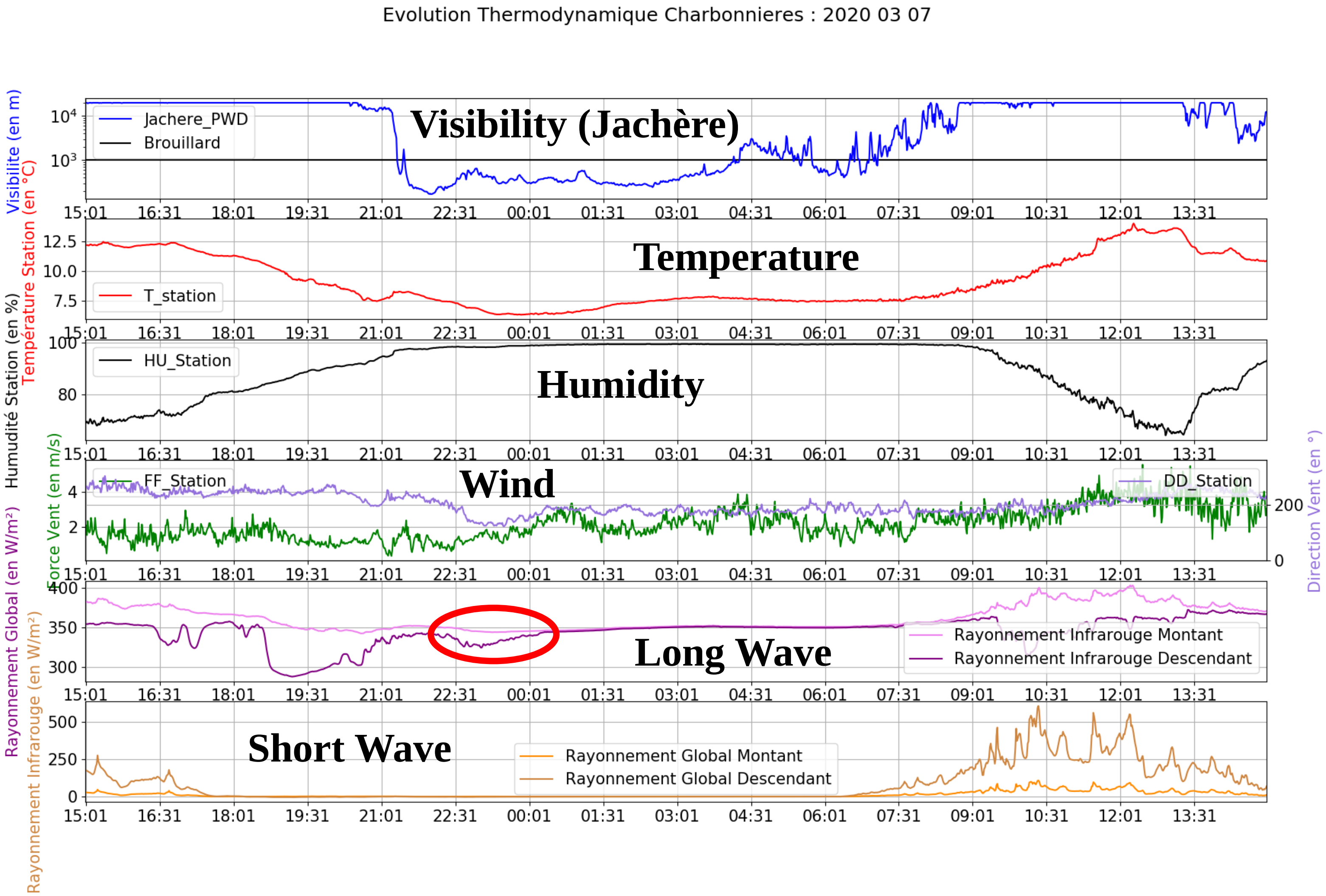
Statistical Analysis :
Few but large droplets near the ground

III) Establishing the transition between thin and thick fog
IOP 14 : Cloud Radar

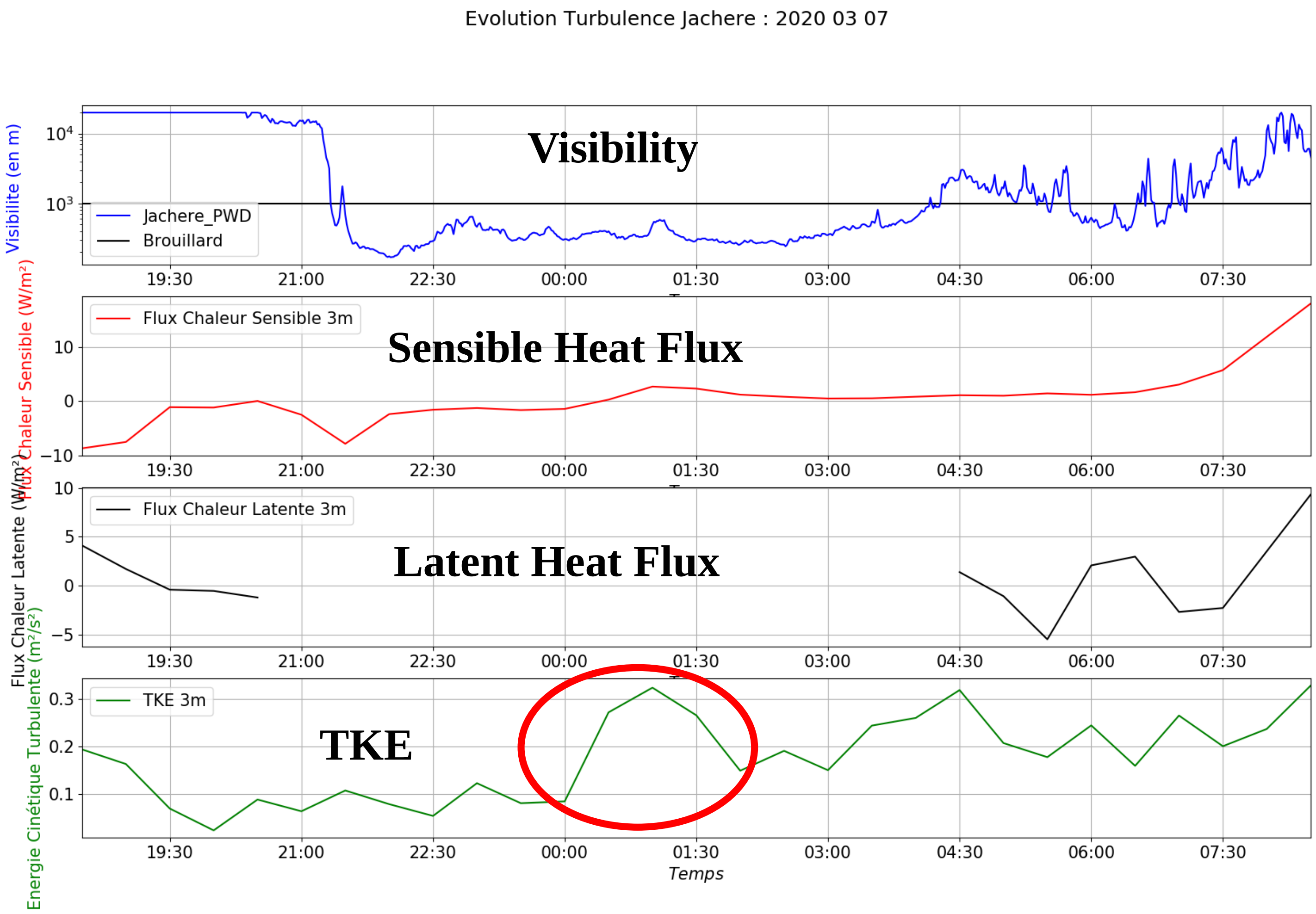


Cloud Radar BASTA reflectivity (colours) overlaid with the CDP flight (black curve), ceilometer from Tuzan, and LWP retrieved from the HATRO radiometer during IOP 14

III) Transition Thin/Thick Fog IOP 14 : Thermodynamical Variables

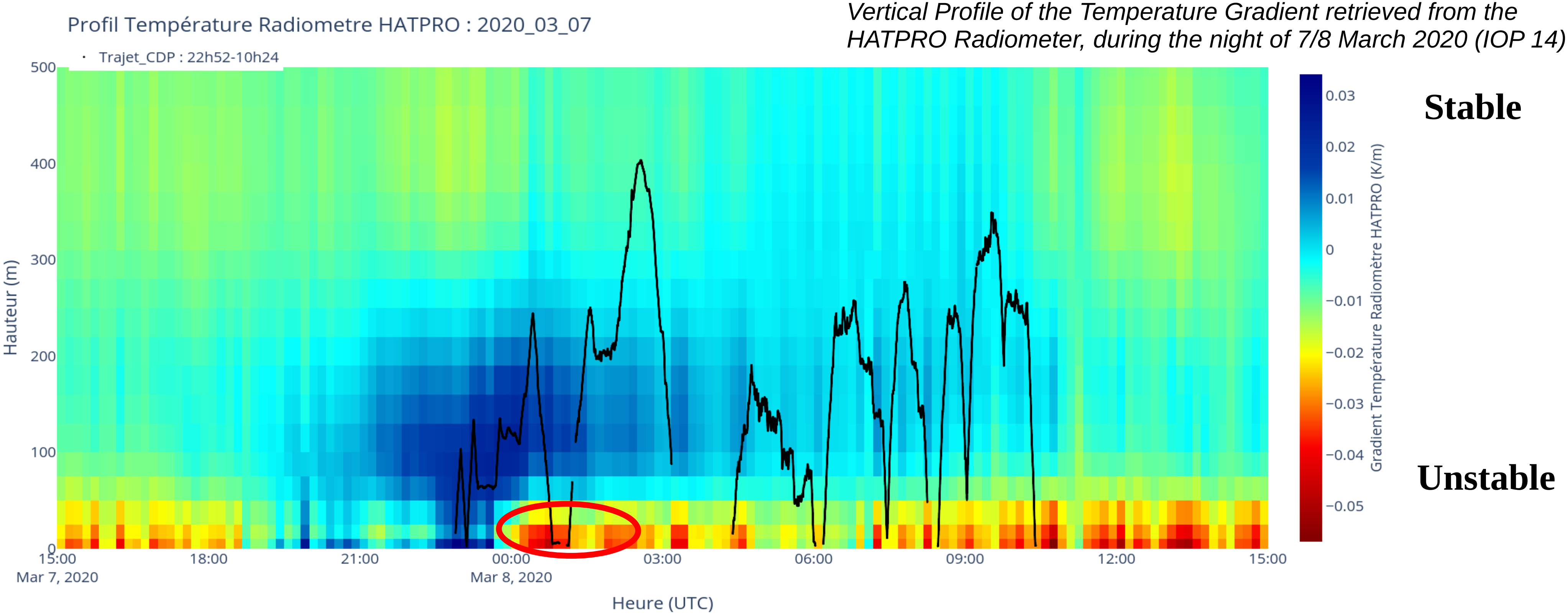


III) Transition Thin/Thick Fog IOP 14 : Turbulence



III) Establishing the transition between thin and thick fog
IOP 14 : Radiometer HATPRO

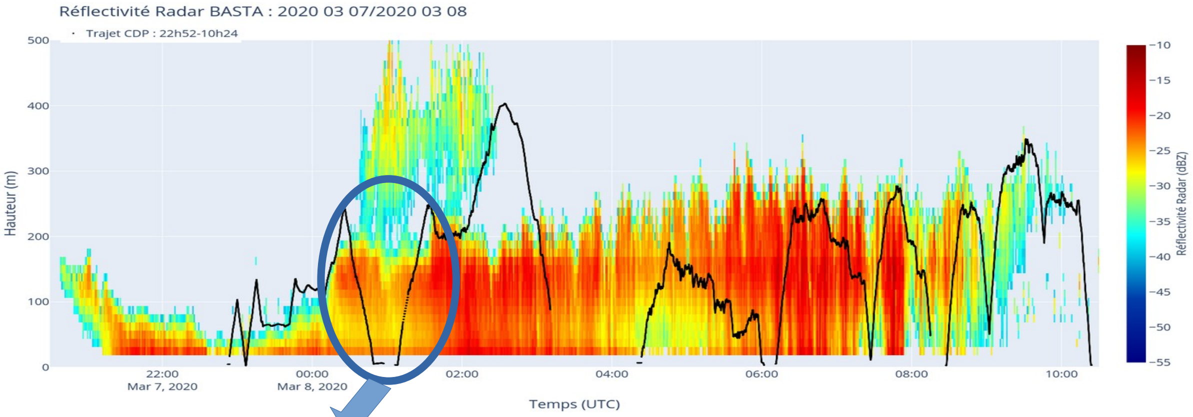
Vertical Profile of the Temperature Gradient retrieved from the HATPRO Radiometer, during the night of 7/8 March 2020 (IOP 14)



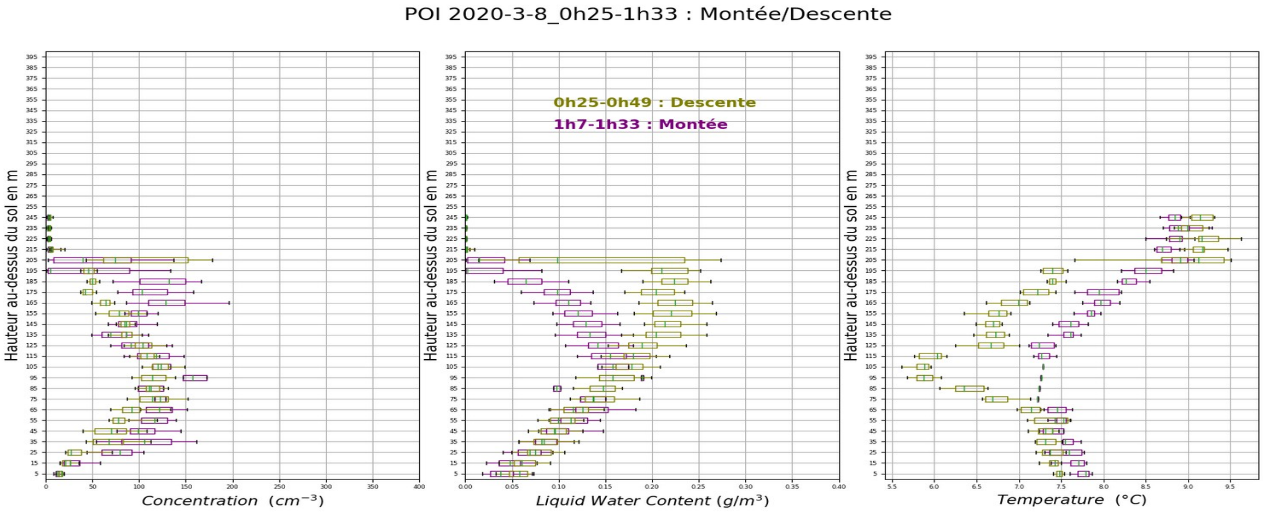
Temporal agreement still in progress between instruments as a proxy in order to establish the transition time between thin and thick fog

IV) Analysis Vertical Profiles : IOP 14

Cloud Radar BASTA : 95 GHz



Cloud Droplet Probe (CDP)



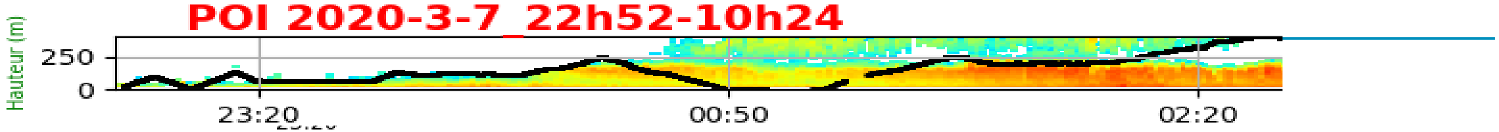
Strong variability of the fog layer during mature phase

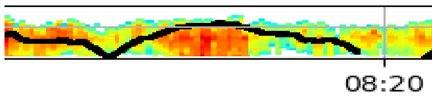
→ **Evaporation, Activation**

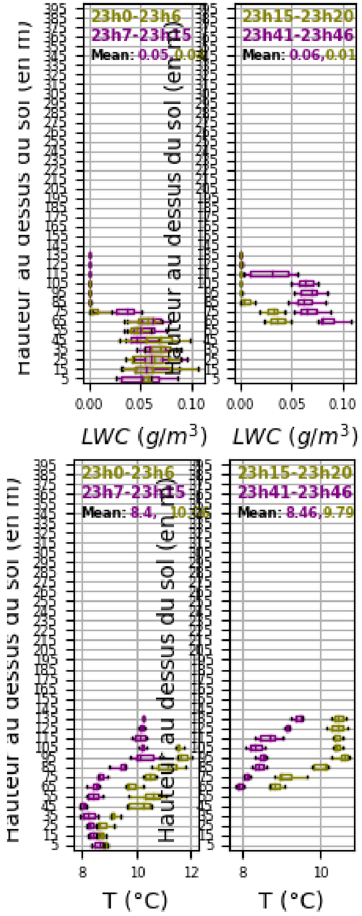
Vertical Profiles of the Droplet Concentration (left), LWC (middle) and Air Temperature (right) during one consecutive ascent and descent of IOP 14

METEO FRANCE

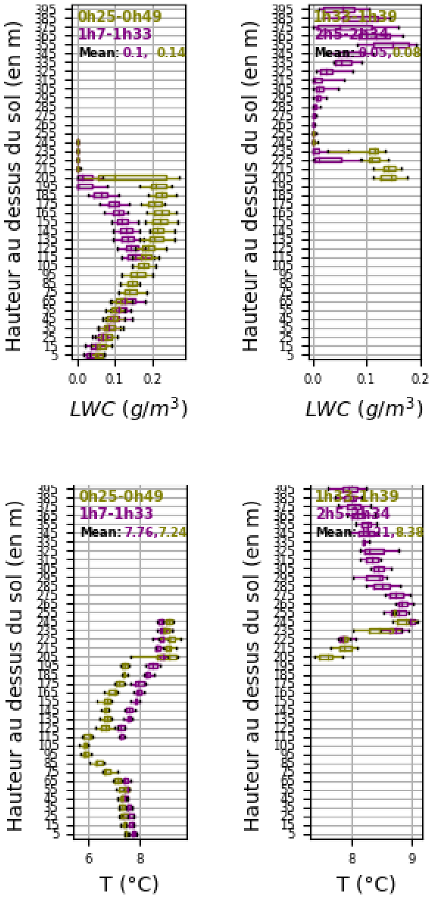
IV) Vertical Profile IOP 14 : Different Phases





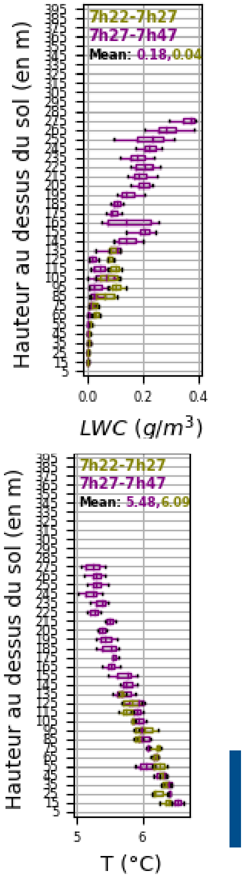


1) **Stable Phase** :
LWC values higher near the ground

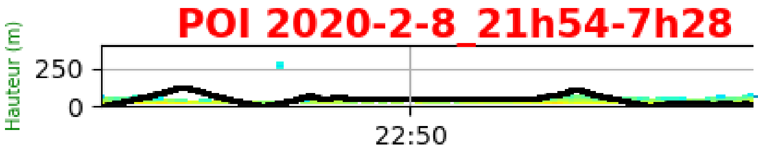


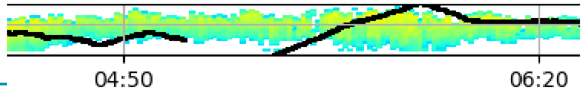
2) **Mature Phase** :
More adiabatic LWC profiles

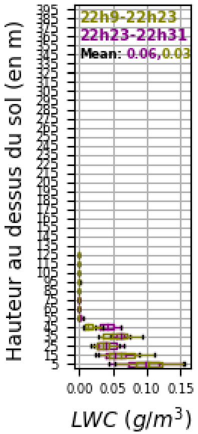
3) **Stratus Phase** :
Adiabatic LWC profiles

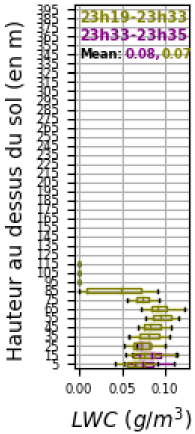


IV) IOP 11 Vertical Profiles



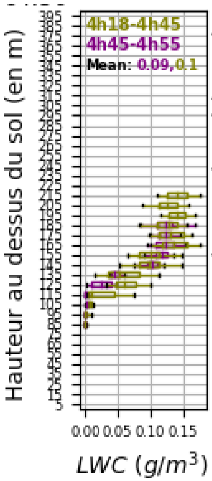


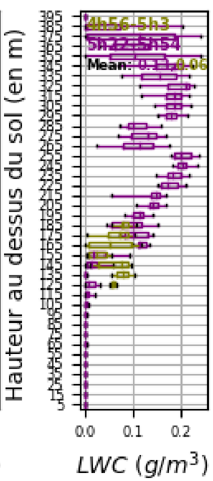


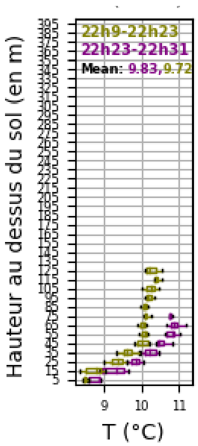


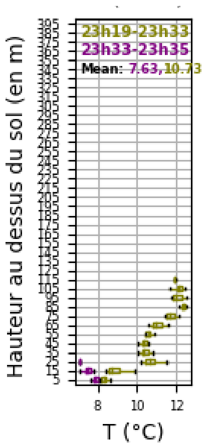
1) Stable phase :
High LWC values near the ground

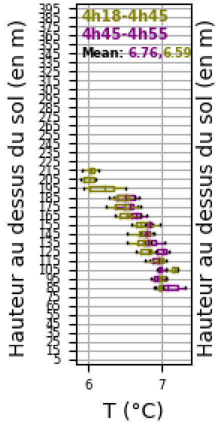
2) Mature/Dissipation phase :
More adiabatic LWC profiles

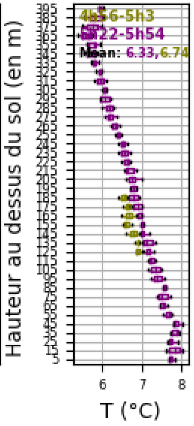






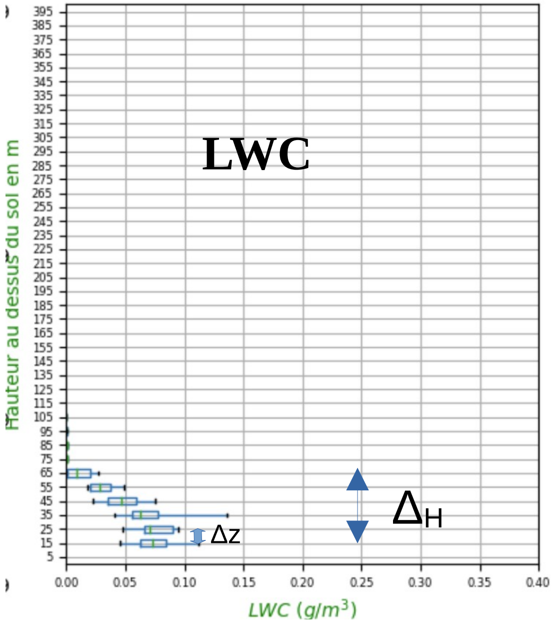


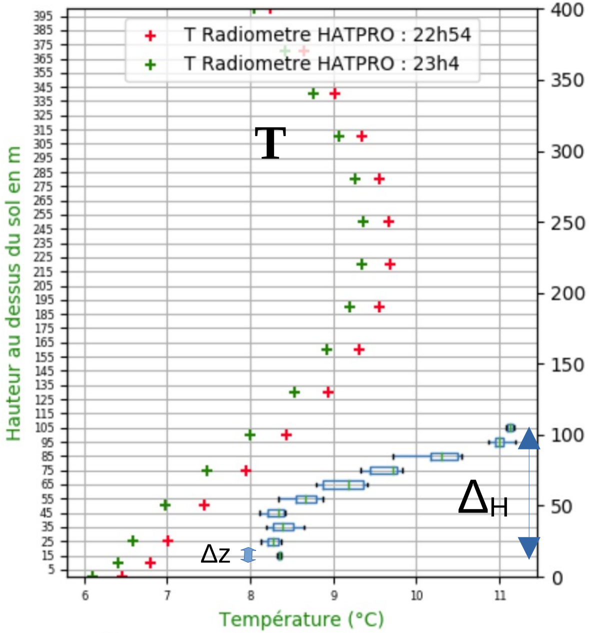




IV) Analysis Vertical Profiles IOP 14 : Transition Thin/Thick Fog : Construction Summary Graph

Vertical Profile of LWC (left) and Température (right) for the ascent between 22h53 and 22h59, during the night of 7/8 Mars 2020 (IOP 14)



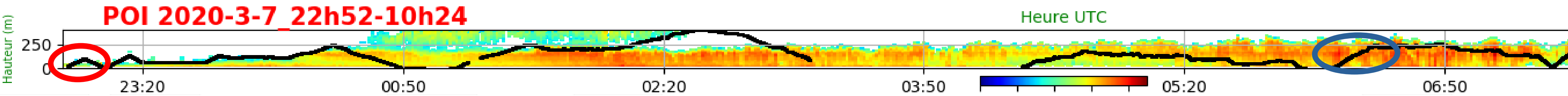


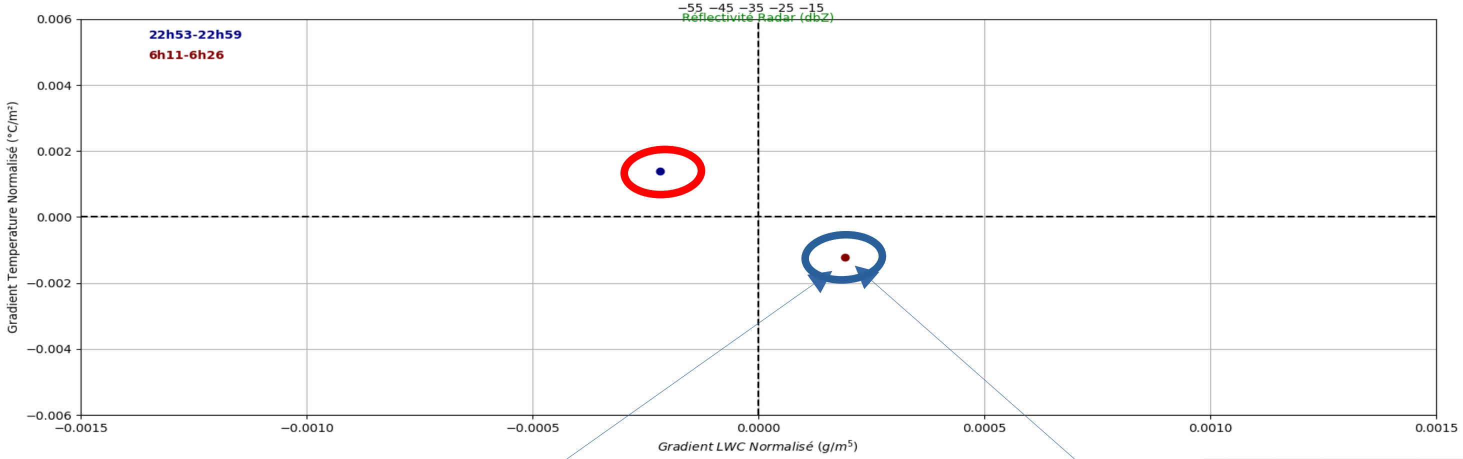
Graph :

$Grad_{Norm\ T} = f(Grad_{Norm\ LWC})$

$$Grad_{Norm\ LWC} = \frac{\sum \frac{LWC_{z+1} - LWC_z}{\Delta_z}}{\Delta_H}$$

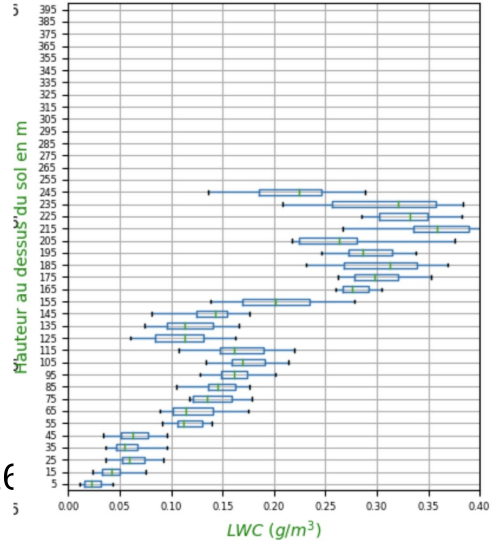
$$Grad_{Norm\ T} = \frac{\sum \frac{T_{z+1} - T_z}{\Delta_z}}{\Delta_H}$$



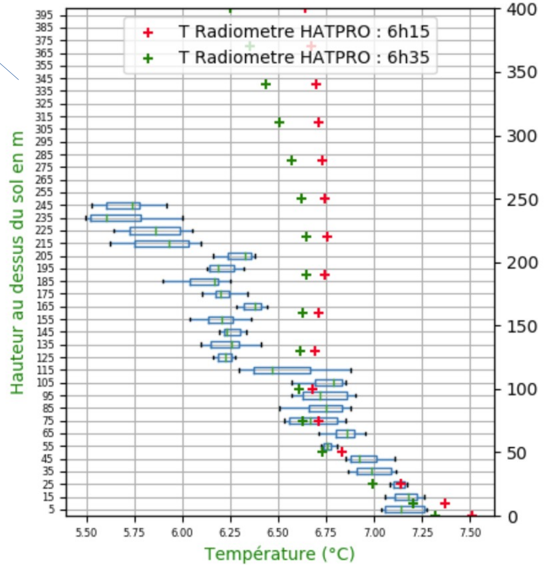


Grad$_{Norm\ T}$

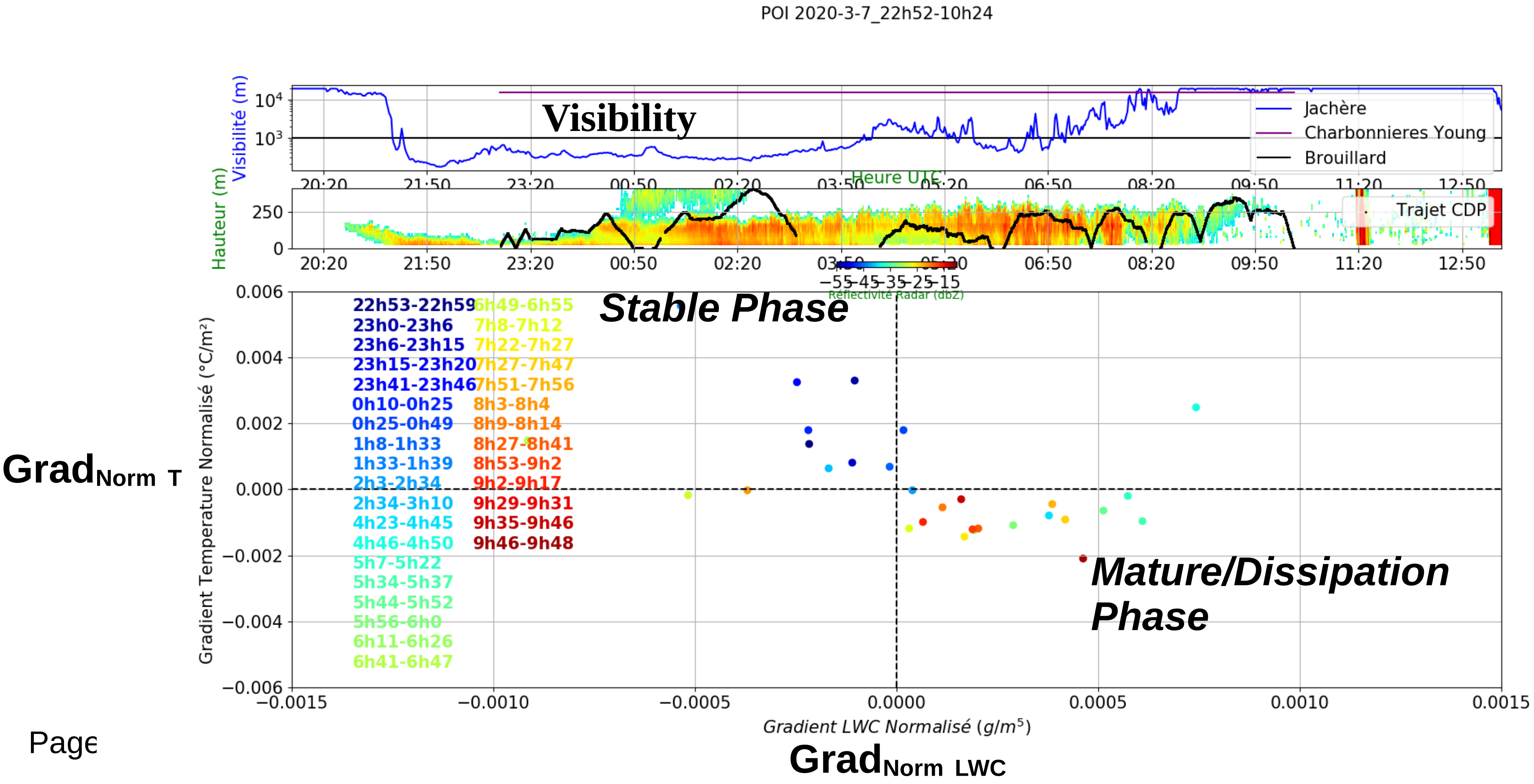
Grad$_{Norm\ LWC}$



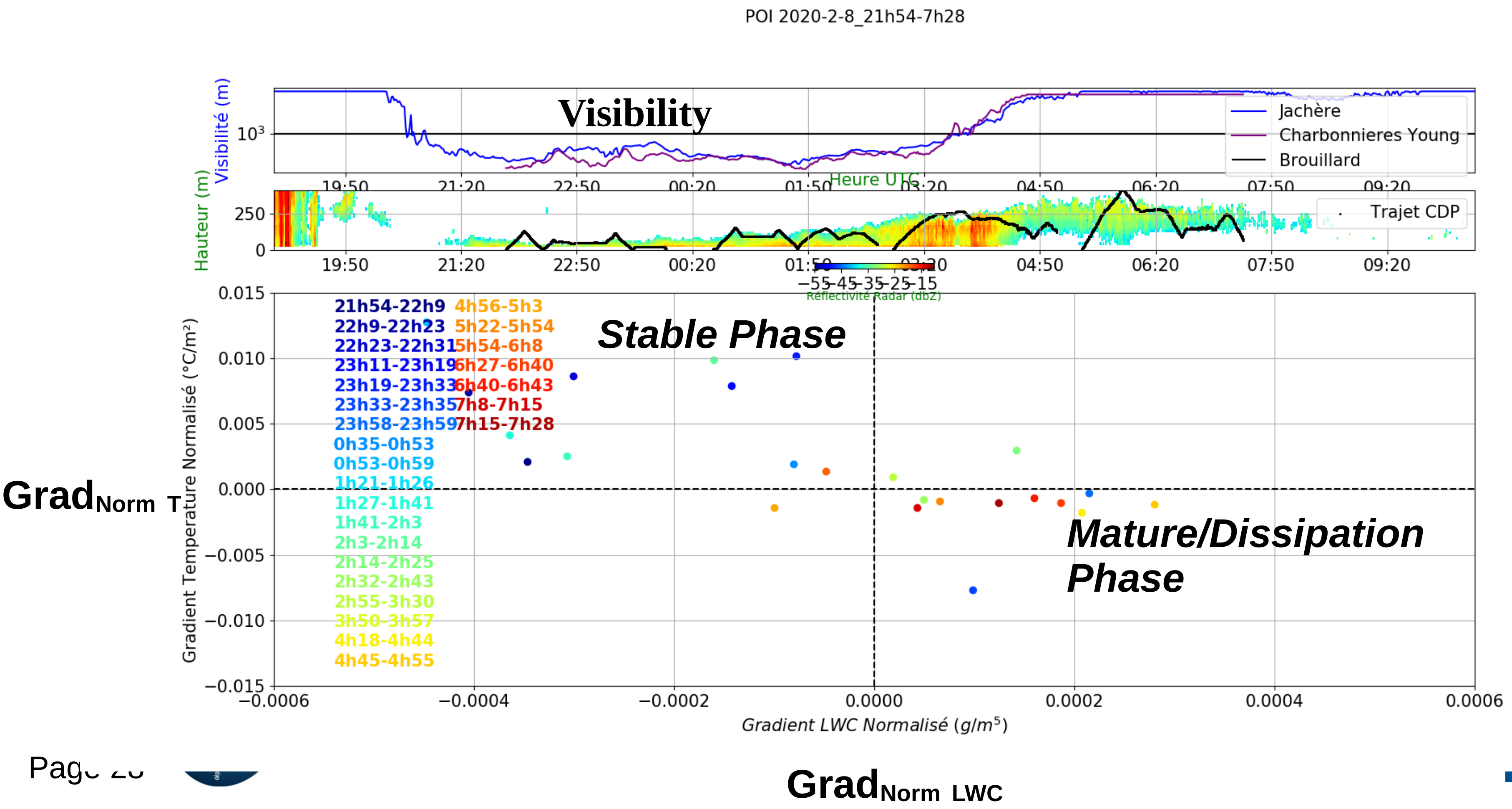
Vertical Profile of LWC (left) and Temperature (right) for the ascent between 6h11 and 6h26, during the night of 7/8 Mars 2020 (IOP 14)



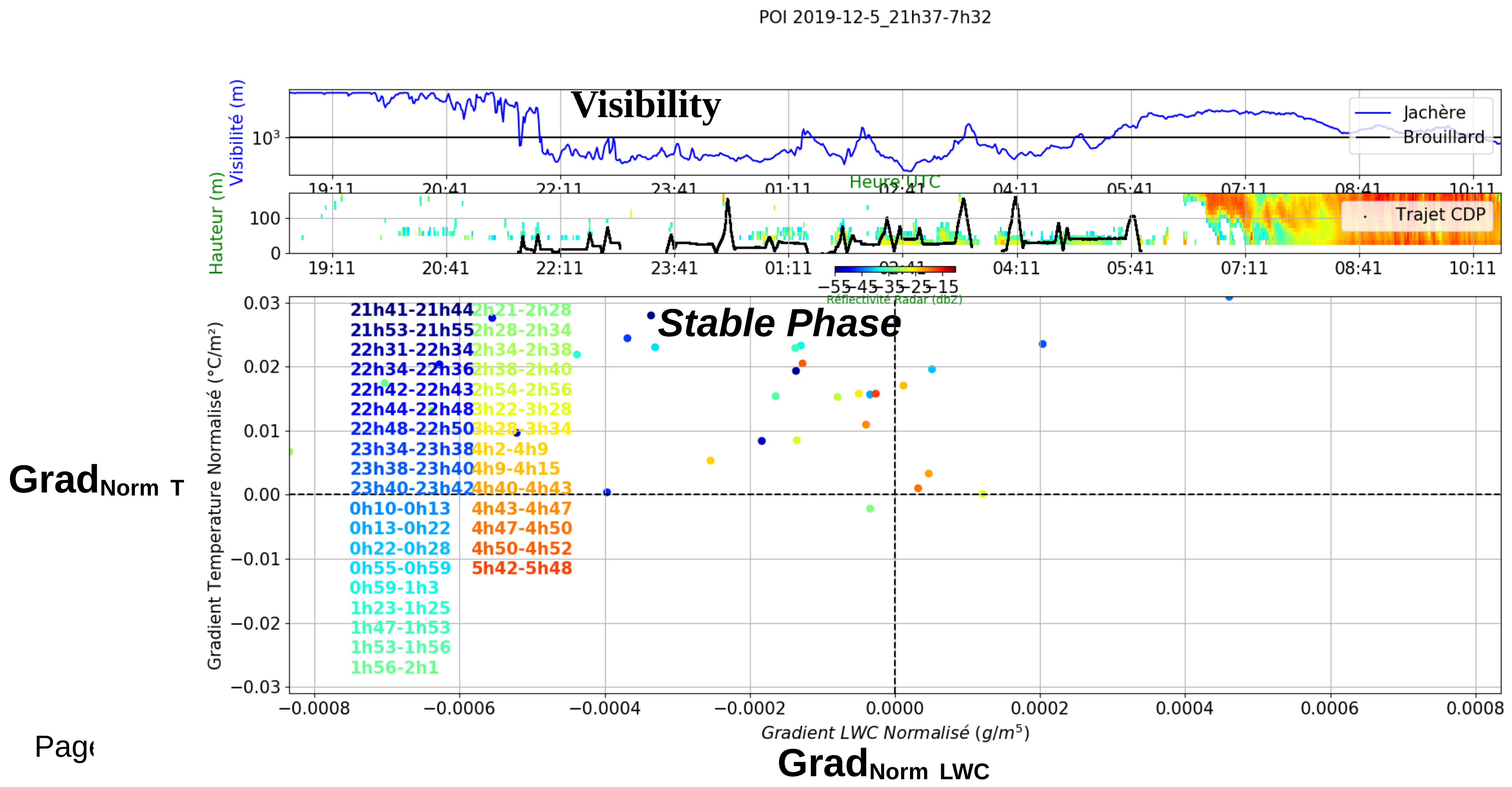
IV) Analysis Vertical Profiles IOP 14 : Transition Thin/Thick Fog : Summary Graph



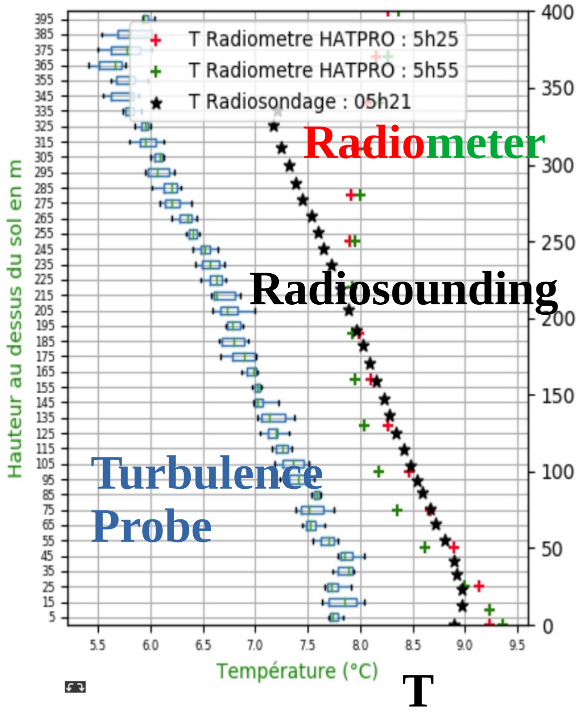
IV) Analysis Vertical Profiles IOP 11 : Transition Thin/Thick Fog : Summary Graph



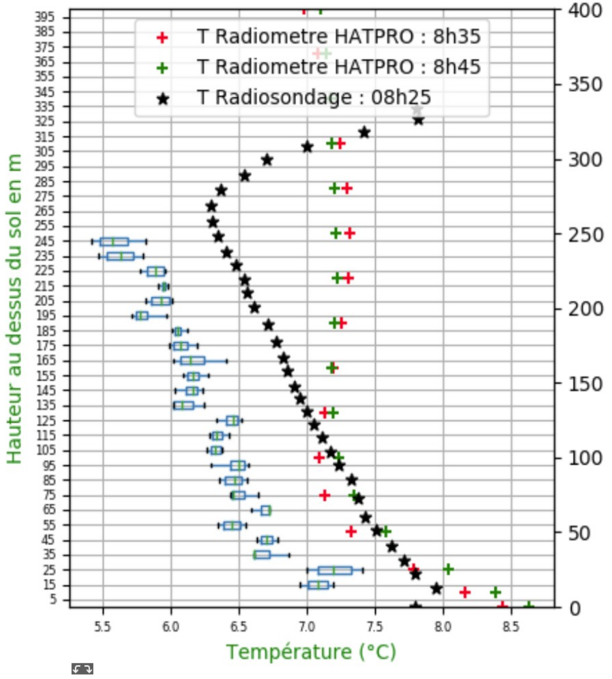
IV) Analysis Vertical Profiles IOP 2 : Transition Thin/Thick Fog : Summary Graph



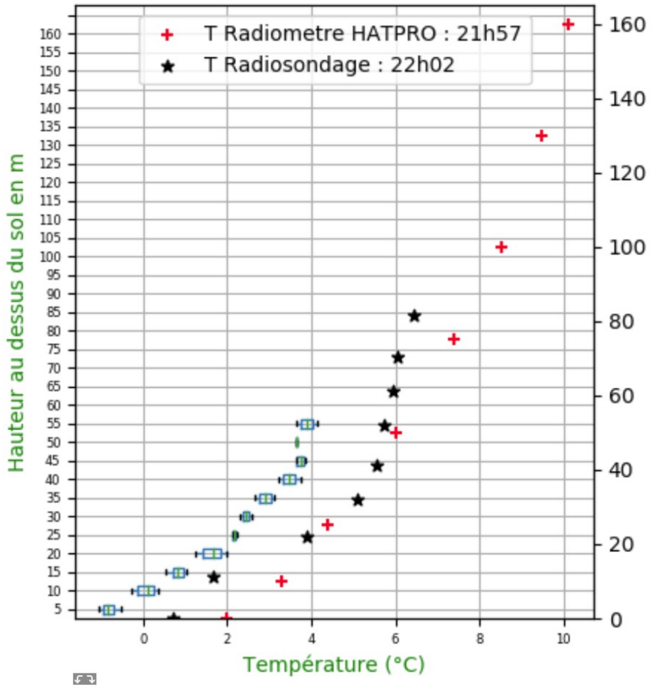
V) Bias Turbulence Probe : Comparison Vertical Profiles



IOP 11 : Ascent 5h22/5h54



IOP 14 : Ascent 8h28/8h41



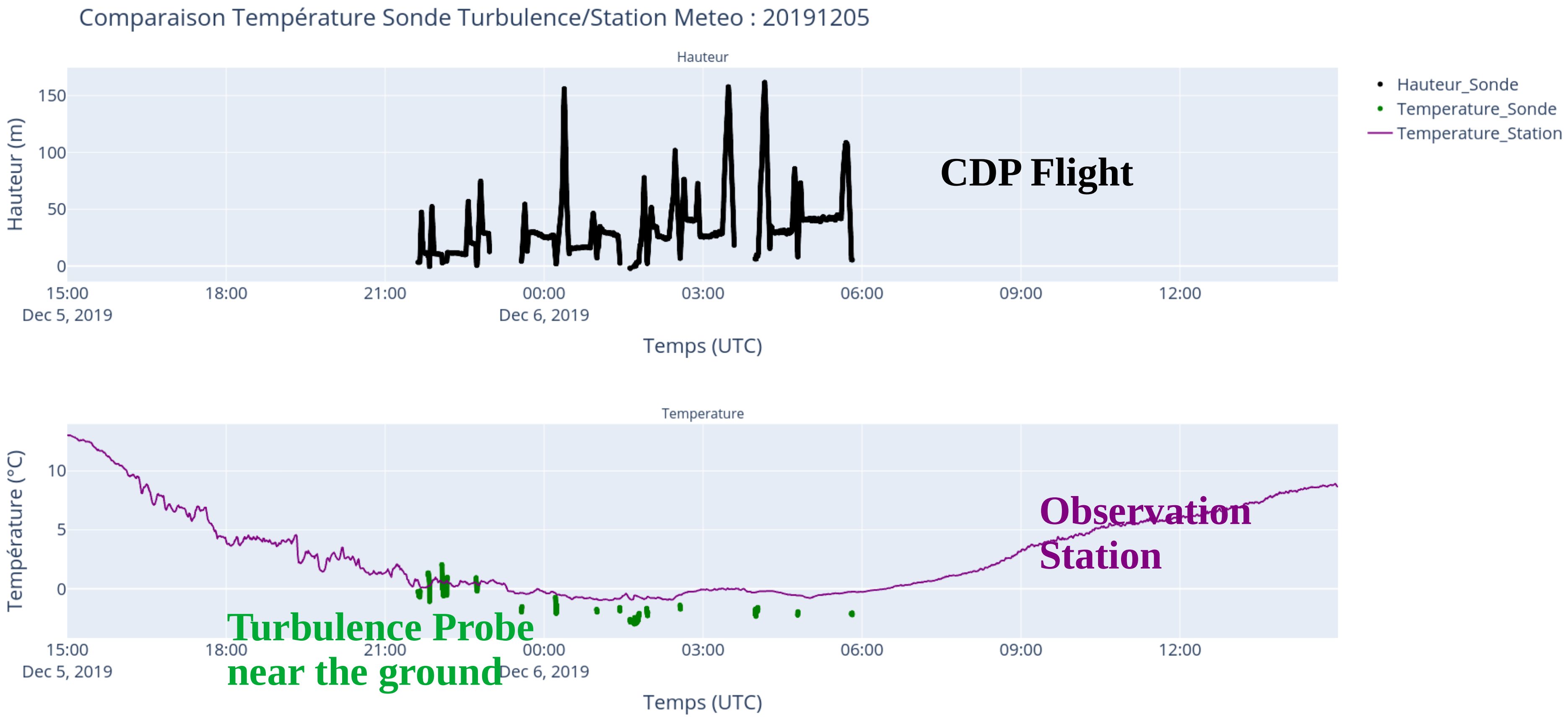
IOP 2 : Ascent 21h50/21h53

Comparison of Vertical Profiles during IOP 11 (left), IOP 14 (middle) and IOP 2 (right) between the turbulence probe, radiosoundings and the HATPRO radiometer

→ **Probably negative bias from the turbulence probe**

V) Bias Turbulence Probe : Comparaison with the station on the ground

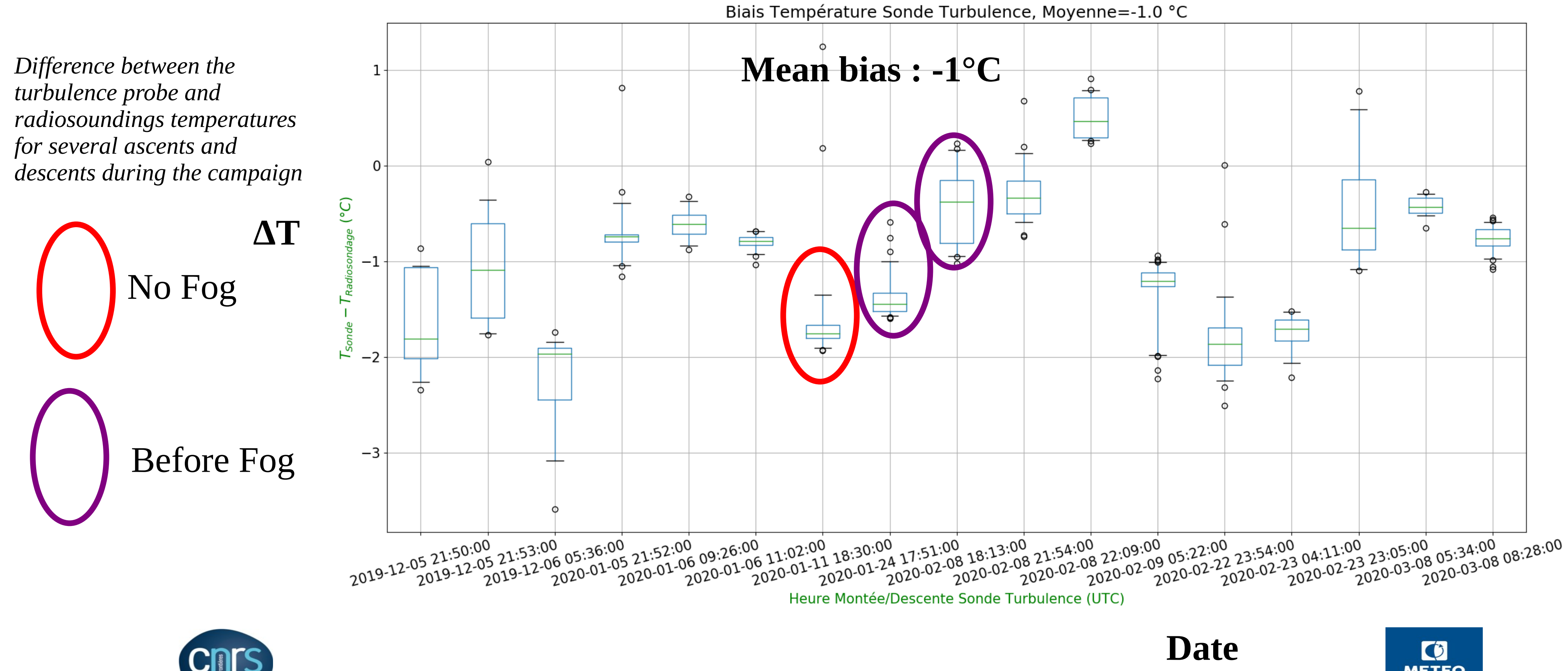
T



Bias turbulence probe with station on the ground

V) Bias Turbulence Probe : Temporal Bias

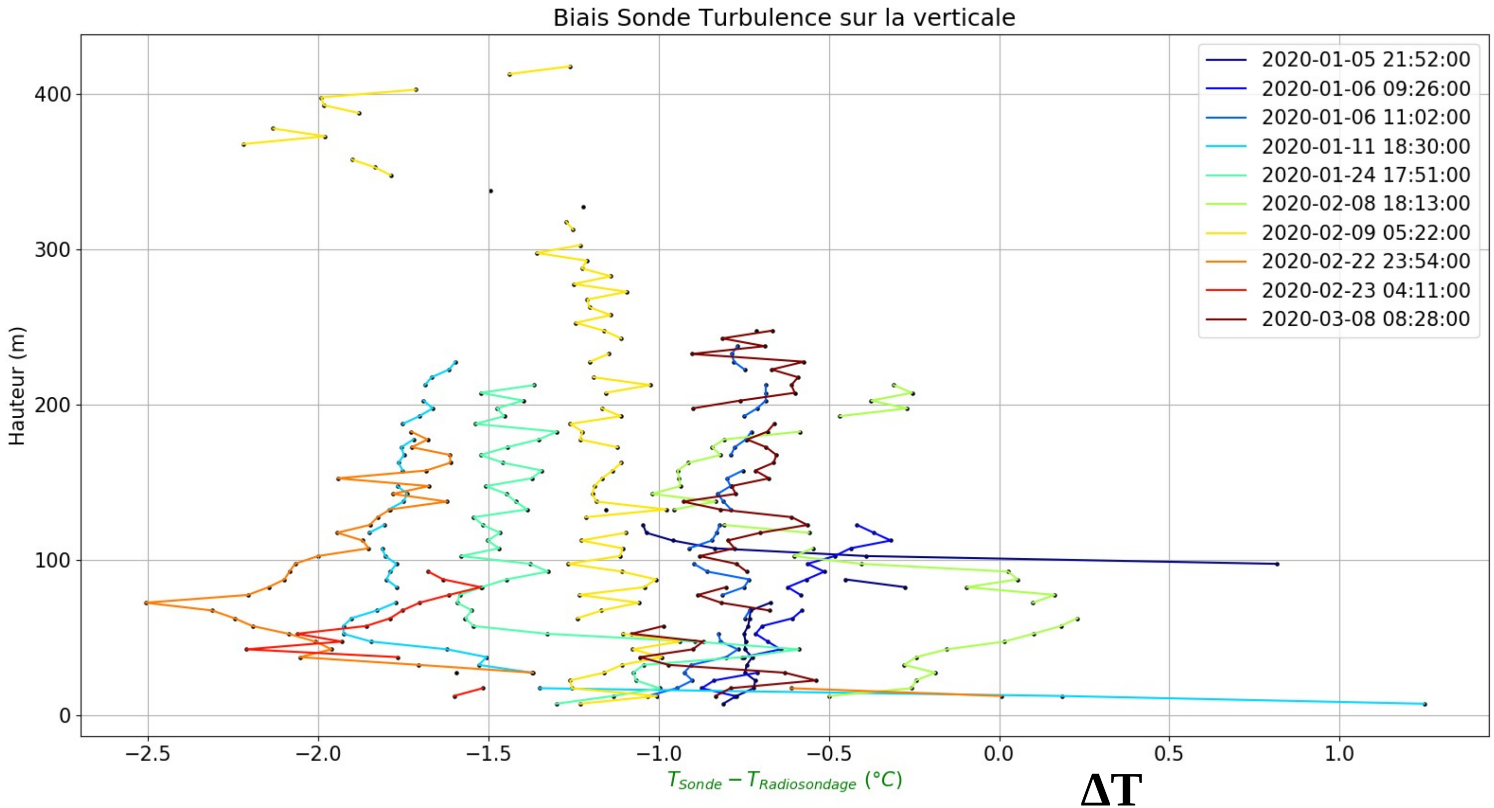
Difference between the turbulence probe and radiosoundings temperatures for several ascents and descents during the campaign



No sign of temporal drift

V) Bias Turbulence Probe : Vertical Bias

Difference between the turbulence probe and radiosounding temperatures at each altitude range for several ascents and descents during the SOFOG3D campaign



ΔT

Bias seems quite homegeneous vertically, except for some cases, especially near the ground

Summary and Future Work

Summary:

- Measurements validation : still in progress between microphysical instruments on the ground
- Statistics : mainly radiative fogs with large but few droplets near the ground
- Transition thin/thick fog: correlation still in progress between instruments in order to establish the transition time between thin and thick fog
- Vertical profiles : - significant vertical variability of the droplets distribution in a short time frame (evaporation, activation)
  - significant vertical variability between stable (High LWC values near the ground) and Mature phases (More adiabatic LWC profile)
- Bias turbulence probe : ~ -1°C Bias noticed from the turbulence Probe

Future Work:

- Document the variability of the droplets distribution at a temporal scale (constant height sections) and deepen the vertical variability.
- Characterize the microphysical properties during the fog life cycle between the ground and aloft
- Impact of aerosols (activation at the top) (M2 Internship Ines Vongpaseut)
- Comparison with Liquid Water Path from the microwave radiometer (Pauline Martinet)