Impact of thermodynamic and turbulent processes on fog dissipation during SOFOG-3D campaign

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Context and objective

Research questions

- What are the main processes involved in fog dissipation over a complex area between mountains and ocean?
- What are the best in-situ and remote sensing instruments to use for fog monitoring and nowcasting?

Flights delayed

Pile-up on the Chaban bridge, Bordeaux

Objective:

- Estimate the onset and dissipation time of fog during the SOFOG-3D field campaign
- Use a conceptual model of adiabatic fog to estimate fog macrophysical characteristics
- Document each processus involved in fog formation and dissipation based on a synergy of in-situ and remote sensing measurements

Data and methodology

Unique dataset collected during SOFOG-3D campaign in automne-winter 2019/2020

- **In-situ and remote sensing data :**
  - Cloud radar BASTA → cloud top height *(CTH)*, Radar Reflectivity
  - *Ceilometer* → *cloud base height* (CBH)
  - Microwave radiometer HATPRO → Liquid Water Path *(LWP), temperature inversion layer*)
  - Visibilimeter → definition of fog : visibility less than 2000 m
  - WindCube V2 wind Lidar → Turbulence and advection
  - Surface measurements & radiosoundings → temperature and wind

- **Adiabatic fog conceptual model (Toledo et al., 2021)**

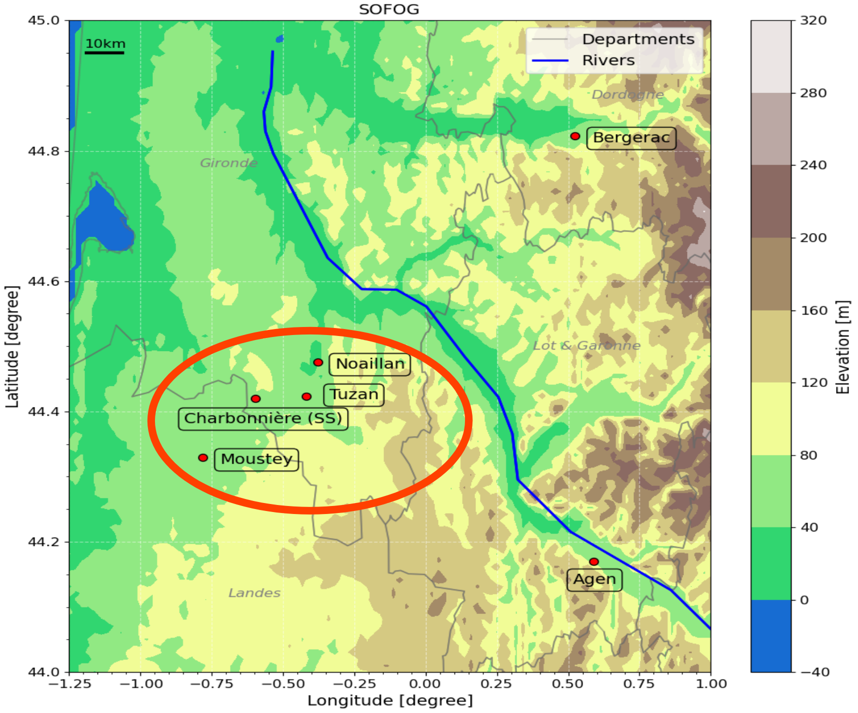
Cloud radar,
Ceilometer,
visibilimeter, microwave radiometer,
& surface measurements

CM →

Fog key parameters:
RLWP, CLWP, equivalent adiabaticity

Identification of case studies

Orography of the Study area



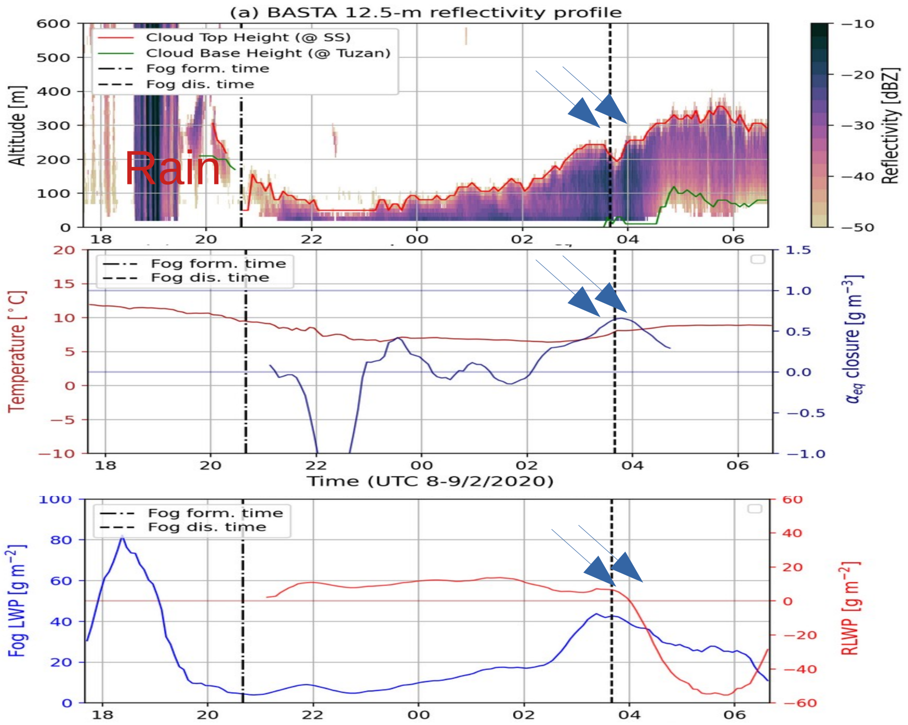
Based on *Tardif and Rasmussen (2007)*
31 fog cases observed at Charbonnière, supersite (SS) *during* Nov 2019 – Mar 2020 period

Focus on 2 IOPs

IOP6 : 5-6/01/2020
IOP11 : 8-9/02/2020

• Fog dissipation characteristics

IOP11: 8-9 February 2020



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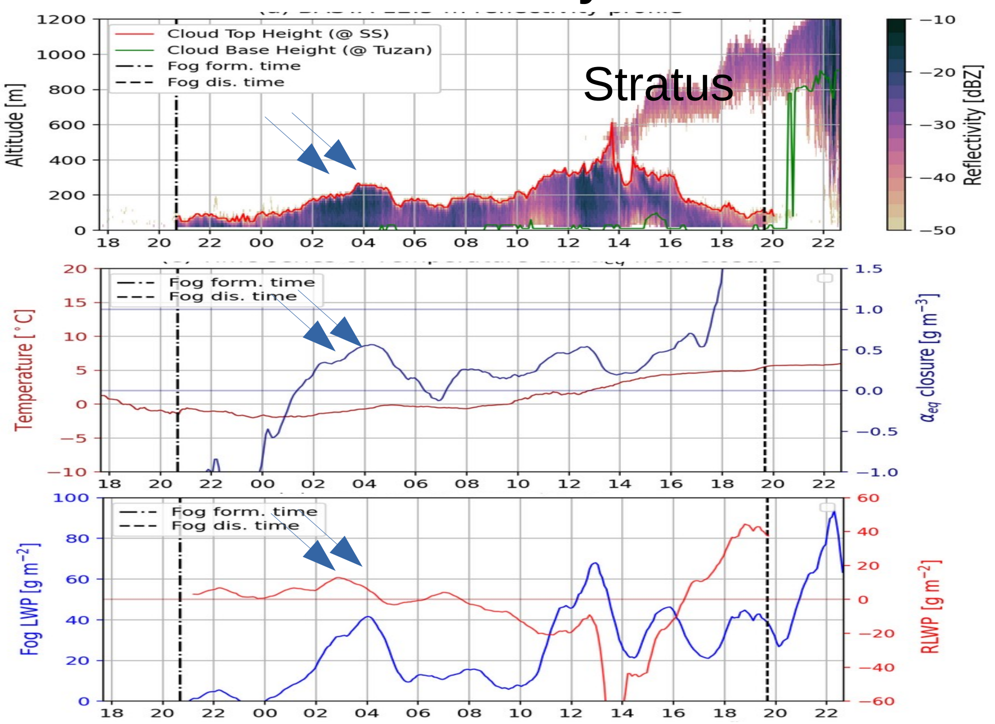
Dissipation by lifting

IOP6: 5-6 January 2020



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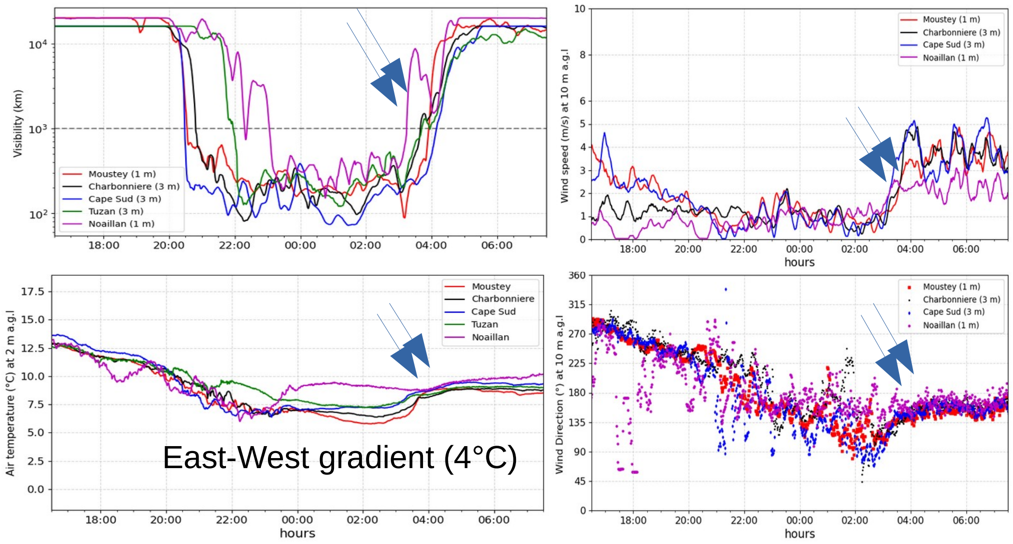
Dissipation by lowering

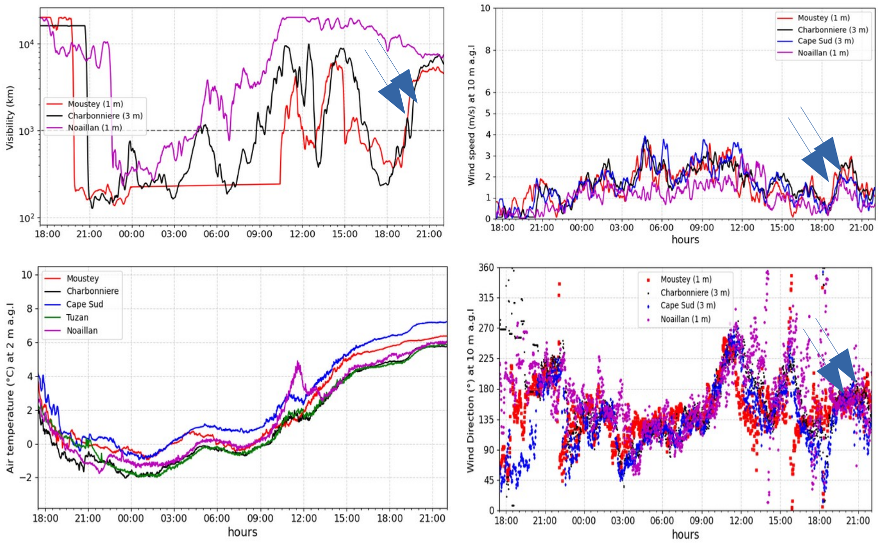
Fog dissipation characteristics

IOP11: 8-9 February 2020



- Spatio-temporal variability of fog formation time (from West to East)
- Fog dissipation time corresponded with a sudden increase of wind (mesoscale circulation)

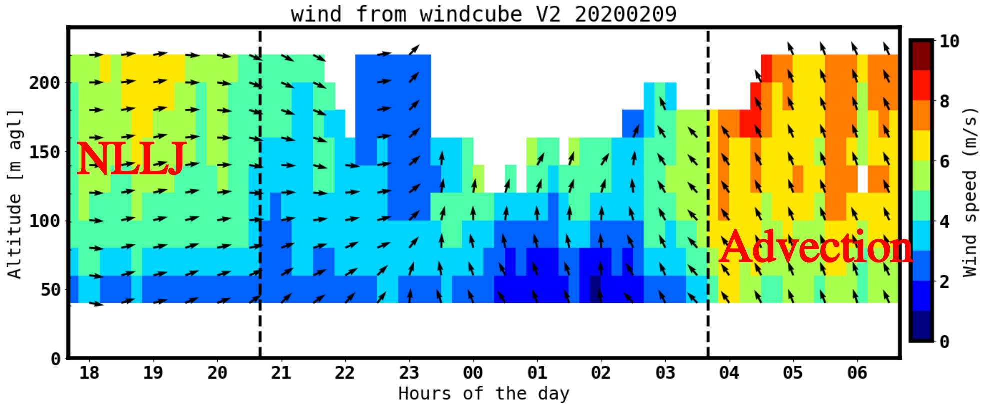
IOP6: 5-6 January 2020

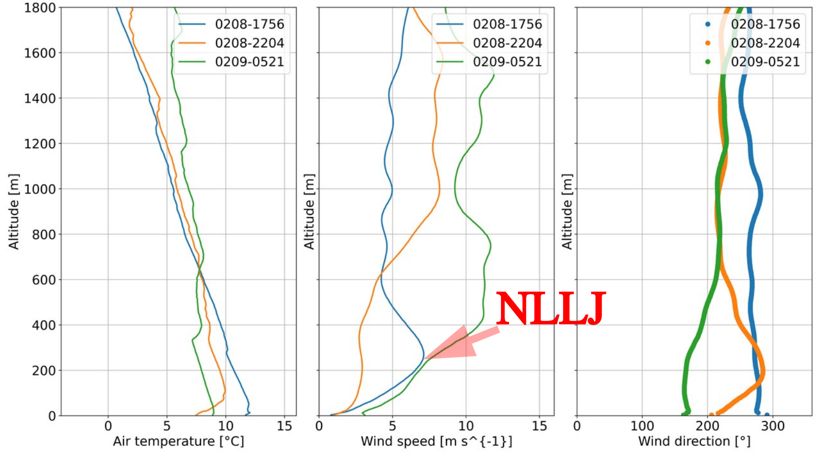


- Intermittent and persistent fog
- Moderate wind

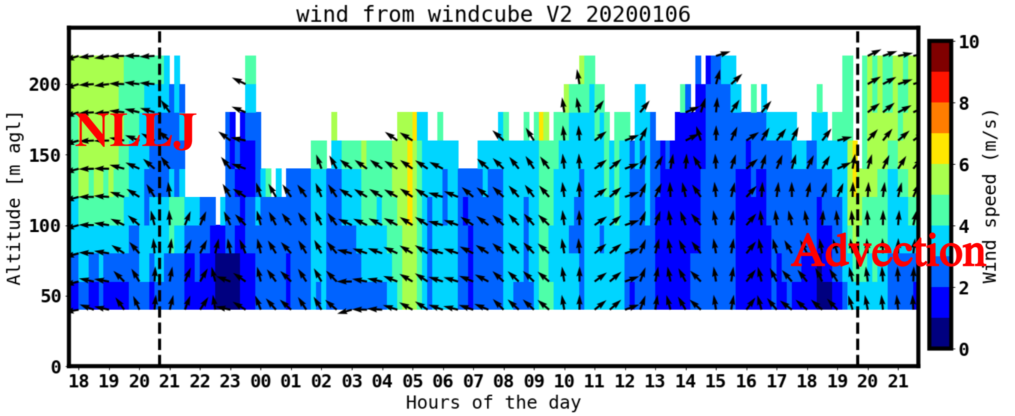
Fog dissipation characteristics

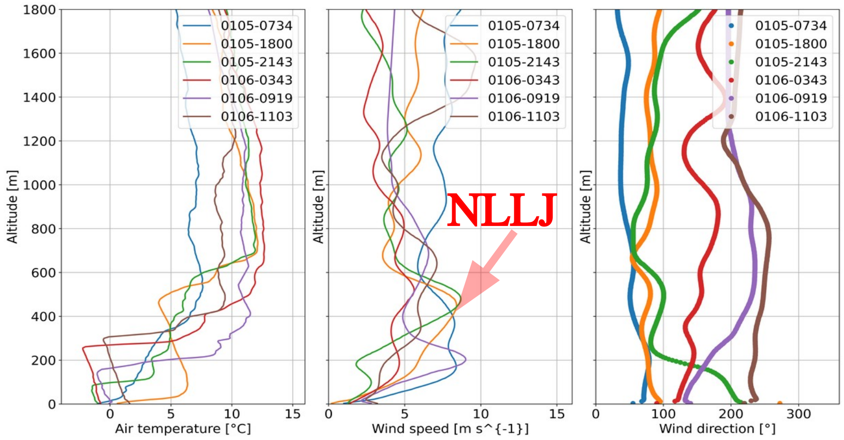
IOP11: 8-9 February 2020





IOP6: 5-6 January 2020

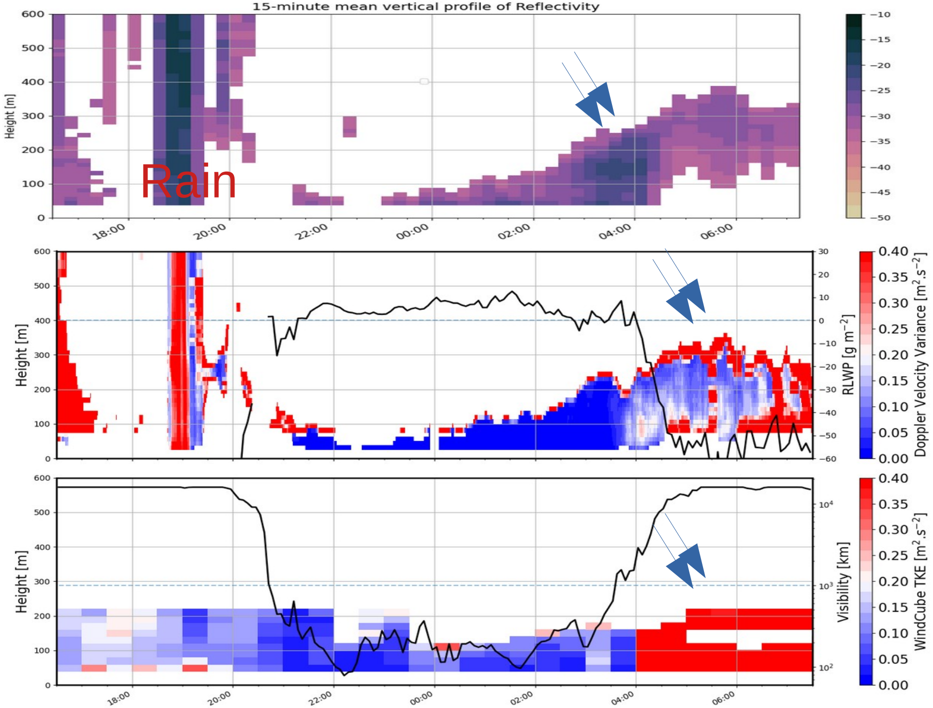




- Stratus lowering formed at the nose of the low-level jet bringing moisture from the ocean to the Landes
- Dissipation by advection

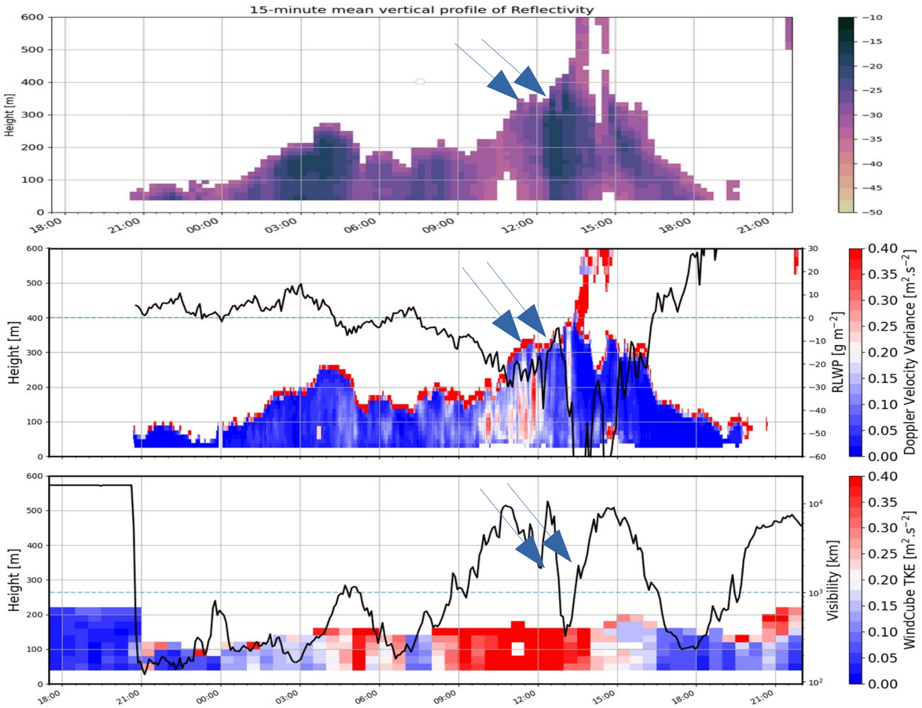
● Turbulence processes

IOP11: 8-9 February 2020



- Fog dissipation by lifting
- Strong turbulence during the dissipation phase (TKE > 0,4 m^2s^{-2})
- Fog thickening favored by moderate turbulence which reduce the RLWP

IOP6: 5-6 January 2020



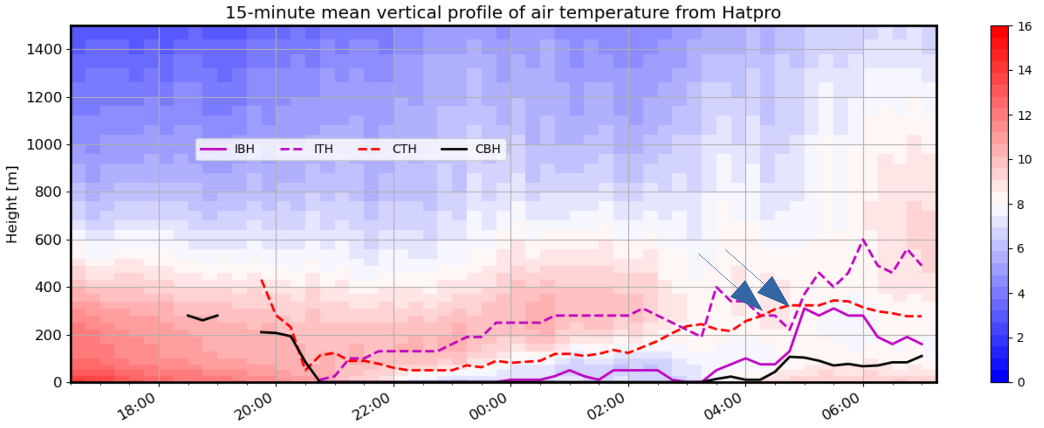
- Fog dissipation by lowering associated with low turbulence

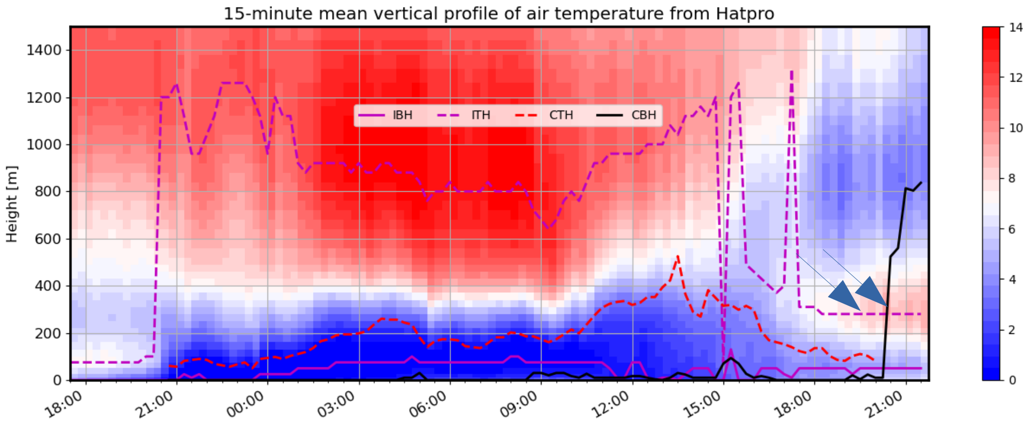
● Thermodynamical processes

IOP11: 8-9 February 2020

IOP6: 5-6 January 2020

IBH = Inversion Base Height
ITH = Inversion Top Height



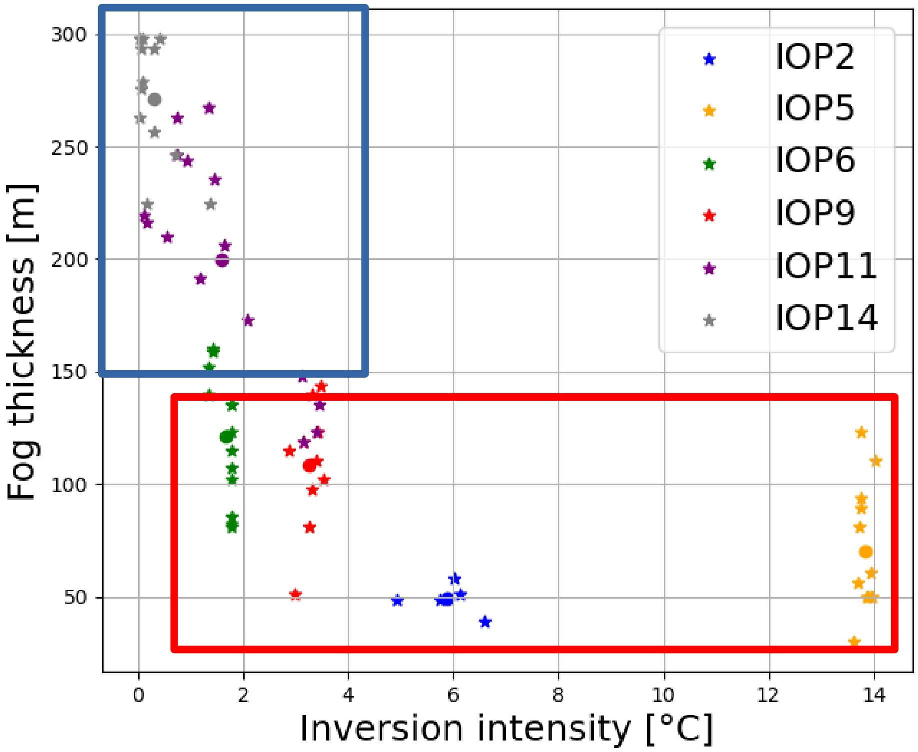


- Thick and light inversion (3,41 °C) after fog formation
- Dissipation phase associated with a warming of the surface layer – Evaporation

- Strong and deep inversion (14 °C)
- Synoptic atmospheric circulations associated with blocking over Europe
- A warm sub-layer between fog and stratus cloud

Thermodynamical processes

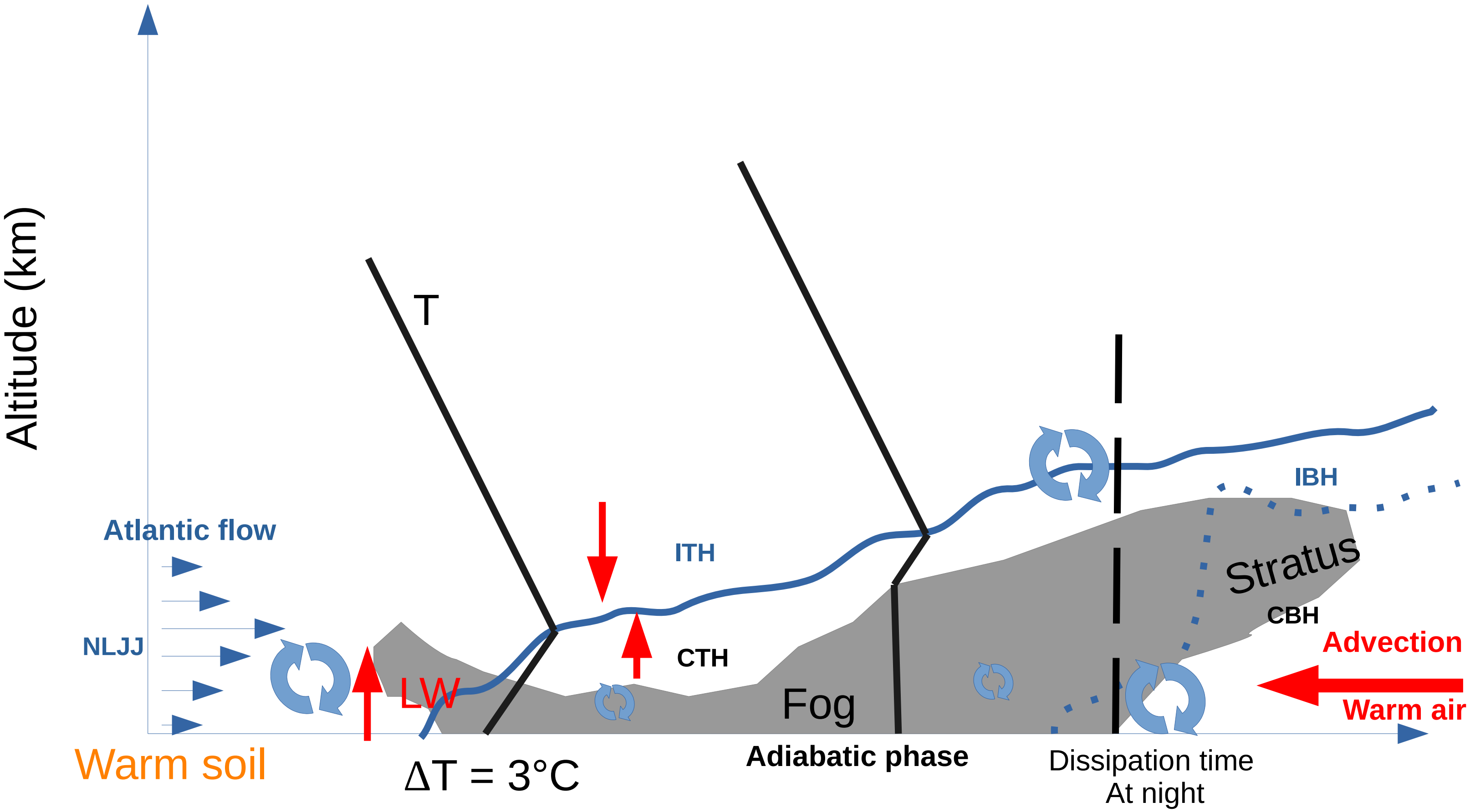
3 hours before fog dissipation time



Fog dissipation by lifting associated with low temperature inversion (local processes)

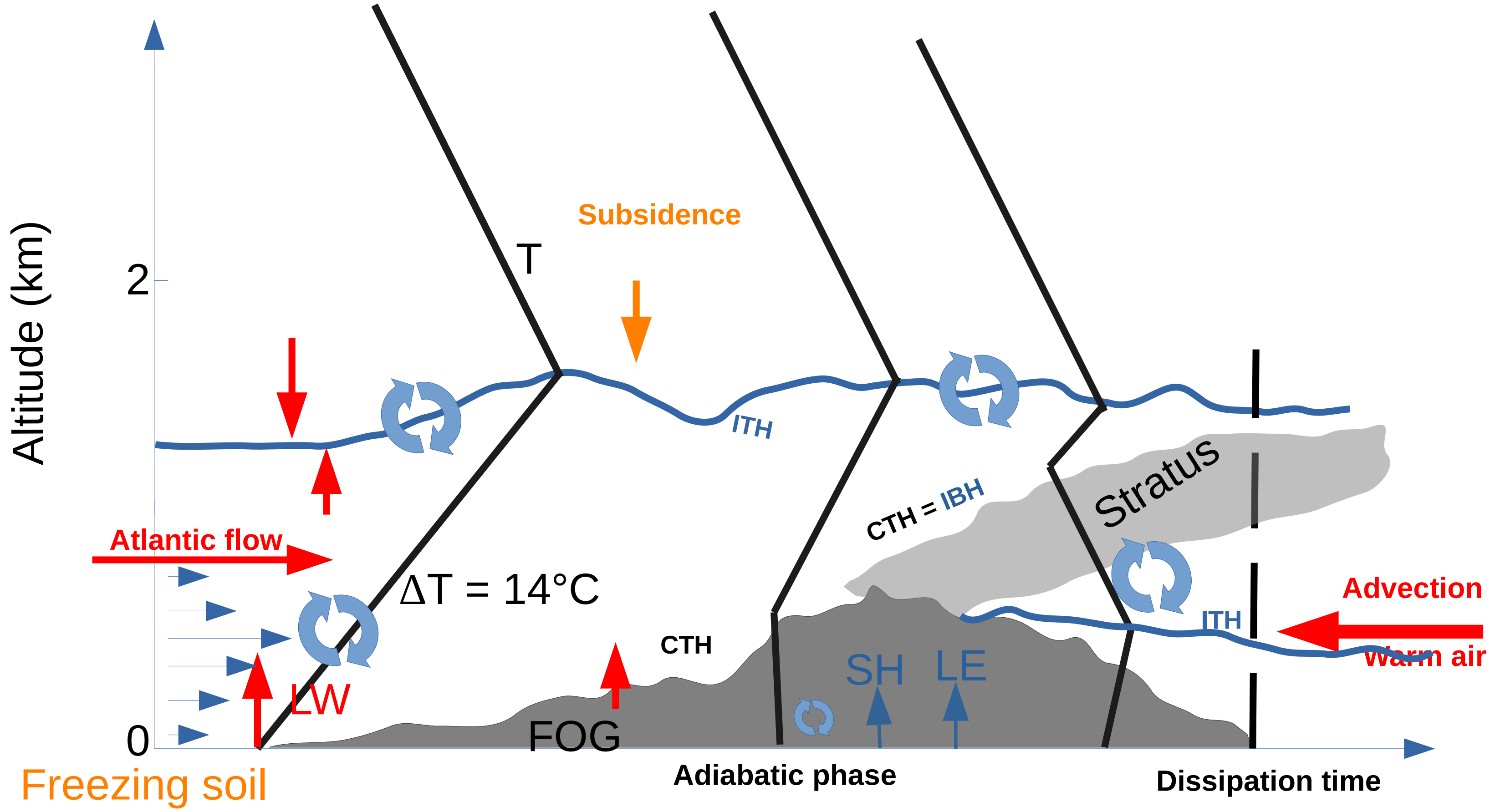
Fog dissipation by lowering associated with strong temperature inversion (synoptic conditions)

IOP11



Altitude (km)
T
Atlantic flow
NLJJ
LW
ITH
CTH
IBH
Stratus
CBH
Advection
Warm air
Fog
Warm soil
ΔT = 3°C
Adiabatic phase
Dissipation time
At night

IOP6



ITH= inversion top height
CTH = cloud top height

Summary

- Using the adiabatic fog conceptual model and cloud radar, we find that fog can be formed by radiative cooling or advection through the westerly sea breeze (nocturnal low-level jet). This model allows to properly document the different phases (stable/adiabatic) of the fog evolution. Fog’s dissipation phase are by lifting of it base or lowering of it top.

- Fog’s dissipation by lifting is associated with a low inversion layer and governed for some IOPs by mechanical turbulence linked to advection of warmer air mass (southerly continental flow) during the night and for others by thermal turbulence linked to solar heating (sensible heat flux) during the day.

- Fog’s dissipation by lowering is associated with strong inversion layer and favoured by warmer air mass advection over the top of the fog which breaks it into two: a stratus layer above and the residual fog which lowering until it dissipation.

- This study also demonstrates the importance of using instrumental synergy to better understand the macrophysical characteristics of fog in order to predict fog formation, evolution and dissipation – baseline to use for better simulations of fog in NWP models

Thank you for your attention

Merci pour votre attention

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Fog Conceptual model

Fog LWC and LWP

Adiabatic fog LWC versus height:

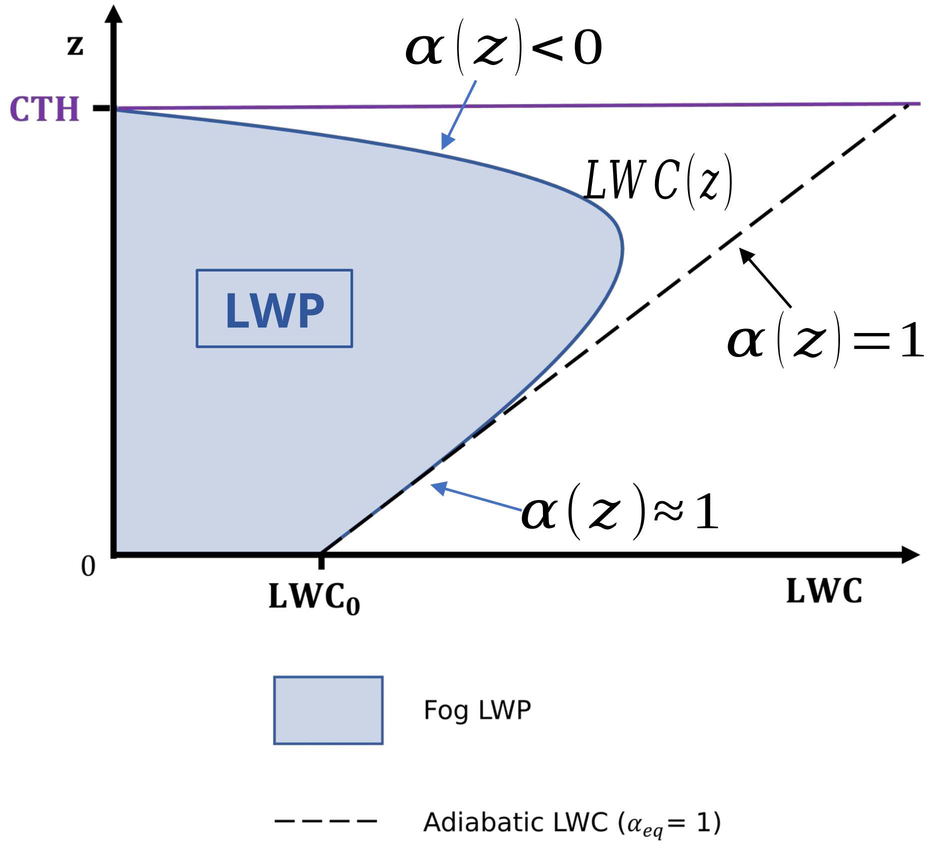
$$\frac{dLWC(z)}{dz} = \alpha(z) \cdot \Gamma_{ad}(T,P)$$

$$LWC(z) = \int_0^z \alpha(z')dz' \, \Gamma_{ad}(T,P) + LWC_0$$

Well-mixed Cloud $LWC(z)$

Fog-only component

- **Adiabaticity**
- adiabatic LWC lapse rate [g m-4]
- Surface temperature [K]
- Surface pressure [Pa]



Fog Conceptual model

Fog LWP:

$$LWP = \int_0^{CTH} LWC(z)dz = \int_0^{CTH} \left(\int_0^{z} \alpha(z')dz' \, \Gamma_{ad}(T,P) + LWC_0 \right) dz$$

Simplification:

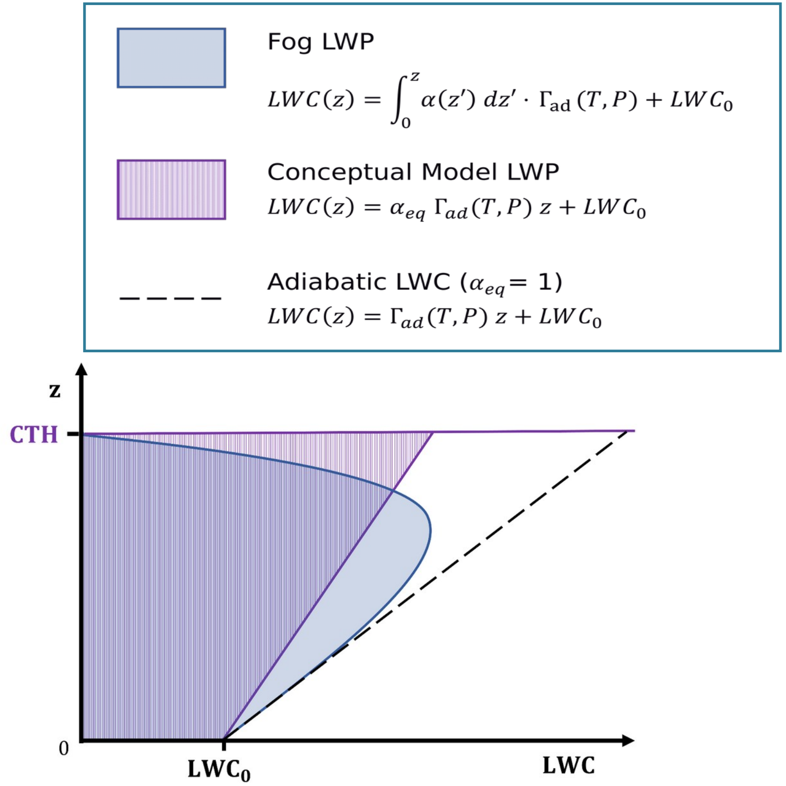
→

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

- The conceptual model simplifies fog equations by introducing an equivalent adiabaticity profile
- Equivalent adiabaticity of the fog layer

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

is a function of column variables, and can be retrieved using the remote sensing instruments



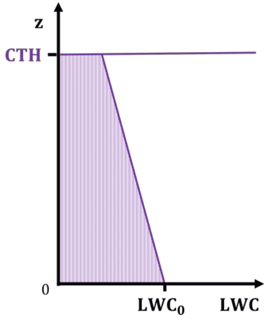
Fog LWP = Conceptual model LWP

Fog Conceptual model

Fog equivalent adiabaticity

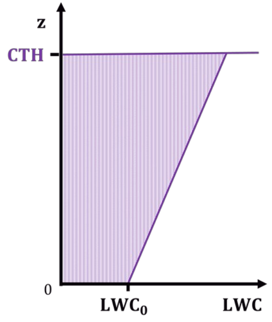
Statistical study of the eq. Adiabaticity (80 Fog cases)

$\alpha_{eq} < 0$

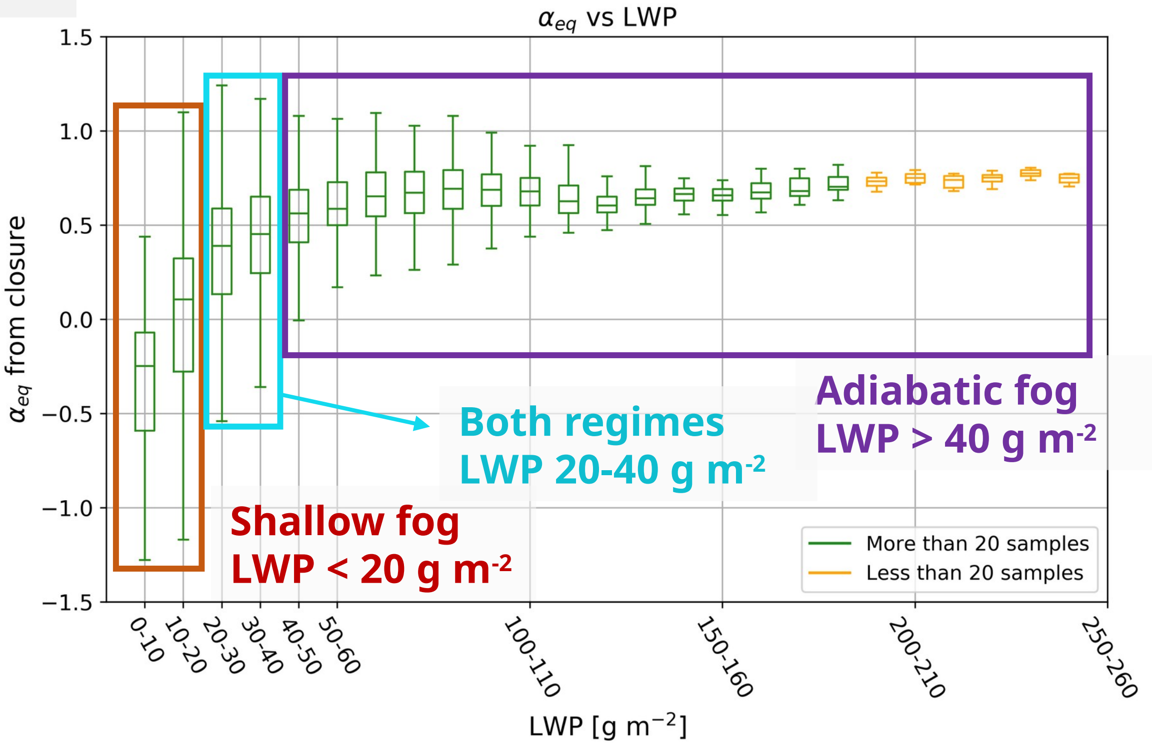


LWC is higher in the lower fog layers:
Shallow stable fog

$\alpha_{eq} > 0$



LWC increases with height
→ Adiabatic fog
→ Fog is transitioning from shallow to adiabatic



- **Fog Conceptual model**

Critical and Reservoir LWP

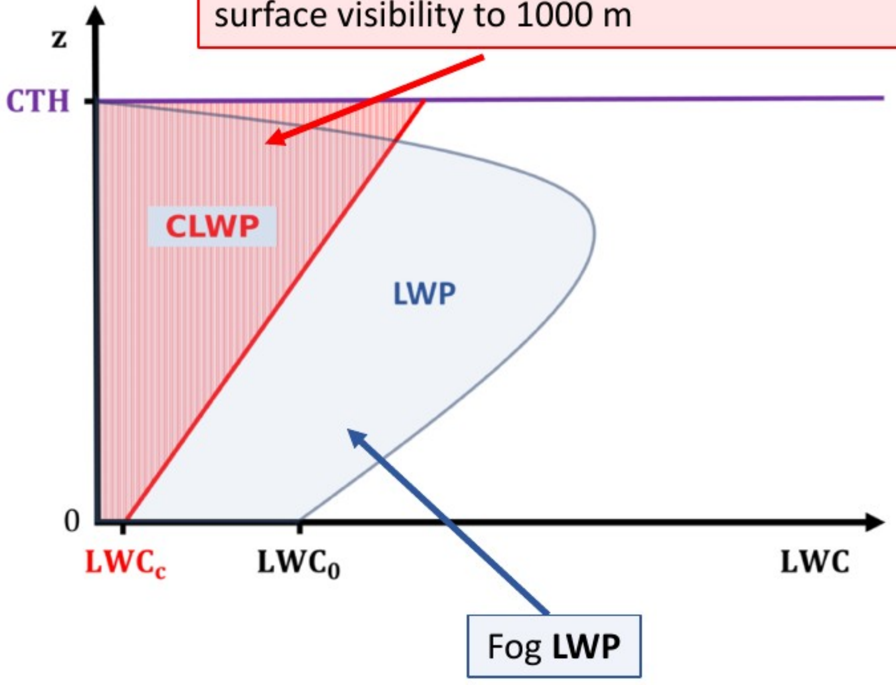
This enables the definition of a new variable, the **Critical LWP** (CLWP)

Critical LWP (CLWP)

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

Surface visibility of 1000 m

CLWP: Minimum LWP needed to fill a fog layer with a thickness of CTH, and reduce surface visibility to 1000 m



- **Fog Conceptual model**

Critical and Reservoir LWP

This defines two new variables, the **Critical LWP** (CLWP) and the **Reservoir LWP (RLWP)**

Critical LWP (CLWP)

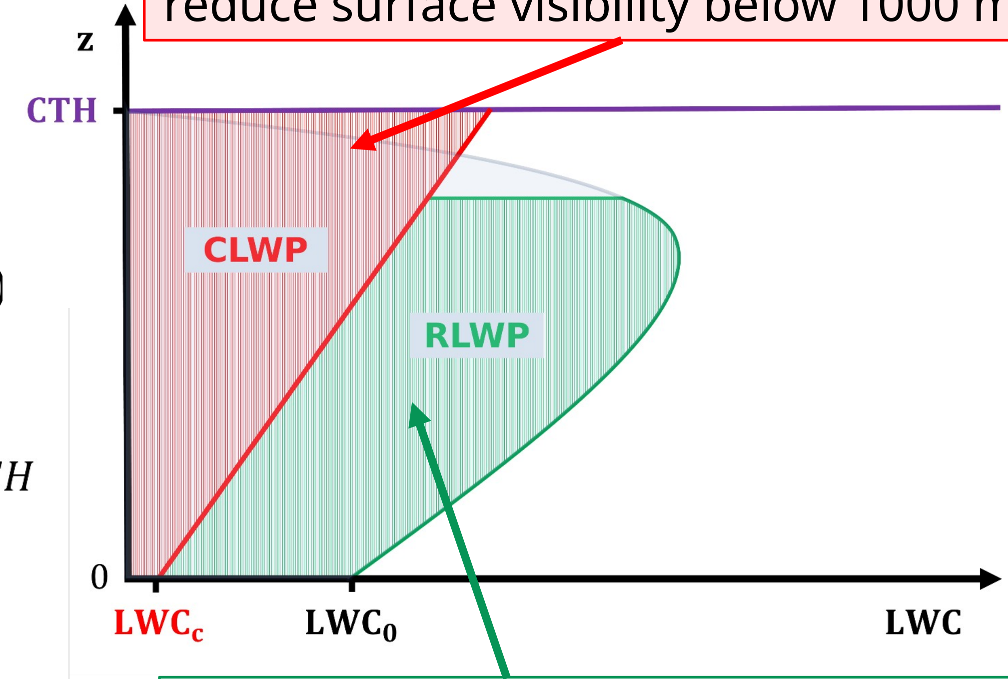
$$CLWP = \frac{1}{2}\alpha_{eq}\,\Gamma_{ad}(T,P)\,CTH^2 + LWC_c\,CTH$$

Reservoir LWP (RLWP)

$$RLWP = LWP - CLWP$$

$$RLWP = RLWP(LWP, CTH, T, P)$$

CLWP: Minimum LWP needed to fill a fog layer with a thickness of CTH, and reduce surface visibility below 1000 m



RLWP: Excess of LWP that enables fog to persist at the surface