Role of thermodynamic and turbulence processes on the fog life cycle during SOFOG3D experiment

Cheikh DIONE, Martial HAEFFELIN, Frederic BURNET, Christine LAC, Guylaine CANUT, Julien DELANOË, Jean-Charles DUPONT, Susana JORQUERA, Pauline MARTINET, Jean-Francois RIBAUD, and Felipe TOLEDO

SOFOG3D final workshop
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Context and objective

Research questions

- What processes contribute to the transition from stable to adiabatic fog?
- What processes contribute to the dissipation of fog?

Tools:

- In-situ and remote sensing measurements during SOFOG3D field campaign
- Adiabatic fog conceptual model to derive additional key fog variables unobserved

Pile-up on the Chaban bridge, Bordeaux

Flights delayed
● Data and studied area

Orography of the Study area

100 x 100 km around the supersite

5 weather stations around the supersite (Visibility, temperature, wind, etc.)
Based on Tardif and Rasmussen (2007)
31 fog cases observed at Charbonnière, supersite (SS)
during Nov 2019 – Mar 2020 period

4 heaviest fogs documented:
- (2) radiation
- (2) radiation-advection
### Methodology

**Visibility at the supersite**

<table>
<thead>
<tr>
<th>Case study number</th>
<th>Formation time</th>
<th>Fog types</th>
<th>Dissipation time</th>
<th>Fog duration (hh:min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Date dd/mm/yyyy</td>
<td>Hours (UTC)</td>
<td>Date dd/mm/yyyy</td>
<td>Hours (UTC)</td>
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<tr>
<td><strong>Rad</strong></td>
<td></td>
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<tr>
<td>IOP 5</td>
<td>28/12/2019</td>
<td>22:40</td>
<td>29/12/2019</td>
<td>11:00</td>
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<td>IOP 6</td>
<td>05/01/2020</td>
<td>20:40</td>
<td>06/01/2020</td>
<td>08:40</td>
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<td>IOP 11</td>
<td>08/02/2020</td>
<td>20:40</td>
<td>09/02/2020</td>
<td>03:40</td>
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<td>IOP 14</td>
<td>07/03/2020</td>
<td>21:20</td>
<td>08/03/2020</td>
<td>04:00</td>
</tr>
</tbody>
</table>

**Date**
dd/mm/yyyy

**Hours (UTC)**

- 22:40
- 20:40
- 21:00

**Fog types**

- Radiation
- Advection-radiation
● Methodology

- Remote sensing at the supersite

Basta Mini Cloud, fog thickness

Windcube V2 Wind & TKE

Radiometer Hatpro LWP & stability

CL31 CBH – fog dissipation
**Methodology**

**Fog conceptual model**

**In-situ and remote sensing data**
T, P, visibility, LWP, CTH

**Fog key parameters:**
equivalent adiabaticity & Reservoir

Toledo et al., 2021

Equivalent adiabaticity by closure

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

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

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

**Fog adiabatic**
● **Methodology**

**Fog conceptual model**

- **SOFOG3D**
  - Low fog LWP at SOFOG3D
  - Equivalent adiabaticity by closure consistent at both sites – used to define the transition stable/adiabatic fog

- **SIRTA**
  - More fog LWP at SIRTA

*Toledo et al., 2021*
Critical and Reservoir LWP

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

**Critical LWP (CLWP)**

\[ CLWP = \frac{1}{2} \alpha_{eq} \Gamma_{ad}(T, P) \cdot CTH^2 + LW C_c \cdot CTH \]

**Reservoir LWP (RLWP)**

\[ RLWP = LWP - CLWP \]

**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 – nowcasting

\[ RLWP = R LWP(LWP, CTH, T, P) \]

*Toledo et al., 2021*
**Methodology**

- **Pre-fog**
  - Visi \( \leq 1000 \text{ m} \)
  - \( \frac{dT}{dz}_{[0-100 \text{ m}]} > 0 \)

- **Stable**
  - Visi \( \leq 1000 \text{ m} \)
  - \( \frac{dT}{dz}_{[0-100 \text{ m}]} > 0 \)

- **Transition**
  - Stable/adiabatic
  - Onset
  - \( dCTH/dt_{t \geq 5 \text{ min}} \geq 25 \text{ m} \)
  - \( \alpha_{\text{eq}} \geq 0.5 \)

- **Adiabatic**
  - CTH > 125 m
  - Visi > 1000 m
  - \( \alpha_{\text{eq closure}} \leq 0.5 \)

- **Definition of fog phases**
  - t1: start of the transition
  - t2: end of the transition
  - td: dissipation time
  - td-30 min
  - td+30 min

- **Fog life cycle**

- **CBH > 0**

- **CTH**

- **Dissipation**
• Fog formation, evolution and dissipation processes

**Rad**

**IOP 5**

- Formation: Cloud free – East-West gradient of fog onset – low wind – cooling rate
- Transition: Increase in wind and temperature
- Dissipation: WS > 2 m/s

**IOP 6**

- Formation: Rain/stratus – East-West gradient – low wind – cooling rate
- Transition: Increase in wind and temperature
- Dissipation: WS > 2 m/s

**Rad-Adv**

**IOP 11**

- Formation: Cloud free – East-West gradient of fog onset – low wind – cooling rate
- Transition: Increase in wind and temperature
- Dissipation: WS > 2 m/s

**IOP 14**

- Formation: Rain/stratus – East-West gradient – low wind – cooling rate
- Transition: Increase in wind and temperature
- Dissipation: WS > 2 m/s
• Fog formation, evolution and dissipation processes

Rad IOP 5

Rad-Adv IOP 11

IOP 6

IOP 14

• Formation: Easterly jet – synoptic

• Stable: $\text{TKE} < 0.2 \text{ m}^2 \text{s}^{-2}$ and $\sigma_w^2 < 0.02 \text{ m}^2 \text{s}^{-2}$

• Transition stable/adiabatic (TKE [0.2 – 0.4 m$^2$ s$^{-2}$] and $\sigma_w^2$ [0.02 – 0.04 m$^2$ s$^{-2}$], SHF [0 – 10 W m$^{-2}$])

• Dissipation by turbulence (TKE $> 0.4 \text{ m}^2 \text{s}^{-2}$ and $\sigma_w^2 > 0.04\text{m}^2\text{s}^{-2}$ and SHF $> 10 \text{ W m}^{-2}$) – thermal and mechanic – RLWP (< 0) estimated an early (1h before) dissipation

• Formation: Westerly jet (Atlantic inflow) –

• Stable: $\text{TKE} < 0.2 \text{ m}^2 \text{s}^{-2}$ and $\sigma_w^2 < 0.02 \text{ m}^2 \text{s}^{-2}$

• Transition stable/adiabatic mechanical turbulence: (TKE [0.2 – 0.4 m$^2$ s$^{-2}$] and $\sigma_w^2$ [0.02 – 0.04 m$^2$ s$^{-2}$], SHF < 0 W m$^{-2}$)

• Dissipation: southerly flow – turbulence (TKE $\geq 0.3 \text{ m}^2 \text{s}^{-2}$ and $\sigma_w^2 > 0.04 \text{ m}^2 \text{s}^{-2}$) – thermal and mechanic – RLWP (< 0) estimated the dissipation time
• Fog formation, evolution and dissipation processes

Rad

IOP 5

- Transition stable/adiabatic more marked in radiation fog – lowering of the inversion top height

Rad-Adv

IOP 11

- Link between temperature inversion strength and fog lifetime

IOP 6

IOP 14
Radiation fog cases have longest lifetime (more than 12 hours) linked to very cold atmospheric conditions associated with a continental easterly nocturnal low-level jet – stable/adiabatic fog transition driven by advection (TKE \([0.2 – 0.4 \text{ m}^2\text{s}^{-2}]\) and \(\sigma_w^2 [0.02 – 0.04 \text{ m}^2\text{s}^{-2}]\), SHF \([0 – 10 \text{ W m}^{-2}]\)) – dissipation in daytime by thermal and mechanical turbulence (TKE > \(0.4 \text{ m}^2\text{s}^{-2}\) and \(\sigma_w^2 > 0.04 \text{ m}^2\text{s}^{-2}\) and SHF > \(10 \text{ W m}^{-2}\)).

Advection-radiation case studies have shortest lifetime linked to the low surface boundary layer stability due to the vertical mixing generated by the westerly strong wind –transition phase is driven by advection (TKE \([0.2 – 0.4 \text{ m}^2\text{s}^{-2}]\) and \(\sigma_w^2 [0.02 – 0.04 \text{ m}^2\text{s}^{-2}]\), SHF < \(0 \text{ W m}^{-2}\)) – the dissipation phase is driven by night-time warm air advection generating mechanical turbulence (TKE at least \(0.3 \text{ m}^2\text{s}^{-2}\) and \(\sigma_w^2 > 0.04 \text{ m}^2\text{s}^{-2}\)).

This study also demonstrates the importance of using instrumental synergy (with microwave radiometer, wind lidar, weather station, and cloud radar) and a fog conceptual model to better predict fog characteristics and dissipation time at nowcasting ranges.
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Questions