Effect of aerosols on the fog life cycle

9th September 2020
SOFOG3D Science Meeting

Sarah Tinorua
Supervisor: Dr Cyrielle DENJEAN
I. Indirect and semi-direct effects of aerosols on radiative fog
I. Indirect and semi-direct effects of aerosols on radiative fog

Formation

Aerosols + water vapor

CCN ACTIVATION

Hygroscopic properties of aerosols

Indirect effect
I. Indirect and semi-direct effects of aerosols on radiative fog

**Formation**

Aerosols + water vapor

**Development**

CCN ACTIVATION

Atmospheric stability:
- wind velocity <3.5 m/s
- RH > 95%

**Semi-direct effect**

**Indirect effect**

Hygroscopic properties of aerosols

**Dissipation**

EVAPORATION
I. Indirect and semi-direct effects of aerosols on radiative fog

Formation

Indirect effect

Hygroscopic properties of aerosols

Semi-direct effect

Chemical composition & granulometry

Development

Atmospheric stability:
- wind velocity <3.5 m/s
- RH > 95%

Dissipation

Optical properties of aerosols
I. Indirect and semi-direct effects of aerosols on radiative fog

Formation
Aerosols + water vapor

Indirect effect
Hygroscopic properties of aerosols

Development
Atmospheric stability:
- wind velocity < 3.5 m/s
- RH > 95%

Semi-direct effect
Chemical composition & granulometry

Dissipation
Optical properties of aerosols

\[ \kappa = \frac{4A^3}{27D_{act}^3 \ln^2(SS_c)} \]

- \( D_{act} \): Minimal diameter of activation
- \( SS_c \): Activation supersaturation
- \( \sigma_w \): Surface tension of water
- \( M_w \): Water molar mass
- \( \rho_w \): Water density

\[ A = \frac{4\sigma_w M_w}{RT \rho_w} \]
I. Indirect and semi-direct effects of aerosols on radiative fog

**Formation**

Aerosols + water vapor

**Indirect effect**

Hygroscopic properties of aerosols

- $K$ parameter
  - Aerosol/water vapor affinity

\[
K = \frac{4 A^3}{27 D_{act}^3 \ln^2 \left( SS_c \right)}
\]

\[
A = \frac{4 \sigma_w M_w}{RT \rho_w}
\]

- $D_{act}$: Minimal diameter of activation
- $SS_c$: Activation supersaturation
- $\sigma_w$: surface tension of water
- $M_w$: water molar mass
- $\rho_w$: water density

**Development**

Atmospheric stability:

- wind velocity <3.5 m/s
- RH > 95%

**Semi-direct effect**

Optical properties of aerosols

- Angström scattering coefficient
  - size

\[
A_{sca} \left( \frac{\lambda_1}{\lambda_2} \right) = -\ln \frac{\sigma_{sca}(\lambda_1)}{\sigma_{sca}(\lambda_2)} \frac{\ln \lambda_1}{\ln \lambda_2}
\]

- $\sigma_{sca}$: scattering coefficient
- $\sigma_{ext}$: extinction coefficient
- $\lambda_1$ and $\lambda_2$: wavelengths

**Dissipation**

EVAPORATION

- $D_{act}$: Minimal diameter of activation
- $SS_c$: Activation supersaturation
- $\sigma_w$: surface tension of water
- $M_w$: water molar mass
- $\rho_w$: water density

**Chemical composition & granulometry**

- $\sigma_{sca}$: scattering coefficient
- $\sigma_{ext}$: extinction coefficient

**Single Scattering Albedo**

\[
SSA(\lambda) = \frac{\sigma_{sca}(\lambda)}{\sigma_{ext}(\lambda)}
\]
I. Internship goals & presentation of the measurements campain

- **Study of the aerosols impact on the fog life cycle**
  - **Aerosol indirect effect**: Temporal and vertical variation of aerosol hygroscopic properties, CCN closure study to determine fog supersaturation, parameterization of the activation process

- **Aerosol semi-direct effect**: Determination of aerosol optical properties relevant to parameterize aerosol radiative effects in models
I. Internship goals & presentation of the measurements campaign

- **Study of the aerosols impact on the fog life cycle**
  - **Aerosol indirect effect**: Temporal and vertical variation of aerosol hygroscopic properties, CCN closure study to determine fog supersaturation, parameterization of the activation process
  - **Aerosol semi-direct effect**: Determination of aerosol optical properties relevant to parameterize aerosol radiative effects in models

- **→ SoFog3D experimental campaign for** 3D fog characterization:
  - Long term measurements
  - Intense Observation Periods if fog event prediction

  Super-site (10*10km):
  - radars/lidars,
  - 2 mâts instrumentés
  - container
  - radiosondes
  - drones flights
  - tethered ballon

  → Aerosols & fog measurements
II. Instruments of the SoFog3D campaign

Surface and airborne instruments for aerosol measurements

- **aerosols**
  - Microphysical properties
    - Size distribution (SMPS + OPC)
    - Total number concentration (CPC)
  - Hygroscopicity
    - CCN concentrations at different SS (2 CCNC)
  - Optical properties
    - Extinction (2 CAPS) & Scattering coefficients (Nephelometer)

- **fog**
  - Microphysical properties
    - Droplet concentration (FM-120)
  - Meteorology
    - Visibility, wind, RH, T… (visibility sensors, PTU sensors)
II. Instruments of the SoFog3D campaign

Surface and airborne instruments for aerosol measurements

- **aerosols**

  - Microphysical properties
    - Size distribution \((SMPS + OPC)\)
    - Total number concentration \((CPC)\)
  
  - Hygroscopicty
    - CCN concentrations at different SS \((2 \text{ CCNC})\)
  
  - Optical properties
    - Extinction \((2 \text{ CAPS})\) & Scattering coefficients \((\text{Nephelometer})\)

- **fog**

  - Microphysical properties
    - Droplet concentration \((FM-120)\)
  
  - Meteorology
    - Visibility, wind, RH, T…
      \((\text{Visibility sensors, PTU sensors})\)

Thethered balloon-borne measurements (vertical)

- OPC
- Mini CCNC

Long term measurements (ground)

- SMPS + OPC
- CPC
- CCNC

- Microphysical properties
  - Size distribution \((OPC)\)

- Hygroscopicty
  - CCN Concentrations at different SS \((\text{mini CCNC})\)
III. Results : Data validation

- **Basic setting check** (flows, T, detectors voltage)
- **Intercomparison of datas**
III. Results : Data validation

- **Basic setting check** (flows, T, detectors voltage)

- **Intercomparison of datas**
  - Total concentrations **SMPS + OPC vs.** Concentrations **CPC** : 21% difference
    - → **CPC data invalidated**
  - For 1 SS: CCN concentrations of **mini-CCNC vs.** CCN concentrations of **CCNC DMT** : coefficient 2 of difference
    - → **CCNC recalibration**
III. Results: Data validation

- **Basic setting check** (flows, T, detectors voltage)

- **Intercomparison of datas**
  - Total concentrations **SMPS + OPC vs. CPC**: Concentrations **CPC**: 21% difference
    → **CPC data invalidated**
  - For 1 SS: CCN concentrations of **mini-CCNC vs. CCN concentrations of CCNC DMT**: coefficient 2 of difference
    → **CCNC recalibration**

- **Global data validation**:

  + **balloon measurements**: 2 IOP where OPC, CDP & mini CCNC checked
III. Results : Description of a fog event

Criteria : Visibility $< 1$km at least for 30 min

Favourable conditions checked :

✔ RH $> 95\%$

✔ $U_{\text{wind}} < 3.5$ m.s$^{-1}$

✔ Drop in $T$

$N_{\text{drop}}$ increases and $N_{\text{aér}}$ decreases (droplet activation + sedimentation)
III. Results: Description of a fog event

- Criteria: Visibility < 1km at least for 30 min

  Favourable conditions checked:
  - RH > 95 %
  - $U_{wind} < 3.5$ m.s⁻¹
  - Drop in $T$

  $N_{drop}$ increases and $N_{aér}$ decreases (droplet activation + sedimentation)
Criteria: Visibility < 1km at least for 30 min

Favourable conditions checked:

- RH > 95 %
- $U_{\text{wind}} < 3.5 \text{ m.s}^{-1}$
- Drop in $T$

$N_{\text{drop}}$ increases and $N_{\text{aér}}$ decreases (droplet activation + sedimentation)
III. Results: Description of a fog event

- Criteria: Visibility < 1km at least for 30 min

  Favourable conditions checked:
  
  ✔ RH > 95 %
  ✔ $U_{\text{wind}} < 3.5 \text{ m.s}^{-1}$
  ✔ Drop in $T$

  $N_{\text{drop}}$ increases and $N_{\text{aér}}$ decreases (droplet activation + sedimentation)

→ 8 of the 34 fog events for which aerosol data are validated
III. Results: Study of aerosols properties at the ground

→ Averaged 1 hour before the fog formation

Determination of $D_{\text{act}}$

Low SS → coarse & accumulation modes

Average size distribution of the 8 fog events with their activation diameters
III. Results: Study of aerosols properties at the ground

→ Averaged 1 hour before the fog formation

Determination of $D_{\text{act}}$

Low SS → coarse & accumulation modes

Significant variability of $\kappa$ between fog events
→ Different aerosol chemical composition

Average size distribution of the 8 fog events with their activation diameters
III. Results: Study of aerosols properties at the ground

→ Averaged 1 hour before the fog formation

**Determination of $D_{\text{act}}$**

Significant variability of $\kappa$ between fog events → Different aerosol chemical composition

**Average size distribution of the 8 fog events with their activation diameters**

Low SS → coarse & accumulation modes

Optical parameters $\bar{\alpha}_{\text{eff}}$ and SSA calculated. The invalidated cases have SSA >1.
III. Results: Study of aerosols properties at the ground

Marine origin + low absorption + low $\text{Å}_{\text{sca},450/550}$ + K~ 0.6
→ Important contribution of hydrophilic & non-absorbing sulfate and sea salts
→ Low amount of hydrophobic & absorbing particles (Black Carbon), which is expected for rural areas
III. Results: Study of aerosols properties at the ground

Marine origin + low absorption + low $\tilde{\alpha}_{sca,450/550}$ + $K \approx 0.6$

→ Important contribution of hydrophilic & non-absorbing sulfate and sea salts

→ Low amount of hydrophobic & absorbing particles (Black Carbon), which is expected for rural areas

Important coarse mode + moderated absorption + $K \approx 0.3$

→ Absorbing Dust particles
III. Results: Study of aerosols properties at the ground

Marine origin + low absorption + low $\tilde{A}_{sca,450/550}$ + $K \sim 0.6$
→ Important contribution of hydrophilic & non-absorbing sulfate and sea salts
→ Low amount of hydrophobic & absorbing particles (Black Carbon), which is expected for rural areas

Satellite pictures from the Spectroradiometer MODIS showing the Mediterranean sand storm of 02/23/20 (NASA)

Important coarse mode + moderated absorption + $K \sim 0.3$
→ Absorbing Dust particles

Satellite pictures from the Spectroradiometer MODIS showing the Mediterranean sand storm of 02/23/20 (NASA)

NMMB/BSC-Dust model simulations

MAP: 72h back-trajectories before fog event simulated with Hysplit model (NOAA)
III. Results: Preliminary study of vertical variability of CCN properties

CCN closure study to determine the fog supersaturation

- $N_{\text{CCN}} \gg N_{\text{drop}} \rightarrow SS_{\text{fog}} \ll SS_{\text{mini CCNC}} \ (0.147 \%)$
III. Results: Preliminary study of vertical variability of CCN properties

CCN closure study to determine the fog supersaturation

Averaged (on 10 m) vertical variability of hygroscopic properties

- \( N_{\text{CCN}} \gg N_{\text{drop}} \rightarrow SS_{\text{fog}} \ll SS_{\text{mini CCNC}} (0.147\%) \)

- \( N_{\text{CCN}} \sim \text{constant} \rightarrow D_{\text{act}} \& \kappa \sim \text{constant} \)
III. Results: Preliminary study of vertical variability of CCN properties

CCN closure study to determine the fog supersaturation

\[ \kappa = \frac{4}{27} \frac{A^3}{D_{act}^3 \ln^2 (SS_c)} \]

\[ SS(z) = \exp \left( \sqrt{\frac{4}{27} \frac{A^3}{D_{hum}(z)^3 \kappa(z)}} \right) \]

- \( N_{CCN} \gg N_{drop} \rightarrow SS_{fog} \ll SS_{mini CCNC} \) (0.147 %)
- \( N_{CCN} \sim \) constant \( \rightarrow \) \( D_{act} \& \kappa \sim \) constant
- \( SS \) decreases with \( z \) \( \rightarrow N_{drop} \) decreases and \( \kappa \sim \) constant

Averaged (on 10 m) vertical variability of hygroscopic properties

\( dN/d\log(D_p) \)

\( D_{act} \)

\( D_p (\text{nm}) \)

\( N_{drop} \)

\( N_{CCN} \)
III. Results: Parameterization of the activation process

- CCN closure study performed on the 8 fog events using ground-based and airborne measurements

- Values of the supersaturation occurring in fog ranged from 0.013 to 0.115 % with a median values of 0.091 %

- 3 different equations:
  - Twomey, 1959
  - Ji et Al., 1998
  - Cohard et Al., 1998

- Strong decrease of N_{act} for SS<0.1%. 

- The parameterization of Cohard et Al., 1998 provides the best fit of the data for lower values of SS, as observed by Mazoyer et al. (2019)
Conclusion

- **Data processing** of the SoFog3D campaign:
  - **Data validation** (base parameters + intercomparison of data & recalibration)
  - 8 fog events with ground measurements and 2 IOP with airborne measurements for which aerosol data are validated
Conclusion

- **Data processing** of the SoFog3D campaign:
  - **Data validation** (base parameters + intercomparison of data & recalibration)
  - 8 fog events with ground measurements and 2 IOP with airborne measurements for which aerosol data are validated

- **Study of aerosols properties** 1h before every fog event:

<table>
<thead>
<tr>
<th>Microphysical</th>
<th>Optical</th>
<th>Hygroscopic</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\text{tot}} \approx 2280 \text{ cm}^{-3}$</td>
<td>SSA $\approx 1$</td>
<td>$0.3 &lt; K &lt; 1.2$</td>
</tr>
<tr>
<td>$\rightarrow$ rural area*</td>
<td>$\rightarrow$ low absorption</td>
<td>$\rightarrow$ rural area*</td>
</tr>
<tr>
<td>Variable coarse mode</td>
<td>$0.14 &lt; \lambda_{\text{sca,450/550}} &lt; 1.29$</td>
<td>$\rightarrow$ Very variable chemical composition</td>
</tr>
<tr>
<td>$\rightarrow$ variable size</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* ACTRIS measurements (Schmale et al., 2018, Asmi et al., 2013)*
Conclusion

- **Data processing** of the SoFog3D campaign:
  - **Data validation** (base parameters + intercomparison of data & recalibration)
  - 8 fog events with ground measurements and 2 IOP with airborne measurements for which aerosol data are validated

- **Study of aerosols properties** 1h before every fog event:
  - Microphysical
    - $N_{\text{tot}} \approx 2280 \text{ cm}^{-3}$
      - rural area*
  - Optical
    - SSA $\approx 1$
      - low absorption
  - Hygroscopic
    - $0.3 < K < 1.2$
      - rural area*
  - Variable coarse mode
    - $0.14 < \langle \text{sca,}450/550 \rangle < 1.29$
      - variable size
    - Very variable chemical composition

* ACTRIS measurements (Schmale et al., 2018, Asmi et al., 2013)

- **Origin of air masses study**: mostly continental/marine + 1 case of dust

- **Preliminary study** of the vertical variability of activation properties

- CCN closure study shows that SS occurring in fog ranged from 0.013 to 0.115%

- **Parameterization of the activation process** by Cohard et al. (1998) provides the best fit of droplet number concentration
- Analyze the vertical variability of aerosol hygroscopic properties and supersaturation on other fog events
- Expand our analysis to the calculation of the wet critical diameters as proposed in Mazoyer et Al. (2019)
- Optical properties of aerosols → impact of the aerosols-induced warming → modelisation of the fog dissipation during and outside the dust event (Méso-NH)
Outlook

- Analyze the vertical variability of aerosol hygroscopic properties and supersaturation on other fog events
- Expand our analysis to the calculation of the wet critical diameters as proposed in Mazoyer et Al. (2019)
- Optical properties of aerosols → impact of the aerosols-induced warming → modelisation of the fog dissipation during and outside the dust event (Méso-NH)

Thanks for your attention
Intercomparaison des appareils

$N_{\text{tot}}(\text{SMPS}) + N_{\text{tot}}(\text{OPC}) \neq N_{\text{tot}}(\text{CPC})$

À SS donnée : $N_{\text{CCN}}(\text{mini-CCNC}) = N_{\text{CCN}}(\text{CCNC DMT})$ ?

Distribution granulométrique SMPS + OPC dans le container

Concentrations CCN du CCNC DMT et du mini-CCNC dans le container avant et après recalibration à SS=0.22 %

<table>
<thead>
<tr>
<th>SS visée (%)</th>
<th>SS réelle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>0.07</td>
<td>0.08</td>
</tr>
<tr>
<td>0.1</td>
<td>0.11</td>
</tr>
<tr>
<td>0.2</td>
<td>0.22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SS visée (%)</th>
<th>SS réelle (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.06</td>
</tr>
<tr>
<td>0.2</td>
<td>0.11</td>
</tr>
<tr>
<td>0.3</td>
<td>0.17</td>
</tr>
<tr>
<td>0.4</td>
<td>0.22</td>
</tr>
<tr>
<td>0.5</td>
<td>0.28</td>
</tr>
</tbody>
</table>
Méthodologie utilisée pour calculer le diamètre d'activation. Les distributions granulométriques du SMPS et de l'OPC, respectivement en haut et en bas à gauche sont rassemblées pour donner la granulométrie totale en haut à droite. Pour une sursaturation donnée, ici 0.11 %, la concentration en CCN représentée en bas à droite N CCN permet d'obtenir D act.
Procédure de calibration simultanée des deux CCNC avec du sulfate d’ammonium.
Distributions granulométriques modélisée par une loi log-normale à deux modes à partir des points de mesures de l’OPC moyennés entre 0 et 10 m en rouge. Mesures du SMPS et l’OPC dans le container au sol en noir. Mesures de l’OPC ballon moyennées entre 0 et 10 m en vert.
Distribution granulométrique normalisée par la concentration totale en aérosols pour les 8 cas de brouillard étudiés, mesurés avec le SMPS et l’OPC.
Comparaison du moyennage tous les 2, 5 ou 10 m des concentrations CCN mesurées par le mini CCNC sur ballon captif, lors du vol du 23/02/20