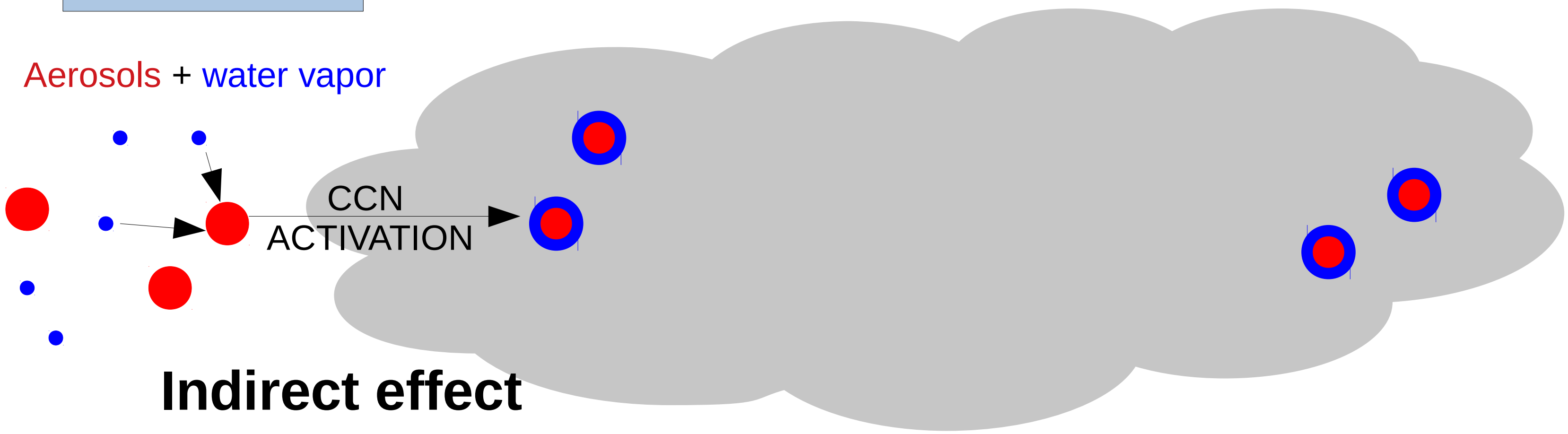
Effect of aerosols on the fog life cycle

9th September 2020
SOFOG3D Science Meeting

Sarah Tinorua
Supervisor : Dr Cyrielle DENJEAN

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

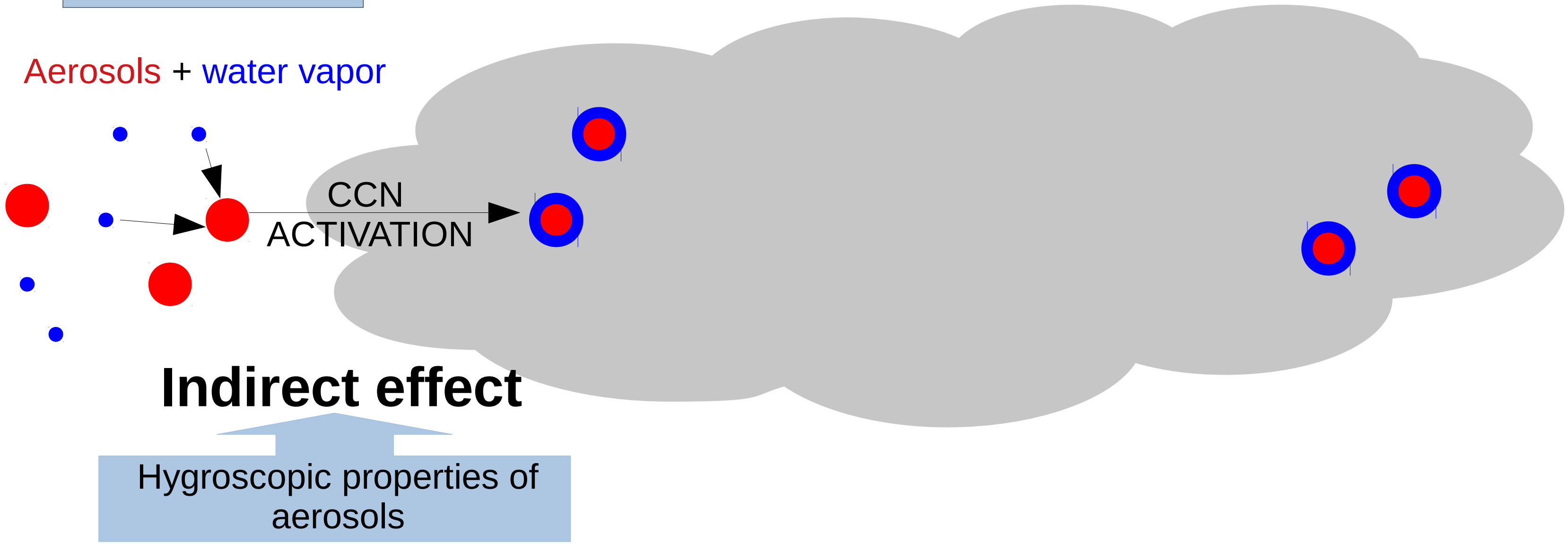
Formation



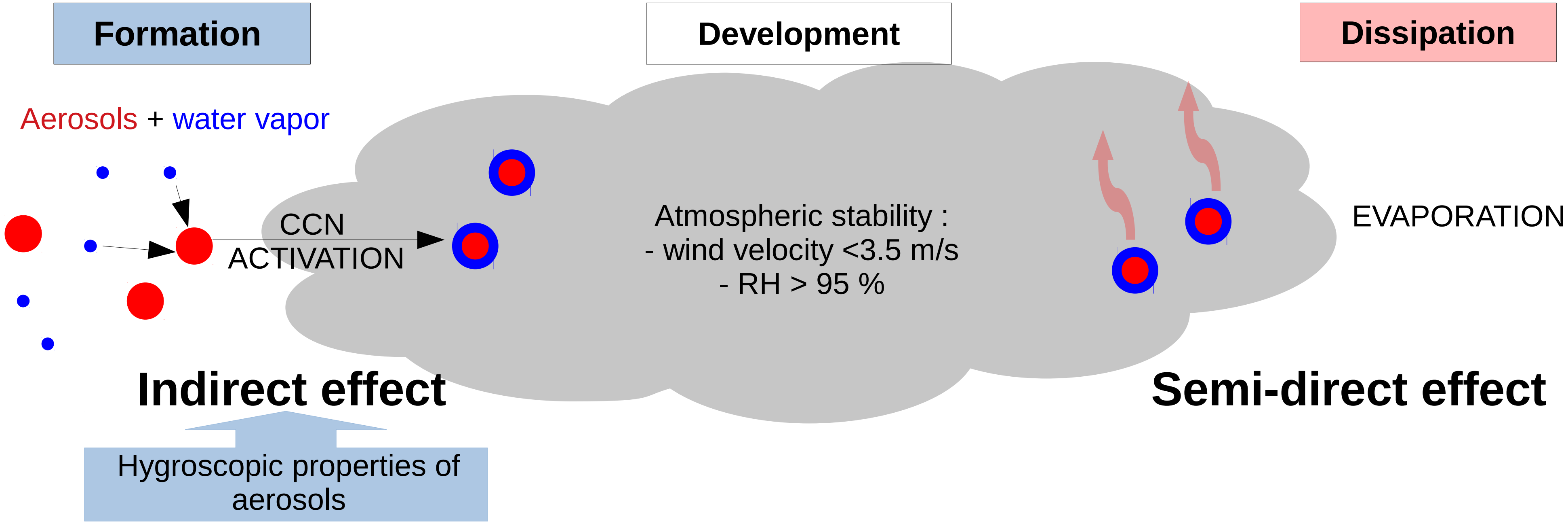
Indirect effect

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

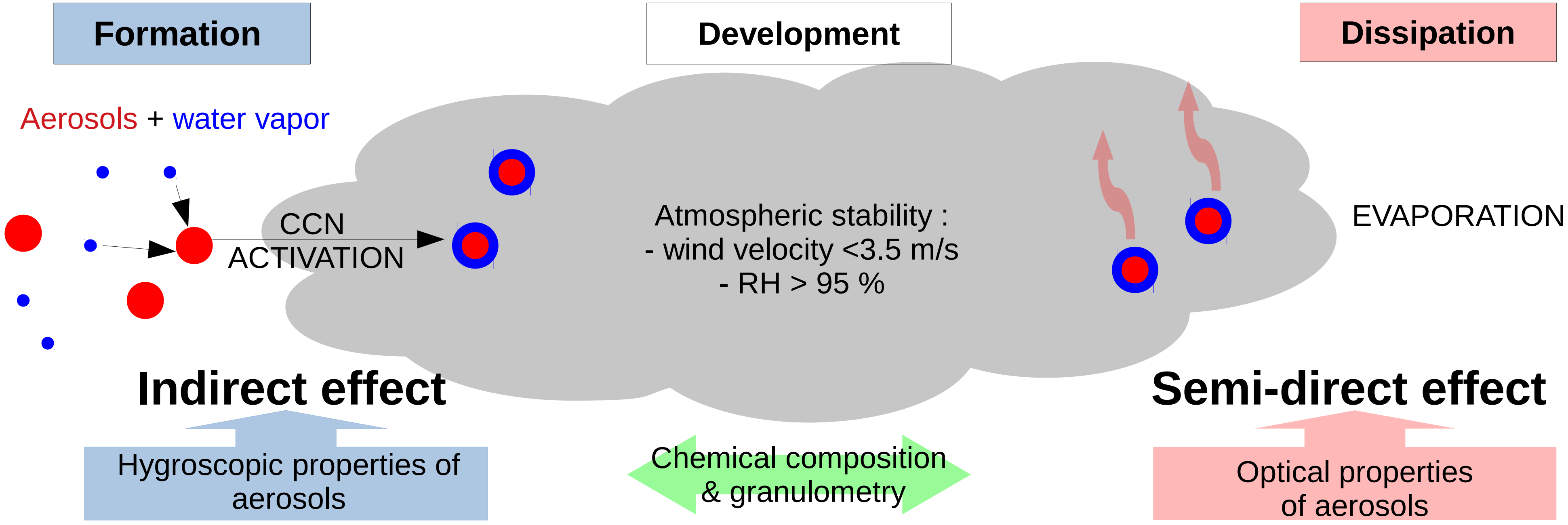
Formation



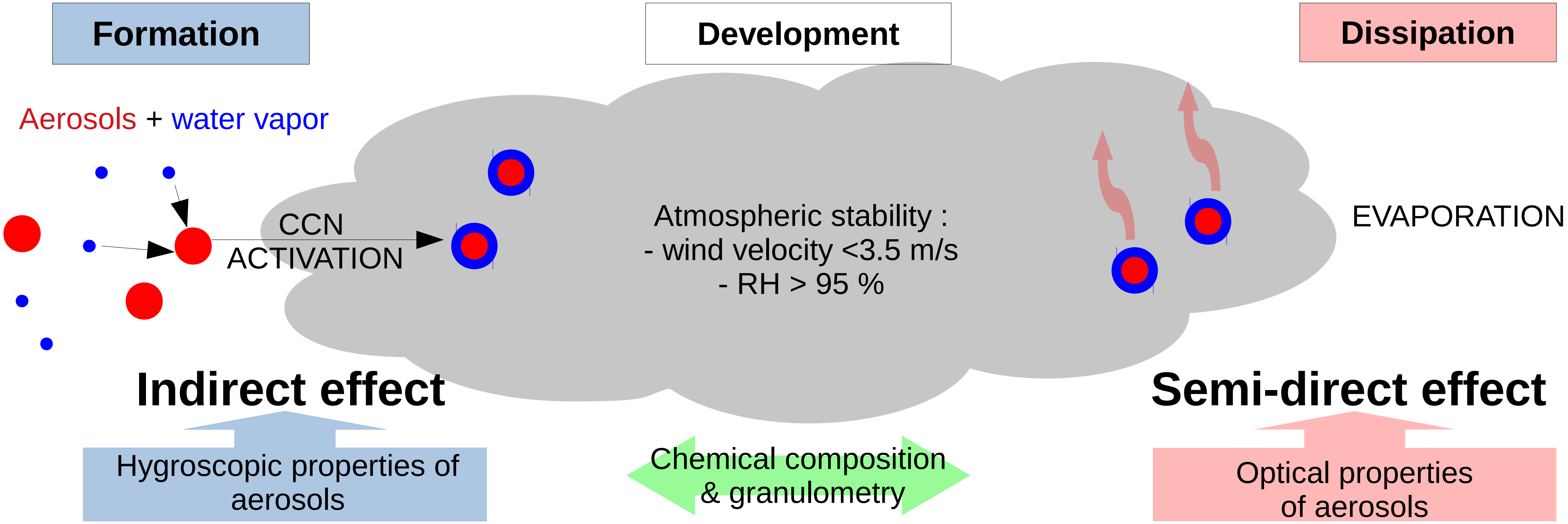
I. Indirect and semi-direct effects of aerosols on radiative fog



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



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



- Κ parameter

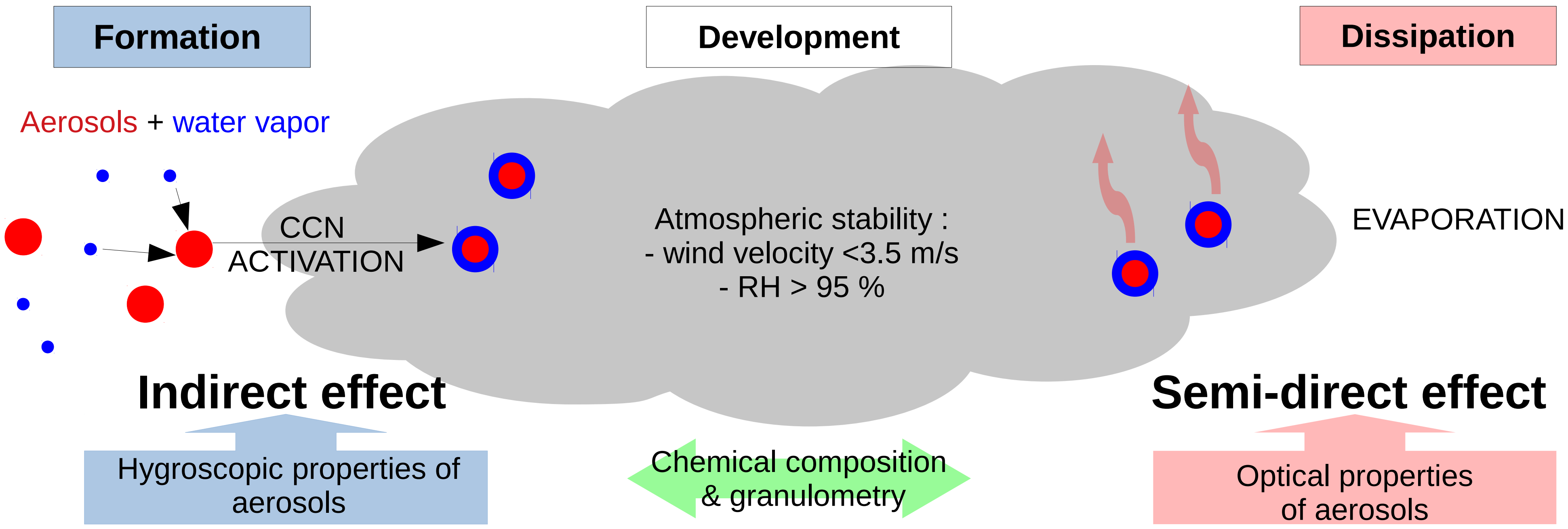
→ Aerosol/water vapor affinity

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

$$A = \frac{4\sigma_w M_w}{RT\rho_w}$$

- D_{act} : Minimal diameter of activation
- SS_c : Activation supersaturation
- σ_w : surface tension of water
- M_w : water molar mass
- ρ_w : water density

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



- Κ parameter
  → Aerosol/water vapor affinity

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

$$A = \frac{4\sigma_w M_w}{RT\rho_w}$$

- D_{act} : Minimal diameter of activation
- SS_c : Activation supersaturation
- σ_w : surface tension of water
- M_w : water molar mass
- ρ_w : water density

- Angström scattering coefficient
  → size

$$\mathring{A}_{sca}\left(\frac{\lambda_1}{\lambda_2}\right) = \frac{-\ln\frac{\sigma_{sca}(\lambda_1)}{\sigma_{sca}(\lambda_2)}}{\ln\frac{\lambda_1}{\lambda_2}}$$

- Single Scattering Albedo
  → Absorption

$$SSA(\lambda) = \frac{\sigma_{sca}(\lambda)}{\sigma_{ext}(\lambda)}$$

- σ_{sca} : scattering coefficient
- σ_{ext} : extinction coefficient
- λ_1 and λ_2 : wavelengths

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

- **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

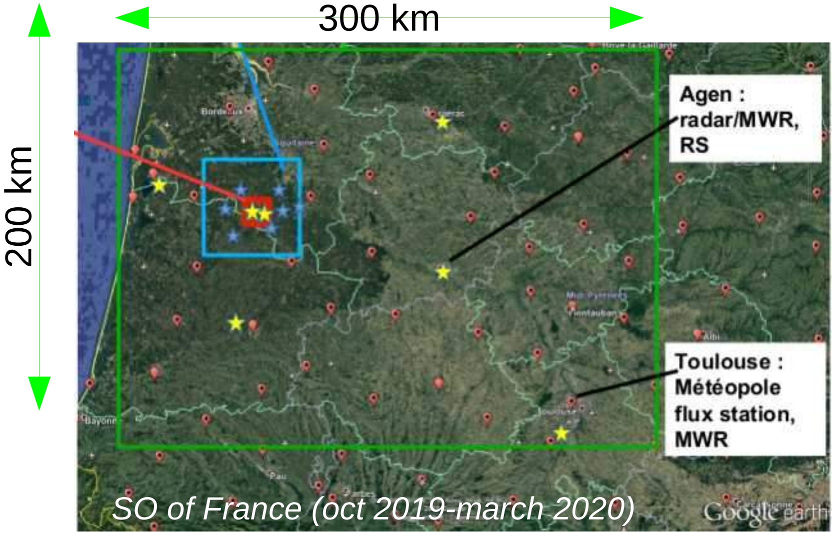
- → **SoFog3D experimental campaign for** 3D fog characterization :

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

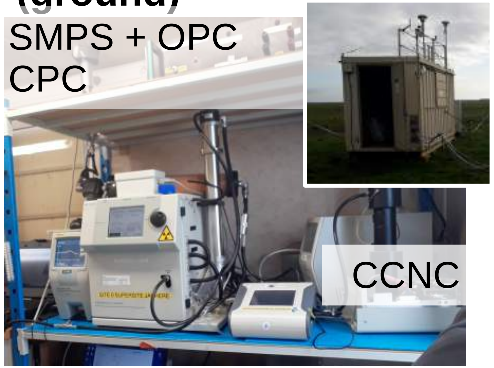


SO of France (oct 2019-march 2020)

II.Instruments of the SoFog3D campaign

Surface and airborne instruments for aerosol measurements

Long term measurements (ground)



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)*

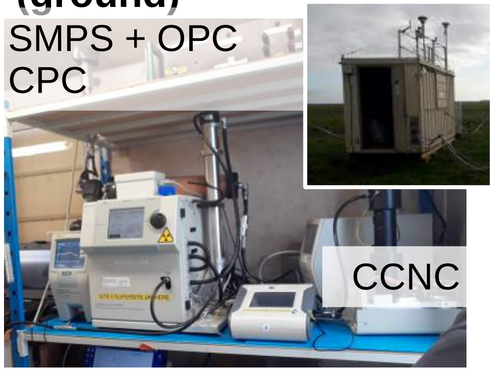
fog

- **Microphysical properties**
  - Droplet concentration *(FM-120)*
- **Meteorology**
  - Visibility, wind, RH, T… *(visibility sensors, PTU sensors)*

Surface and airborne instruments for aerosol measurements

aerosols | **fog**

Long term measurements (ground)



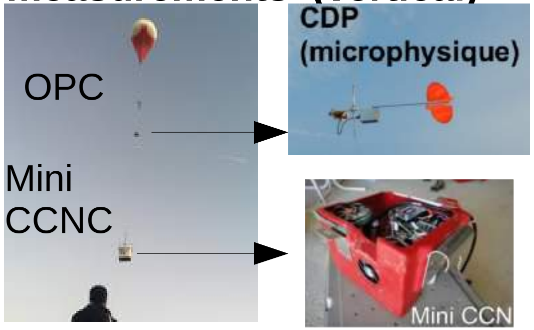
aerosols

- **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)*

Thethered balloon-borne measurements (vertical)



aerosols

- **Microphysical properties**
  - Size distribution *(OPC)*
- **Hygroscopicity**
  - CCN Concentrations at different SS *(mini CCNC)*

fog

- **Microphysical properties**
  - Droplet concentration *(CDP)*

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.** 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 :**

O Validated data P Partial data

	OCTOBRE																														
Jour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CPC																	O	P	P		O	O									O
SMPS																	O	O	O	O	O	P							O	O	O
OPC											O	O		O			O	O	O	O	O	O	O	O	O	O	O	O			O
Mini-CCNC																															
CCNC commercial																															

	NOVEMBRE																														
Jour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
CPC	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O						O	O	
SMPS	O	O	O	O	O	O	O	O	O		O	O	O	O	O	O	O	O	O		O	O	O	O		O	O	O	O	O	
OPC	O	O	O	O	O	O	O					O	O	O	O	O	O	O	O	O	O	O	O						O	O	
Mini-CCNC																															
CCNC commercial																															

	DECEMBRE																														
Jour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CPC	O	O	O	O	O	O	O	O	P	P	P	P																	O	O	O
SMPS	O			O	O	O	O	O	P	P	P	P				O	O	O	O	O				O			O	O	O		
OPC	O	O	O	O	O	O	O	O	O		O	O				O	O	O	O				O			O		O			O
Mini-CCNC																															
CCNC commercial																															

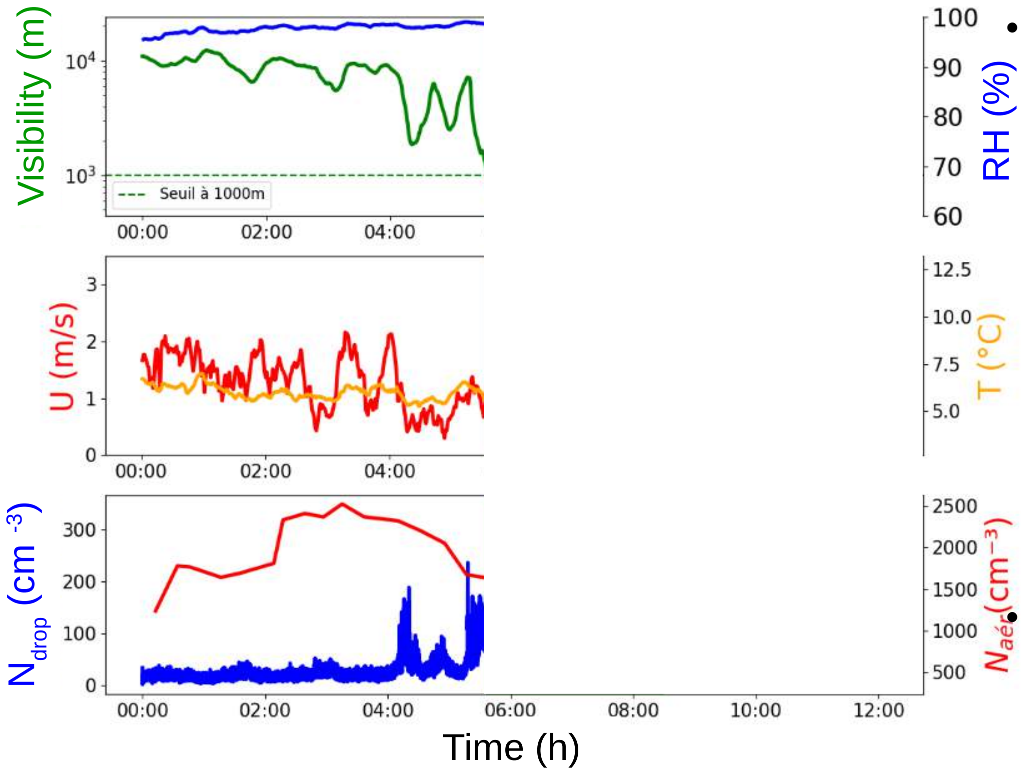
	JANVIER																														
Jour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CPC				P	P	P	P	P	P																						
SMPS										P	O	O	O	O	O	O	P				O	O	O	O	O	O	O	O	O	O	O
OPC				O	O	O	O	O	O	O		O	O	O	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O	
Mini-CCNC												O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
CCNC commercial																			O	O	O	O	O	O	O	O	O	O	O	O	O

	FEVRIER																														
Jour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29		
CPC																															
SMPS			O	O	O	O	O	O	O	P	P	O	O	O	O	O			O	O	O	O	O	O	O	P	P	O	P		
OPC									O	O		O	O	O	O	O	O	O	O	O		O		O	O	O	O	O	O		
Mini-CCNC	P	P	P	O		O	O	O	O	O		O	O	O	O	O			O	O		O	O	O	O	O	O	O	O		
CCNC commercial	O	O	O	O	O	O	O					O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O		

	MARS																														
Jour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
CPC																															
SMPS	P	P	P	P	P	P	P	P	P	P	P	P																			
OPC	O	O	O	O	O	O	O	O	O	O	O	O																			
Mini-CCNC	O	O	O	O	O	O	O	O	O	O	O	O																			
CCNC commercial	O	O	O	O	O	O	O	O	O	O	O																				

+ balloon measurements : 2 IOP where OPC, CDP & mini CCNC checked

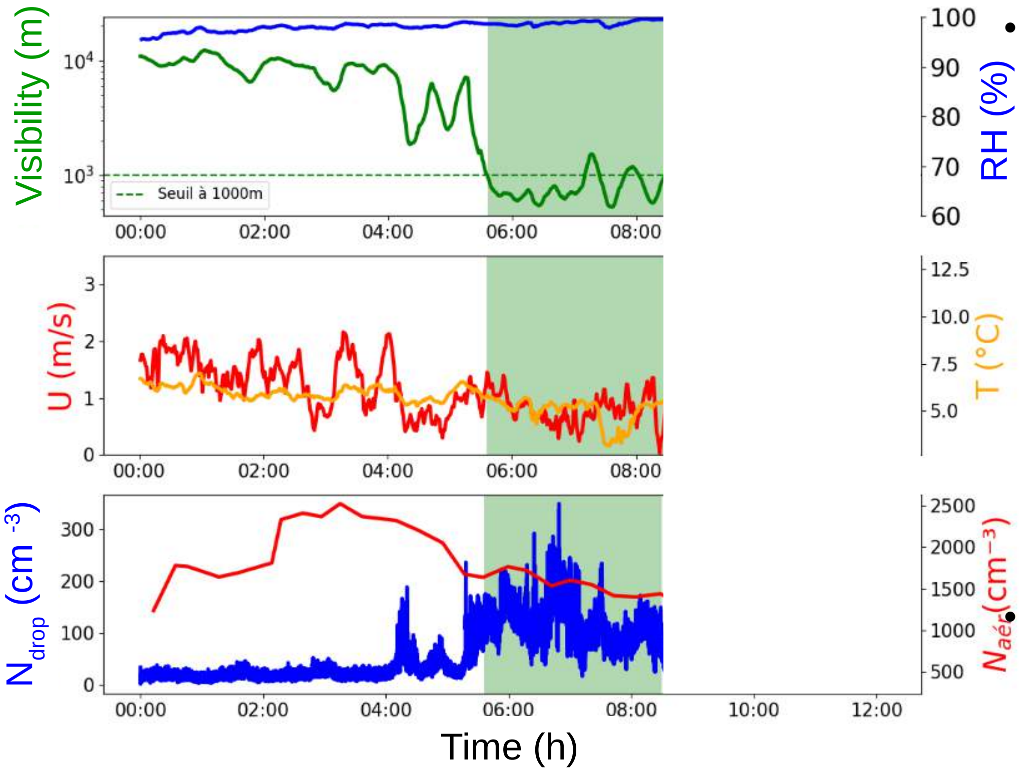
III. Results : Description of a fog event



- 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)

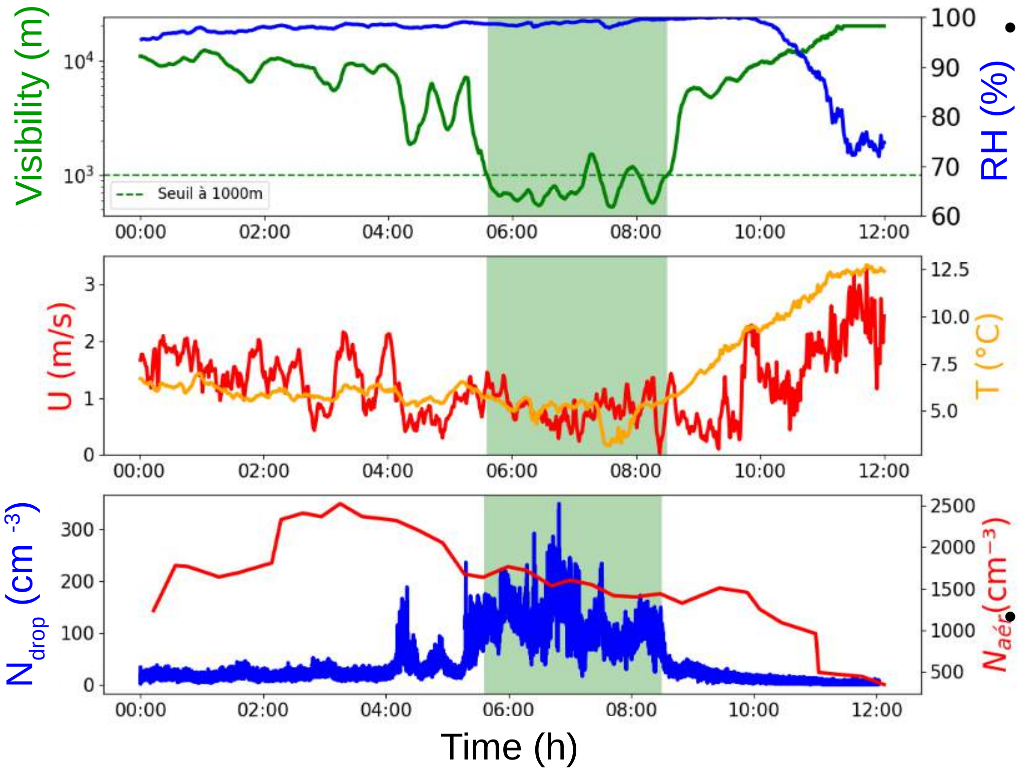


- Criteria : Visibility < 1km at least for 30 min

Favourable conditions checked :

- ✔ RH > 95 %
- ✔ U_{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

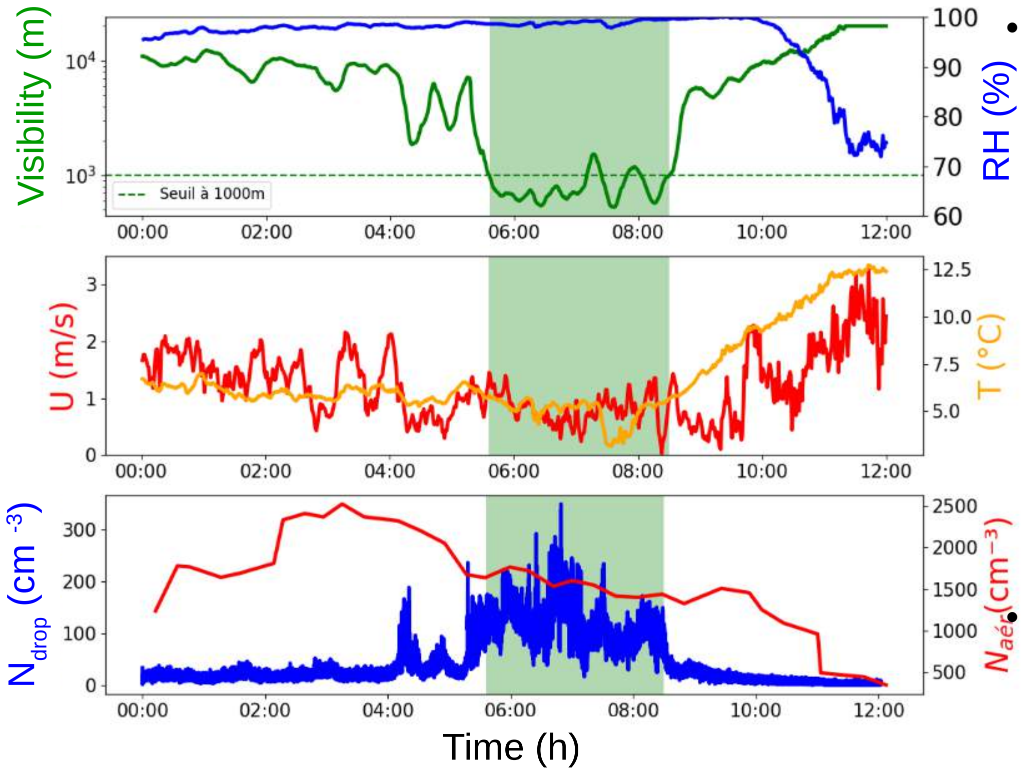
  Favourable conditions checked :

  ✔ RH > 95 %

  ✔ U_{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_{wind} < 3.5 m.s^{-1}
- ✔ Drop in T

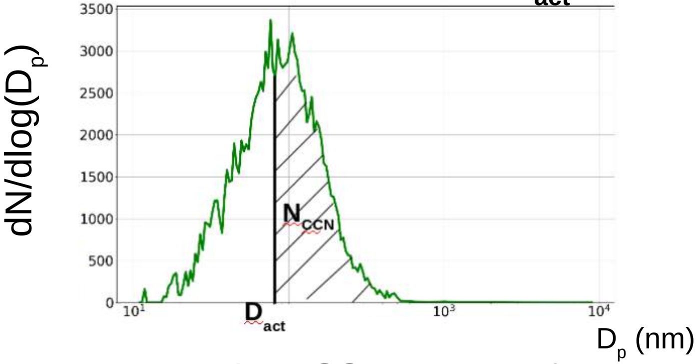
- N_{drop} increases and $N_{aér}$ decreases (droplet activation + sedimentation)

→ 8 of the 34 fog events for which aerosol data are validated

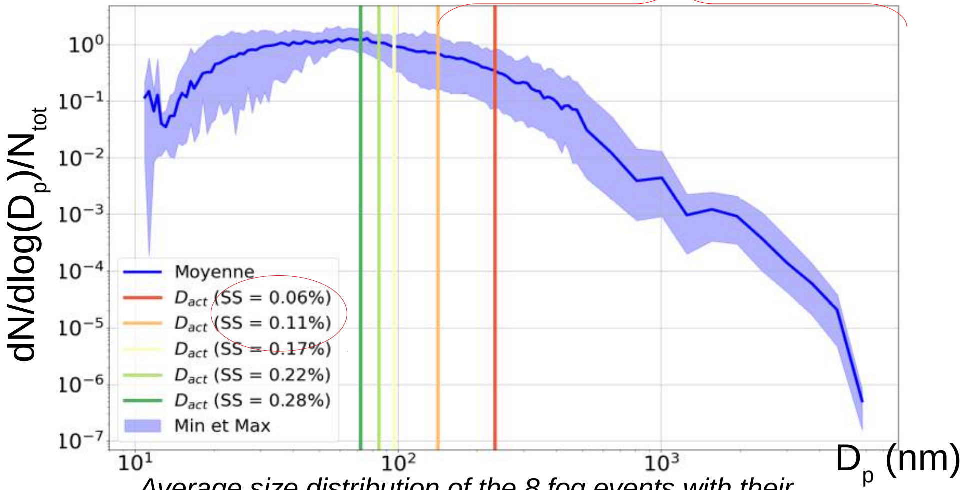
III. Results : Study of aerosols properties at the ground

→ Averaged **1 hour** before the fog formation

Determination of D_{act}



Low SS → coarse & accumulation modes

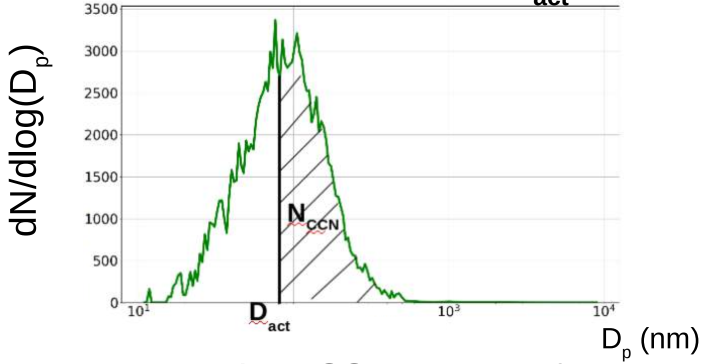


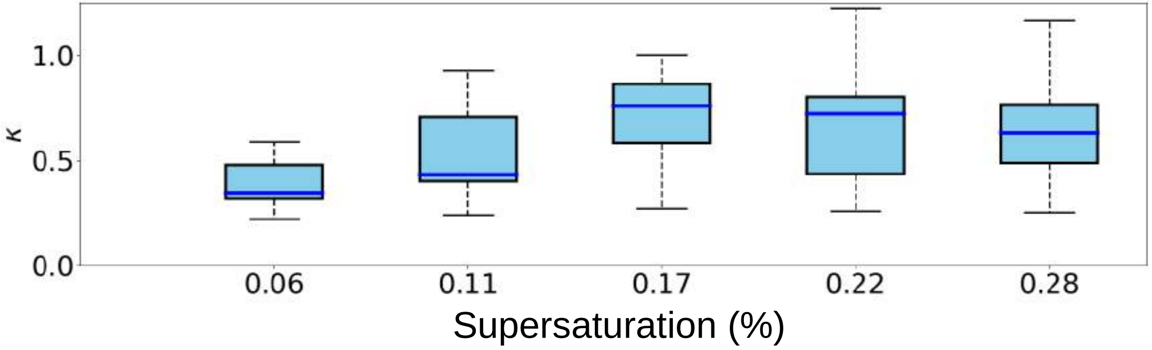
Average size distribution of the 8 fog events with their activation diameters

III. Results : Study of aerosols properties at the ground

→ Averaged **1 hour** before the fog formation

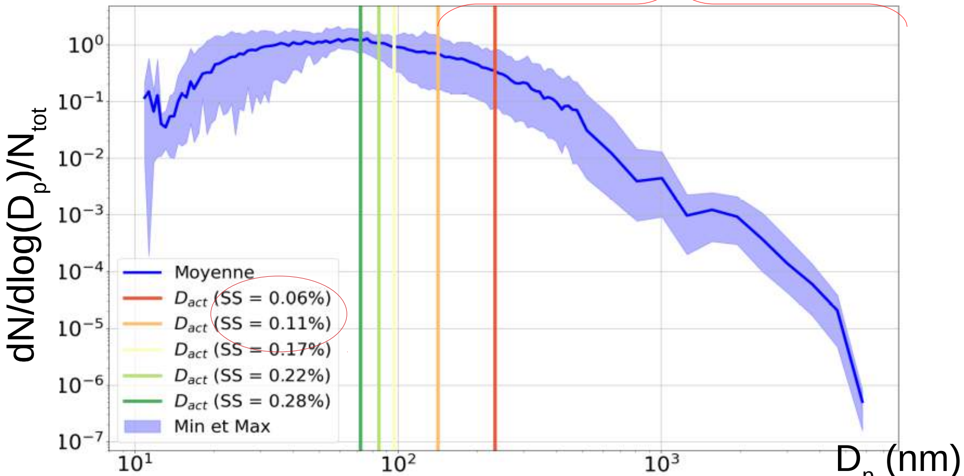
Determination of D_{act}





Low SS → coarse & accumulation modes

Significant variability of κ between fog events
→ Different aerosol chemical composition

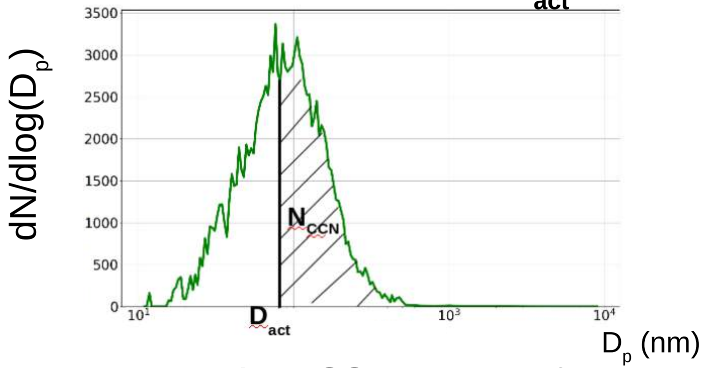


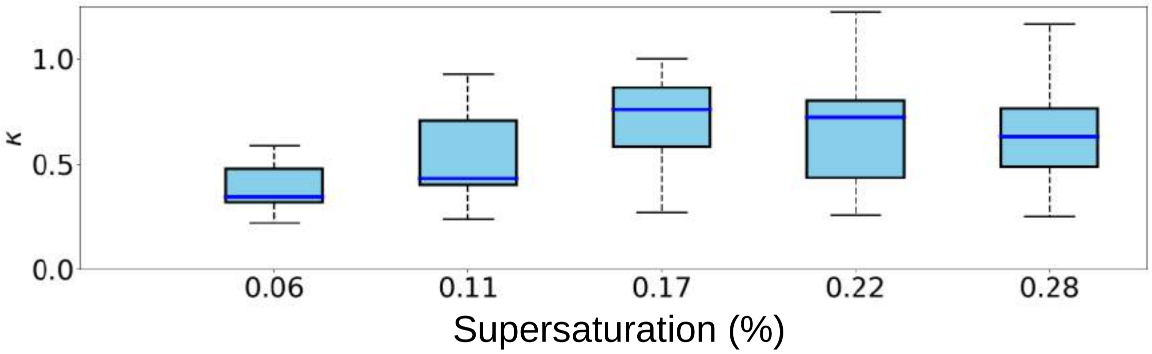
Average size distribution of the 8 fog events with their activation diameters

III. Results : Study of aerosols properties at the ground

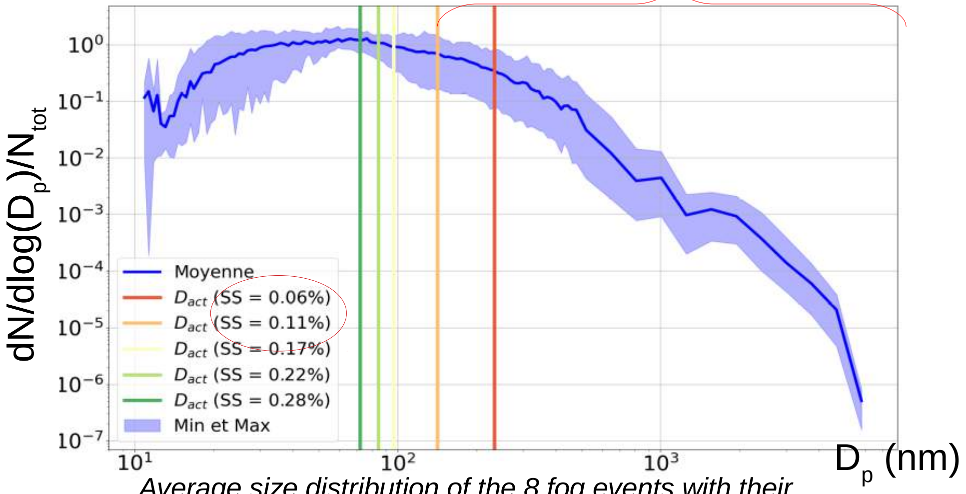
→ Averaged **1 hour** before the fog formation

Determination of D_{act}





Low SS → coarse & accumulation modes



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

Significant variability of κ between fog events

→ Different aerosol chemical composition

Date	H-1	$Å_{diff}$	SSA			
			450 nm		525nm	
		450/550	Moyenne	ΔSSA	Moyenne	ΔSSA
23/01/20	20h34	1.598	1.109	0.065	0.928	0.054
25/01/20	00h00	1.148	0.933	0.054	0.801	0.047
29/01/20	04h36	0.933	1.048	0.061	0.76	0.044
14/02/20	02h21	0.137	0.959	0.056	0.864	0.05
23/02/20	00h00	1.295	1.061	0.062	0.918	0.054
23/02/20	20h00	2.062	1.08	0.063	0.942	0.055
07/03/20	20h24	0.644	0.909	0.053	0.877	0.051
08/03/20	03h27	1	1.038	0.061	0.957	0.056

Optical parameters $Å_{diff}$ and SSA calculated. The invalidated cases have SSA >1.

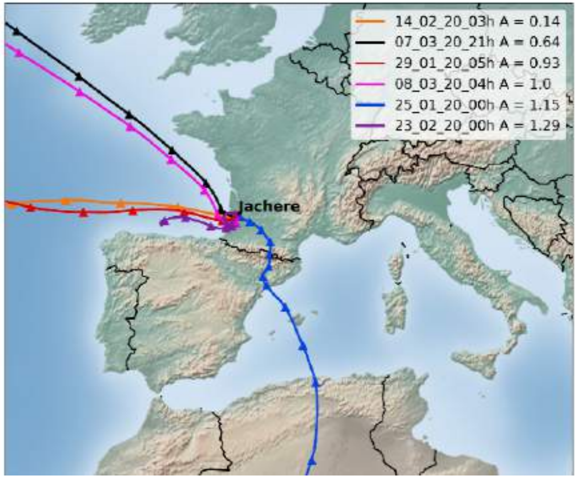
Globally
SSA ~ 1
→ Low absorption
+
2 cases with moderately absorbing aerosol

III. Results : Study of aerosols properties at the ground

Marine origin + low absorption + low $Å_{sca,450/550}$ + 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

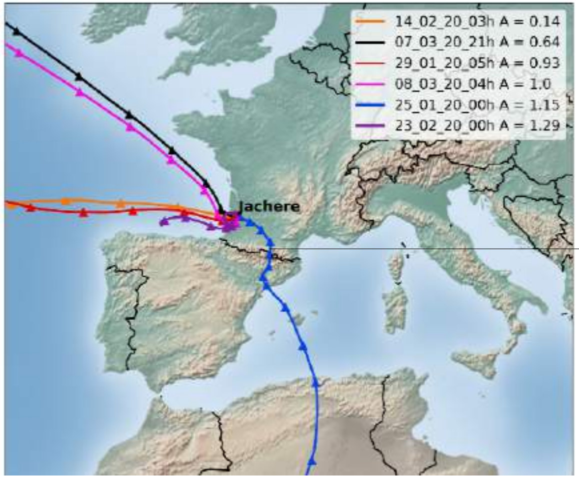


72h back-trajectories before fog event simulated with Hysplit model (NOAA)

Marine origin + low absorption + low $Å_{sca,450/550}$ + 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



72h back-trajectories before fog event simulated with Hysplit model (NOAA)

Important coarse mode + moderated absorption + K~ 0,3

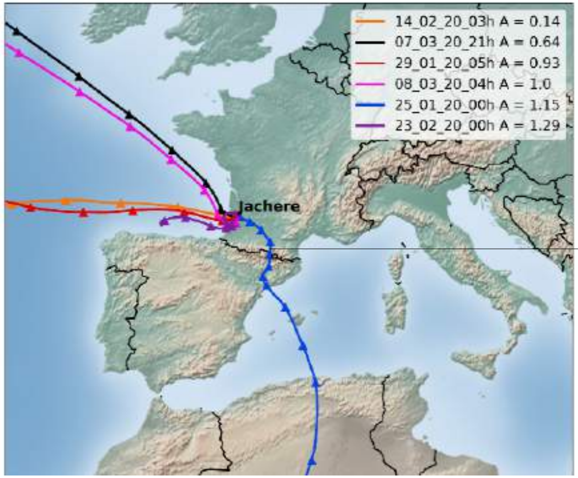
→ Absorbing Dust particles

III. Results : Study of aerosols properties at the ground

Marine origin + low absorption + low $Å_{sca,450/550}$ + K~ 0,6

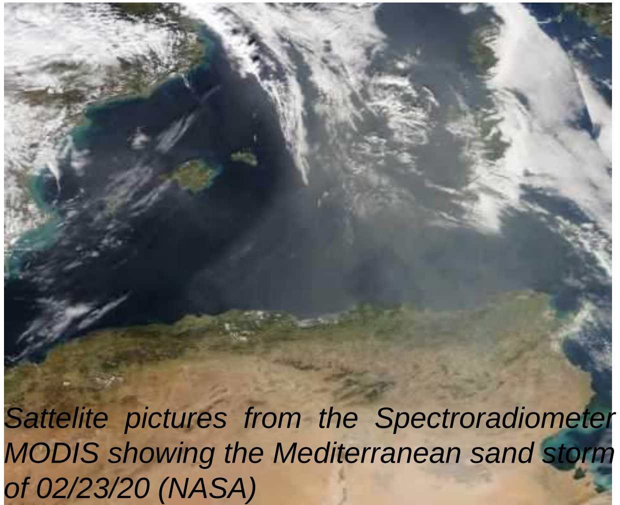
→Important contribution of hydrophilic & non-absorbing sulfate and sea salts

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

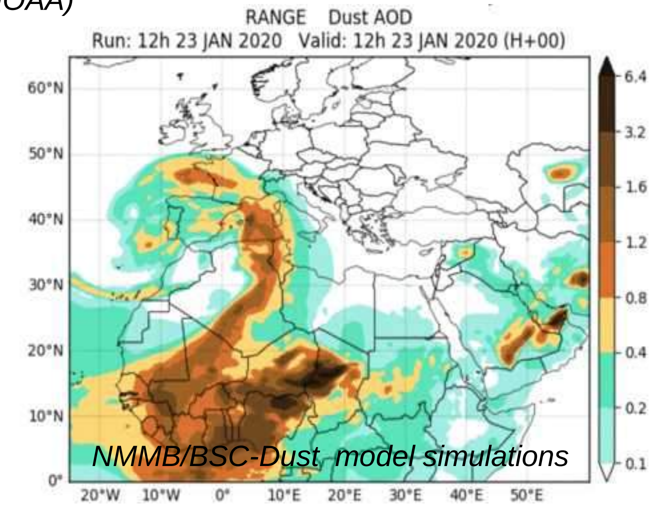


72h back-trajectories before fog event simulated with Hysplit model (NOAA)

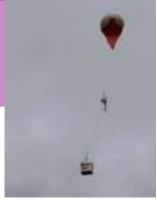
Important coarse mode + moderated absorption
+ K~ 0,3
→ Absorbing Dust particles



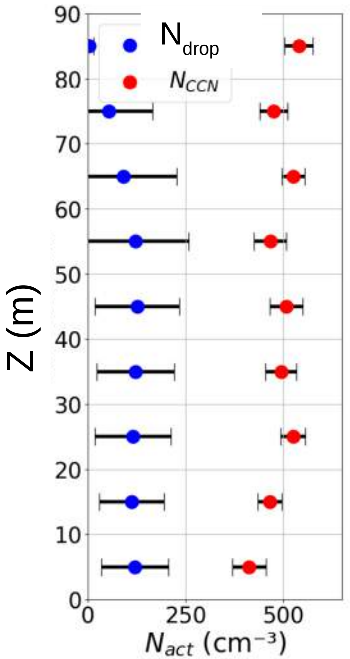
Sattelite pictures from the Spectroradiometer MODIS showing the Mediterranean sand storm of 02/23/20 (NASA)



NMMB/BSC-Dust model simulations

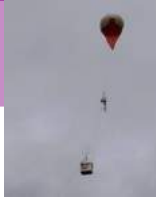


CCN closure study to determine the fog supersaturation

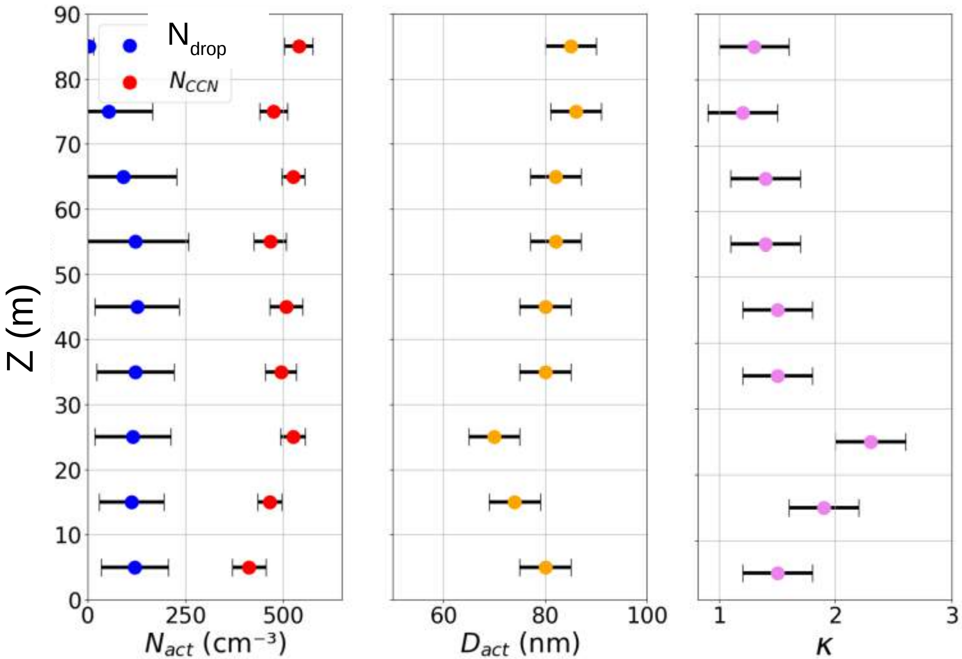


Averaged (on 10 m) vertical variability of hygroscopic properties

- $N_{CCN} >> N_{drop} \rightarrow SS_{fog} << SS_{mini\ CCNC}$ (0.147 %)



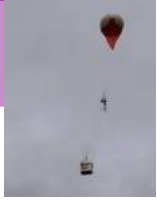
CCN closure study to determine the fog supersaturation



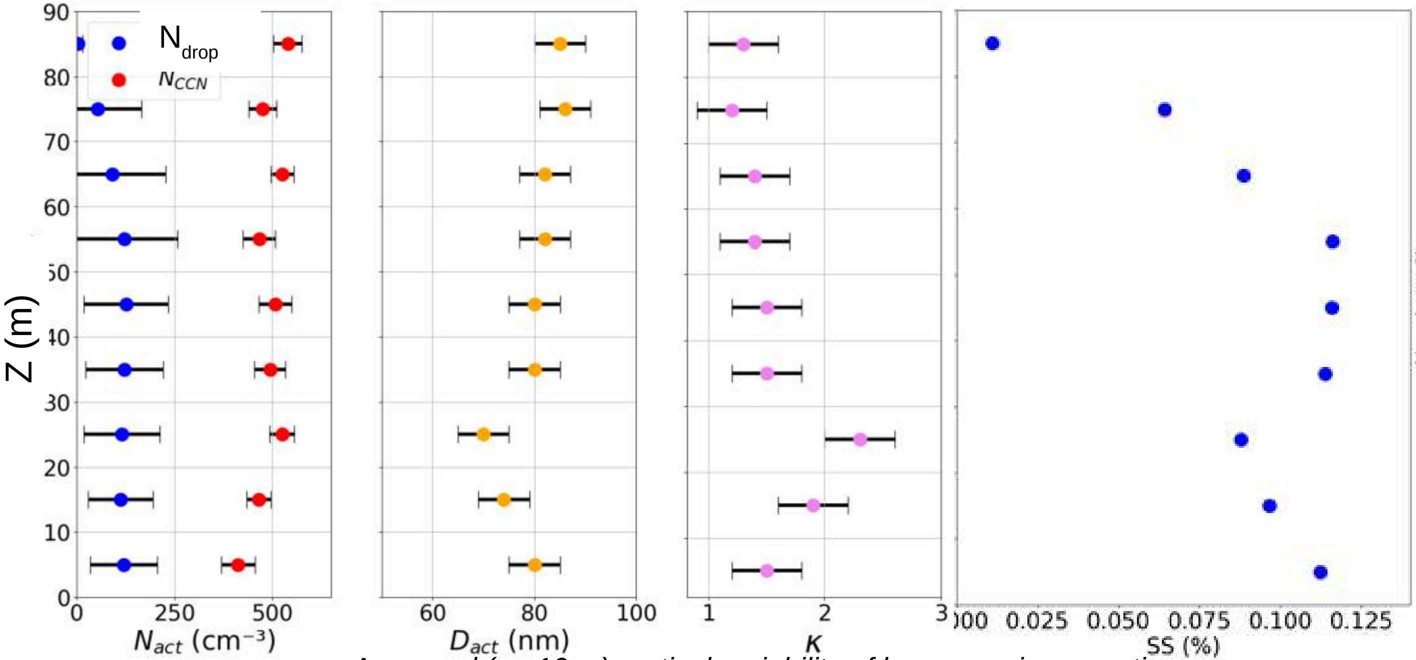
Averaged (on 10 m) vertical variability of hygroscopic properties

- N_{CCN}>> N_{drop} → SS_{fog}<< $SS_{mini\ CCNC}$(0.147 %)
- N_{CCN} ~ constant → D_{act} & κ ~ constant

III. Results : Preliminary study of vertical variability of CCN properties



CCN closure study to determine the fog supersaturation

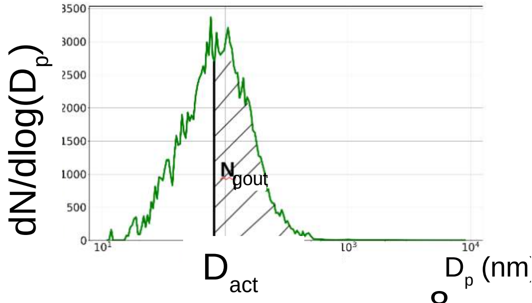


Averaged (on 10 m) vertical variability of hygroscopic properties

SS(z) calculation :

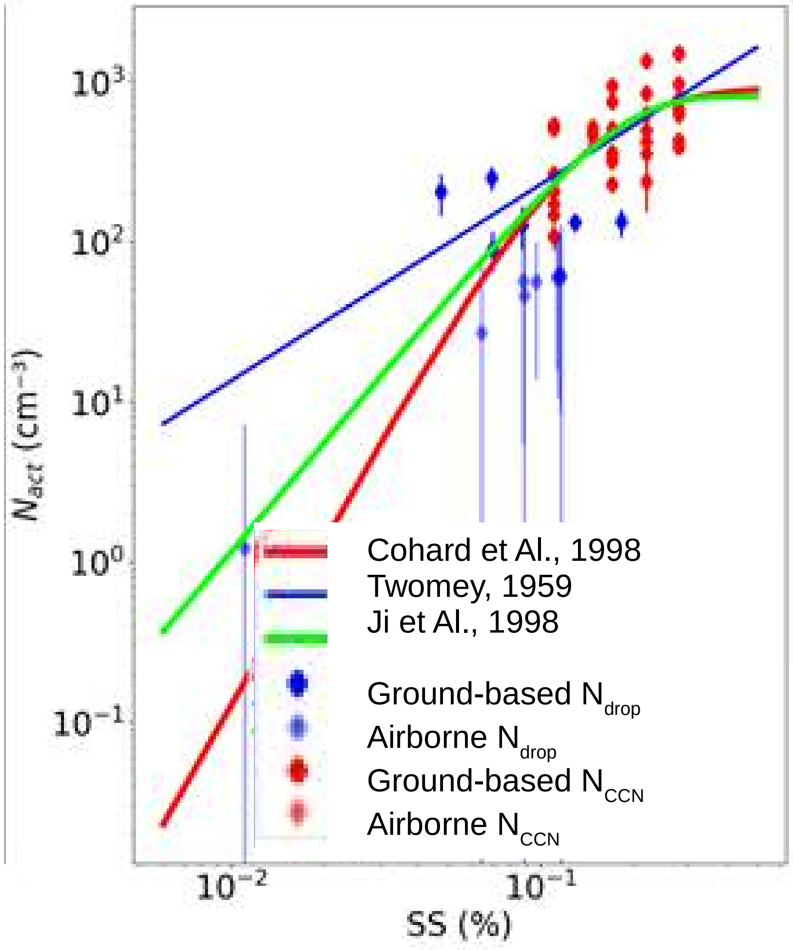
$$\kappa = \frac{4A^3}{27 D_{act}^3 \ln^2(SS_c)}$$

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



- N_{CCN}>> N_{drop} → SS_{fog}<< $SS_{mini\ CCNC}$ (0.147 %)
- N_{CCN} ~ constant → D_{act} & κ ~ constant
- SS decreases with z → N_{drop} decreases and Κ ~ constant

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 Nact 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 :

Microphysical	Optical	Hygroscopic
$N_{tot} \approx 2280\ cm^{-3}$ → rural area*	SSA ≈ 1 → low absorption	0.3 < Κ < 1.2 → rural area*
Variable coarse mode	$0.14 < Å_{sca,450/550} < 1.29$ → variable size	→ Very variable chemical composition

** 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	Optical	Hygroscopic
$N_{tot} \approx 2280\ cm^{-3}$ → rural area*	SSA ≈ 1 → low absorption	0.3 < Κ < 1.2 → rural area*
Variable coarse mode	$0.14 < Å_{sca,450/550} < 1.29$ → 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 occuring 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

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)

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)

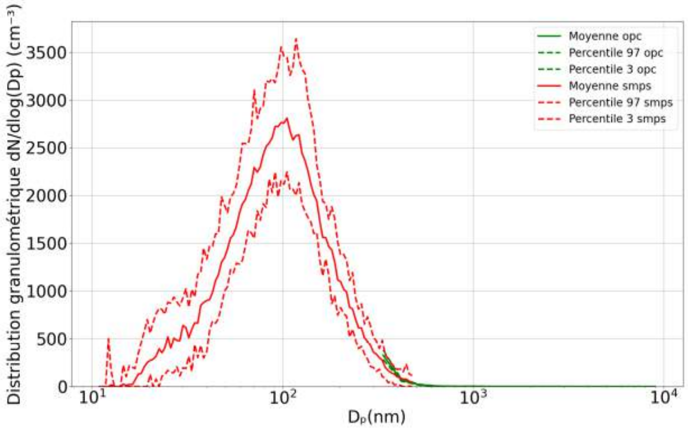
Thanks for your attention

Intercomparaison des appareils

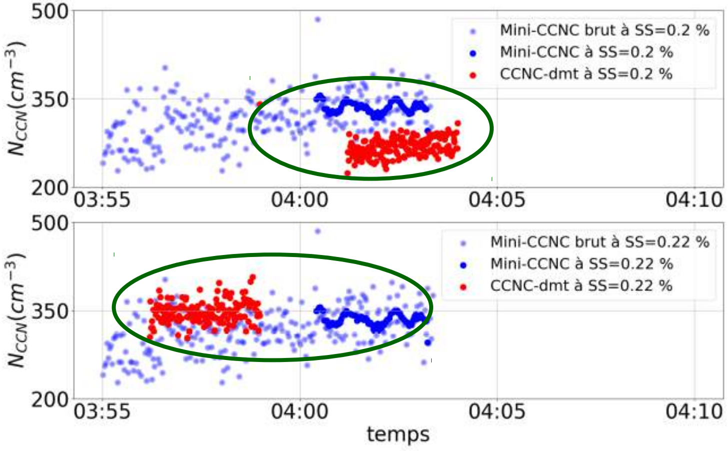
→ N_{tot}(SMPS) + N_{tot}(OPC) ≠ N_{tot}(CPC)

→ À $SS_{donnée}$: N_{CCN}(mini-CCNC) = N_{CCN} (CCNC DMT) ?

Mini CCNC	
SS visée (%)	SS réelle (%)
0.05	0.06
0.07	0.08
0.1	0.11
0.2	0.22



Distribution granulométrique SMPS + OPC dans le container

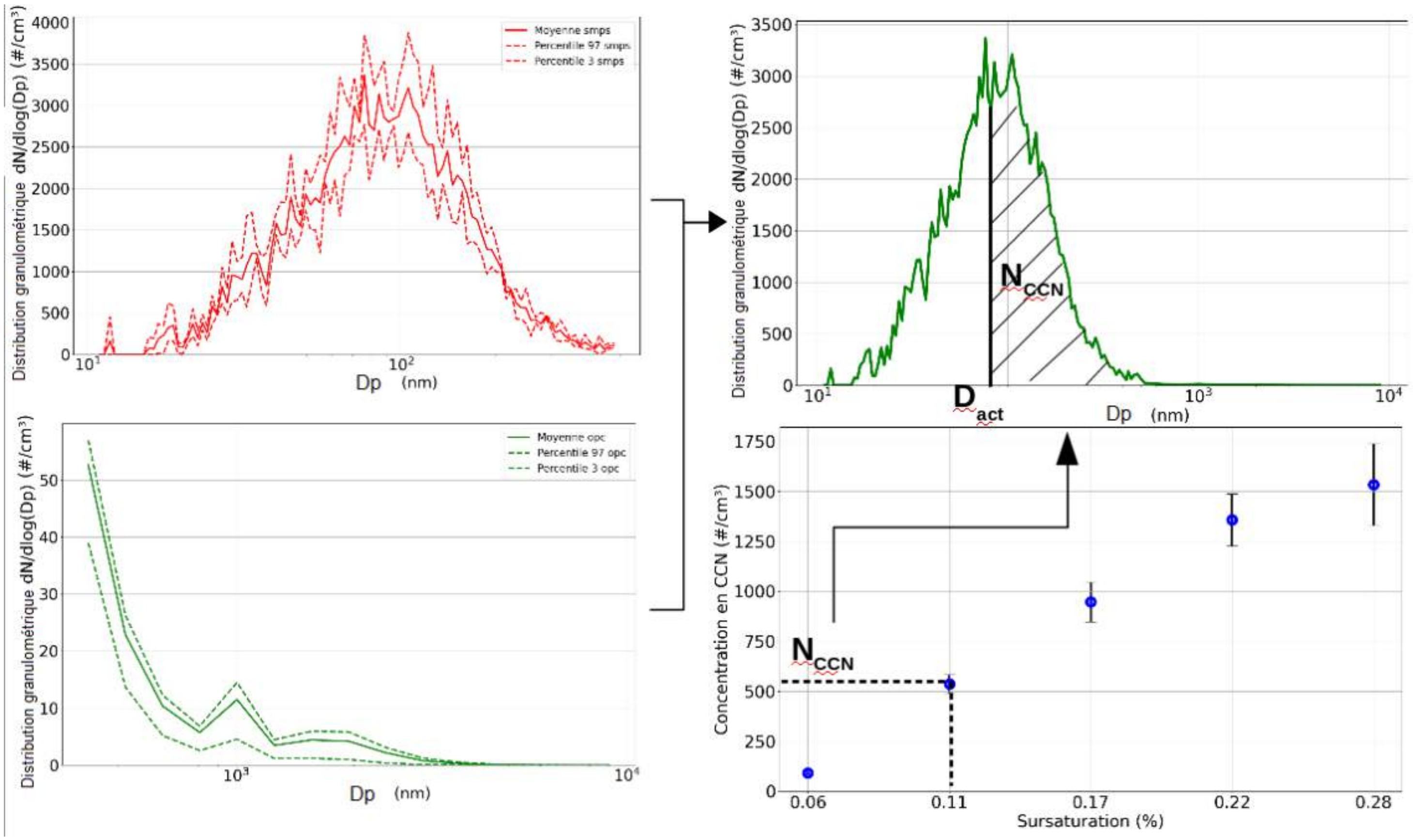


Concentrations CCN du CCNC DMT et du mini-CCNC dans le container avant et arpès recalibration à SS=0.22 %

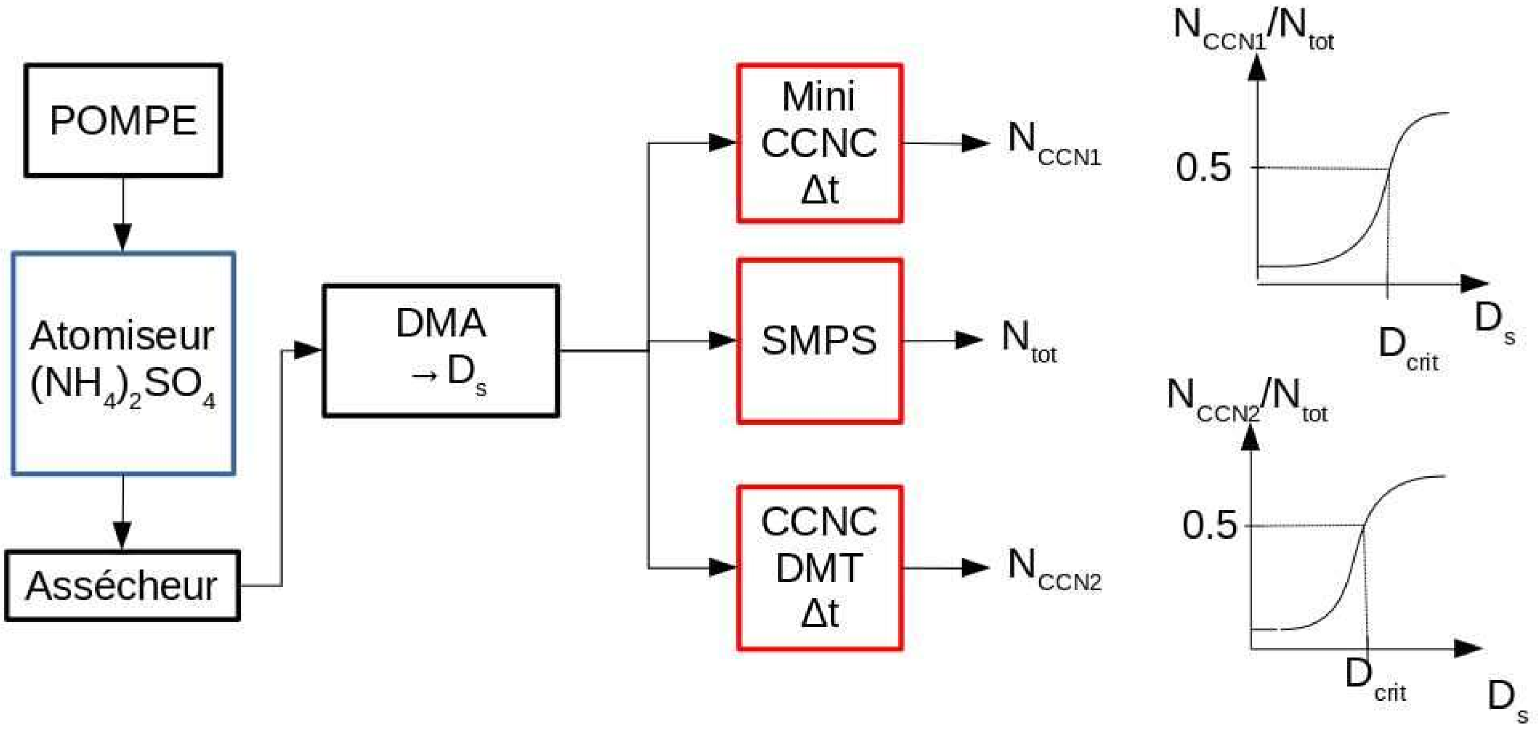
Recalibration

CCNC DMT	
SS visée (%)	SS réelle (%)
0.1	0.06
0.2	0.11
0.3	0.17
0.4	0.22
0.5	0.28

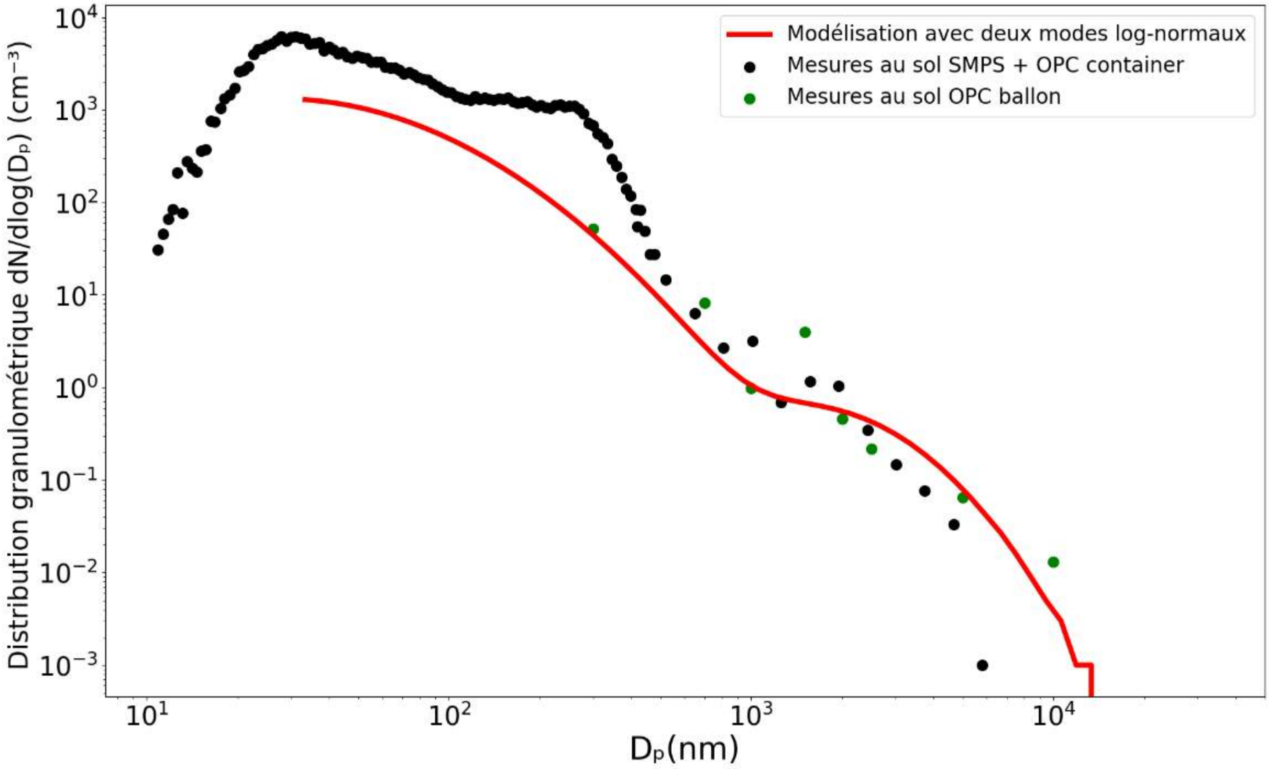
/ 2



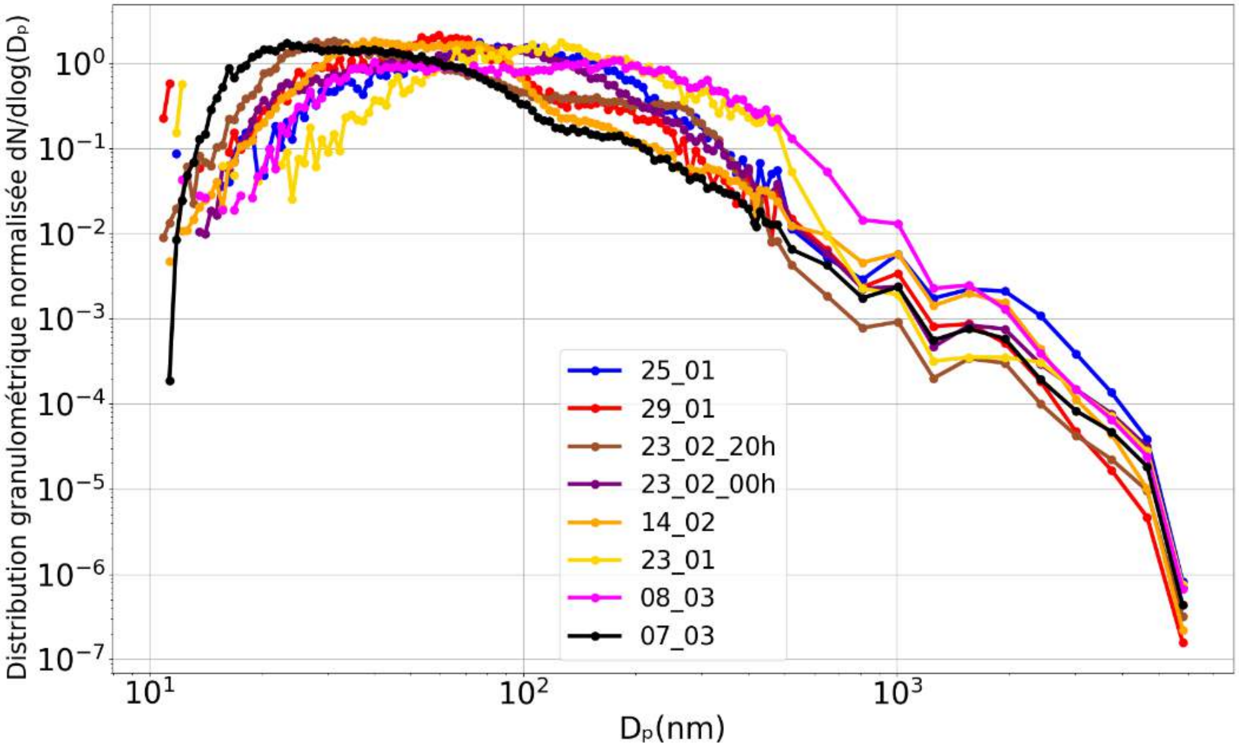
Méthodologie utilisée pour calculer le diamètre d'activation. Les distributions granulométriques du SMPS et de l'OPC, respectivement en haut et en bas à gauche sont rassembléespour donner la granulométrie totale en haut à droite. Pour une sursaturation donnée, ici 0.11 %, la concentration en CCN représentée en bas à droite N CCN permet d'obtenir D act .



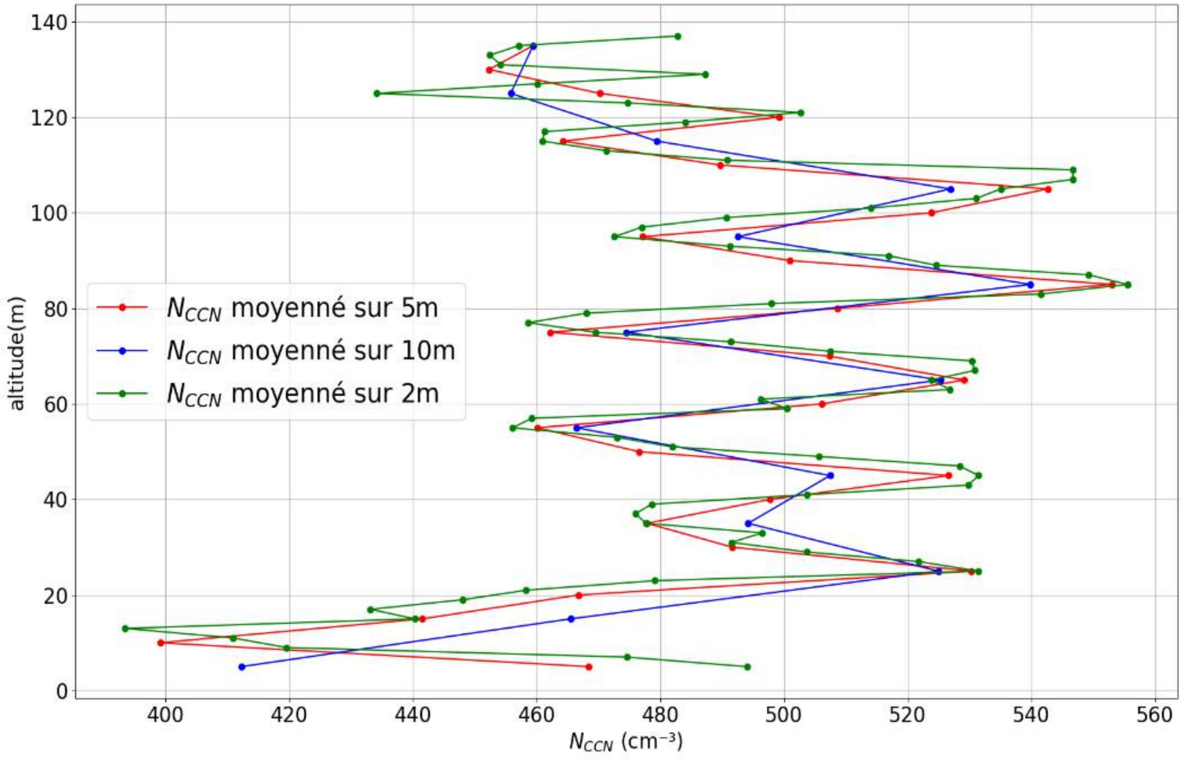
Procédure de calibration simultanée des deux CCNC avec du sulfate d'ammonium.



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