Evaluation of fog and low stratus cloud microphysical properties derived from in-situ sensor, cloud radar and SYRSOC algorithm

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SUMMARY

The study focuses on the analysis of 3 case studies where the tethered balloon is deployed during several hours in order to derive the relationship between Liquid Water Content (LWC), Effective Radius (Re) and Cloud Droplet Number Concentration (CDNC) measured by the LOAC in-situ granulometer and the BASTA cloud radar reflectivity.

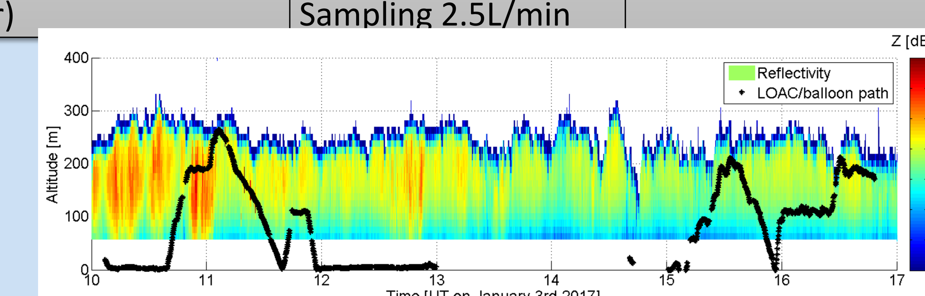
The well-known relationship $Z = \alpha \times LWC^{\beta}$ has been optimized with a [0.02 0.0.097] and b [1.91 2.51]. Similar analysis is done to optimize the relationship Re=f(Z) and CDNC=f(Z).

Two methodologies have been applied to normalize the particle size distribution measured by the LOAC granulometer with a visible extinction closure (R^2 ϵ [0.73 0.93]) and to validate the LWC profile with a liquid water closure using the HATPRO microwave radiometer (R^2 ϵ [0.83 0.91]).

Observational dataset

Active and passive remote sensing instruments and the in-situ sensors deployed at the SIRTA

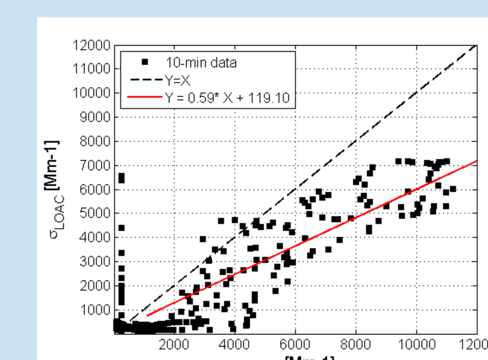
Type of the instruments	Name	Parameters	Sampling	Uncertainty
Remote sensing instruments	BASTA cloud radar (95 GHz)	Reflectivity, Doppler velocity, cloud top height	12 sec	0.5 dBZ, 0.2m/s
	HATPRO microwave radiometer	Liquid water path	5min	LWP ± 20g/m²
	CL31 Ceilometer	Cloud base height	1min	7.5m
	CHM15K Ceilometer	Cloud base height	1min	7.5m
In-situ sensors	Degreane DF320 diffusometer	Horizontal visibility (km) at 4m agl	1 min	± 10-25 %
	LOAC granulometer	Particle Size Distribution for particles ranging from 0.2 to 50µm (in diameter)	1 min Sampling 2.5L/min	



Visible extinction normalization for LOAC validation

$$\sigma_{loac} = \sum_{Dmin}^{Dmax} \frac{\pi D^2}{4} N_D Q_{ext(m,D)}, \text{ and } \sigma_{DF} = \frac{-ln(VC)}{Visi}$$

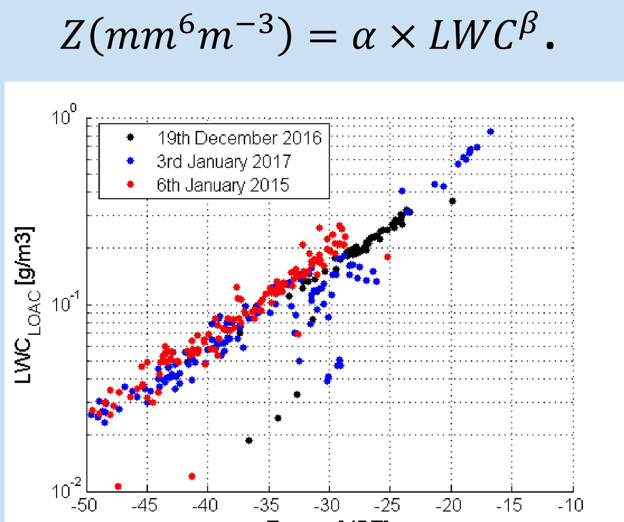
Normalization procedure	Slope	#	r	Average temp. [° C]	Average wind speed [m/s]	Average CDNC [#/cm3] total, and >10µm	Average visibility [m]
6th January 2015	8.2	86	0.93	-1.2	2.2	840 / 40	670
19th December 2016	0.59	76	0.88	3.4	0.5	465 / 55	500
3rd January 2017	0.92	157	0.73	0.9	1.8	930 / 35	180
17th February 2017*	4.2	45	0.83	7.6	1.1	270 / 110	320



LWC, Re and CDNC retrievals

We derive the microphysical properties such as Liquid Water Content (LWC), Effective Radius (Re) and Cloud Droplet Number Concentration (CDNC) measured by the LOAC granulometer from BASTA cloud radar reflectivity (Z). We compare LWC, Re, CDNC and Z along the tethered balloon path.

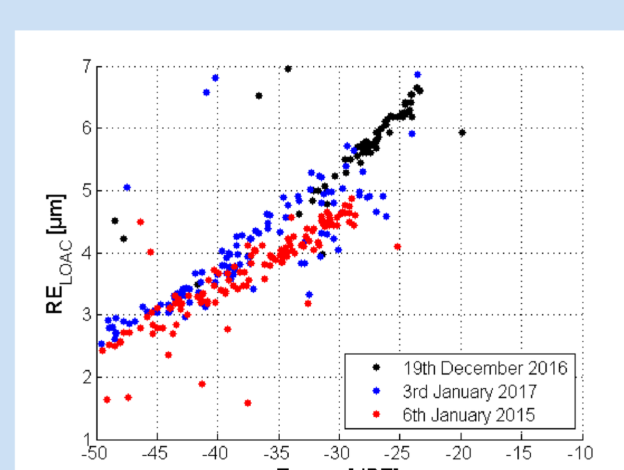
$$Z(mm^6 m^{-3}) = \alpha \times LWC^{\beta}.$$



Relationship between Liquid Water Content measured with LOAC sensor and BASTA for the three case studies.

	a	b	Number of samples	r	Average Z (min, max) [dBZ]	Average LWC (min, max) [g/m3]
Atlas, 1954	0.048	2	/		/	/
Sauvageot and Omar, 1987;	0.030	1.7	/	0.67	/	/
Fox and Illingworth, 1997	0.012	1.16	/	0.82	/	/
Flight 1. 6th January 2015	0.020	1.91	62	0.79	-33.4 (-52.5 -20.1)	0.07 (0.03 0.26)
Flight 2. 19th December 2016	0.049	2.06	43	0.88	-22.7 (-43.5 -14.8)	0.19 (0.02 0.35)
Flight 3. 3rd January 2017	0.097	2.51	81	0.74	-25.1 (-43.4 -11.5)	0.10 (0.01 0.85)

$$Z(dBZ) = \gamma \times log10(Re) + \delta$$

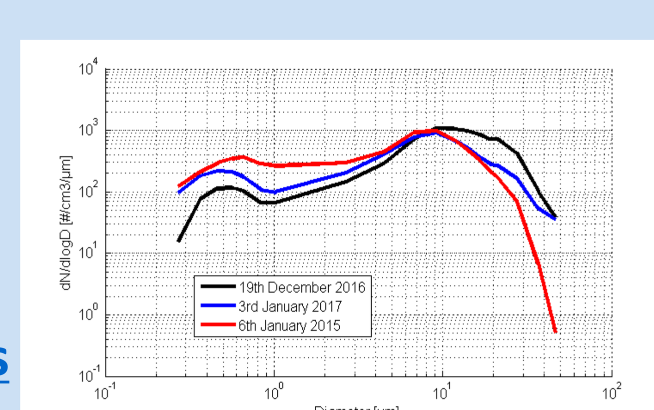


Relationship between Effective Radius measured with LOAC sensor and BASTA for the three case studies.

	g	d	Average Re* (min max) [µm]	Number of samples	r	Average Z (min, max) [dBZ]	Average Re (min, max) [µm]
Fox and Illingworth, 2007	40.9	-64.2	4	/	/	/	/
Flight 1. 6th January 2015	65.0	-74.2	4.9 (0.8 8.6)	62	0.74	-33.4 (-52.5 -20.1)	3.6 (1.1 4.9)
Flight 2. 19th December 2016	52.0	-69.2	6.8 (1.1 9.4)	43	0.86	-22.7 (-43.5 -14.8)	5.7 (2.1 7.2)
Flight 3. 3rd January 2017	69.2	-80.7	5 (0.8 12.6)	81	0.78	-25.1 (-43.4 -11.5)	4.3 (1.7 9.5)

$$CDNC = \frac{LWC}{\frac{4}{3}\pi \times \rho_l \times \mathrm{Re}^3}$$

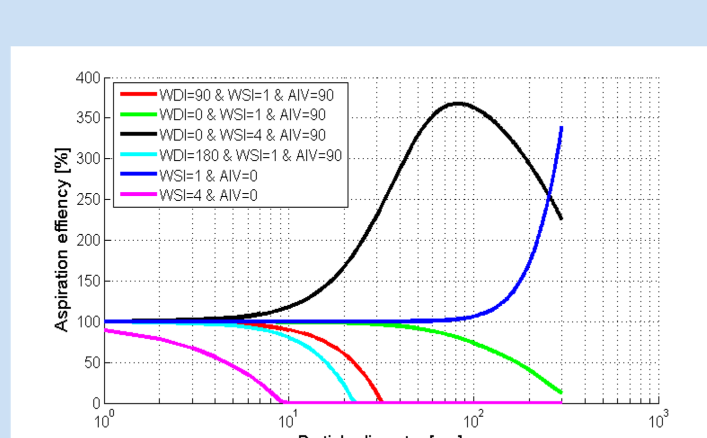
	CDNC* [#/cm3]	Average Z (min, max) [dBZ]	Average CDNC (min, max) [#/cm3]
Flight 1. 6th January 2015	108	-33.4 (-52.5 -20.1)	113 (95 166)
Flight 2. 19th December 2016	58	-22.7 (-43.5 -14.8)	65 (62 97)
Flight 3. 3rd January 2017	54	-25.1 (-43.4 -11.5)	13 (5 55)



Discussion on the validity of these relationships

Impact of aspiration efficiency

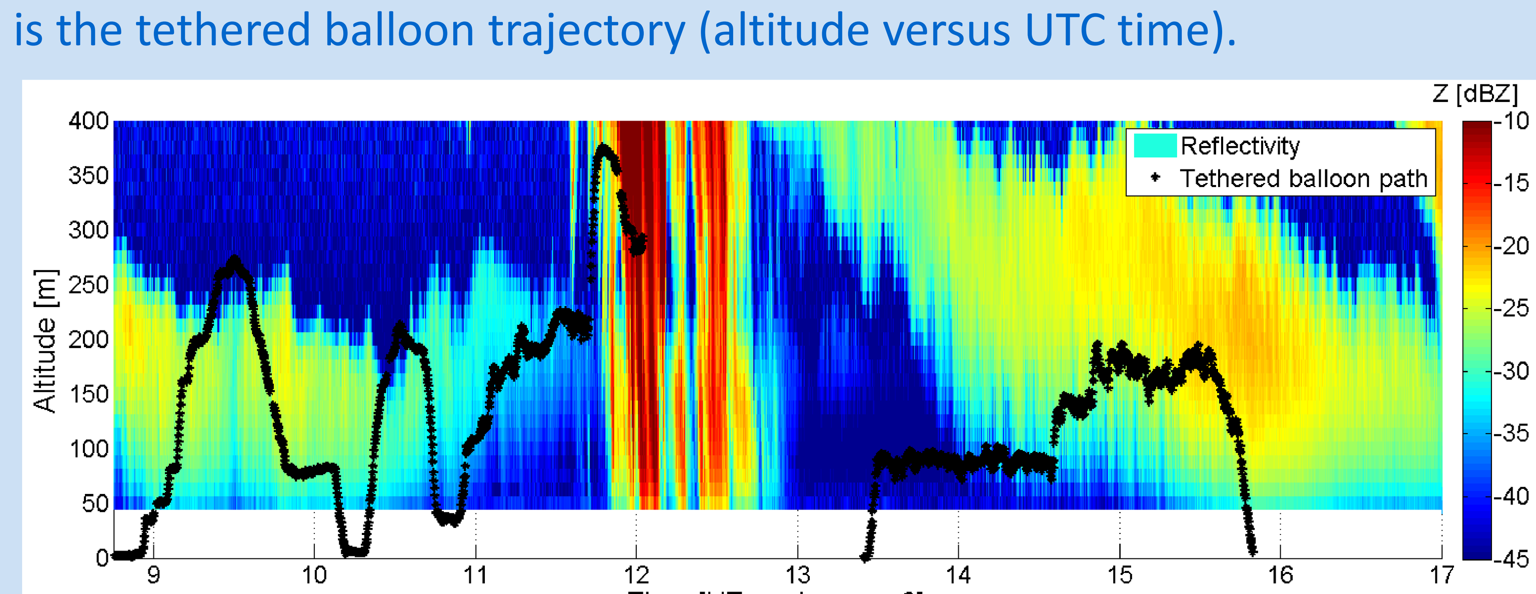
To better understand the impact of drizzle and dynamics on the droplet collection by the LOAC sensor, we apply the [Grinshpun et al., 1993] methodology to derive the aspiration efficiency (noted *AE*) of a thin sampler in calm air and low velocity. For the test, we consider a temperature around 283.15K, atmospheric pressure of 1013hPa, particle volumic mass of 1000kg/m³ with an inlet tube diameter of 8mm with a sampling rate of 2.5L/min. We quantified the relationship between the aspiration efficiency and the particle size ranging from 1 to 300µm. We tested the sensitivity (1) to the external wind direction compared to the inlet, noted *WDI*, (2) to external wind speed compared to the inlet flow, noted *WSI*, and (3) to the angle of inlet attack from the vertical, noted *AIV*.



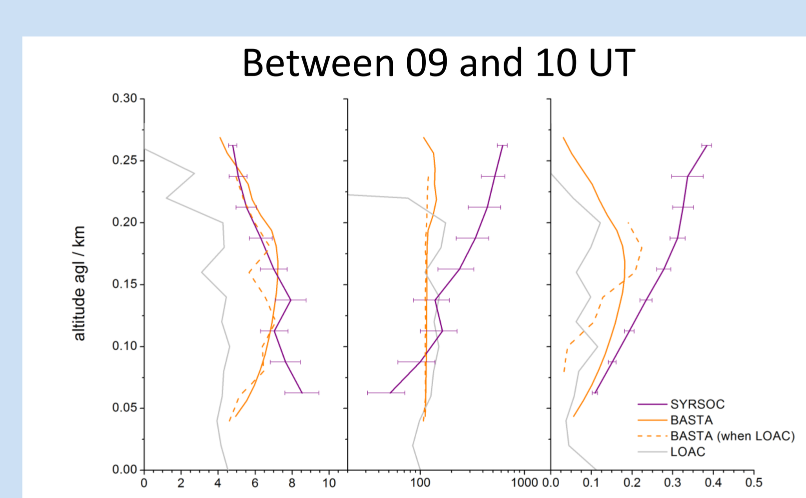
Grinshpun, S., Willeke, K., and Kalatoor, S. (1993), A general equation for aerosol aspiration by thin-walled sampling probes in calm and. moving air, Atmos. Environ. A-Gen., 27, 1459–1470.

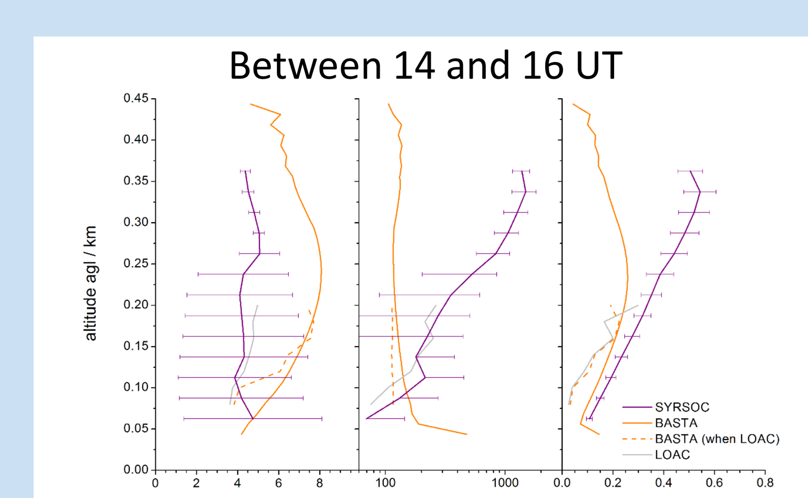
Comparisons and discussions of stratus-fog events

On 6th January 2015, a tethered balloon flight was performed during 6 hours of a stratus-fog event as shown in the figure below. 2D-color corresponds to the radar reflectivity and black curve is the tethered balloon trajectory (altitude versus UTC time).



Times series of cloud radar reflectivity on 6th January 2015 and tethered balloon flight trajectory in cloud layer (black markers).





Vertical profile of Re (left), CDNC (middle), LWC (right) derived from LOAC, BASTA, and SYRSOC algorithm on 6th January 2015. Error bars on SYRSOC profiles indicate standard deviation of the mean over the 1-hour period.

Discussion of SYRSOC results

SYRSOC (SYnergistic Remote Sensing Of Clouds) is an algorithm for the calculation of microphysical cloud property profiles from collocated cloud radar, ceilometer or lidar, and microwave radiometer data

The cloud base in any fog layer is at ground level. However, BASTA has a blind zone in the lowest 40 m and a height range of incomplete overlap of outgoing radiation and receiver field of view from 40 m to 240 m [Delanoë et al., 2016]. The fog layer observed in the morning of 6th January 2015 was less than 300 m deep. In this case, nearly the whole layer was affected. Radar reflectivity was corrected from 120 to 240 m. Below 120 m, reflectivity was assumed constant, using an average value. This correction introduced a discontinuity in the profiles at 120 m.

The three studied periods revealed limitations of SYRSOC, but also ways of improving the algorithm. Performance in fog was improved by correcting for the near field behavior of the cloud radar. An overall improvement of SYRSOC was the implementation of an entrainment factor, taking into account entrainment of dry air at cloud top, causing a more realistic shape of the LWC profile, decreasing at cloud top.

Delanoe et al. (2016), BASTA: A 95-GHz FMCW Doppler Radar for Cloud and Fog Studies, Journal of Atmospheric and Oceanic Technology, American Meteorological Society, 33 (5), 1023-1038, doi:10.1175/JTECH-D-15-0104.1.