Surface Tension of Surfactant-Containing, Finite Volume Droplets

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This display describes key results from a recent paper:
Bzdek et al., PNAS, 2020

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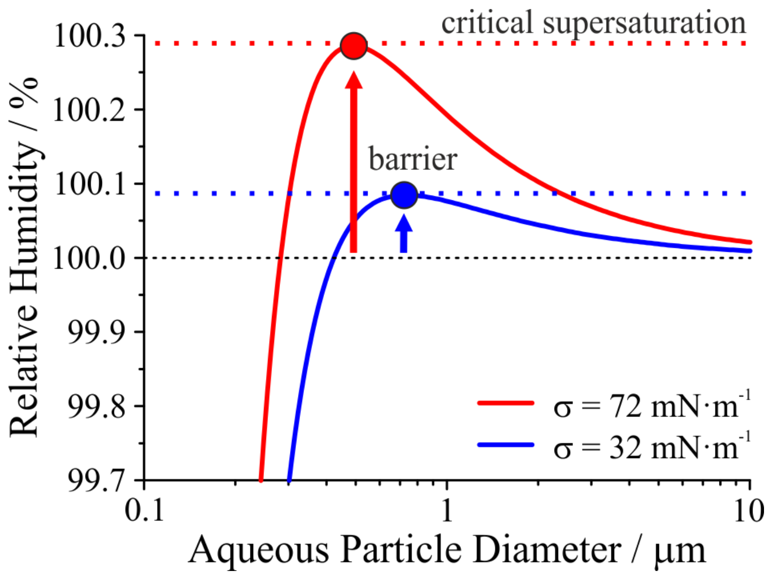
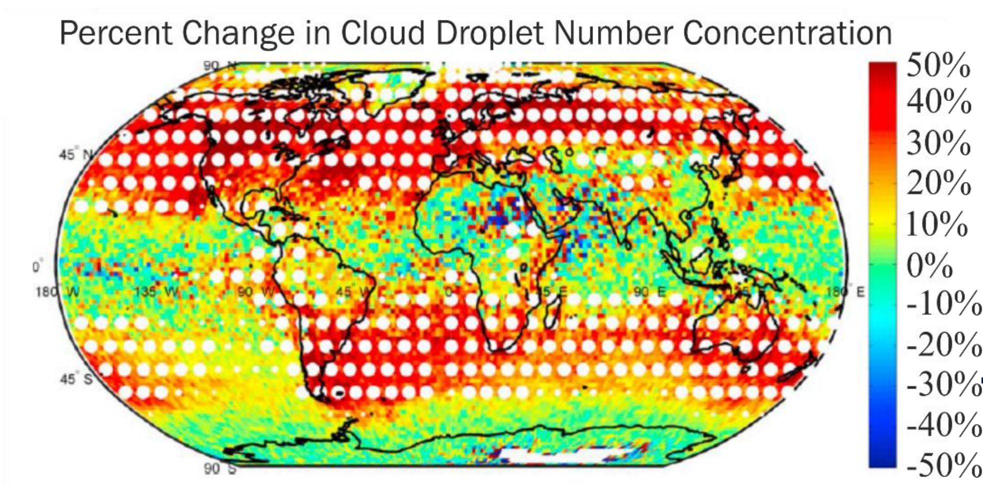
Surface Tension Is Key for Cloud Droplet Activation

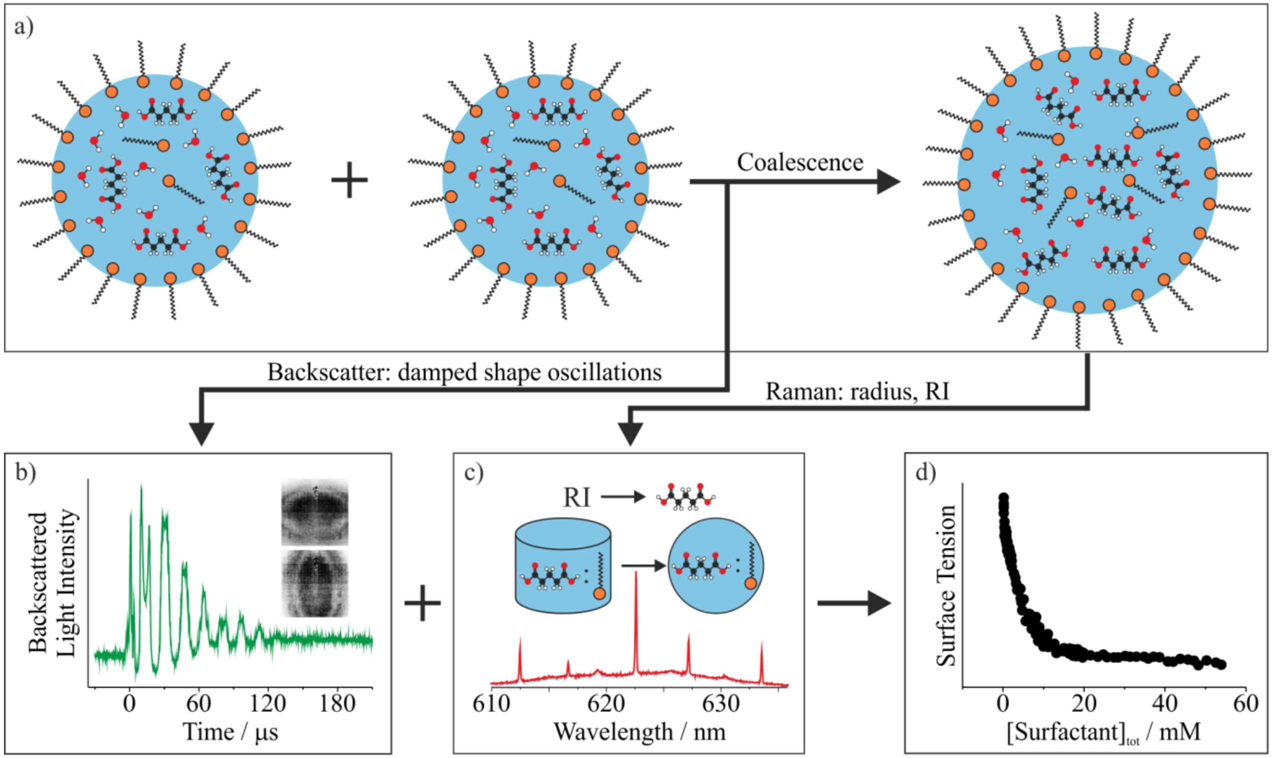
- Surface tension influences critical supersaturation
- Surfactants are key components of aerosol composition
  (e.g. Gerard, EST, 2016; Kroflic, EST, 2018; Facchini, Nature, 1999)
- Surface-bulk partitioning of surface active molecules alters the Köhler curve
  (e.g. Sorjamaa, ACP, 2004; Petters and Petters, JGR, 2016)





- Potentially large surfactant effects on cloud droplet number concentration
  (Prisle, GRL, 2012)

Direct Surface Tension Measurements of Picolitre Droplets



$$\sigma = \frac{\omega_l{}^2 a^3 \rho}{l(l-1)(l+2)}$$

σ = surface tension
ω = oscillation frequency
l = oscillation mode
a = droplet radius
ρ = droplet density

- Study coalescence of two optically trapped droplets (part a)
- Resulting shape oscillations recorded (part b); frequency (ω) extracted
- Droplet's Raman spectrum gives size (a) and composition (part c)
- Combined, obtain precise measurements of droplet surface tension (part d; see equation)
- More information: Bzdek et al., Chem. Sci., 2016; Bzdek et al., PNAS, 2020

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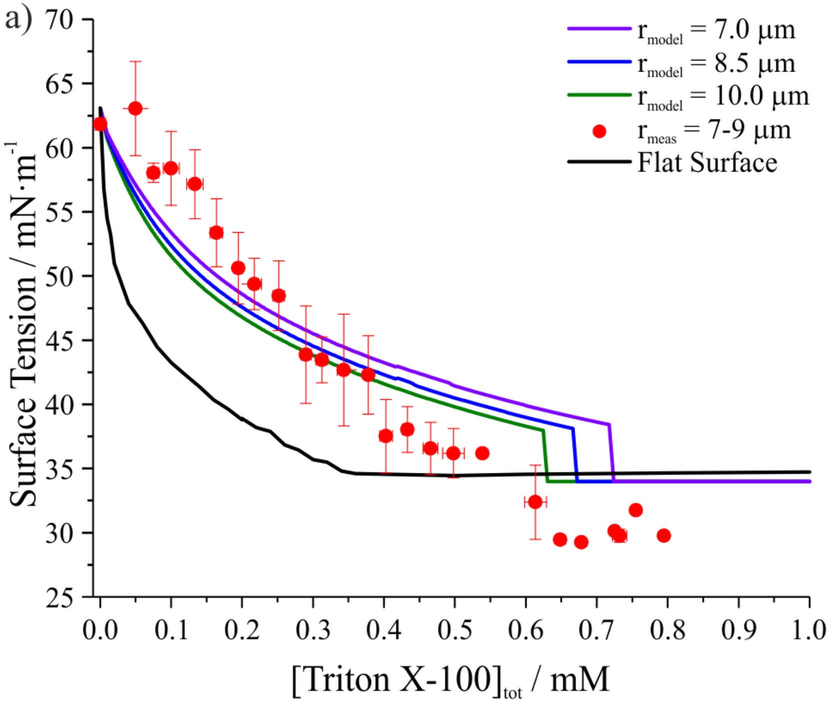
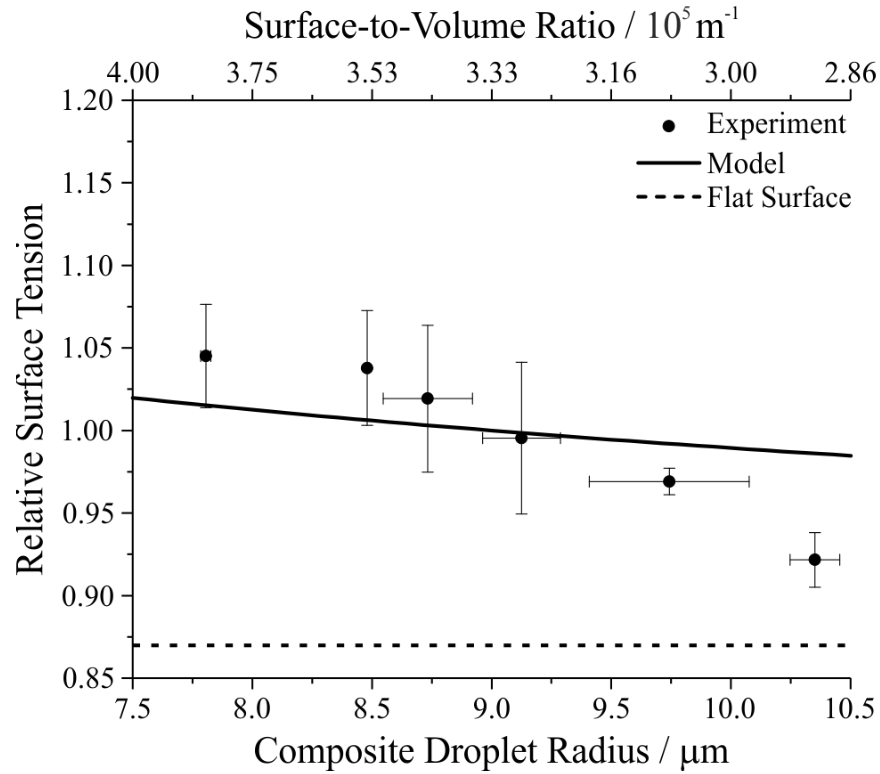
Droplet Surface Tension Not Equivalent to Bulk Value

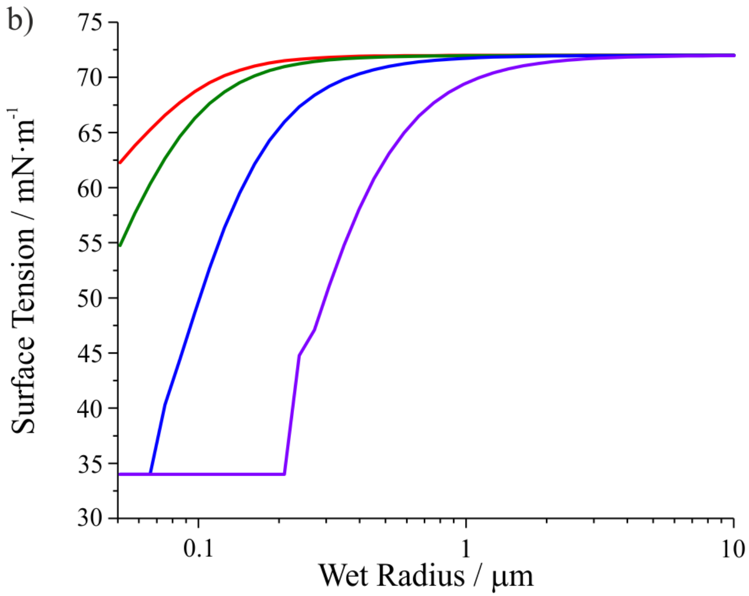


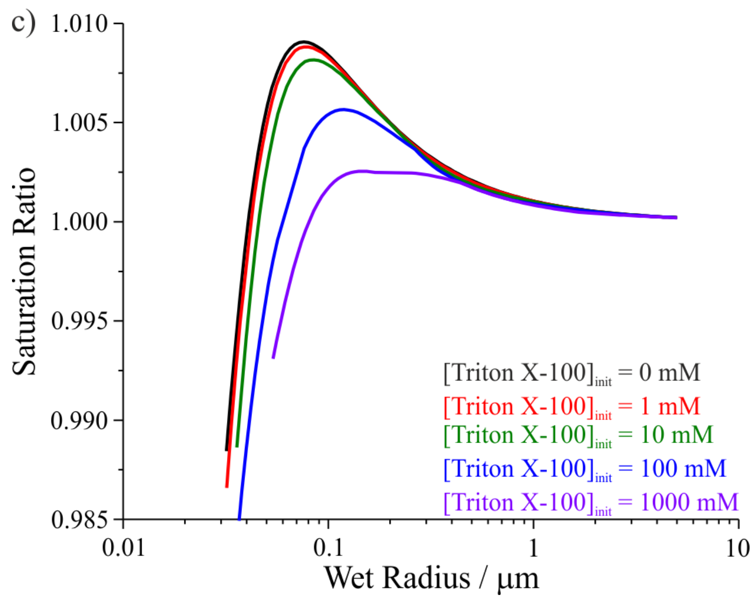


- Droplets containing Triton (surfactant) have surface tensions (red symbols) lower than that of water but higher than that of the solutions that produced them (black line)
- Partitioning model calculations (coloured lines) confirm observation is due to droplets' high surface-to-volume ratios

- As surface-to-volume ratio changes, surface tension changes
- See Bzdek et al., PNAS, 2020 for more details

Potentially Significant Climate Impacts





- Accurately accounting for surface-bulk partitioning allows predictions of evolving surface tension during hygroscopic growth…
- …which alters activation parameters (e.g. critical radius, critical supersaturation) as the initial surfactant concentration is varied

Table 1. Parameters for droplets with initial composition (at 0.05-μm radius) indicated in Fig. 5*A*

[Triton X-100]$_{tot,init}$, mM	R_c, μm	SS_c, %	γ_c, mN·m^{-1}	$\Delta N_d/N_{d,est}$	IRE_{est}, W·m^{-2}
0	0.076	0.91	67		
1	0.076	0.89	67	0.054	−0.22
10	0.085	0.82	64	0.088	−0.48
100	0.12	0.57	55	0.32	−1.6
1,000	0.15	0.25	34	0.99	−4.9

R_c: critical radius, SS_c: critical supersaturation, γ_c: surface tension at activation, $\Delta N_d/N_{d,est}$: estimated fractional change in N_d, IRE_{est}: estimated *IRE* when compared to the reference case.

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Key Conclusions

- Surfactants can significantly reduce aerosol droplet surface tension below the value for water, but surface tension reduction is size dependent and does not correspond exactly to the macroscopic solution value
- Independent monolayer partitioning model confirms size-dependent surface tension arises from high surface-to-volume ratios in finite-sized droplets
- Predictions of aerosol hygroscopic growth using the model are consistent with a reduction in critical supersaturation for activation, potentially substantially increasing cloud droplet number concentration and modifying radiative cooling relative to current estimates assuming a water surface tension
- Improved constraints on identities, properties, and concentrations of atmospheric aerosol surfactants is required
- Further reading: Bzdek et al., PNAS, 2020; Malila and Prisle, JAMES, 2018
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