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# SIMULATING COLLISIONS OF CHARGED CLOUD DROPS IN ABC FLOW

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# Motivation

- Electric charge occurs in a wide range of clouds
- It can lead to an attractive force between cloud drops even if they are like charged
- How does charge influence the collision statistics of cloud drops?
- Can charge increase the collisions of drops and enhance the production of larger drops?

# Cloud model

- Simulations are conducted with a lagrangian model for charged drops falling in gravity in a turbulent flow
- Direct simulation of collisions of cloud drops
- Calculation of interaction of electric forces between drops is very expensive → simplified turbulent flow to save computational time
- Instead of DNS of small turbulent scales, the flow is approximated by ABC flow
- Acceleration of drops according to Stokes' law

# Cloud model

- ABC flow is a solution of the Euler equation and creates chaotic trajectories for cloud drops

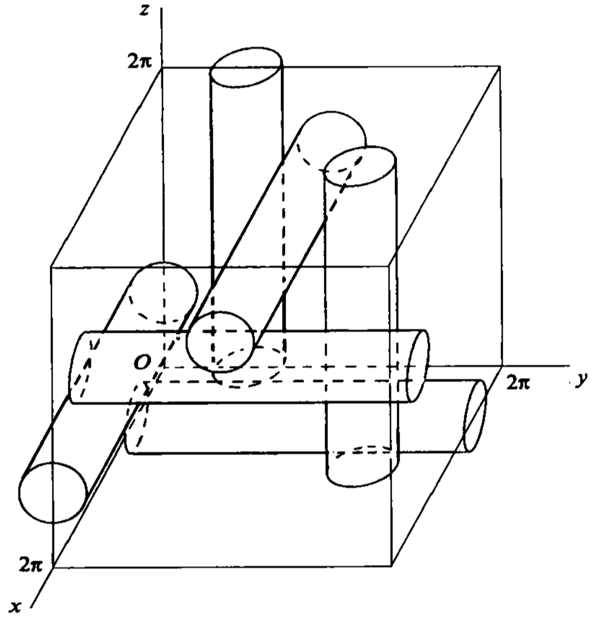



Fig. 1: Schematic of the vortices comprising the ABC flow (from Dombre et al.1986)

Velocity equations in ABC flow:

$$u = A\sin(z) + C\cos(y)$$

$$v = B\sin(x) + A\cos(z)$$

$$w = C\sin(y) + B\cos(x)$$

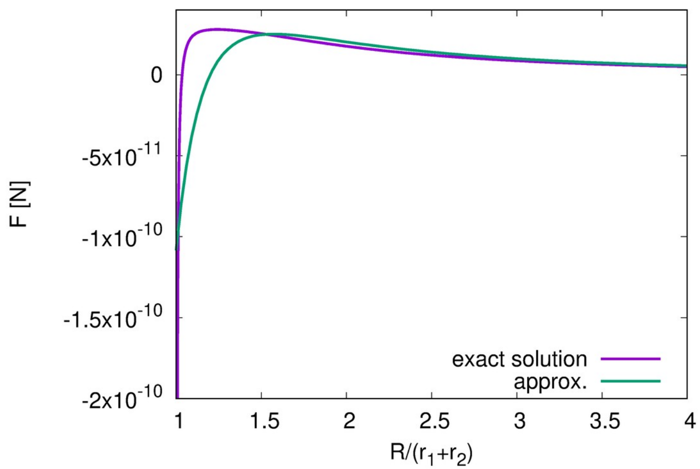
with x,y, and z the position and the coefficients set to A=1, $B=(2/3)^{0.5}$ and $C=(1/3)^{0.5}$ for chaotic advection.

# Model setup

- 50000 cloud drops
- 6 size bins between 10 and 60 µm radius
- Charge is either proportional to mass or radius
- Charge on 10 µm drops either 1000e or 10000e (e being the elementary charge)
- Triple periodic boundary conditions
- Cubic domain with L=0.046 m
- Timestep: 0.001 s

# Electric charge in water drops

- If two drops carry charge of the same polarity they experience a repulsive force according to Coulomb's law
- However, on short distance, due to the effect of image charges of opposite signs, an attractive force starts to dominate (s. fig. 2)




For the simulations presented here, a simple approximation of the exact solution is used. The exact solution is very expensive to calculate and consists of an infinite series of image charges.

Fig. 2: Electric force between two like charged water drops over distance normalised by the sum of radii for r1=30 µm and r2=40 µm (exact solution in purple, approximation in green).

# Results

- Four different simulations:

I: 1000e on 10 µm drops with charge being proportional to drop radius, 10 to 60 µm drop radius

II: 1000e on 10 µm drops with charge being proportional to drop mass, 10 to 60 µm drop radius

III: 10000e on 10 µm drops with charge being proportional to drop radius, 10 to 60 µm drop radius

IV: 60000e on 60 µm drops with charge being proportional to drop radius, 60 to 69 µm drop radius

# Results

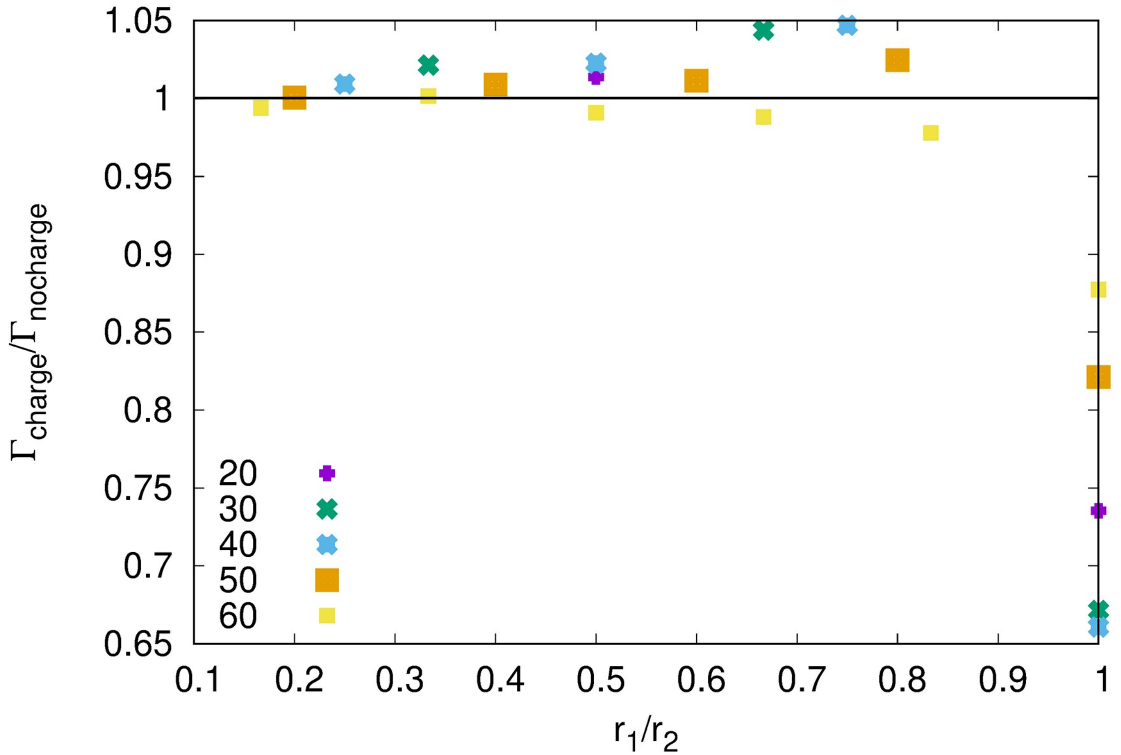



Fig 3.: Ratios of collision kernels from simulations with and without charge over the ratio of radii of colliding drops. The charge was set to 1000e on 10 µm drops and proportional to the drop mass. Different colors are different radii of $r_2$.

# Results

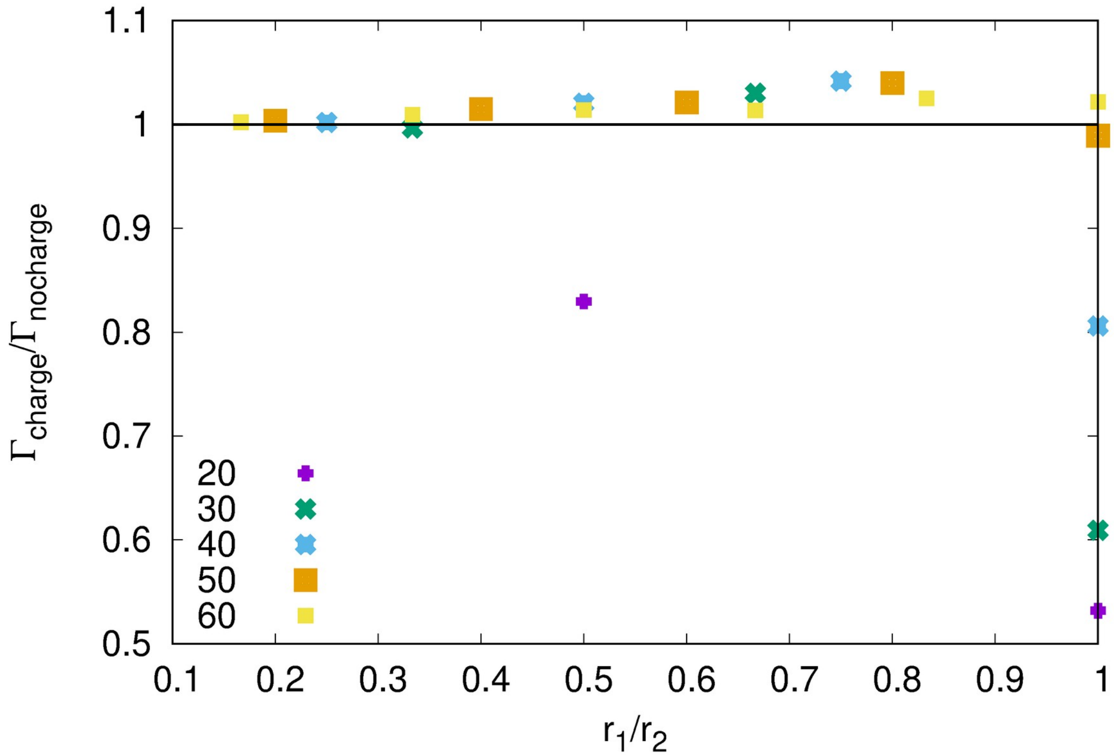



Fig 4.: Ratios of collision kernels from simulations with and without charge over the ratio of radii of colliding drops. The charge was set to 10000e on 10 µm drops and proportional to the drop radius. Different colors are different radii of $r_2$.

# Results

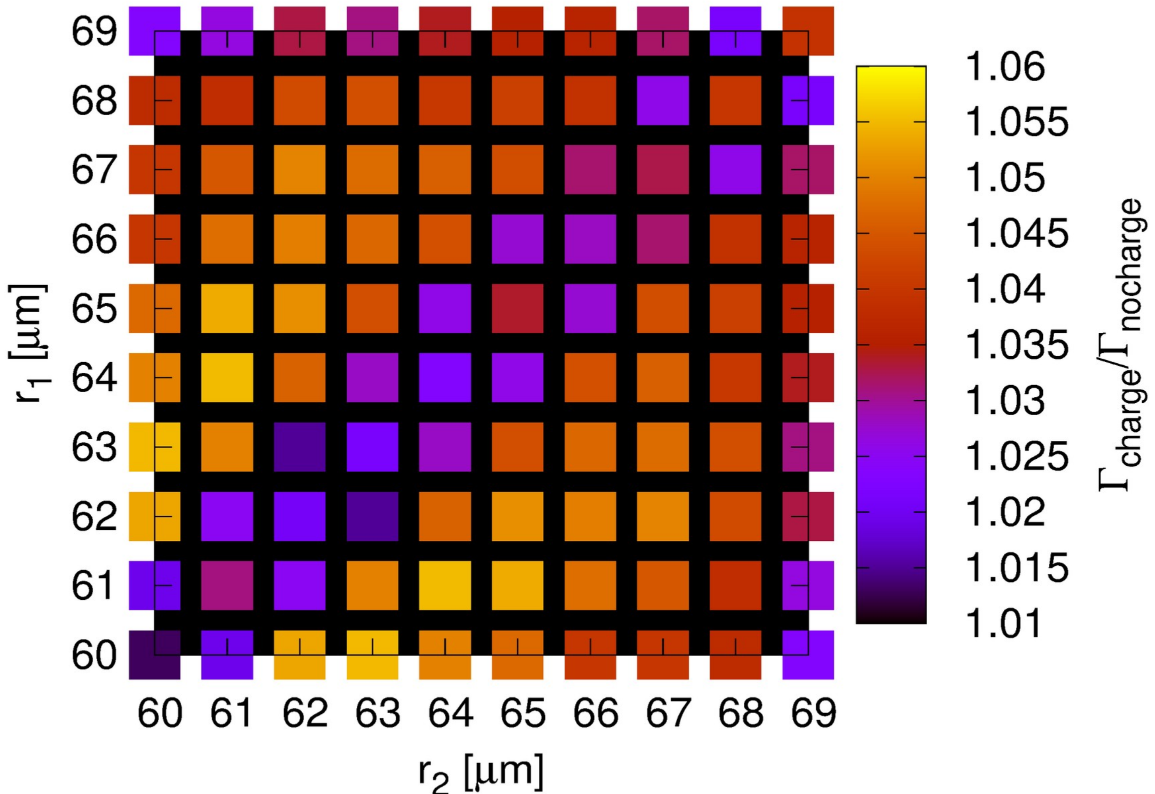



Fig 5.: Ratios of collision kernels from simulations with and without charge for different radii of colliding drops. The charge was set to 60000e on 60 µm drops and proportional to the drop radius.

# Results

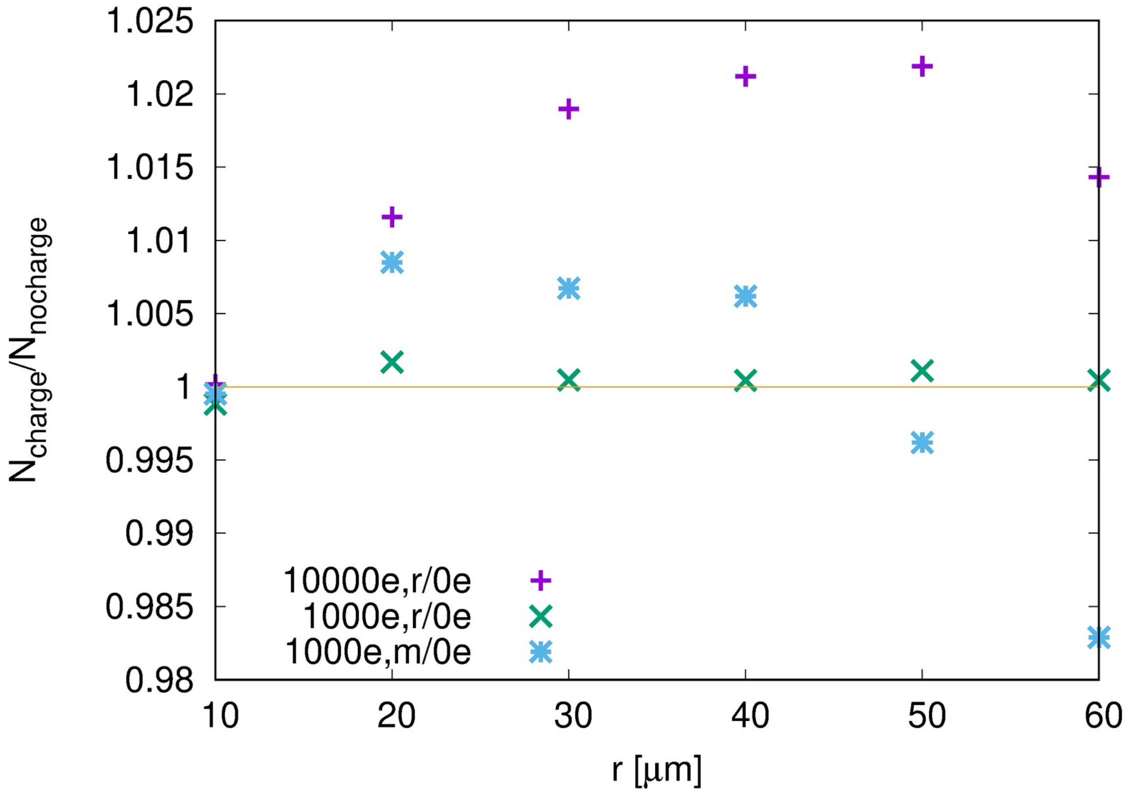



Fig 6.: Ratio of the total number of collisions for different drop sizes from simulations with and without charge for different drop charges. Simulations with charge proportional to mass are indicated by ‘m‘ and those with charge proportional to radius are indicated by ‘r‘.

# Discussion

- Fig. 3 shows an enhancement of collision kernels due to electric charge, especially for larger drop size ratios and larger drops.
- For same sized drops, collisions are supressed by electric charge.
- Fig. 4 is similar but while in fig. 3 some drop size combinations experience a decrease in collision kernel, in fig. 4 all drop size ratios experience and enhancement with the largest effect for larger drop size ratios and larger drops (except same sized drops)

# Discussion

- Fig. 5 shows the ratio of collision kernels for drops between 60 and 69 μm
- The enhancement effect of electric charge is stronger for these drops than for the smaller drops in the previous figures.
- Even same sized drops experience a small enhancement in collision kernel in this size range.
- As drop size increases, the enhancement starts to decrease from a certain drop size onwards.

# Discussion

- Fig. 6 shows the total number of drop collisions in each size bin between 10 and 60 µm
- For 10000e on 10 µm and charge proportional to radius there is a clear increase in collisions in all size bins except for 10 µm drops.
- The enhancement is increasing with drop size until 50 µm. 60 µm drops experience slightly less enhancement than 50 µm drops.
- The picture is similar for 1000e on 10 micrometer and charge proportional to mass
- However, for 50 and 60 µm drops the number of collisions reduces due to the large charge.

# Conclusion

- There is an enhancement of collisions due to electric charge in certain setups.
- In the size range of 10 to 60 µm the collision kernel between same sized drops is reduced due to the electric charge.
- Large charges (>1000e) are needed for a significant enhancement effect.
- If charges become too large the enhancement effect becomes weaker or even changes sign

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*Reference: Dombre, T., Frisch, U., Greene, J. M., Henon, M., Mehr, A. And Soward, A. M., 1986: Chaotic streamlines in the ABC flows. Journal of Fluid Mechanics, 167, 353-391.*