The Effect of Liquid Water on Thunderstorm Charging

Review of the Saunders et al. (1991) paper

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ATS 780

Motivation

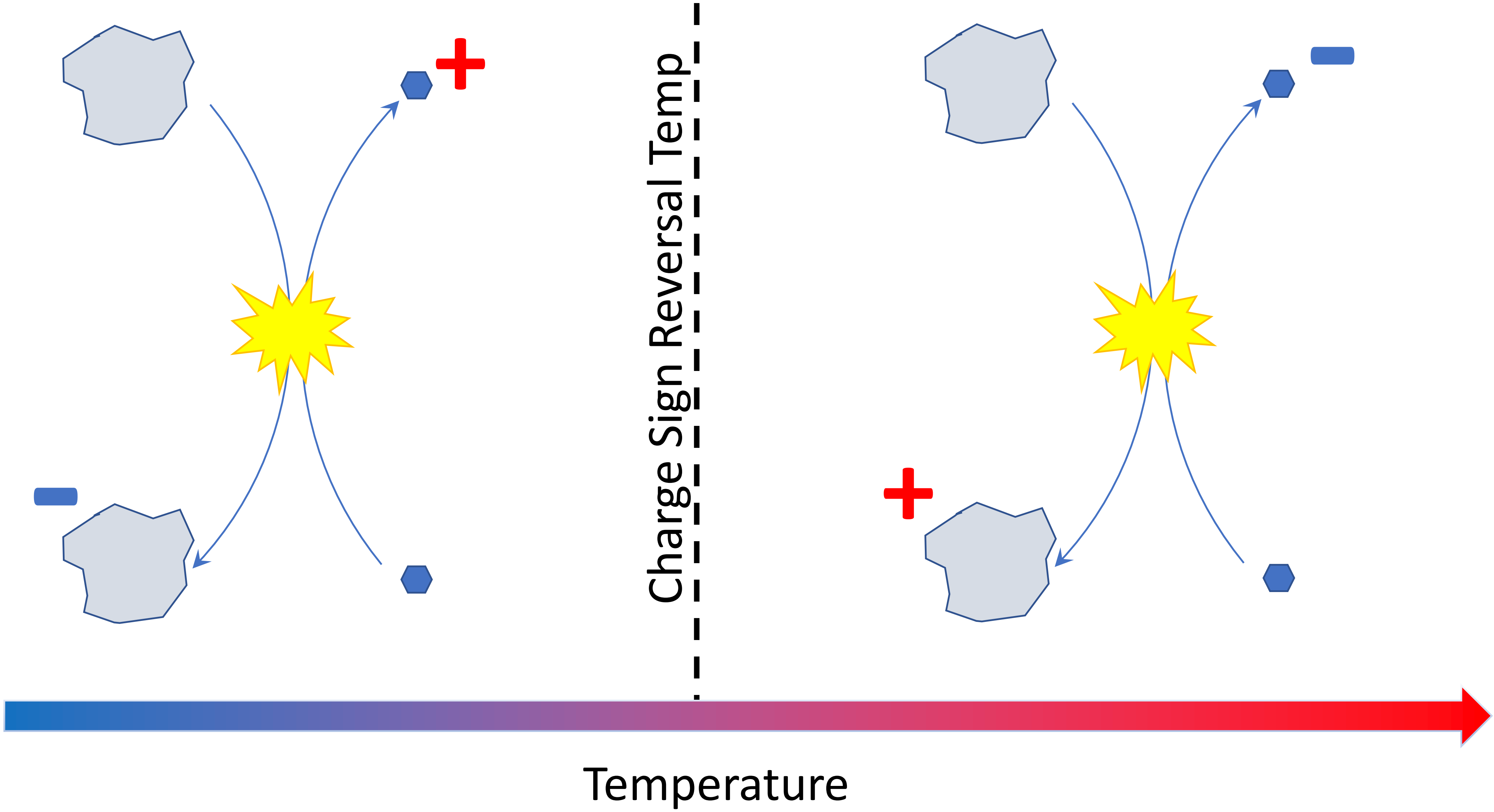
- Liquid water content is an essential ingredient to charge separation events
  - Charge separation of only one sign occurs with low LWC
  - Magnitude of charge transfer too low to be of significance in thunderstorms
- Other variables have been tested with liquid water content held constant
  - Temperature, ice crystal size and velocity
- Need to better understand the impact of liquid water content

Review

- Thunderstorms are observed to be separated into distinct charge layers
  - Charge separation creates electric potential difference within cloud
  - This is what leads to lightning

- Charge separation likely occurs due to non-inductive charging
  - Riming graupel pellets collide with smaller ice crystals
  - Sign of charge left on colliders a function of temperature, liquid water content, fall speed, other things
  - Exact mechanism for charge separation not fully understood

Non-inductive Charging in a Nutshell



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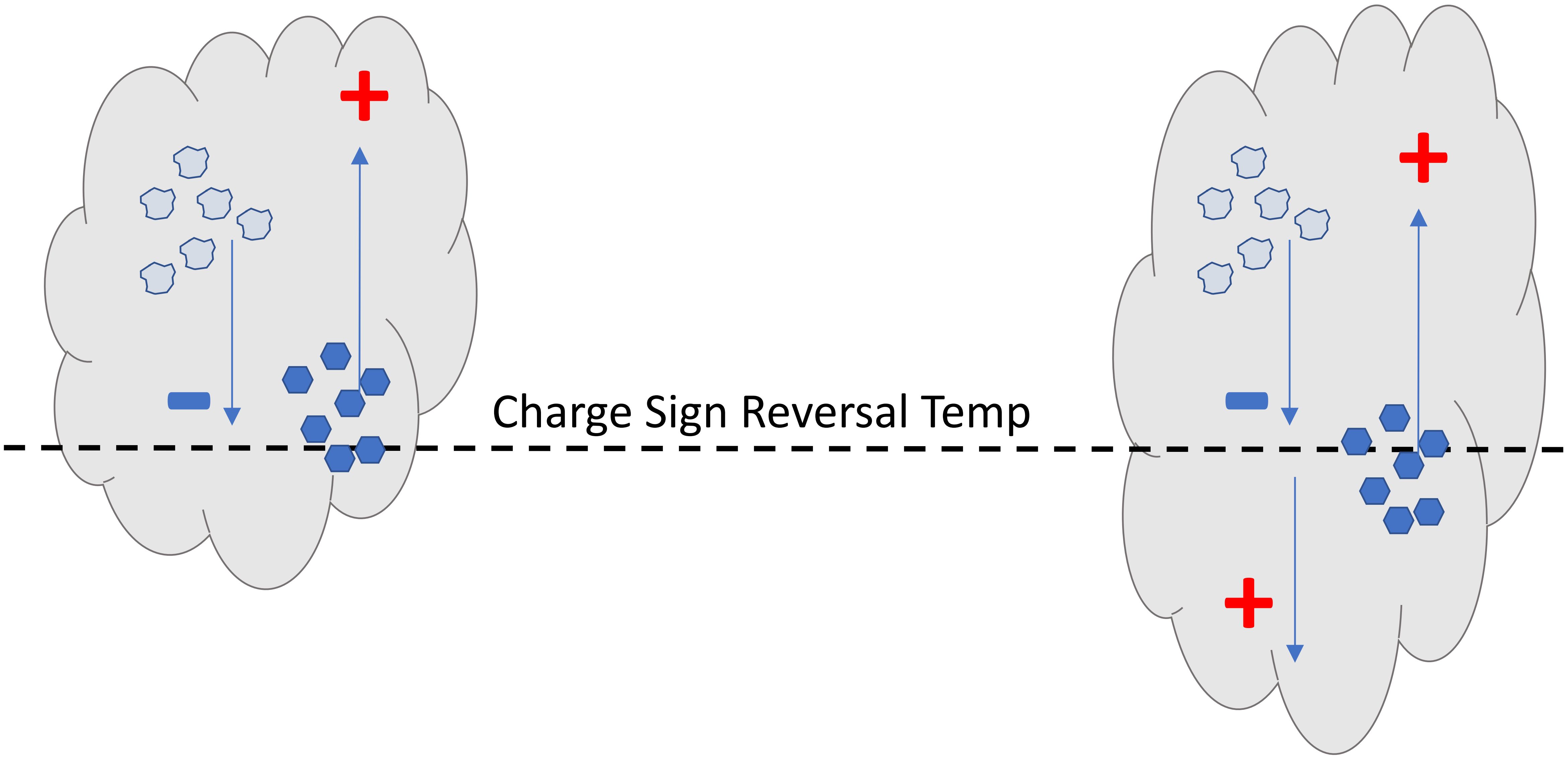
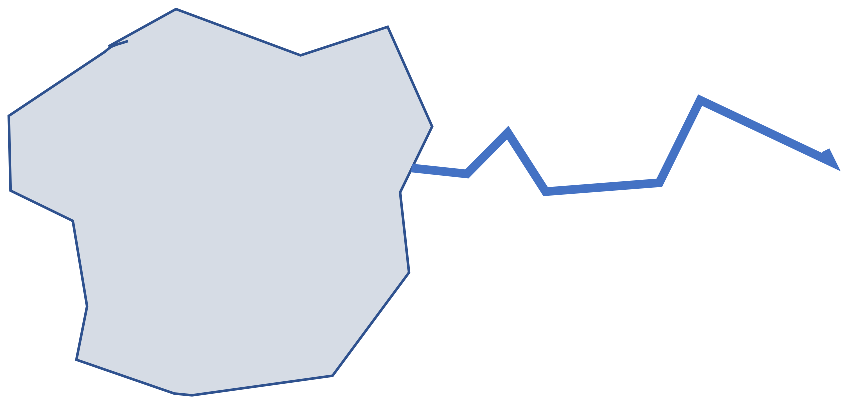


Proposed Charging Mechanisms: Positive Charging

- Caused by temperature gradient within surface of riming graupel
- Ice filaments grow out from graupel
  - Warmer on tips of filaments due to latent heat of deposition/freezing
  - More mobile protons move to base of filament, leaving tip negatively charged
  - Edge of filament breaks off, leaving positively charged graupel



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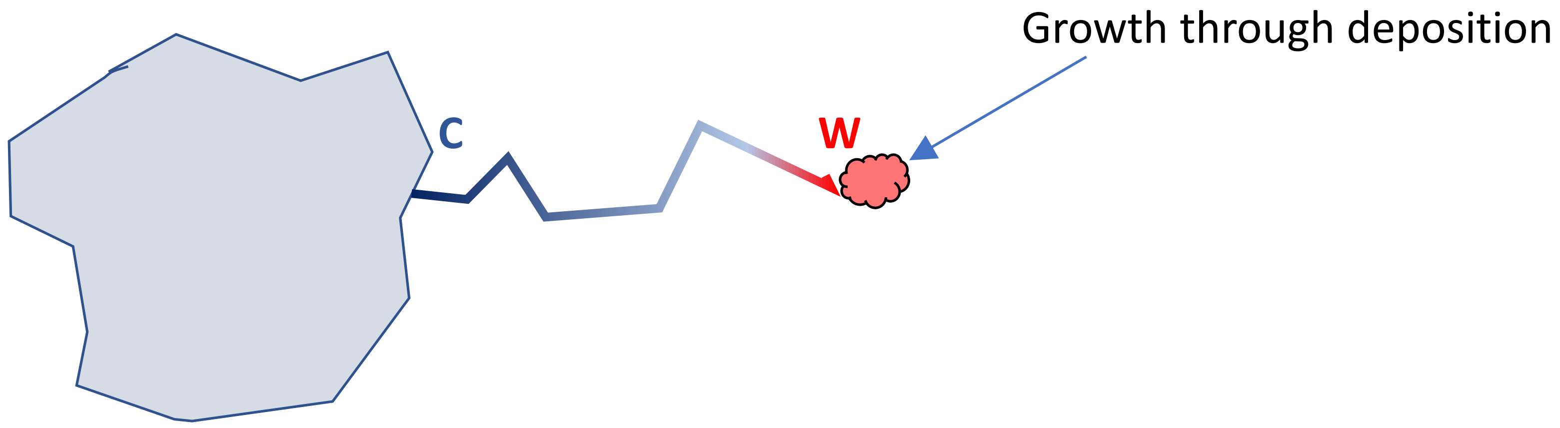

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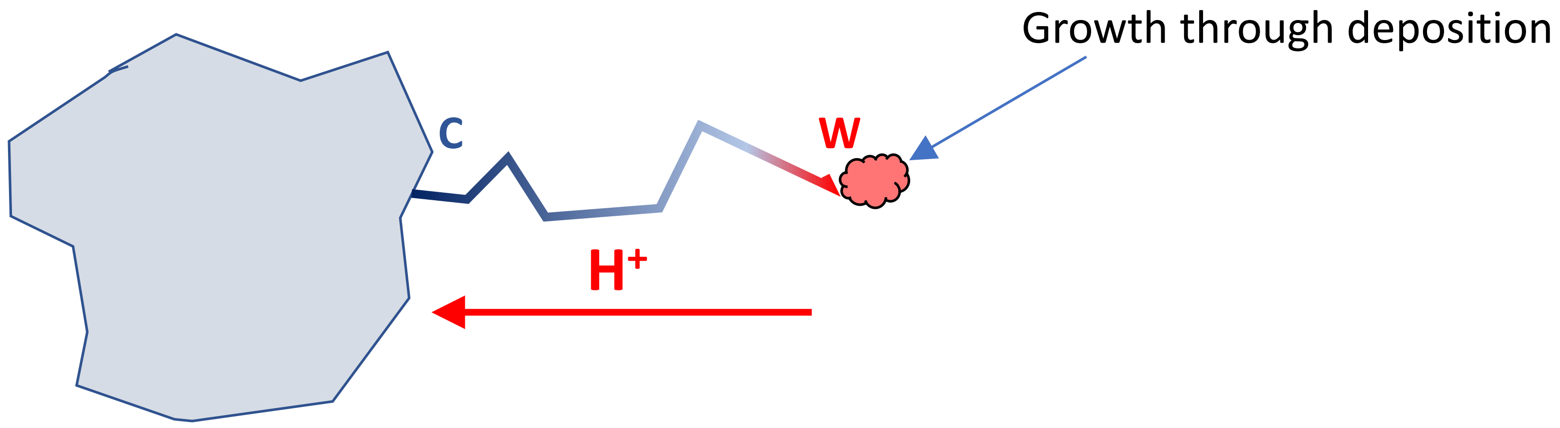

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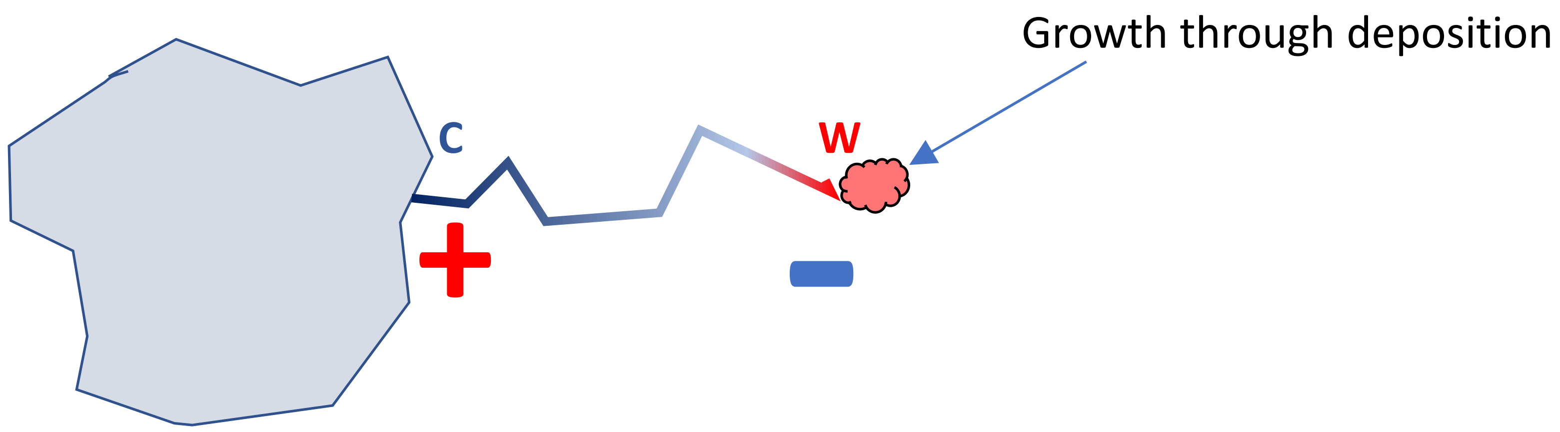

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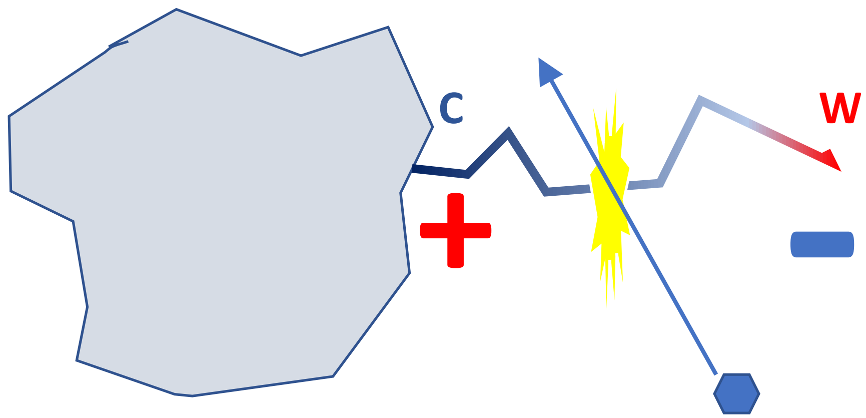

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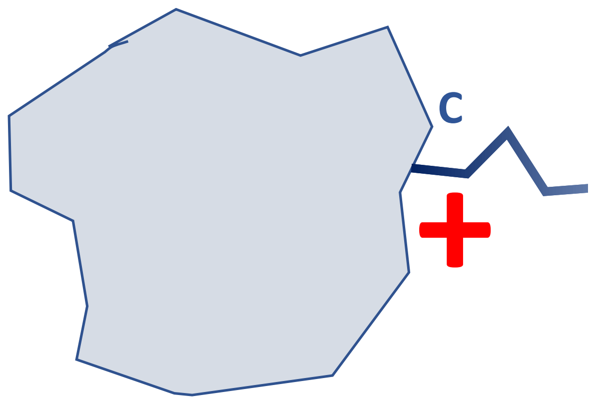
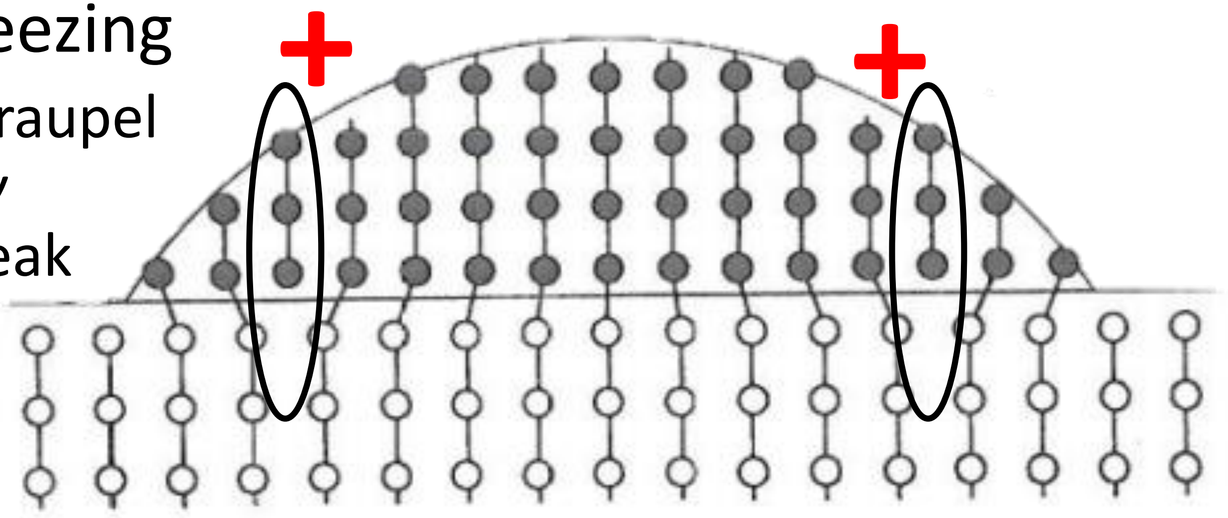


Proposed Charging Mechanisms: Negative Charging

- Difference in contact potential between graupel and ice pellets
  - Substantial amount of ions exist in quasi-liquid layer around ice particles
  - H^+ transfer upon contact between the two leaves graupel with a excess of electrons (negative charge)

- Dislocations in ice lattice upon freezing
  - Dislocation in ice lattice between graupel and accreting ice leads to *positively* charged dislocations, which can break off on contact with ice crystals.

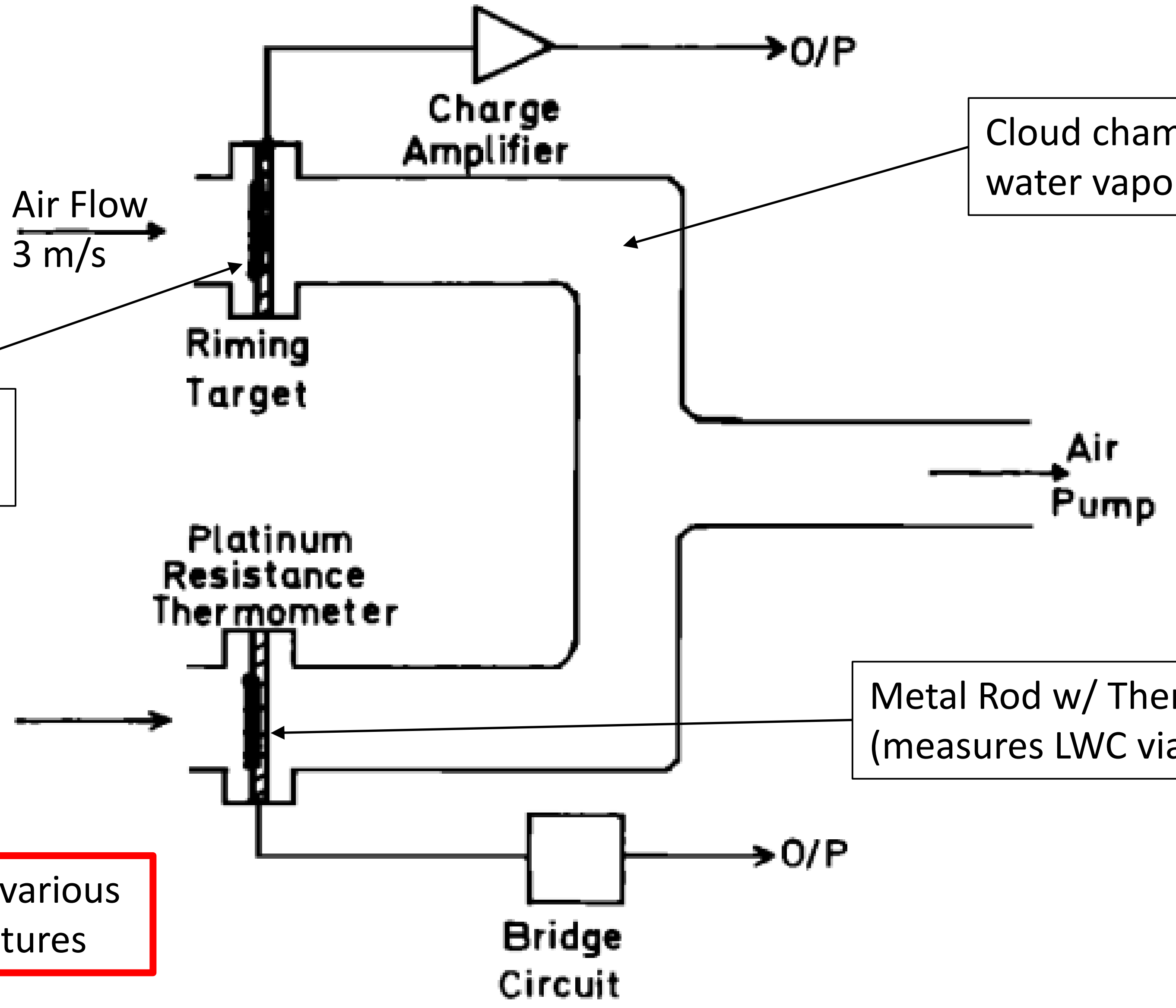


Proposed Charging Mechanisms

- Both negative and positive charging mechanisms happening simultaneously
- Environmental factors determine which one “wins out”

- Ex: Dislocation charging
  - Warmer temperatures → slower freezing →less dislocations → <u>less</u> negative charging of graupel
  - Lower liquid water content → fewer drops on surface → faster freezing → more dislocations → <u>more</u> negative charging of graupel

Experimental Set Up



Charge on rod measured at various effective LWCs and temperatures

Results

- Charge Sign Reversal Temp = Zero-crossing of temperature lines
  Ex: When LWC is 0.9, reversal temp is -21 °C

- LWC increase -> Reversal temp decrease

- Negative charging at
  LWC < 0.22 g/m^3 and T < -16 °C

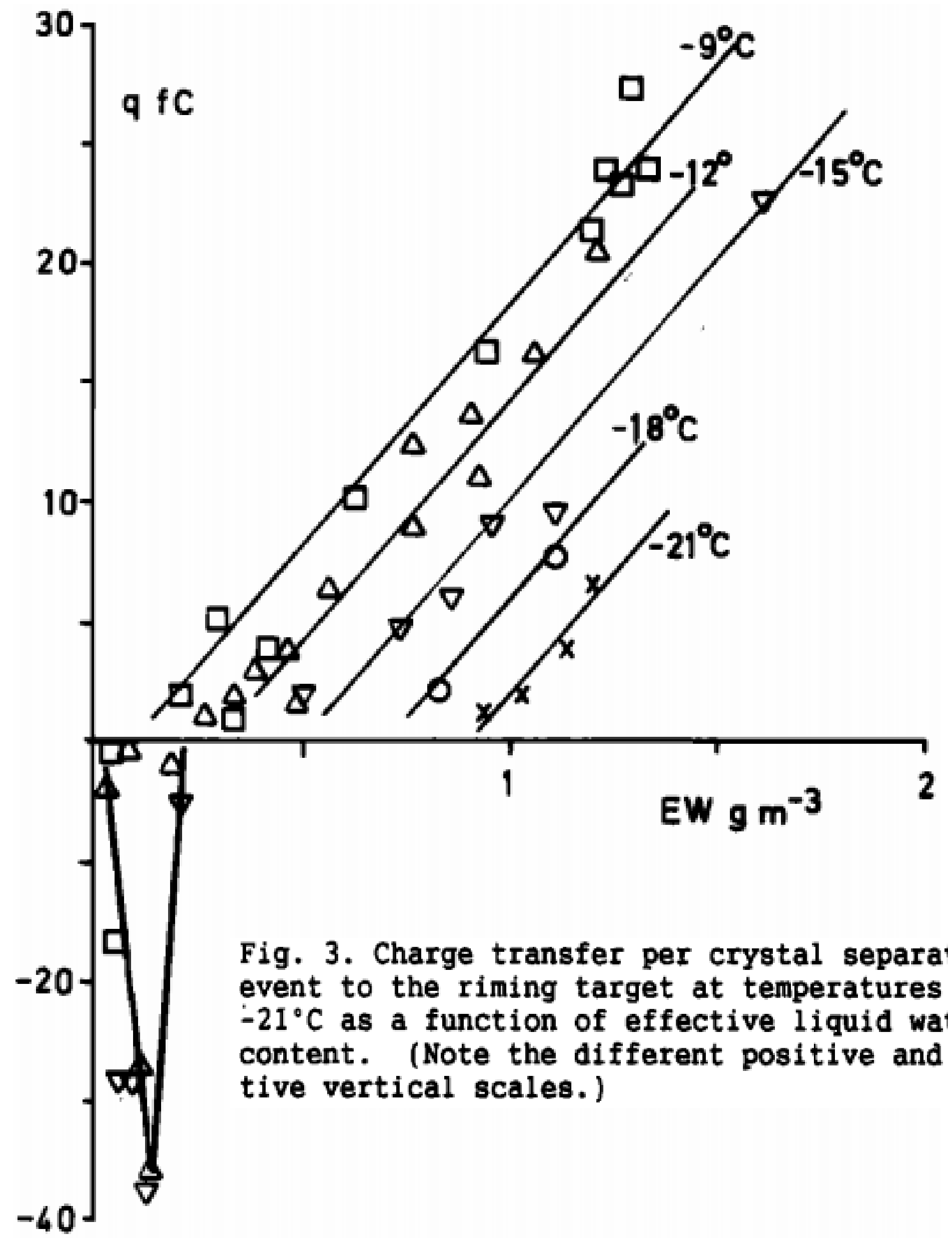


Fig. 3. Charge transfer per crystal separation event to the riming target at temperatures down to -21°C as a function of effective liquid water content. (Note the different positive and negative vertical scales.)

Results

- Negative charge independent of temperature once you get below -21 °C
- Strong positive charge at low LWCs

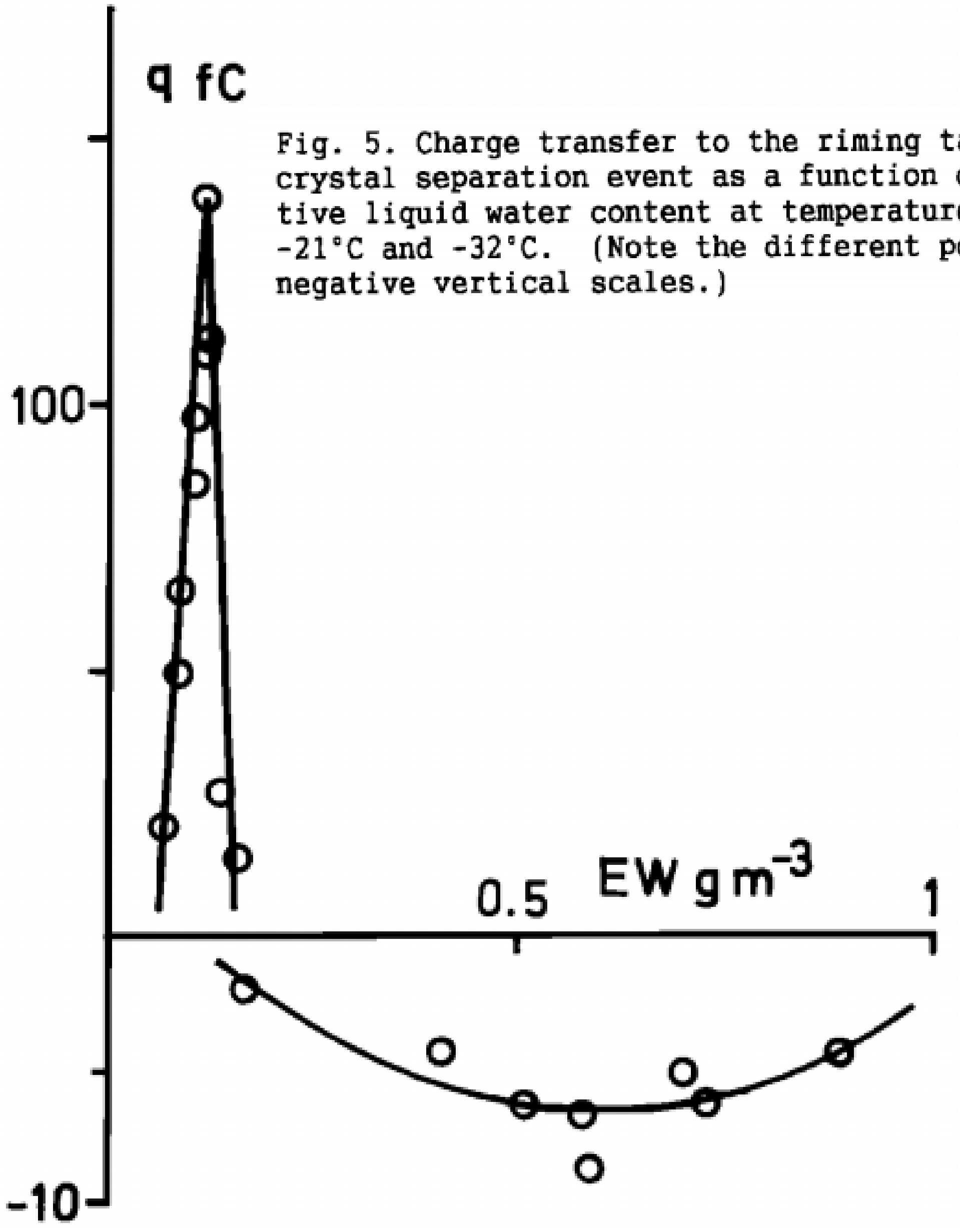


Fig. 5. Charge transfer to the riming target per crystal separation event as a function of effective liquid water content at temperatures between -21°C and -32°C. (Note the different positive and negative vertical scales.)

Discussion

- Temperature and LWC effect efficiency of various charge separation mechanisms

Temperature

Less dislocation (slower freezing)
Decreased contact potential

More dislocation (faster freezing)
Increased contact potential
Higher supersaturation for ice filament growth

LWC

More vapor available for ice filament growth

Less vapor available for ice filament growth
More dislocation (fewer droplets freeze faster)

Positive charging mechanism Negative charging mechanism

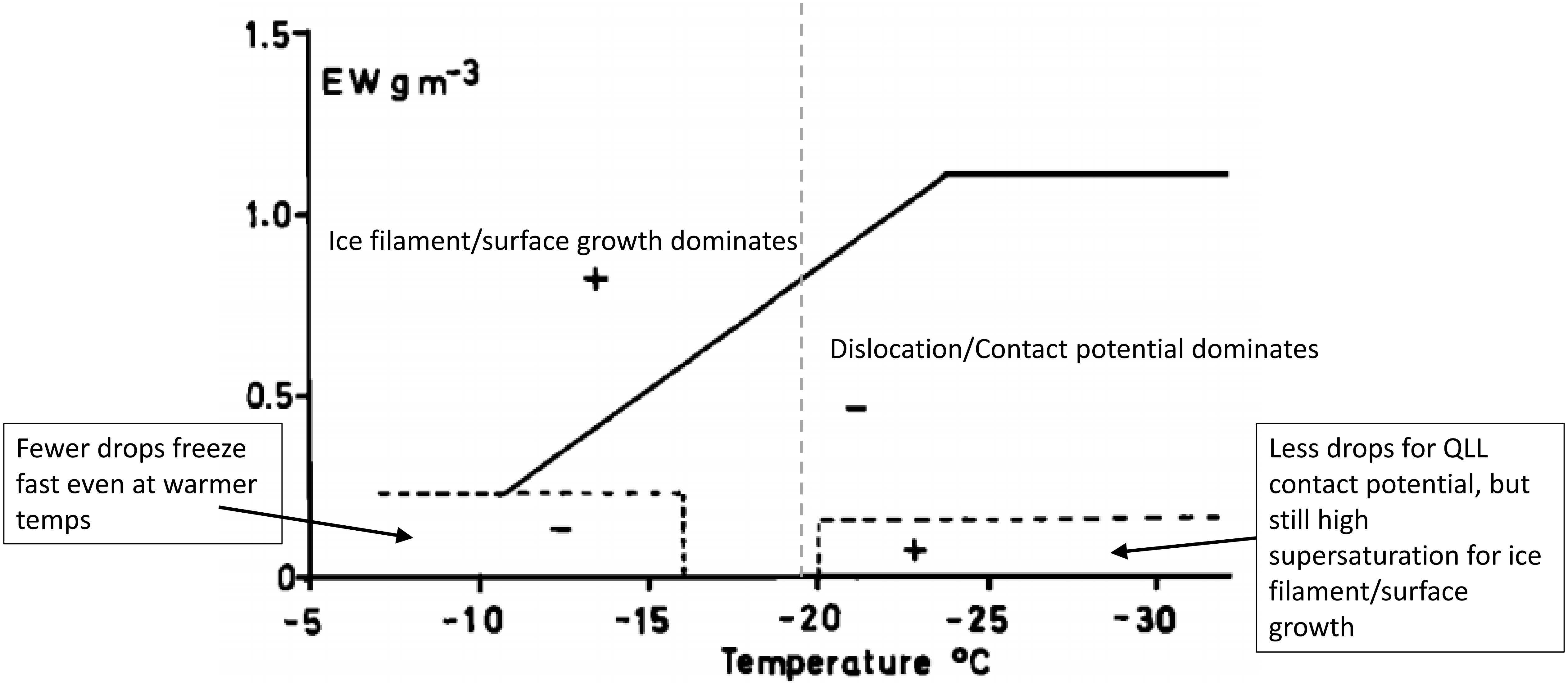
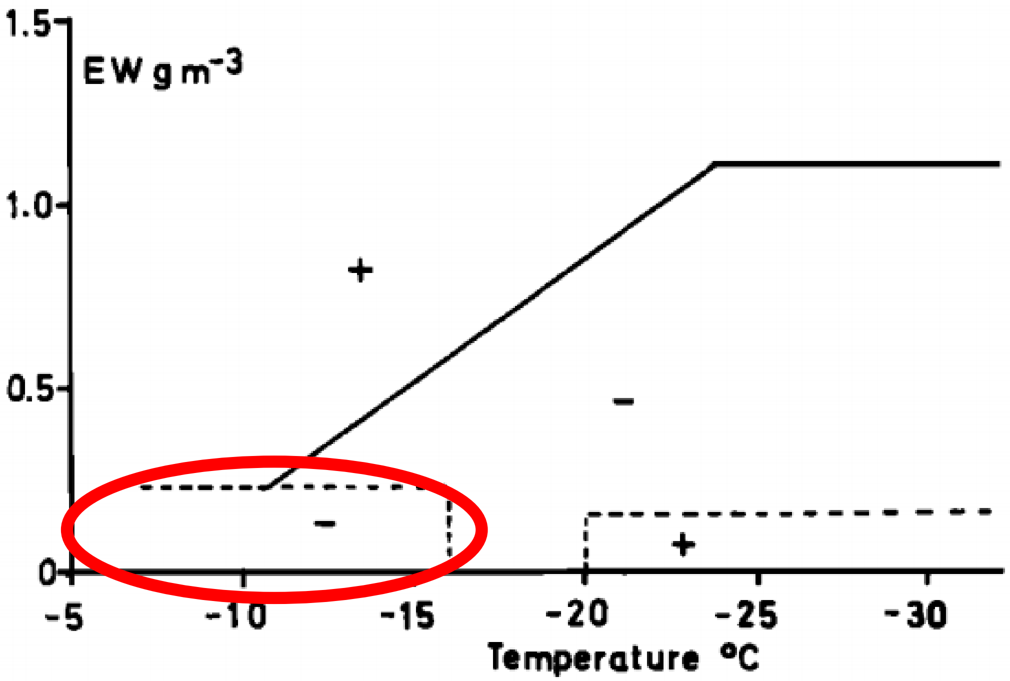
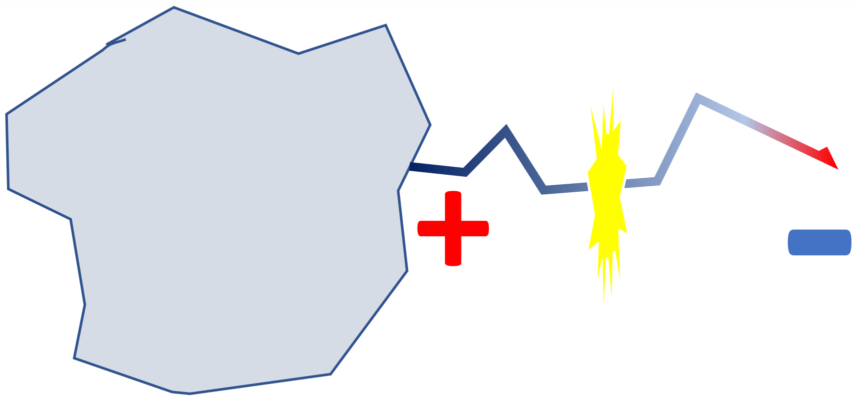


Fig. 7. The positive and negative target charging zones as a function of temperature and effective liquid water content.

Discrepancy with Takahashi (1978)

- Takahashi's work did not find evidence of the negative charging at high temp/low LWC regimes
- Possible explanations:
  - Measurement method may have enhanced surface rime break up
  - Overestimation of liquid water content





Conclusions

- Liquid water content decrease leads to reversal temperature (+ → -) increase
- Very low can lead to different effects
  - Negative charging at high temperature
  - Positive charging at low temperature
- Differences with Takahashi paper may be due to their method of charge calculation, which may have enhanced positive charge results