Cooling the air: assessing the effect of evaporative cooling through seawater spraying on salt dispersion for kilometer-scale climate intervention applications

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Introduction

Marine Cloud Brightening (MCB) is a climate intervention technique aimed at enhancing the reflectivity of marine low-level clouds through seawater spraying into the lower atmosphere, originally proposed by Latham et al. 2008. **Fig. 1** shows the strong evaporative cooling due to water spraying[2], in addition to its capacity to saturate a large volume of air with water vapor.

We aim to study the impact of seawater spraying on the stratocumulus cloud albedo, including the evaporative cooling of the sprayed water, the dispersion of salt, and its enhancement of the local cloud droplet concentration.

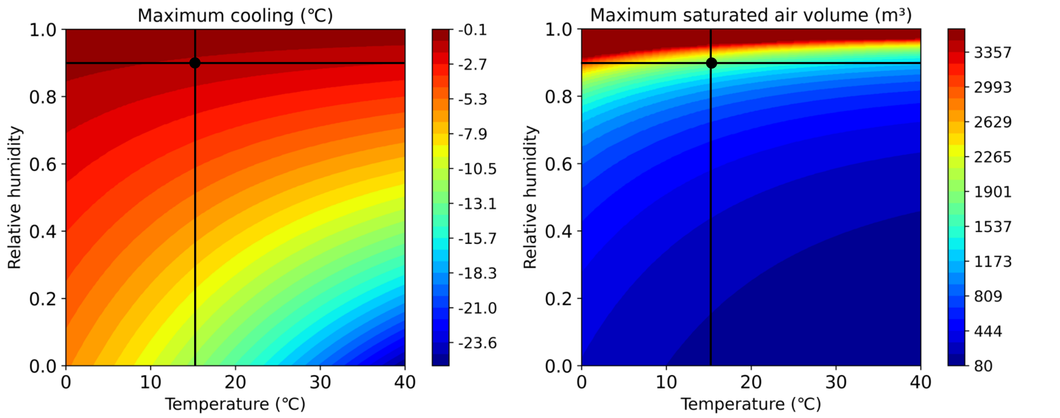


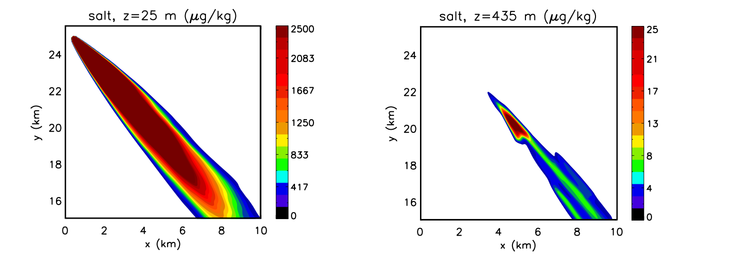
Figure 1. The maximum evaporative cooling (left) and the maximum amount of saturated air volume per kg sprayed water (right) as a function of the temperature and relative humidity. The filled black circle indicates the meteorological regime for the case study. The dark red color applied in the colorbar on the right represents values between 3357 m^3 and the solution for RH → 1 (∞) .

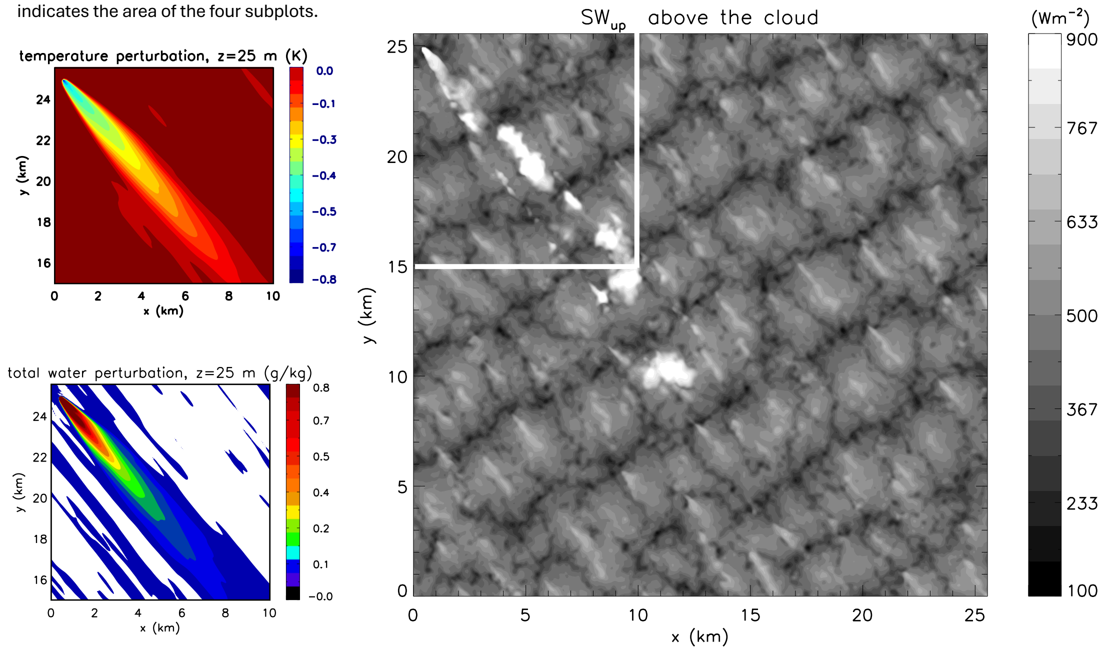
Set-up

- We studied effects of seawater spraying with the Dutch Atmospheric Large Eddy Simulation model (DALES)[3]. We used the FIRE I stratocumulus model intercomparison case, which was based on observations collected off the coast of California[4] .
- A domain size of 25.6x25.6x1.28 km^3 was applied with a horizontal (vertical) mesh size of 50 (10) m.
- To identify the impact of evaporative cooling we performed simulations without and with a local source of water at a spraying rate of 1 kg/s, at a height of 50 m. All the simulations were performed with a spraying source of salt at a rate of 0.03 kg/s at the same location.
- The water spraying is included in DALES by the addition of a liquid water source term in the prognostic equations for the liquid water potential temperature and total water specific humidity.
- Since the focus of our study is on evaporative cooling we applied a somewhat simplified approach of the cloud droplet formation resulting from the sprayed salt particles. It was assumed that the salt crystals have a uniform dry radius of 100 nm. Each salt crystal can be activated to grow into a cloud droplet, thereby adding to a background cloud droplet number concentration of 50 cm^{-3}

From seawater spraying to changing the cloud albedo

Figure 2. The hourly mean perturbations of the total specific humidity and temperature at a height of 25 m (left, below). The hourly mean salt concentration near the surface and in the middle of the cloud layer, at z=25 and 435 m, respectively (top right). The instantaneous upward solar radiation flux (SW_{up}) above the cloud layer 1 hour after the start of the seawater spraying for the full LES domain (lower right). The white box indicates the area of the four subplots.





- Hourly mean plume structures of salt, temperature and total water that result from water spraying resemble Gaussian plumes.
- The spraying of water at a rate of 1 kg/s leads to a kilometer-scale evaporative cooling with values on the order of a few tenths of a Kelvin. The theoretical maximum cooling rate within this regime is 1.12 K.
- Close to the spray source the humidification and evaporative cooling of the air causes a local saturation of the air. Such a formation of a local plume of water droplets has been observed during a field campaign performed at the Great Barrier Reef[5], at a relatively low seawater spraying rate of 68 ml/s.
- Maximum salt concentrations at mid-cloud level (z=435 m) are only a small fraction of the values near the spraying source.
- Similar to ship tracks, a local increase in SW_{up} above the cloud is clearly visible in the area of the salt plume. The albedo increase is partly due to a plume of liquid water droplets near the water spraying source well below the stratocumulus cloud deck.

Outlook

- As part of the Refreeze the Arctic Foundation (RAF) project, new simulations will be performed with DALES including improved cloud-aerosol parametrizations to further evaluate cloud adjustments.
- The RAF project aims to perform a water spraying field experiment in the Netherlands.
- The LES modelling technique will be applied to study the effect of a continuous source of seawater spraying for a fixed location in the Netherlands and for a longer period of time (~ months).

Effect of evaporative cooling on the dispersion of salt

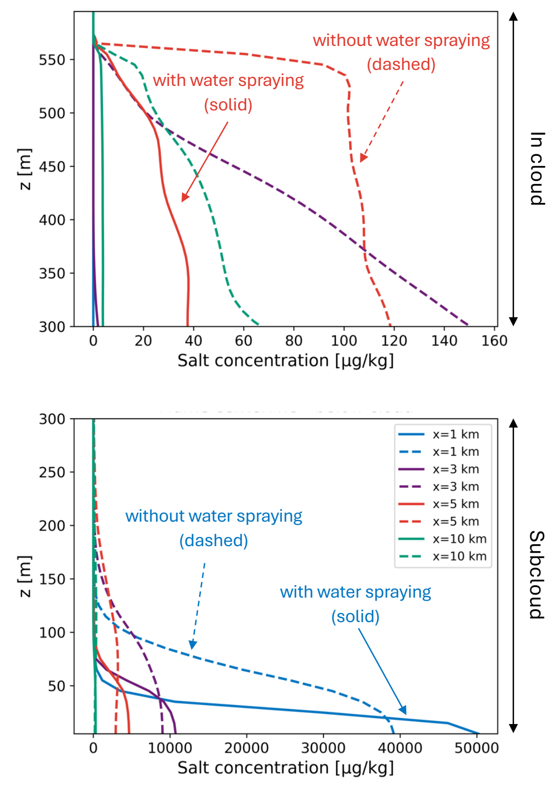


Figure 3. The hourly mean vertical profiles of the salt concentration following the plume centerline for simulations including (solid) and excluding (dashed) water spraying for horizontal x-coordinates in the subcloud layer (up to 300 m, lower plot) and in the cloud layer (300-600 m, upper plot). The plume centerline (x,y) is obtained from finding the maxima of the vertical integral of the salt concentrations for all x-y in the subcloud and cloud layers, respectively.

- Evaporative cooling due to water spraying hinders the vertical dispersion of salt, which leads to higher concentrations of salt in the plume near the surface as compared to the simulations without water spraying.
- By contrast, the salt concentration in the cloud layer is significantly smaller if the effect of evaporative cooling is taken into account.
- We note that above the North Sea the annual mean salt concentration has been observed[6] to be around 10 μg/kg.

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Acknowledgements

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